GWINNETT COUNTY
STORMWATER MANAGEMENT MANUAL
2020 EDITION

VOLUMES 1 AND 2

Gwinnett

The revision of this Manual was facilitated by the Atlanta Regional Commission and was a collaborative effort led by the following agencies:

American Rivers
Atlanta Regional Commission
Chatham County – Savannah Metropolitan Planning Commission
City of Atlanta
City of Cornelia
City of Garden City
City of Johns Creek
City of Roswell
City of Savannah
City of Statesboro
City of Valdosta
Council for Quality Growth
Douglasville/Douglas Co. Water & Sewer Authority
Georgia Department of Transportation
Georgia Environmental Finance Authority
Georgia Environmental Protection Division
Georgia Industry Environmental Coalition
Gwinnett County
Mercer University
The Conservation Fund
United States Environmental Protection Agency
University of Georgia

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Forward

Preface

Stormwater management has entered a new phase in the state of Georgia that recognizes the need for more innovative policies and practices. The requirements for National Pollutant Discharge Elimination System (NPDES) municipal and industrial permits, Total Maximum Daily Loads (TMDLs), watershed assessments and the desire to protect and increase the quality of human life, property, and aquatic habitats has brought home the pressing need to manage both stormwater quantity and quality from our developed and developing areas.

This Manual will continue to help Georgia move forward with a comprehensive approach to stormwater management that integrates drainage design, stormwater quantity, and water quality considerations and views stormwater as an important resource and opportunity for our communities. Building on the previous version, the goal of this Manual continues to be to refine and promote a consistent and effective approach of stormwater management throughout Georgia.

Acknowledgements

This Manual is the culmination of a collaborative effort between the Atlanta Regional Commission (ARC), the Georgia Environmental Protection Division, Georgia Environmental Finance Authority, cities, counties, and other organizations throughout the state of Georgia. These documents reflect the hard work, time and contributions of many individuals.

The cities, counties, and other organizations involved in this Manual update that helped guide this effort via the Technical Advisory Group (TAG), include:

American Rivers
Chatham County – Savannah Metropolitan Planning Commission
City of Atlanta
City of Cornelia
City of Garden City
City of Johns Creek
City of Roswell
City of Savannah
City of Statesboro
City of Valdosta
Council for Quality Growth
Douglasville/Douglas Co. Water & Sewer Authority
Georgia Department of Transportation
Georgia Environmental Finance Authority
Georgia Environmental Protection Division
Georgia Industry Environmental Coalition
Gwinnett County
Mercer University
The Conservation Fund
United States Environmental Protection Agency
University of Georgia

This project was also made possible in part through a U.S. EPA 319(h) grant administered through the Georgia Environmental Protection Division as well as funding provided by the Georgia Environmental Finance Authority.

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Finally, thank you to all those throughout the state who took the time and effort to provide review comments and constructive suggestions on the draft versions of the Manual. These individuals represent an even larger segment of stakeholders beyond the TAG and include large and small cities, trade organizations, product manufactures, federal agencies, and others.

Gwinnett County Version

The Gwinnett County Stormwater Management Manual (GCSMM) was developed using the Georgia Stormwater Management Manual (GSMM) as a base, and adjusting for the needs of Gwinnett County. Development of the GCSMM required coordinating the perspectives of three County Departments: Planning & Development (P&D), Department of Water Resources (DWR), and Department of Transportation (DOT), while keeping in mind that the goal is to protect the natural environment. There were many individuals who worked diligently over a nine month period to read all of the Gwinnett County Stormwater Systems and Facilities Installation Standards and Specifications (SSFISS) and compare it to the applicable sections of the GSMM, choosing what to add or edit in the GSMM. There is no way to acknowledge all the staff that worked on this project so, it is important to give each Department credit for their diligence in addressing the daunting task. Without the hard work of all the staff this would never have been completed. Much thanks to all!

We also need to acknowledge the efforts of the Development Community and the Stormwater Authority that came forward, on a monthly basis, to review the final edits and comment where applicable. Without their substantive input we would not have accomplished this task. Again, thanks to all who helped to make the GCSMM a better document!

Click here for Volume 1: Local Government Guide

Click here for Volume 2: Technical Handbook

GWINNETT COUNTY
STORMWATER MANAGEMENT MANUAL
2020 EDITION

VOLUME 1: LOCAL GOVERNMENT GUIDE

Gwinnett

GO TO VOL 2

Volume 1: Local Government Guide

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1. Introduction

1.1 Objective of the Manual

The objective of the Gwinnett County Stormwater Management Manual is to provide guidance on the latest and best post-construction stormwater management practices applicable to Gwinnett County to minimize the negative impacts of increasing stormwater runoff and its associated pollutants. Building on the previous version, this updated Manual will help Gwinnett County take a comprehensive approach to stormwater management that integrates drainage design, stormwater quantity, and water quality considerations. The goal is to provide an effective tool for local governments and the development community to reduce both stormwater quality and quantity impacts and protect downstream areas and receiving waters.

Stormwater management has entered a new phase in the state of Georgia that recognizes the need for more innovative policies and practices. The requirements for NPDES municipal and industrial permits, TMDLs, watershed assessments and the desire to protect human life, property, aquatic habitats and the quality of life in our communities has brought home the pressing need to manage both stormwater quantity and quality from our developed and developing areas.

1.2 Organization of the Manual

The Gwinnett County Stormwater Management Manual is organized as a two volume set, with each volume published as a separate document. You are currently reading Volume 1 of the GCSMM.

Volume 1 of the Manual, the *Local Government Guide to Stormwater Management*, is designed to provide guidance for local jurisdictions on the basic principles of effective urban stormwater management. Volume 1 covers the environmental, economic and social problems resulting from urban stormwater runoff and the need for local communities to address urban stormwater quantity and quality through recommended stormwater management standards and local stormwater programs. It also provides an overview of integrated stormwater management and technologies and tools for implementing stormwater management programs.

Volume 2 of the Manual, the Technical Handbook, provides guidance on the techniques and measures that can be implemented to meet a set of recommended stormwater management standards for new development and redevelopment. Volume 2 is designed to provide the site designer or engineer, as well as the local plan reviewer or inspector, with all of the information on best management practices (BMPs) required to effectively address and control both water quality and quantity on a development site. This includes guidance on site planning, better site design practices, hydrologic techniques, criteria for the selection and design of stormwater BMPs, and drainage system design, as well as construction and maintenance information.

The *Georgia Pollution Prevention Guidebook*, Volume 3 of the GSMM, is a separate compendium of stormwater pollution prevention practices for use by local jurisdictions, businesses and industry, and local citizens. Volume 3, the ***Georgia*** *Pollution Prevention Guidebook* can be found at the following website: http://northgeorgiawater.org/wp-content/uploads/2015/05/GSMMVol3.pdf

1.3 Users of This Volume

Volume 1 of the Manual is primarily intended to provide guidance for local government officials and staff on implementing stormwater management programs. The audience for Volume 1 also includes public agencies, such as Regional Commissions, and other organizations concerned with land use, development, and stormwater runoff management.

Other interested parties and the general public may also find Volume 1 helpful because it describes how managing stormwater improves water quality and quantity, helps protect the State's valuable natural resources and contributes to other social and economic benefits. Traditional urban stormwater management had unintended negative environmental, economic, and social consequences, including deteriorating water quality, reduced stream base flows, unstable stream banks, lakes filling with sediment, and flooding. Adoption of new comprehensive management strategies using low impact development (LID) concepts will reduce these negative impacts of stormwater runoff. These LID concepts help reduce runoff from new and re-development sites by using BMPs that encourage infiltration, evapotranspiration, and or harvest and use of stormwater runoff onsite.

1.4 How to Use This Volume

The following provides a guide to the various chapters of Volume 1 of the Manual.

- **Chapter 1 – Introduction.** This chapter identifies the objective of the manual and the target audience, provides a brief overview of the rest of Volume 1, and introduces and defines the concept of LID. Much of the guidance in Volume 1 is intended to encourage the adoption of LID practices, as they can be very effective at addressing the negative stormwater impacts of development, impervious cover, and runoff.
- **Chapter 2 – Background on Post-Construction Stormwater Management.** This chapter begins with a discussion of the negative impacts of stormwater pollution, followed by explanations and summaries of the regulatory framework for local stormwater management in Georgia, including the state and federal laws, regulations, and programs, which are required of local communities in Georgia or may impact local stormwater management activities.
- **Chapter 3 – Better Site Design.** This chapter provides a detailed description of better site planning and design principles, discusses how those principles affect stormwater management, and provides guidance on how a local government can (and should) implement better site planning and design practices.
- **Chapter 4 – Instituting Local Stormwater Management Programs.** This chapter presents a set of recommended stormwater management standards for new development and redevelopment that communities can adopt as part of their local development code, and it identifies the components of a stormwater management plan. A range of development types, including subdivisions, linear projects, and redevelopment projects, are also discussed.
- **Chapter 5 – Elements of Stormwater Management Programs.** This chapter covers many of the key aspects of a local stormwater management program, including sections on site plan review and enforcement procedures and operation and maintenance requirements. In addition, Chapter 5 provides a toolbox to address development activities, which includes:
  - » Geographical Information Systems (GIS)
  - » Asset Management
  - » Funding
  - » Adapting the Program to Meet Local Needs and Challenges
  - » Watershed-Based Stormwater Planning
- **Appendix A – Contact Agencies for Stormwater Management Regulations and Programs.** This appendix includes contact information for the various regulatory and other programs covered in Chapter 2.
- **Appendix B – Stormwater Site Plan Review Checklists.** This appendix provides example checklists outlining the necessary steps to prepare preliminary and final stormwater management site plans.
- **Appendix C – Stormwater Construction Inspection Checklists.** This appendix includes construction forms for each type or group of best management practices (BMPs) included in Volume 2.
- **Appendix D – Example Stormwater Maintenance Agreement.** This appendix contains an example maintenance agreement for stormwater management facilities between a local government and a private party.

1.5 Low Impact Development

Much of the guidance in Volume 1 is focused on the concept of LID, and the idea that implementation of LID can help communities achieve social and economic goals while they improve water quality and quantity and protect their natural resources. Low Impact Development is an approach to land development or redevelopment that seeks to emulate the natural water cycle as much as possible and reduce the negative impacts of development and impervious cover. This is done by minimizing the production of runoff through the application of better site design techniques (see Chapter 3) that direct development to appropriate areas, preserve natural features that aid in water management, and minimize impervious cover. These better site design techniques are combined with BMPs (see Volume 2, Chapter 4) that manage stormwater at the source as much as possible through processes that include infiltration, evapotranspiration, rainwater harvesting, and extended filtration.

The terms Low Impact Development, or LID, and Green Infrastructure (GI) are often used interchangeably, as their meanings are very similar, especially when considered at the individual property or development level. However, the meaning of GI can vary depending on the site scale. According to the Environmental Protection Agency (EPA), "At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water" (US EPA). Given the variability in the meaning of "green infrastructure," and this manual's emphasis on the neighborhood and site scale, Low Impact Development and LID are used instead throughout this manual.

While this manual concentrates mainly on the neighborhood and site scale, application of regional or landscape-scale GI is an important complement, and is necessary to help communities reduce the serious and costly problems that can be created by traditional stormwater management practices. Regional and landscape-scale GI approaches to identify and conserve natural areas may include:

- Create a community-wide natural resources inventory that prioritizes conservation of forests, floodplains, stream buffers and wetlands in order to establish a community network of landscape scale green infrastructure to provide essential ecosystem services.
- Identify flood prone areas in the community and address them by acquiring floodplain properties, restricting development in these watersheds, or requiring runoff volume reduction or greater stormwater detention in those areas.
- Prepare comprehensive plans and zoning that allow the community to choose where and how densely development should (and should not) occur, or where redevelopment will be encouraged/incentivized.
- Establish legal mechanisms and incentives to encourage preferable types of development, for example, cluster developments, conservation subdivisions, city centers and conservation easements, which will allow more of the land area to be left in a natural state and reduce the stormwater impacts of the developed area.

See Section 3.3.1 and Section 3.3.2 for more information on community- and site-level conservation approaches.

Key Principles for LID

Low Impact Development is more than an alternative set of stormwater BMPs. LID can best be achieved if viewed in the context of the larger design process. The Low Impact Development Manual for Michigan highlights the following principles and key components of an LID design approach:

- **Plan first.** To minimize stormwater impacts, stormwater management and LID should be integrated into the community planning and zoning process.
- **Prevent.** Then mitigate. A primary goal of LID is preventing stormwater runoff by incorporating nonstructural practices into the site development process. This can include preserving natural features, clustering development, and minimizing impervious surfaces. Once prevention as a design strategy is maximized, then the site design — using structural BMPs — can be prepared.
- **Minimize disturbance.** Limiting the disturbance of a site reduces the amount of stormwater runoff control needed to maintain the natural hydrology.
- **Manage stormwater as a resource — not a waste.** Approaching LID as part of a larger design process enables us to move away from the conventional concept of runoff as a disposal problem (and disposed of as rapidly as possible) to understanding that stormwater is a resource for groundwater recharge, stream base flow, lake and wetland health, water supply, and recreation.
- **Mimic the natural water cycle.** Stormwater management using LID includes mimicking the water cycle through careful control of peak rates as well as the volume of runoff and groundwater recharge, while protecting water quality. LID reflects an appreciation for management of both the largest storms, as well as the much more frequent, smaller storms.
- **Disconnect. Decentralize. Distribute.** An important element of LID is directing runoff to BMPs as close to the generation point as possible, in patterns that are decentralized and broadly distributed across the site.

- **Integrate natural systems.** LID includes careful inventorying and protection of a site's natural resources that can be integrated into the stormwater management design. The result is a natural system that not only provides water quality benefits, but greatly improves appearance and minimizes infrastructure.
- **Maximize the multiple benefits of LID.** LID provides numerous stormwater management benefits, but also contributes to other environmental, social, and economic benefits. In considering the extent of application of LID, communities should consider these other benefits.
- **Use LID everywhere.** LID can work on redevelopment, as well as new development, sites. In fact, LID can be used on sites that might not traditionally be considered for LID techniques, such as in combined sewer systems, along transportation corridors, and on brownfield sites. Broad application of LID techniques improves the likelihood that the desired outcome of water resource protection and restoration will be achieved.
- **Make maintenance a priority.** The best LID designs lose value without a commitment to maintenance. An important component of selecting a LID technique is understanding the maintenance needs and institutionalizing a maintenance program. Selection of optimal LID BMPs should be aligned with both the nature of the proposed land use/building program and the owners/operators of the site, for implementation of effective future maintenance activities.

Other Environmental, Economic, and Social Benefits of Implementing LID

In addition to the significant stormwater and water quality benefits (reduced stormwater pollutant levels, improved aquatic biodiversity, increased stream base flows, groundwater recharge, reduced flooding, etc), implementation of LID strategies can provide many additional direct and indirect benefits for homeowners, developers, and communities.

HOMEOWNERS

- Preserved mature trees can shade homes, which can reduce air conditioning needs and energy costs.
- Directing stormwater runoff to vegetated areas and utilizing native plants reduces irrigation needs.
- Treating stormwater runoff close to its source with a distributed system may reduce nuisance flooding problems.

DEVELOPERS

- Preserving natural features and vegetation reduces the cost of land clearing and grading.
- Minimizing impervious cover reduces the cost of infrastructure (sidewalks, curbs, streets, etc.).
- As described in several of the studies highlighted below, incorporating LID into a site design can decrease overall stormwater management costs.
- Mature trees and other vegetative amenities can increase property values.

COMMUNITIES

- Reduced irrigation demands improve water supply reliability.
- Infiltrating LID BMPs contribute to groundwater recharge.
- Reduced impervious cover and increased evaporative cooling decreases the urban heat island effect.
- Runoff reduction decreases the magnitude and frequency of combined sewer overflow events.

Cost Effectiveness of LID

Cost issues are among the main objections to implementing LID. However, many studies have shown that properly applied LID approaches and BMPs can be more cost effective than more conventional stormwater management approaches. The list below includes case studies, research, recommendations, and site specific costs for implementing LID:

- "Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs" (US EPA, 2013) — This report seeks to educate stormwater professionals on the potential benefits of LID and Green Infrastructure (GI) programs using thirteen (13) case studies from a variety of communities around the country. http://water.epa.gov/polwaste/green/upload/lid-gi-programs_report_8-6-13_combined.pdf

- "Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices" (US EPA, 2007) — This document summarizes seventeen (17) case studies comparing the costs of LID methods to the costs of conventional development methods. In many cases, the LID methods proved to be both less costly and more environmentally beneficial than the traditional methods: http://water.epa.gov/polwaste/green/costs07_index.cfm
- "The Economics of Low-Impact Development: A Literature Review (ECONorthwest, 2007) — This paper discusses the costs and benefits of LID practices as well as their proper application. http://www.econw.com/our-work/publications/the-economics-of-low-impact-development-a-literature-review
- "Low Impact Development Versus Conventional Development" (Shaver, 2009) — This report discusses LID practices applied in New Zealand and the USA. Nine (9) case studies were analyzed (3 in New Zealand and 6 in the USA) and LID costs were compared to conventional measures. In every case, LID was shown to be more cost effective than using conventional measures.
- "Forging the Link, Linking the Economic Benefits of Low Impact Development and Community Decisions" - Chapter 3 from the Economics of LID (UNH, 2011) — Chapter 3 of this document discusses the costs associated with LID practices and how incorporating LID/GI into a project can reduce the cost of stormwater management. http://www.unh.edu/unhsc/recent-projects/forging-link-linking-economic-benefits-low-impact-development-and-community-decision

1.6 Regulatory Status of the Manual

The Georgia Stormwater Management Manual is designed to provide Georgia communities with comprehensive guidance on a Low Impact Development (LID)-based approach to natural resource protection, stormwater management and site design that they can use to better protect the state's valuable natural resources from the negative impacts of land development and nonpoint source pollution.

It is recommended that all Georgia communities use the information presented in this manual, or an equivalent post-construction stormwater management manual, to regulate new development and redevelopment activities. For those communities that are covered under the National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Program, adoption of this manual, specifically Volume 2 (or an equivalent), is required.

Communities are encouraged to review and modify the contents of this manual, as necessary, to meet local watershed and stormwater management goals and objectives while still maintaining the essence of a Low Impact Development (LID)-based approach for stormwater management.

Gwinnett County has chosen to modify the Georgia Stormwater Management Manual by merging it with the previous County Design Manual, the SSFISS. The result is this new manual, the Gwinnett County Stormwater Management Manual (GCSMM).

1.7 How to Find the Manual on the Internet

All three volumes of the Georgia Stormwater Management Manual are also available in Adobe Acrobat PDF document format for download at the following Internet address: http://www.georgiastormwater.com

The Gwinnett County Stormwater Management Manual (GCSMM) is available in Adobe Acrobat PDF document format for download on the Gwinnett County Website.

1.8 Contact Information

If you have any technical questions or comments on the GSMM, please send an email to: info@georgiastormwater.com

If you have any technical questions or comments concerning guidance in the GCSMM contact the Gwinnett County Department of Planning and Development, or the Gwinnett County Department of Water Resources.

References

ECONorthwest. 2007. *The Economist of Lost Impact Development: A Literature Review*. ECONorthwest, Portland, Oregon.

Shaver, Earl. 2009. Low Impact Design Versus Conventional Development: Literature Review of Developer-related Costs and Profit Margins. Auckland Regional Council, Auckland New Zealand.

Southeast Michigan Council of Governments. 2008. *Low Impact Development Manual for Michigan: A Design Guide for Implementors and Reviewers.* SEMCOG, Detroit, Michigan.

University New Hampshire Stormwater Center. 2011. Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions. UNH Stormwater Center, Durham, New Hampshire.

U.S. Environmental Protection Agency 2013. Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs. U.S. Environmental Protection Agency, Washington D.C.

U.S. Environmental Protection Agency 2007. Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. U.S. Environmental Protection Agency, Washington D.C.

U.S. Environmental Protection Agency. "What is Green Infrastructure?". U.S. Environmental Protection Agency, Washington D.C.

2. Background on Post-Construction Stormwater Management

2.1 Introduction to Stormwater Pollution

Description: Development often has negative effects on both the quality and quantity of stormwater runoff. The additional impervious surfaces cause increases in peak flows and total runoff volume. Further, the additional runoff picks up greater concentrations of many pollutants, degrading water quality in receiving waters.

KEY CONSIDERATIONS

When not properly managed, the land development's negative impacts on stormwater runoff quantity and quality leads to:

- Increased Peak Flows and Decreased Base Flows in Streams
- Erosion and/or Sedimentation of Streams
- Loss of Riparian Trees
- Increased Floodplain Elevations
- Degraded Fish Habitat
- Increased Pollution from Nutrients, Hydrocarbons, Toxic Substances, Trash, etc.



The growth and development of Georgia's towns, cities, and suburbs have profoundly altered natural drainage systems and water resources in our state. Urbanization changes not only the physical, but also the chemical and biological, conditions of our waterways. This chapter describes the impacts of development and urban stormwater runoff.

2.1.1 Impacts of Development Changes on Stormwater Runoff

When land is developed, the hydrology, or the natural cycle of water is disrupted and altered. Streams and waterways are so sensitive to development that significant impacts to stream water quality become evident with as little as 10% impervious cover in a watershed. Land clearing removes vegetation that would otherwise intercept and slow runoff, allowing it to return to the air through evaporation and transpiration. Grading flattens hilly terrain and fills in natural depressions that slow and provide temporary storage for rainfall. The topsoil is scraped and removed, and the remaining subsoil is compacted. Rainfall that once seeped into the ground now runs off the surface. The addition of buildings, roadways, parking lots and other surfaces that are impervious to rainfall further reduces infiltration and increases runoff. Figure 2.1-1 is an example of the changes that take place as an area is developed.

This type of development is not limited to a few urban areas. Population growth has been increasing throughout much of Georgia, and development density has increased along with it. Figure 2.1-2 illustrates the significant increase in housing density from 1970 to 2000 and predictions for 2030.



Figure 2.1-1 Typical Changes in Land Surface for a Commercial Site
(City of Roswell, Georgia – 1958 and 2015)

Depending on the magnitude of changes to the land surface, the total runoff volume can increase dramatically, as illustrated in Figure 2.1-3. Development can not only increase the total volume of runoff, but also accelerate the rate at which runoff flows across the land. This effect is further exacerbated by drainage systems such as gutters, storm sewers, and lined channels that are designed to quickly carry runoff to rivers and streams.

Development and impervious surfaces also reduce the amount of water that is infiltrated into the soil and groundwater, thus reducing the amount of water that can recharge aquifers and increase stream base flows.

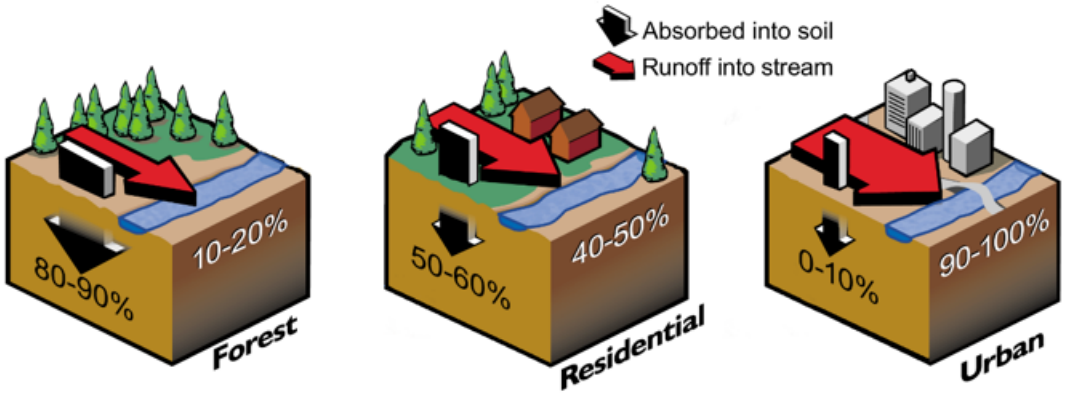
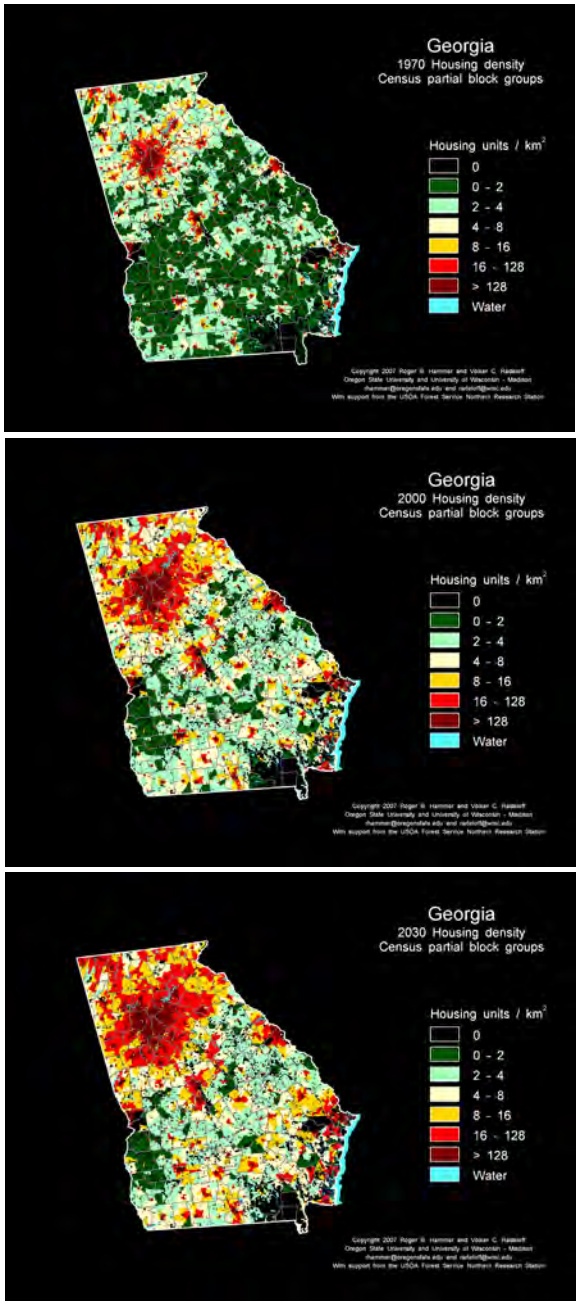


Figure 2.1-3 Changes in Hydrology and Runoff Due to Development Based on Marsh, 1983. Graphic courtesy of Atlanta Journal-Constitution

Figure 2.1-2 Changes in Housing Density in Georgia from 1970 – 2030 (Source: Radeloff, et al)



Finally, development and urbanization affect not only the quantity of stormwater runoff, but also its quality. Development increases the concentration and number of different pollutants carried by runoff. As it runs over rooftops, lawns, parking lots, and industrial sites, stormwater picks up and transports a variety of pollutants to downstream waterbodies. The loss of the original topsoil and vegetation removes a valuable filtering mechanism for stormwater runoff.

The cumulative impact of development and urban activities, and the resultant changes to stormwater quantity and quality in the land area that drains to a stream, river, lake or estuary determines the conditions of the waterbody. This land area that drains to the waterbody is known as its watershed. Urban development within a watershed has a direct impact on downstream waters. The impacts of development on watersheds can be placed into four interrelated categories, which are discussed over the next several pages:

- Changes to stream flow
- Changes to stream geometry
- Impacts to aquatic habitat
- Water quality impacts

2.1.2 Changes to Stream Flow

Urban development alters the hydrology of watersheds and streams by disrupting the natural water cycle, which typically results in:

- Increased Runoff Volumes – Land surface changes can dramatically increase the total volume of runoff generated in a developed watershed, as shown in Figure 2.1-4.
- Increased Peak Runoff Discharges – Increased peak discharges for a developed watershed can be two to five times higher than those for an undeveloped watershed.
- Greater Runoff Velocities – Impervious surfaces and compacted soils, as well as improvements to the drainage system, such as storm drains, pipes, and ditches, increase the speed at which rainfall runs off land surfaces within a watershed.
- Timing – As runoff velocities increase, it takes less time for water to run off the land and reach a stream or other waterbody.
- Increased Frequency of Bankfull and Near Bankfull Events – Increased runoff volumes and peak flows increase the frequency and duration of smaller bankfull and near bankfull events which are the primary channel forming events.
- Increased Flooding – Increased runoff volumes and peaks also increase the frequency, duration and severity of out-of-bank flooding as shown in Figure 2.1-5.
- Lower Base Flows (Dry Weather Flows) – Reduced infiltration of stormwater runoff causes streams to have less baseflow during dry weather periods and reduces the amount of rainfall recharging groundwater aquifers.



Figure 2.1-4 Impervious Cover Increases Stormwater Runoff and Pollutants

Streams in developed areas are often characterized as very "flashy" or "spiky" because of the increased volume of stormwater runoff, greater peak flows, and quicker hydrologic response to storms. This characterization translates into the sharp peak and increased size of the post-development hydrograph, as shown in Figure 2.1-6. This diagram shows the hydrograph for a typical 30-acre residential site during a 10-year storm event.



Figure 2.1-5 Increased Runoff Peaks and Volumes Increase Stream Flows and Flooding
(Right Photo Source: Augusta Chronicle / Photo by Cindy Blanchard)

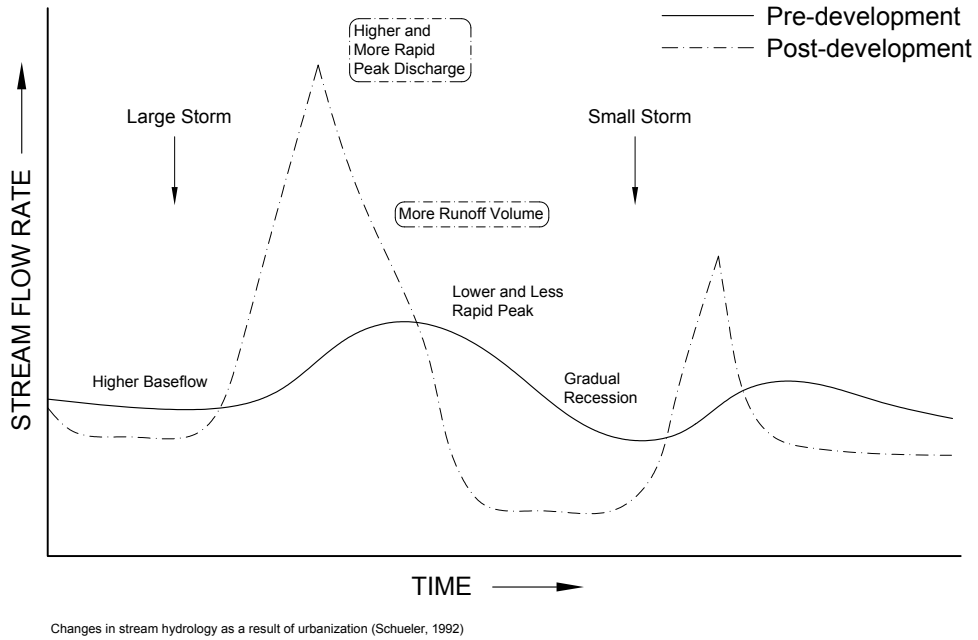


Figure 2.1-6 Hydrograph under Pre- and Post-Development Conditions
(Source: Schueler, 1992)

2.1.3 Changes to Stream Geometry

Changes in the rates and amounts of runoff generated from developed watersheds directly affect the morphology, or physical shape and character, of Georgia's streams and rivers. Some of the common impacts of urban development include:

- Stream Widening and Bank Erosion – Stream channels widen to accommodate and convey the increased runoff and higher stream flows from developed areas. More frequent small and moderate runoff events undercut and scour the lower parts of the stream bank, causing the steeper banks to erode and collapse during larger storms. Higher flow velocities further increase stream bank erosion rates. A stream can widen to many times its original size due to post-development runoff, as illustrated in Figure 2.1-7.
- Stream Downcutting – Another way that streams accommodate higher flows is by downcutting their streambed, as shown in Figure 2.1-8. This causes instability in the stream profile, or elevation along a stream's flow path, which increases velocity and triggers further channel erosion both upstream and downstream.
- Loss of Riparian Tree Canopy – As stream banks are gradually undercut and slump into the channel, trees that had protected the banks are exposed at the roots. This leaves trees less stable and more likely to be uprooted during major storms, which further weakens bank structure.
- Changes in Channel Bed Due to Sedimentation – Due to channel erosion and other sources upstream, sediments are deposited in the stream as sandbars and other features, covering the channel bed, or substrate, with shifting deposits of mud, silt, and sand.
- Increase in Floodplain Elevation – To accommodate the higher peak flow rate, a stream's floodplain elevation typically increases following development in a watershed. This problem is compounded by development in floodplains, which causes flood heights to rise even further. Property and structures that had not previously been subject to flooding may now be at risk.



Figure 2.1-7 Example of Stream Bank Erosion

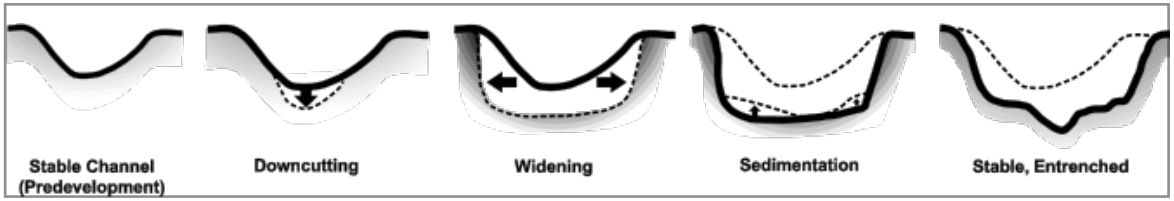


Figure 2.1-8 Changes to a Stream's Physical Character Due to Watershed Development

2.1.4 Impacts to Aquatic Habitat

Along with changes in stream hydrology and morphology, the habitat value of streams diminishes due to development in a watershed. Impacts on habitat include:

- Degradation of Habitat Structure – Higher and faster flows due to development can scour channels and wash away entire biological communities. Stream bank erosion and the loss of riparian vegetation reduce habitat for many fish species and other aquatic life, while sediment deposits can smother bottom-dwelling organisms and aquatic habitat.

- Loss of Pool-Riffle Structure – Streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with "riffles" or shoals of shallower, faster flowing water. These pools and riffles provide valuable habitat for fish and aquatic insects. As a result of the increased flows and sediment loads from urban watersheds, these pools and riffles can disappear and be replaced with more uniform (and often shallower) streambeds that provide less varied aquatic habitats.

- Reduced Baseflows – Reduced baseflows due to increased impervious cover in a watershed and the loss of rainfall infiltration into the soil and water table adversely affect in-stream habitats, especially during periods of drought.

- Increased Stream Temperature – Runoff from warm impervious areas, storage in impoundments, loss of riparian vegetation, and shallow channels can all cause an increase in temperature in urban streams. Increased temperatures can reduce DO levels and disrupt the food chain. Certain aquatic species can only survive within a narrow temperature range. Thermal problems are especially critical for many Piedmont streams, which straddle the borderline between cold water and warm water stream conditions.

- Decline in Wildlife Abundance and Biodiversity – When there is a reduction in various habitats and habitat quality, both the number and the variety, or diversity, of organisms (wetland plants, fish, macro invertebrates, etc.) are also reduced. Sensitive fish species and other life forms disappear and are replaced by those organisms that are better adapted to the poorer conditions. The diversity and composition of benthic (or streambed) habitats have frequently been used to evaluate the health of urban streams. Aquatic insects are also a useful environmental indicator as they are sensitive to changes in water quality.

Fish and other aquatic organisms are impacted by habitat changes brought on by increased stormwater runoff, as well as by water quality changes, due to development and resultant land use activities in a watershed. These impacts are discussed over the next several pages.



Figure 2.1-9 Impacts to Aquatic Habitat Can Eliminate Sensitive Fish Species and Other Aquatic Organisms

2.1.5 Water Quality Impacts

A water body is considered "impaired" when it fails to meet the water quality criteria associated with its designated uses. In Georgia, these uses may include: (1) fishing, (2) drinking water supply, (3) recreation, (4) coastal fishing, (5) wild river and (6) scenic river (GEPD d). Nonpoint source pollution, which is the primary cause of polluted stormwater runoff and water quality impairment, comes from scattered sources — many of which are associated with human activities within a watershed. Development concentrates and increases the amount of nonpoint source pollutants. As stormwater runoff moves across the land, it picks up and carries away both natural and human-made pollutants, depositing them into Georgia's streams, rivers, lakes, wetlands, coastal waters and marshes, and underground aquifers. Nonpoint source pollution is the leading source of water quality degradation in Georgia, as shown in Figure 2.1-10.

Water quality degradation in urbanizing watersheds starts when development begins. Erosion from construction sites and other disturbed areas contributes large amounts of sediment to streams. As construction and development proceed, impervious surfaces replace the natural land cover, and pollutants from human activities begin to accumulate on these surfaces. During storm events, these pollutants are washed off into streams. Stormwater can also cause discharges from sewer overflows and leaching from septic tanks. There are many other causes of nonpoint source pollution in urban areas, including leaking sewer pipes, sanitary sewage spills, and illicit discharges of wastewater and wash waters to storm drains. Table 2.1-1 provides a summary of major stormwater pollutants and their potential effects.

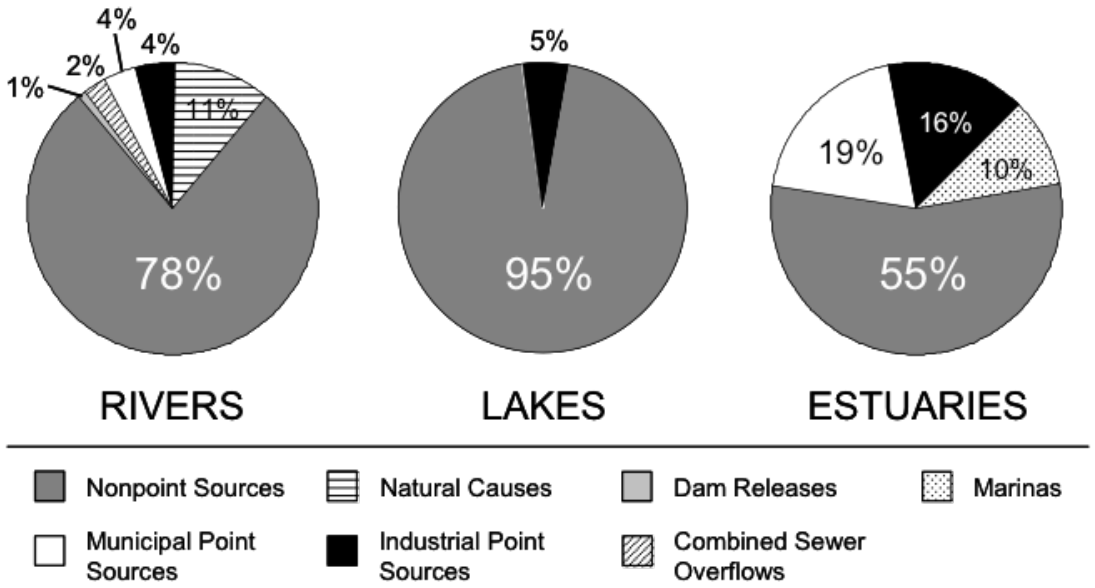


Figure 2.1-10 Causes of Water Quality Impairment in Georgia. In rivers, lakes, and estuaries, nonpoint sources (polluted stormwater runoff) are the major contributor to water quality impairments.

Source: State of Georgia 303(d) List of Impaired Waters, 2001

- Sediments – Eroded soils are a common component of urban stormwater and are a pollutant in their own right. Excessive sediment can be detrimental to aquatic life by interfering with photosynthesis, respiration, growth, and reproduction. Sediment particles transport other pollutants that are attached to their surfaces, such as nutrients, metals, and hydrocarbons. High turbidity due to sediment increases the cost of treating drinking water and reduces the value of surface waters for industrial and recreational uses. Sediment may also fill ditches, streams, storm sewers, and pipes, which can restrict flow and lead to flooding and property damage. Sedimentation can reduce the capacity of reservoirs and lakes, block navigation channels, and fill harbors and silt estuaries. Erosion from construction sites, exposed soils, street runoff, and stream bank erosion are the primary sources of sediment in urban runoff.

Table 2.1-1 Pollutants in Urban Stormwater (Nonpoint Sources)

Constituents	Potential Effects
Sediments — Suspended Solids, Dissolved Solids, Turbidity	• Stream turbidity • Habitat changes • Recreation and aesthetic losses • Contaminant transport • Filling of lakes and reservoirs • Unsafe drinking water
Nutrients — Nitrogen and Phosphorus Compounds	• Algae blooms • Eutrophication • Ammonia and nitrate toxicity • Recreation and aesthetic losses
Pathogens — Total and Fecal Coliforms, Fecal Streptococci, Viruses, E. Coli, Enterococci	• Ear and intestinal infections • Shellfish bed closure • Recreation and aesthetic losses
Reduced Oxygen in Streams — Vegetation, Sewage, Other oxygen demanding substances	• Dissolved oxygen depletion • Odors • Fish kills
Hydrocarbons — Oil, Greases, Gasoline, Leaking vehicles, Improper disposal of motor oil	• Danger to aquatic species • Recreational loss • Unsafe drinking water
Toxic Materials — Heavy metals (cadmium, copper, iron, lead, magnesium, nickel, zinc), Organics, Pesticides/Herbicides	• Human and aquatic toxicity • Bio-accumulation in the food chain • Unsafe drinking water
Thermal Pollution — Changes in water temperature	• Dissolved oxygen depletion • Habitat changes • Growth of harmful substances in water • Fish kills
Trash and Debris — Floatables	• Recreation and aesthetic losses • Human and aquatic toxicity

Source: State of Georgia 303(d) List of Impaired Waters, 2001

- Nutrients – Runoff from urban and rural watersheds can contain increased nutrients, such as nitrogen or phosphorus compounds. Increased nutrient levels can be a problem as they promote weed and algae growth in lakes, streams, estuaries, and bays. Algae blooms can block sunlight from reaching underwater grasses, deplete oxygen when the organic matter decomposes (eutrophication), and cause public service water drinking systems to be contaminated. Further, nitrification of ammonia by microorganisms can consume dissolved oxygen (DO), while nitrates can contaminate water supplies. Sources of nutrients in the environment include fertilizers and vegetative litter; animal waste; sewer overflows and leaks from public, commercial, and residential systems; septic tank seepage; and detergents. Deposition from atmospheric nitrogen into surface waters is also an important source.

- Pathogens – Pathogens are harmful to human health and in natural waters may consist of bacteria, protozoa, viruses, and other microscopic organisms. The sources of pathogens in urban stormwater and streams may be leaking private or public sewer lines, combined sewer overflows, malfunctioning septic tanks, animals, pets, and birds. Agricultural runoff from livestock management areas, manure spreading, and concentrated animal feeding operations (CAFOs) can also contribute to pathogenic contamination. Pathogens can also contaminate shellfish beds, preventing their harvesting and human consumption. Historically the fecal coliform group of bacteria has been used as indicator that pathogens may be present. However correlation between the presence of fecal coliforms and occurrence of illness is not strong; other pathogen indicators such as the e. coli group in freshwater and enterococci group in saltwater correlate better with human illness from swimming at bathing beaches.

- Reduced Oxygen in Streams – The decomposition process of organic matter uses up DO in the water, which is vital for fish and other aquatic life. As organic matter in the watershed is taken up by stormwater and conveyed to receiving waters, and as weed and algae growth occurs due to increased nutrient loading, DO levels can be rapidly depleted. If the DO deficit is severe enough, fish kills may occur and stream life can weaken and die. In addition, oxygen depletion can affect the release of toxic chemicals and nutrients from sediments deposited in a waterway. All forms of organic matter in urban stormwater runoff such as leaves, grass clippings, and pet waste contribute to this problem. Additionally, there are non-stormwater discharges of organic matter to surface waters, such as sanitary sewer leakage and septic tanks leaching. While organic material is necessary for aquatic life, an overabundance of organic matter can contribute to these challenges.

- Hydrocarbons – Oils, greases, and gasoline contain a wide array of hydrocarbon compounds, some of which have been shown to be carcinogenic, tumorigenic, and mutagenic in various species of fish and other lifeforms. In large quantities, oil can impact drinking water supplies and affect recreational use of waters. Oils and other hydrocarbons wash off roads and parking lots, primarily due to vehicle leaks. Other sources include improper disposal of motor oil in storm drains and streams, spills at fueling stations, and restaurant grease traps.

- Toxic Materials – Besides oils and greases, urban stormwater runoff can contain a wide variety of other toxicants and compounds, including heavy metals such as lead, zinc, copper, and cadmium, as well as organic pollutants that include pesticides, PCBs, and phenols. These contaminants are of concern because they are toxic to aquatic organisms and can bio-accumulate in the food chain. They also impair drinking water sources and human health. Many toxicants accumulate in the sediments of streams and lakes. Sources of these contaminants include industrial and commercial sites, urban surfaces such as rooftops and roadways, vehicles and other machinery, improperly disposed of household chemicals, landfills, hazardous waste sites, and atmospheric deposition.

- Thermal Pollution – As runoff flows over impervious surfaces, such as asphalt and concrete, it increases in temperature before reaching a stream or pond. Water temperatures are also increased due to shallow ponds and impoundments along a watercourse and fewer trees along streams to shade the water. Since warm water holds less DO than cold water, this "thermal pollution" further reduces oxygen levels in urban streams. Temperature changes can severely impact certain aquatic species, such as trout and stoneflies, which can survive only within a narrow temperature range.

- Trash and Debris – Considerable quantities of trash and other debris are washed through storm drain systems and into streams, lakes and bays, as shown in Figure 2.1-11. The presence of trash is an indicator of other anthropomorphic effects on water quality, stream structure, and aquatic habitat. The primary impacts are aesthetic "eyesores" in waterways, reduction in recreational value, and harm to aquatic life. Terrestrial and aquatic animals can be harmed when they consume or become entangled/engulfed in solid waste. Debris can also cause blockages of the stream channels and stormwater infrastructure, which can result in localized flooding and erosion. Stormwater infrastructure is directly affected by trash and debris-caused blockages resulting in reduction in capacity; increased maintenance is thus needed to restore to proper condition.

2.1.6 Effects on Lakes, Reservoirs, and Estuaries

Stormwater runoff into lakes and reservoirs can have some unique negative effects. A notable impact of urban runoff is the filling in of waterbodies with sediment. Another significant water quality impact on lakes related to stormwater runoff is nutrient enrichment, which can result in the undesirable growth of algae and aquatic plants. Lakes do not flush contaminants out as quickly as streams, so they act as sinks for nutrients, metals and sediments. This means that lakes can take longer to recover if contaminated.

Stormwater runoff can also impact estuaries, especially if runoff events occur in pulses, disrupting the natural salinity of an area and providing large loads of sediment, nutrients, and oxygen-depleting materials. These rapid pulses or influxes of fresh water into the watershed may be two to ten times greater than normal and may lead to a decrease in the number of aquatic organisms living in the unique estuarine environment. Tidal flow patterns can also effectively trap and concentrate runoff pollutants.



Figure 2.1-11 Trash and Debris Impact the Visual and Recreational Value of Waterbodies

2.2 Stormwater Impacts on Georgia Communities

Description: Stormwater runoff can have significant impacts on the health of our water resources; this can be due to changes in both water quality and water quantity. Yet stormwater runoff does not only lead to environmental issues. Improperly managed stormwater runoff often has physical and economic impacts on communities in Georgia and downstream.

KEY CONSIDERATIONS

Improperly managed stormwater can created many negative impacts on a community, including:

- Increased Flooding
- Endangerment of Human Life from Floodwaters
- Property and Structural Damage Due to Flooding
- Impairment of Drinking Water Supplies (Surface and Groundwater)
- Increased Cost of Treating Drinking Water
- Loss of Recreational Opportunities
- Declining Property Values of Waterfront Homes and Businesses
- Loss of Sport and Commercial Fisheries
- Closure of Shellfish Harvesting Areas
- Reduced Drought Resiliency
- Increased Litigation
- Reduction in Quality of Life



As discussed in Section 2.1, stormwater runoff can have significant impacts on the health of our water resources, due to changes in both water quality and water quality. Yet stormwater run-off does not only lead to environmental issues. Improperly managed stormwater runoff often has real physical and economic impacts on communities in Georgia. For example:

- Increased Flooding – The increased stormwater runoff rates and volumes resulting from the land development process also cause an increase in the frequency, duration and severity of overbank and extreme flooding events (Figure 2.2-1). In other words, as more development occurs without proper stormwater management, our natural and man-made infrastructure becomes more vulnerable to flooding.

- Endangerment of Human Life from Floodwaters – A primary concern of many local governments is that of public safety. Development changes the hydrology of a watershed such that increased runoff peak flows and volumes can potentially overwhelm under-designed stormwater drainage facilities, structural controls, and downstream conveyances, putting human life at risk. Floodwaters can cause driving hazards by overtopping roadways and washing out bridges, as well as by carrying sediment and debris onto streets and highways.

- Property and Structural Damage Due to Flooding – Due to upstream development, properties that were previously outside the 100-year floodplain may now find themselves subject to flood damage. Areas that previously flooded only once every 10 years may now flood far more frequently and with more severity. Increased property and infrastructure damage can also result from stream channel widening, undersized runoff storage and conveyance facilities, and development in the floodplain.

- Impairment of Drinking Water Supplies (Surface and Groundwater) – Water quality degradation from polluted stormwater runoff can contaminate surface and groundwater drinking water supplies, making them potentially unfit for community use.

- Increased Cost of Treating Drinking Water – Even if a drinking water supply remains viable, heavy concentrations of contaminants, such as sediment and bacteria, can increase the cost of water treatment.



Figure 2.2-1 Flooding and Pollution from Stormwater Runoff





Figure 2.2-2 Flooding Endangers Human Life and Property
(Left Photo Source: Augusta Chronicle / Photo by Jeff Janowski)

- Loss of Recreational Opportunities – Turbidity from sediment, trash, toxic pollutants, and microbial contamination in stormwater runoff all reduce the viability of receiving waterbodies for recreational activities, such as swimming, boating and fishing. Additionally, aesthetic losses along these waterways also reduce the experience for many noncontact recreational activities, including picnicking, jogging, biking, camping, and hunting.
- Declining Property Values of Waterfront Homes and Businesses – Stormwater pollution affects the appearance and quality of downstream waterbodies, influencing the desirability of working, living, traveling, or owning property near the water.
- Loss of Sport and Commercial Fisheries – Commercial fisheries are a significant part of Georgia's economy, generating over $20 million annually. Only 22% of all Georgia lakes are safe for fish consumption. A significant part of the problem is attributable to polluted stormwater runoff.
- Closure of Shellfish Harvesting Areas – Only 35% of Georgia's estuaries are safe for shellfish consumption. Again, a major source of impairment is stormwater runoff.



Figure 2.2-3 Water Quality Problems Due to Runoff Impact Drinking Water Supplies and Recreational Use of Streams, Rivers, Lakes, and Beaches



Figure 2.2-4 Waterfronts are an Important Resource to Georgia Communities that Should Be Protected from the Effects of Polluted Stormwater

(Columbus Riverwalk (left) and Savannah Waterfront (right). Photos by Ed Jackson)

- Reduced Drought Resiliency – Increased stormwater runoff volumes resulting from land development reduces the amount of rainfall available to recharge shallow groundwater aquifers and feed freshwater rivers and streams during dry weather. Thus, streams have lower base flow, and are less able to withstand extended periods of drought.
- Increased Litigation – Legal action can be brought against local governments that have not adequately addressed stormwater runoff drainage and water quality problems.
- Reduction in Quality of Life – Stormwater quantity and quality impacts can reduce the quality of life in a community, making it a less desirable place to live, work, and play.



Figure 2.2-5 Polluted Stormwater Runoff Impacts Sport and Commercial Fisheries and Shellfish Harvesting

CASE STUDY

Impacts of Development on the Chattahoochee River National Recreation Area

In 1978, the Atlanta region benefited from the acquisition by the United States Department of Interior, National Park Service of 48-miles of Chattahoochee River buffer and open space for the creation of the Chattahoochee River National Recreation Area (CRNRA). Crossing four counties, nine municipalities, and three congressional districts, it is located in the North Georgia Metropolitan Planning District. The CRNRA's 6,700 acres is an excellent example of the community benefits that result when land is purchased to conserve nature. Treasured by local residents and visitors to Georgia alike, the CRNRA land and water resources are worthy of protection.

However, the CRNRA, like many of Georgia's water resources, has seen significant impacts from development. Water quality data provided by the State of Georgia for the Upper Chattahoochee watershed shows that the watershed is not meeting Georgia's water quality standards for many pollutants. Watersheds along the Chattahoochee are polluted for bacteria and sediment with reduced biodiversity in fish and macro-invertebrates. In addition, Georgia's water quality standards are not being met for other pollutants, including lead, PCBs in fish tissue, tetrachloroethylene, chlorophyll-A (nutrients), copper, and zinc. The probable sources contributing to the pollution are listed as primarily non-point source and unspecified urban stormwater. Data and information about Georgia streams and rivers can be found in the United States Environmental Protection Agency's ATTAINS database at http://iaspub.epa.gov/tmdl_waters10/attains_state.control?p_state=GA.

Often, the most visible sign of an impaired river system can be seen on the banks itself. Stream bank erosion caused by high volumes and rates of stormwater runoff is a common site in developed watersheds.

Improving water quality along the Chattahoochee and protecting the CRNRA will require action by all local governments with contributing watersheds. Application of LID at the site scale – conserving natural landscapes, reducing impervious cover, and implementing sound best management practices – through the principles put forth in the Georgia Stormwater Management Manual is one of several important steps in achieving this goal. However, application of LID and green infrastructure at the regional and neighborhood scale will be essential as well. Identification and preservation of natural resources and open spaces that naturally retain and cleanse stormwater should be undertaken at the regional scale, while construction of water quality and quantity retrofits, such as stormwater wetlands and bioretention should be done at the neighborhood scale, in key locations where they can be most beneficial for both communities and the CRNRA. With these efforts, the National Park Service should be better able to meet its mission, to leave the Chattahoochee River National Recreation Area "unimpaired for the enjoyment of future generations."



Figure 2.2-6 Crooked Creek, Norcross, GA: Creek Entrenchment and Stream Bank Instability
(Photo: Bob Howard, 8/27/15)



Figure 2.2-7 Chattahoochee River bank erosion caused by fallen tree undermined by scouring in high flows
(Photo: CRNRA, National Park Service, 9/5/15)

2.3 Benefits of Addressing Stormwater Impacts for Georgia Communities

Description: Stormwater management can have many positive impacts beyond improvements to water quantity and water quality management.

KEY CONSIDERATIONS

The following benefits of stormwater management are discussed in this section:

Community Development
- Public Health
- Beautification
- Public Space

Water Quantity
- Disaster Preparedness, Resiliency, and Flood Control
- Combined Sewer Overflow (CSO) Reductions
- Community Rating System (CRS) Credits

Water Quality
- Resiliency of Water Supply / Source Water Protection
- Healthy Receiving Waters
- Public Health
- Recreation

Regulatory Benefits
- Municipal Separate Storm Sewer Systems (MS4s)
- Total Maximum Daily Loads (TMDLs)
- Off-Site Compliance



Section 2.2 discusses the many negative impacts that can be caused by development and insufficient, improper, or non-existent stormwater management. Proper stormwater management and the implementation of sound stormwater management practices, especially LID, can eliminate or alleviate many of those impacts. In addition, there are many other benefits that can be realized by Georgia communities when a proactive approach to stormwater management and the implementation of LID practices is taken. Communities should consider these benefits along with their stormwater management goals when selecting a stormwater management approach.

COMMUNITY DEVELOPMENT BENEFITS

- Public Health – Provision of greenspace and pedestrian connectivity allows for more opportunities to recreate and exercise, which can encourage community members to be more physically active. Improved access to nature also contributes to improved overall health and wellness.
- Beautification – Installation of LID and green infrastructure creates additional greenspace in communities, which can improve the aesthetic qualities of urban areas.
- Public Space – Stormwater facilities can be designed to incorporate community gathering spaces. Smart design of stormwater facilities allows them to provide multiple benefits.
- Community Rating System (CRS) Credits – The Federal Emergency Management Agency (FEMA) offers reductions in flood insurance premiums for private property owners in communities that have earned credit for flood resiliency activities, including stormwater projects. Through the CRS, these premium reductions can be up to 45%. See Section 5.5.3.

WATER QUANTITY BENEFITS

- Disaster Preparedness, Resiliency, and Flood Control – Communities that plan and implement projects to meet their stormwater management needs are generally better able to convey stormwater runoff from flood events to detention facilities or receiving water bodies, and away from sensitive properties and infrastructure.
- Combined Sewer Overflow (CSO) Reductions – Implementation of sound stormwater management practices, especially low impact development (LID) practices within CSO areas, can lead to a reduction in overflow events. Many communities have found that implementing LID stormwater management practices is a more cost effective technique to address CSOs than constructing large storage facilities or sewer separation projects.
- Waterway Resiliency – Utilization of Better Site Design and LID stormwater management practices that reduce runoff and increase infiltration can reduce the intensity of flooding events while at the same time increasing base flows between storm events, leading to healthier, more resilient waterways.

WATER QUALITY BENEFITS

- Resiliency of Water Supply / Source Water Protection – Conservation of land, open space, and forest resources reduces the threat of contaminants being introduced to drinking water supplies.
- Healthy Receiving Waters – Effective stormwater management practices will lead to reduced erosion and sedimentation in our waterways, as well as a reduction in nutrient loads that contribute to algae blooms and fish kills.
- Public Health – Preserving water quality and reducing pollution, through implementation of stormwater projects and best practices, allow for safe recreation in receiving waters.
- Recreation – Rivers, lakes, streams, and oceans have long been major destinations for recreation and enjoyment for many of Georgia's residents and visitors. Removal of debris and prevention of contamination improves recreational experiences for all water-goers.

REGULATORY BENEFITS

- Municipal Separate Storm Sewer Systems (MS4s) – Stormwater management and the implementation of best practices help municipalities comply with their MS4 permit.
- Total Maximum Daily Loads (TMDLs) – Completion of stormwater projects leads to nutrient and other pollutant reductions, which is vital to the implementation of TMDL plans that have been developed for certain impaired waters.
- Off-site Compliance – Regional facilities can create economies of scale that reduce the financial resources and land required to manage stormwater in a community. See Section 5.7 for more information on off-site compliance.



Figure 2.3-1 Sewer Overflow in the Chattahoochee River National Recreation Area (Photo: National Parks Service)

2.4 Integrating Post-Construction Stormwater Management

Description: Post-Construction Stormwater Management is only one of several important ways to address the effects of stormwater runoff. Additional programs and approaches are needed to achieve a comprehensive watershed and stormwater management program.

KEY CONSIDERATIONS

The following six areas should be addressed at a minimum, which form the "umbrella" of comprehensive watershed and stormwater management:

- Watershed Planning
- Development Requirements
- Erosion and Sediment Control
- Floodplain Management
- Operations and Maintenance
- Pollution Prevention



For a number of reasons — including public health and safety, environmental and economic concerns, legal liability, regulatory responsibility, and to improve quality of life — cities and counties across Georgia must manage development and stormwater runoff in their communities.

The focus of this Manual is how to effectively deal with the impacts of urban stormwater runoff through effective post-construction stormwater management at the site scale. However, site-scale post-construction stormwater management is only one aspect of a comprehensive watershed and stormwater program. Comprehensive watershed and stormwater management involves both the prevention and mitigation of stormwater runoff quantity and quality impacts through a variety of methods and mechanisms. Addressing watershed and stormwater management, and more specifically, green infrastructure at the landscape scale and neighborhood scale can provide significant benefits that cannot be achieved with site-scale efforts alone. By looking at stormwater management at various scales, stormwater managers can influence the impacts of development in a number of ways. For example, land use planning and zoning can be used to direct growth away from sensitive aquatic and terrestrial resources; land acquisition can be used to conserve valuable natural resources; and better site design techniques can be used to minimize land disturbance on development sites. Comprehensive stormwater management requires stormwater managers to be active in helping a community craft policies that achieve the goal of preserving natural resources. In this way, engaging in growth and development discussions can be considered the "first stormwater best management practice." For a detailed discussion of how stormwater management intersects with broader growth and development decisions, see Chapter 3, Land Use Planning as the First BMP in the manual *Managing Stormwater in Your Community, A Guide for Building an Effective Post-Construction Program.*

In general, comprehensive watershed and stormwater management can be broken down into the following six areas:

- **Watershed Planning** – Using the watershed as the framework for managing land use and developing large-scale solutions to regional stormwater quantity and quality issues. The Environmental Protection Agency (EPA)'s *Handbook for Developing Watershed Plans to Restore and Protect Our Waters,* and the Center for Watershed Protection (CWP)'s *An Integrated Framework to Restore Small Urban Watersheds* are both useful watershed planning resources.

  Stormwater master planning and watershed planning help to establish the priorities for stormwater management decision-making and should be incorporated early into an effective local program. Watershed planning is a tool which allows a community to assess current and future stormwater problems as well as potential solutions within a drainage basin. It can be used to assess the health of existing water resources and make informed land use, transportation, greenspace and other community-level decisions based upon current and projected land use and development within a watershed and its associated subwatersheds. Watershed plans assist communities in developing and evaluating stormwater management scenarios and alternatives.

  Watershed and stormwater master plans can be used to identify drainage system and stream segments in need of channel improvement or restoration, and potential locations for regional stormwater control facilities. Watershed planning can also provide a community with the necessary information for conserving natural areas and open space as well as the development of riparian buffers and greenways. In addition, they may also promote a wide range of additional goals including water supply protection, wetland protection and preservation, streambank and stream corridor restoration, habitat protection, protection of historical and cultural resources, enhancement of recreational opportunities, and aesthetic and quality of life issues.

  In addition to providing better opportunities for managing stormwater problems and watershed resources, the watershed planning approach also involves stakeholders and provides community consensus in the land use and stormwater management decision-making process. Further, watershed plans promise a reduction in the overall capital and operation and maintenance costs for stormwater management from reduced downstream flooding and optimal siting and sizing of stormwater control measures. Other benefits include contributions to community land use plans, and increased equity and opportunities for developers.

- **Development Requirements** – Addressing the stormwater impacts of new development and redevelopment through stormwater management requirements and minimum standards. Development requirements are discussed in Chapter 4 and Section 5.1, with detailed specifications in Volume 2, Chapter 4.

  Volume 2 of this Manual is a comprehensive technical document for stormwater management which can be adopted by a community as its primary design aid for developers. Volume 2 is designed to support the recommended stormwater management standards and includes information and criteria on stormwater site plan preparation, recommended hydrologic methods, structural stormwater control selection and design, drainage system design, and inspection and maintenance provisions. A community may wish to prepare an addendum to Volume 2 which includes any specific local criteria and/or additional material. Additional design aids may be necessary depending on a local community's requirements.

- **Erosion and Sediment Control** – Controlling erosion and soil loss from construction areas and resultant downstream sedimentation. For more information on Erosion and Sediment Control, see the *Manual for Erosion and Sediment Control in Georgia*.

  Sediment loadings to receiving waters are highest during the construction phase of development. Consequently, erosion and sediment control on construction sites is an important element of a comprehensive stormwater management program for water quality and habitat protection. A combination of clearing restrictions, erosion prevention, and sediment controls, coupled with a diligent plan review and strict construction enforcement are needed to help mitigate these impacts.

  It is essential that erosion and sediment control be considered in stormwater concept plans and implemented throughout the construction phase to prevent damage to natural stormwater drainage systems and post-construction structural stormwater controls and conveyance facilities.

- **Floodplain Management** – Preserving the function of floodplain areas to reduce flood hazards, minimize risks to human life and property, reduce modifications to streams, and protect water quality. For further information on Floodplain Management, see the Floodplain Management in Georgia Quick Guide, prepared by the Georgia Department of Natural Resources. http://www.floods.org/PDF/QuickGuide/GAQG2009_ScreenView.pdf

  Floodplain management involves the designation of flood-prone areas and the limiting of their uses to those compatible with a given degree of risk. It is also aimed at minimizing modifications to streams, reducing flood hazards and protecting the water quality of streams. As such, floodplain management can be seen as a subset of the larger consideration of surface water and stormwater management within a local community.

  Though it is often considered separately in most communities, there are many areas in which floodplain management directly overlaps with other areas of stormwater management. The development of riparian buffers and greenway corridors along streams and rivers can also preserve floodplain areas and protect their function in safely conveying floodwaters. Floodplain regulations and development restrictions, particularly when based upon the full build-out 100-year floodplain, can greatly reduce future flooding impacts and may allow communities to waive stormwater quantity control (detention) requirements for larger storm events in some areas.

  Ideally, flooding and floodplains should be managed at the watershed level, and floodplain management should be an important goal of comprehensive watershed plans. Consequently, floodplain management activities should be fully integrated into comprehensive stormwater management programs and handled in a complementary and coordinated approach.

- **Operations and Maintenance** – Ensuring that stormwater management systems and structural controls work as designed and constructed. Operation and maintenance activities are discussed in Section 5.2, with recommendations for individual best management practices (BMPs) included in Volume 2 Appendix E.

  Ongoing operation and maintenance of the various components of a stormwater system is an essential component of a comprehensive

stormwater management program. Failure to provide effective maintenance can reduce the hydraulic capacity and the pollutant removal efficiency of stormwater controls and conveyance systems.

Operations and maintenance activities can include cleaning and maintenance of catch basins, drainage swales, open channels, storm sewer pipes, stormwater ponds, and water quality BMPs. Street sweeping and other pollution reduction activities also fall under operations and maintenance. Ideally, the best program addresses operations and maintenance concerns proactively instead of reacting to problems that occur such as flooding or water quality degradation.

A clear assignment of stormwater inspection and maintenance responsibilities, whether they be accomplished by the local government, land owners, private concerns, or a combination of these, is essential to ensuring that stormwater management systems function as they were intended. Maintenance requirements are an important consideration in the selection and design of structural stormwater controls and therefore site designs should strive to make their systems as simple and maintenance free as possible.

Stormwater system operations and maintenance can also include the retrofitting of existing development to meet water quantity and/or water quality goals.

- **Pollution Prevention** – Preventing stormwater from coming into contact with contaminants and becoming polluted through a number of management measures. This is discussed further in the *Georgia Stormwater Management Manual, Volume 3: Pollution Prevention Guidebook*, available at http://northgeorgiawater.org/wp-content/uploads/2015/05/GSMMVol3.pdf

  Also known as "source controls," pollution prevention management practices are an important way to prevent water quality problems in stormwater runoff from a variety of sources. The intent of source control practices is to prevent stormwater from coming in contact with pollutants in the first place rather than providing structural controls for treatment and pollutant removal. Pollution prevention include categories of measures such as:

  » Materials management (use, exposure, and disposal/recycling controls)
  » Spill prevention and cleanup
  » Removal of illicit connections
  » Prevention of illegal dumping
  » Street and storm drain maintenance
  » Public information and education

  Examples of source control practices include covering piles of soil to prevent erosion, safe hazardous waste storage, dry weather screening of stormwater outfalls to detect illicit connections, storm drain stenciling, street sweeping, fertilizer use restrictions, leaf collection programs, and efforts to educate and influence citizen's actions (such as proper motor oil disposal and household hazardous waste management) that impact stormwater runoff quality.

  Many of these practices are easily implemented and are cost-effective means of reducing stormwater contaminants. As such, they should be considered, where appropriate, for all residential, commercial, industrial, institutional, and municipal projects and activities. In addition, many are required activities for NPDES municipal stormwater management programs.

Together these six categories create the "umbrella" of comprehensive watershed and stormwater management, shown in Figure 2.4-1.



Figure 2.4-1 The "Umbrella" of Comprehensive Stormwater Management

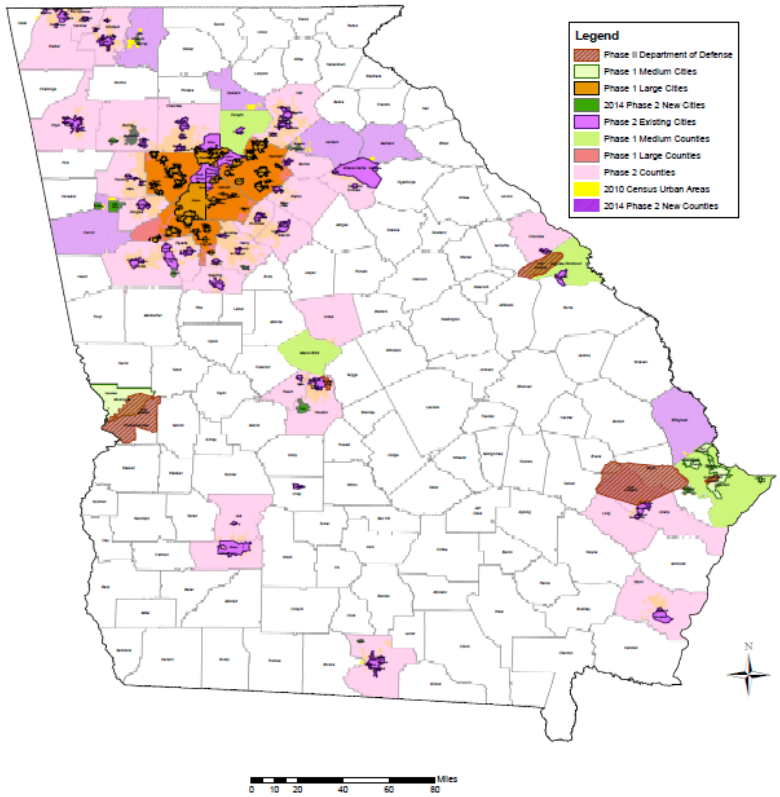
2.5 National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Program Requirements

Description: The National Pollutant Discharge Elimination System (NPDES) was established by the Clean Water Act in 1972 to address discharges containing pollutants from point and non-point sources. Municipal Separate Storm Sewer System (MS4) permitting requirements were established under the NPDES program beginning in 1987, requiring certain municipalities to minimize pollutants in stormwater runoff to the maximum extent practicable (MEP). Under Georgia EPD's MS4 permit program, communities in regulated areas are required to establish a comprehensive stormwater management program (SWMP) to address stormwater issues.

KEY CONSIDERATIONS

Many of the urban water bodies in Georgia are impaired, and untreated stormwater runoff is typically a major cause of those impairments. The NPDES MS4 program represents an effort to regulate stormwater runoff and return these water bodies to conditions that support their designated uses. There are two types of MS4 permits. Phase I communities are medium and large cities and certain counties with populations of 100,000 or more. Phase II communities are smaller communities in urbanized areas, as determined by the U.S. Census Bureau. Both Phase I and Phase II MS4 communities must meet certain requirements to improve the water quality of stormwater runoff.

Georgia 2014 MS4s and Urban Areas



The National Pollutant Discharge Elimination System (NPDES) permit system was originally established by the Clean Water Act of 1972 to control wastewater discharges from various industries and wastewater treatment plants known as "point" sources. Congress amended the Clean Water Act with the Water Quality Act of 1987 to expand the NPDES permit program to address "non-point" source pollution. The Municipal Separate Storm Sewer System (MS4) stormwater discharge permitting program under the NPDES regulations establishes requirements for municipalities to minimize pollutants in stormwater runoff to the "maximum extent practicable."

Under Georgia EPD's Municipal Separate Storm Sewer System (MS4) permit program, local governments in regulated areas are required to establish a comprehensive stormwater management program (SWMP), develop a plan and program to control stormwater pollution discharges to waters of the State to the maximum extent practical, and eliminate non-stormwater discharges from entering the stormwater system.

This is accomplished through the implementation of a municipal program which includes such measures as structural and non-structural stormwater controls, development standards, best management practices (BMPs), regular inspections, enforcement activities, stormwater monitoring and public education efforts. Stormwater management ordinances, erosion and sediment control ordinances, development regulations and other local regulations provide the necessary legal authority to implement the stormwater management programs.

Phase I communities are issued individual MS4 permits, while Phase II communities are regulated under a general permit, rather than receiving an individual MS4 permit

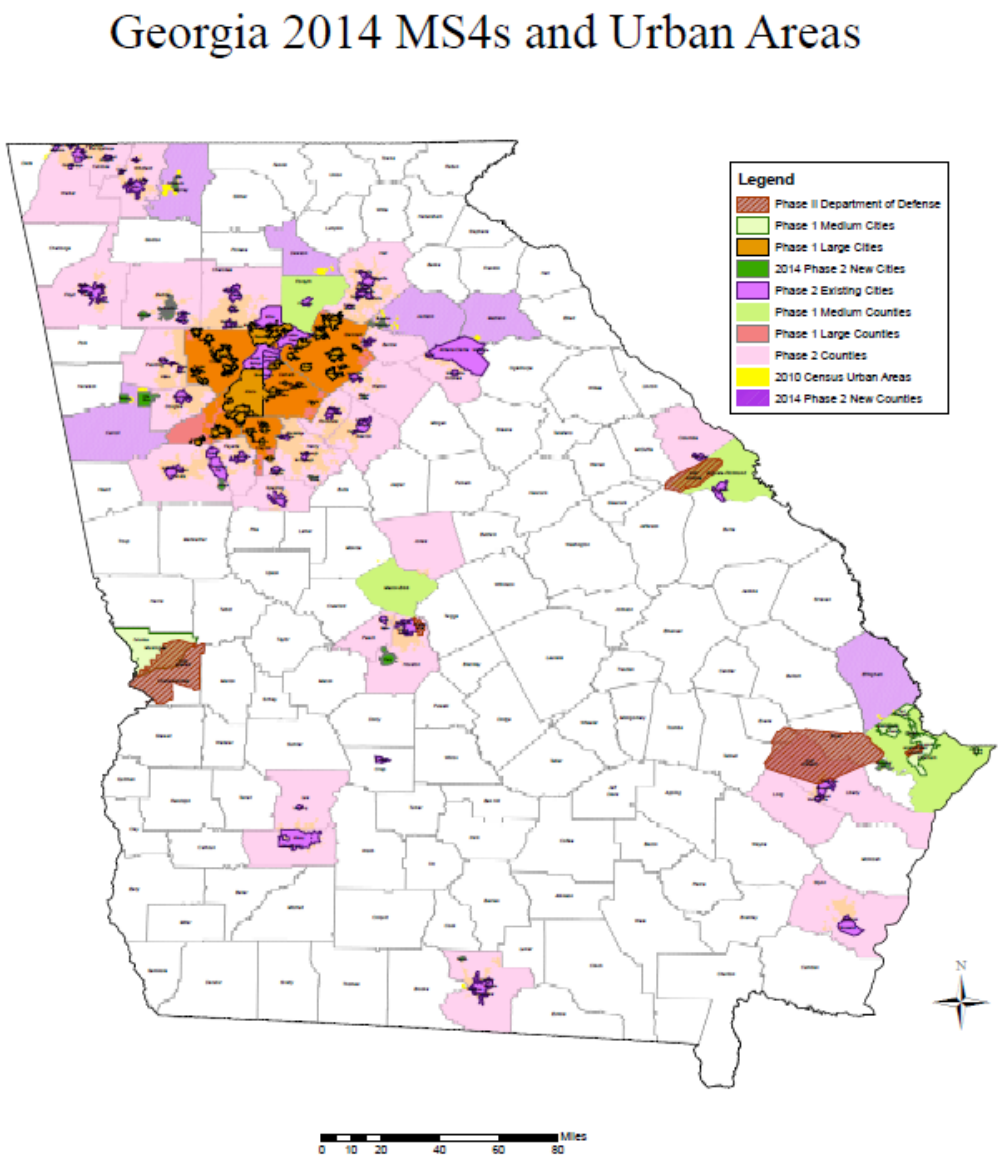
2.5.1 MS4 Phase I Permits

Since 1993, the Phase I permit requirements have applied in Georgia to large and medium municipal separate storm sewer systems (defined by a population greater than 250,000 and population between 100,000 and 250,000, respectively). Phase 1 permits typically include requirements on the following :

- Structural and Source Control Measures
  - » Stormwater System Mapping
  - » Stormwater System Inspection and Maintenance
  - » Street Maintenance and Cleaning
  - » Evaluation of Flood Management Projects
  - » Inventory and Inspection of Municipal Waste Facilities
  - » Program to Reduce Pesticide, Fertilizer, and Herbicide Pollution
- Illicit Discharge Detection & Elimination Program
- Industrial Facility Stormwater Runoff Control Program
- Inventory and Inspection of Highly Visible Pollutant Sources
- Construction Site Management Program
- Post-Construction Development Standards
- Employee Training Programs
- Impaired Water Monitoring Plan for 305(b)/303(d) Listed Areas
- Public Education and Public Involvement Programs
- Green Infrastructure Inventory, Inspection and Maintenance Programs
- Enforcement Response Plan

Within each permit issued, requirements are defined and explained for how the community should meet the permit standards. As of 2015, the Phase I program includes the following jurisdictions:

Acworth
Alpharetta
Atlanta
Austell
Avondale Estates
Berkley Lake
Bloomingdale
Buford
Chamblee
Chatham County
Clarkston
Clayton County
Cobb County
College Park
Columbus
Dacula
Decatur
DeKalb County
Doraville
Duluth
East Point
Fairburn
Forest Park
Forsyth County
Fulton County
Garden City
Grayson
Gwinnett County
Hapeville
Jonesboro
Kennesaw
Lake City
Lawrenceville
Lilburn
Lithonia
Lovejoy
Macon-Bibb County
Marietta
Morrow
Norcross
Palmetto
Pine Lake
Pooler
Port Wentworth
Powder Springs
Richmond County
Riverdale
Roswell
Savannah
Smyrna
Snellville
Stone Mountain
Sugar Hill
Suwanee
Thunderbolt
Tybee
Union City



2.5.2 MS4 Phase II Permits

Federal regulations were adopted in 1999 to extend the NPDES MS4 permit program to smaller (Phase II) communities, with populations below 100,000. Phase II rules take a slightly different approach for implementing local stormwater management programs by requiring the SWMP to consist of six "minimum control measures." The six minimum control measures are listed below, with excerpts from the General NPDES Storm-water Permit for Stormwater Discharges Associated with Small Municipal Separate Storm Sewer Systems. Guidance on developing a stormwater management program that complies with the six minimum measures can be found here: http://epd.georgia.gov/storm-water, and the EPA has developed helpful fact sheets on each minimum measure: http://www3.epa.gov/npdes/pubs/fact2-9.pdf.

Figure 2.5-1 Phase I and Phase II MS4 Communities in Georgia
Note: For some counties, the MS4 permit covers the entire county, while for others the MS4 permit covers only the urbanized area of the county.)
Source: Georgia Environmental Protection Division

1. Public Education and Outreach on Storm Water Impacts "The permittee must implement a Public Education Program to distribute educational materials to the community and/or conduct equivalent outreach activities about the impacts of stormwater discharges on water bodies and the steps that the public can take to reduce pollutants in storm water runoff." EPA's Nonpoint Source (NPS) Outreach Toolbox (http://cfpub.epa.gov/npstbx) provides many resources for developing a public education and outreach program.

2. Public Involvement / Participation "The permittee must, at a minimum, comply with State and local public notice requirements when implementing a public involvement / participation program. The permittee is encouraged to make the approved SWMP publicly accessible electronically or by other means." EPA's Public Involvement / Participation website provides many resources for developing a public outreach program: http://www.epa.gov/international-cooperation/public-participation-guide-internet-resources-public-participation

3. Illicit Discharge Detection and Elimination (IDDE) "The permittee must develop, implement and enforce a program to detect and eliminate illicit discharges...into its MS4." The Center for Watershed Protection's manual, Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments, details all of the techniques involved in developing an effective IDDE program: http://www.cwp.org/online-watershed-library/

4. Construction Site Storm Water Runoff Control "The permittee must develop, implement and enforce a program to reduce pollutants in any storm water runoff to the MS4 from construction activities that result in a land disturbance of greater than or equal to one acre. Storm water discharges from construction activity disturbing less than one acre must be included in the permittee's program if that construction activity is part of a larger common plan of development or sale that would disturb one acre or more." Information on developing a construction site runoff control program can be found on the EPA fact sheet: http://www3.epa.gov/npdes/pubs/fact2-6.pdf

5. Post-Construction Storm Water Management in New Development and Redevelopment "The permittee must develop, implement and enforce a program to address storm water runoff into the MS4 from new development and redevelopment projects, including projects less than one acre if they are part of a larger common plan of development or sale... The program must ensure that controls are in place that will prevent or minimize water quality impacts. At a minimum, the Post-Construction Storm Water Management in New Development and Redevelopment Program must contain the following requirements:
   - » Develop and implement strategies which include a combination of structural and/or non-structural BMPs appropriate for your community;
   - » Use an ordinance or other regulatory mechanism to address post-construction runoff from new development and redevelopment projects to the extent allowable under State and local law; and
   - » Ensure adequate long-term operation and maintenance of the BMPs.
   - » Develop an inventory of GI/LID Structures"

Section 4.2 includes recommended standards for post-construction stormwater management in Georgia.

6. Pollution Prevention / Good Housekeeping for Municipal Operations "The permittee must develop and implement an operation and maintenance program that includes a training component with the ultimate goal of preventing or reducing pollutant runoff from municipal operations. Using training materials available from the USEPA and other organizations as guidance, the permittee must, as a part of this program, include employee training to prevent and reduce storm water pollution from activities such as park and open space maintenance, fleet and building maintenance, new construction and land disturbances, and storm water system maintenance." The Center for Watershed Protection's manual, Urban Subwatershed Restoration Manual Series Manual 9: Municipal Pollution Prevention / Good Housekeeping Practices provides "how to" guidance on pollution prevention and good housekeeping activities: http://www.cwp.org/online-watershed-library/

As of 2015, the following communities are Phase II MS4s:

Albany (Dougherty County)
Allenhurst (Liberty County)
Athens-Clarke County
Auburn (Barrow County)
Barrow County
Bartow County
Bogart (Oconee County)
Braselton (Jackson County)
Brookhaven (DeKalb County)
Brunswick (Glynn County)
Byron (Peach County)
Canton (Cherokee County)
Carroll Co.
Cartersville (Bartow County)
Catoosa County
Centerville (Houston County)
Chatsworth (Murray County)
Cherokee County
Chickamauga (Walker County)
Columbia County
Conyers (Rockdale County)
Cordele (Crisp County)
Covington (Newton County)
Coweta County
Cumming (Forsyth County
Dallas (Paulding County)
Dalton (Whitfield County)
Dawson Co.
Dougherty County
Douglasville-Douglas County WSA (Douglas County)
Dunwoody (DeKalb)
Effingham Co.
Emerson (Bartow County)
Eton (Murray County)
Euharlee (Bartow County)
Fayette County
Fayetteville (Fayette County)
Flemington (Liberty County)
Flowery Branch (Hall County)
Floyd County
Fort Benning
Fort Gordon
Fort Oglethorpe (Catoosa County)
Fort Stewart
Gainesville (Hall County)
GDOT
Glynn County
Griffin (Spalding County)
Grovetown (Columbia County)
Hahira (Lowndes County)
Hall County
Hampton (Henry County
Henry County
Hephzibah (Richmond County)
Hinesville (Liberty County)
Hiram (Paulding County)
Holly Springs (Cherokee County)
Hoschton (Jackson County)
Houston County
Hunter AAF
Jackson Co.
John's Creek (Fulton County)
Jones County
Lee County
Leesburg (Lee County)
Liberty County
Locust Grove (Henry County)
Loganville (Walton County)
Long County
Lookout Mountain (Walker County)
Lowndes County
Madison Co.
McDonough (Henry County
Milton (Fulton County)
Mountain Park (Fulton County)
Murray Co.
Newnan (Coweta County)
Newton County
Oakwood (Hall County)
Oconee County
Oxford (Newton County)
Paulding County
Peach County
Peachtree City (Fayette County)
Peachtree Corners (Gwinnett)
Perry (Houston County)
Porterdale (Newton County)
Remerton (Lowndes County)
Richmond Hill (Bryan County)
Ringgold (Catoosa County)
Robins AFB
Rockdale County
Rome (Floyd County)
Rossville (Walker County)
Sandy Springs (Fulton County)
Senoia (Cowweta County)
Spalding County
Stockbridge (Henry County)
Temple (Carroll County)
Tunnel Hill (Whitfield County)
Tyrone (Fayette County)
Valdosta (Lowndes County)
Varnell (Whitfield County)
Villa Rica (Carroll County)
Walker County
Walnut Grove (Walton County)
Walthourville (Liberty County)
Walton County
Warner Robins (Houston County)
Watkinsville (Oconee County)
Whitfield County
Winterville (Clarke County)
Woodstock (Cherokee County

2.6 Other Related Regulatory Requirements

Description: In addition to the MS4 Permit, other regulatory requirements exist to address point and nonpoint source pollution and stormwater quality. These programs, permits, and acts were created to provide businesses, industries, and the public with standards for preserving or improving water quality.

KEY CONSIDERATIONS

MS4 permits are not the only regulatory requirement related to non-point source pollution and stormwater quality. Numerous federal and state requirements define what is required of local governments and others in preserving or improving water quality. The regulatory requirements discussed in this section include:

- Industrial NPDES Stormwater Permit Program
- NPDES Stormwater Permits for Construction Areas
- NPDES Municipal Wastewater Discharge Permit Program and Watershed Assessments
- Erosion and Sedimentation Control Act
- Total Maximum Daily Load (TMDL) Program
- Georgia Planning Act
  - River Corridor Protection
  - Water Supply Watersheds
  - Groundwater Recharge Areas
- Safe Drinking Water Act – Wellhead Protection Program
- Source Water Assessment Program (SWAP)
- Metropolitan River Protection Act (Atlanta metro area only)
- Wetlands – Federal 404 Permits and the Georgia Planning Act
- Coastal Management Program
- Coastal Marshlands Protection Act
- Georgia Greenspace Program



2.6.1 Industrial NPDES Stormwater Permit Program

In addition to MS4 regulation, the NPDES program also requires that the discharge of stormwater from certain types of industrial facilities be regulated under a permit program. Industrial stormwater is defined as that discharged from any conveyance that is used for collecting and conveying stormwater, which is directly related to manufacturing, processing, or materials storage areas. Discharge of stormwater from regulated industrial facilities is managed under a single general permit that was re-issued by Georgia EPD in 2012.

Currently, nine categories of industrial facilities are required to have an industrial stormwater NPDES permit in Georgia for their stormwater discharge. These include:

- Manufacturing facilities, such as paper mills, chemical plants, and timber mills
- Mining, oil, and gas operations
- Hazardous waste treatment, storage, or disposal facilities
- Recycling facilities
- Steam electric power generating facilities
- Transportation facilities
- Facilities treating domestic sewage or sewage sludge
- Landfills, land application sites, and open dumps
- Facilities subject to effluent guidelines and new performance standards under 40 CFR Subchapter N (for example, cement and phosphate manufacturing; petroleum refining; coal, ore and mineral mining; asphalt, etc.)
- Construction activities

See Appendix D of GAR05000, the Industrial Stormwater General Permit, for a list of Standard Industrial Classification (SIC) codes that require coverage.

New industrial facilities are required to submit a Notice of Intent 7 days prior to commencing discharge. Provisions of the permit require preparation of a Stormwater Pollution Prevention Plan and annual certification of plan implementation. Industrial facilities must comply with the requirements of the general industrial stormwater permit, including preparation of Stormwater Pollution Prevention Plans and submittal of Annual Reports.

2.6.2 NPDES Stormwater Permits for Construction Areas

The NPDES stormwater permits for construction activities are directed toward controlling the quality of stormwater runoff from construction activities. The permits emphasize the application of best management practices to control erosion and sedimentation processes during the construction phase of development (similar to the Erosion and Sedimentation Act below). Construction managers need to obtain stormwater permits from Georgia EPD by filing a Notice of Intent (NOI) prior to initiating construction activities that disturb an area equal to or greater than one acre (See Section 2.6.4)

2.6.3 NPDES Municipal Wastewater Discharge Permit Program and Watershed Assessments

Georgia local governments applying for new or expanded NPDES permits with municipal wastewater treatment facilities of at least 1 million gallons per day are required by the Georgia EPD to develop and implement comprehensive watershed assessments and protection plans for the areas within their political boundaries. These plans encompass point and nonpoint sources and document best management practices to improve water quality. The plans are part of EPD's implementation of the US EPA's Total Maximum Daily Load (TMDL) program (see Section 2.3).

2.6.4 Erosion and Sedimentation Control Act

The Erosion and Sedimentation Control Act (ESCA) was established for controlling erosion and sedimentation from land-disturbing activities. Georgia law directs local governments to enact erosion and sedimentation ordinances. These ordinances require that permits be obtained for land-disturbing activities within the jurisdiction. Permit applicants must submit an erosion and sedimentation control plan that incorporates specific conservation and engineering practices, known as best management practices (BMPs).

The ESCA includes special requirements for land-disturbing activities in stream buffer zones. Land disturbing activities are not allowed within 25 horizontal feet of any State waters with wrested vegetation unless a variance is granted by EPD. The Act also includes special requirements for trout streams.

This program relates directly to requirements under the NPDES stormwater Permits for Construction Areas (See Section 2.6.2), as that program also requires sediment and erosion controls for all disturbed areas greater than one acre. One erosion and sediment control plan for a site will typically suffice for the NPDES and state erosion and sedimentation control permit requirements.

2.6.5 Total Maximum Daily Load (TMDL) Program

Under Section 303(d) of the Clean Water Act, the State of Georgia is required to develop a list of impaired waters that do not meet water quality standards and require a Total Maximum Daily Load (TMDL) to be developed. The Georgia EPD must then establish priority rankings for waters on the list and develop Total Maximum Daily Loads (TMDLs) for the listed waters. The TMDL specifies the maximum amount of a specific pollutant of concern that a designated segment of a water body can receive and still meet water quality standards. The TMDL also allocates the pollutant loadings among both point and nonpoint pollutant sources, including stormwater runoff. A number of TMDLs have been issued for water bodies across the state.

For each pollutant identified, a TMDL implementation plan is developed. The implementation plan identifies sources of the pollutant and provides a list of actions or management measures needed to reduce the pollutant, a schedule for implementing controls, milestones for implementation, and a monitoring program to measure progress. Controls and management measures need to be in place five years after the plan is developed. The TMDL program has a broad impact on local stormwater management programs because nonpoint sources of pollutants must be addressed at the local level.

2.6.6 Georgia Planning Act

The Georgia Planning Act (GPA) was created and implemented to help communities plan ahead for development. It takes coordination and planning at the local, regional, and state levels to properly develop a community. Within the planning act, there are different methods to help plan new development areas while protecting nearby waters and natural areas.

2.6.6.1 RIVER CORRIDOR PROTECTION

The GPA establishes corridors along some large rivers as critical natural resource areas. The river corridors and other critical natural resources are to be protected through comprehensive planning at the local levels. Each local government with a protected river in its jurisdiction is directed to develop and implement a river corridor protection plan that meets minimum planning standards established by the Georgia EPD. Minimum standards are designed to protect large rivers from the impacts of human activities on land immediately adjacent to the river (100 feet on each side). Communities must comply with the requirements of the state's River Corridor Protection criteria if stormwater activities are within the protected areas of this plan.

2.6.6.2 WATER SUPPLY WATERSHEDS

The GPA identifies water supply watersheds as key natural resources and sets regulatory activities to protect the quality and quantity of water available from watersheds that are used for public water supply. Water supply watersheds are defined as land contained within a drainage basin that has a governmentally-owned public drinking water intake downstream. Georgia EPD requires that development and associated stormwater runoff within the watershed not contaminate the water source to a point where the water cannot be treated to meet drinking water standards. Reservoir management plans must be submitted to EPD for all reservoirs in water supply watersheds. Requirements are specified based on the type of water supply watershed (small or large) and on the location, as shown in Table 2.6-1.

Table 2.6-1 Minimum Criteria for the Protection of Water Supply Watersheds in Georgia

Watershed Size (mi2)	Reservoir Present?	Vegetative Buffer around Reservoir (ft)	Vegetative Buffer along Perennial Streams (ft)		Setback for Impervious Surfaces along Perennial Streams (ft)		Overall Impervious Surface Density
			within 7 mile radius*	outside radius*	within 7 mile radius*	outside radius*	
> 100	No	none	none	none	none	none	no criteria
> 100	Yes	150	100	none	150	none	no criteria
> 100	No	none	100	50	150	75	25% or less
> 100	Yes	150	100	50	150	75	25% or less

* "7 mile radius" means within 7 miles upstream of a reservoir boundary if present or of the surface water intake if no reservoir is present

The water supply watershed requirements provide for the development of alternative criteria to these standards. Alternative criteria must provide equal or better protection of the water supply watershed, and all local governments within the watershed must approve of and adopt the criteria.

2.6.6.3 GROUNDWATER RECHARGE AREAS

The GPA identifies groundwater recharge areas as key natural resources. The Georgia EPD has established minimum criteria for groundwater recharge areas in order to prevent groundwater contamination from development. These criteria are to be incorporated within local comprehensive plans. In Georgia, minimum criteria have only been established for the most significant recharge areas, which cover approximately 23 percent of the state. For new residences served by septic systems, the criteria specify minimum lot sizes greater than those required for residences not in a significant recharge area. Permanent stormwater infiltration basins are prohibited in areas having high pollution susceptibility.

2.6.7 Safe Drinking Water Act – Wellhead Protection Program

Under the Federal Safe Drinking Water Act (FSDWA), Georgia EPD administers a wellhead protection program to protect public water supplies that use groundwater. Wellhead protection is the practice of managing an area around a water well or spring to prevent any contaminants released at the ground's surface from reaching the subsurface drinking water. Within the wellhead protection area, some stormwater management activities involving the infiltration of runoff, particularly from hotspot areas, may be limited or prohibited.

2.6.8 Source Water Assessment Program (SWAP)

The 1996 amendments to the FSDWA brought about a new program for clean and safe drinking water served by public water supplies, known as the Source Water Assessment Program (SWAP). The U.S. EPA is advocating prevention as an important tool in the protection of public drinking water sources from contamination. In order to implement source protection, an assessment of potential pollutant sources in water supply watersheds must be conducted. The goals of this assessment project will be reached through implementation of a four-step method, which includes watershed delineation, inventory of potential pollutant sources within the watershed, analysis of susceptibility of a water intake to the pollutant sources, and communication of this information to the public.

As many pollutants can enter waterways and reservoirs through stormwater drainage systems, SWAP efforts will provide an informational resource for local stormwater pollution prevention and mitigation programs. Future water supply protection efforts to control the identified potential pollution sources should be coordinated with and included as part of a local stormwater program.

2.6.9 Metropolitan River Protection Act (Atlanta metro area only)

The Metropolitan River Protection Act (MRPA) was passed by the Georgia General Assembly in 1973, in recognition of the Chattahoochee River's value as a resource and its vulnerability to the effects of urban development. The stated purposes of the MRPA include protection of water quality, erosion control, reduction of flood hazards, protection of recreational values, and protection of property rights. The MRPA created a corridor extending 2,000 feet from each bank of the Chattahoochee and its impoundments, which originally covered the 48 miles of river between Buford Dam and Peachtree Creek. In 1984, the MRPA was amended to require local governments in the river basin to adopt buffer zone ordinances for tributaries outside of the 2,000 foot corridor. In 1998, the MRPA was amended again to extend the corridor to the downstream limits of Fulton and Douglas Counties.

The MRPA authorizes the Atlanta Regional Commission to adopt a plan for the corridor that established criteria for all land-disturbing activity to protect the corridor's land and water resources. All land-disturbing projects and proposed activities in the corridor are subject to review for consistency with the standards of the adopted Corridor Plan. These standards include: natural vegetative buffers and impervious surface setbacks along the river and tributary streams, limits on land disturbance and impervious surface, and requirements in the river floodplain. Outside of the corridor, projects need to adhere to the local tributary buffer requirements.

2.6.10 Wetlands – Federal 404 Permits and the Georgia Planning Act

The U.S. Army Corps of Engineers administers a permit program for activities in, on, or around waters of the U.S. Regulated activities include excavating, dredging, or depositing fill materials into waters of the U.S. The permit program protects wetlands and all "waters of the United States" across Georgia. Waters of the U.S. include all surface waters, such as coastal and navigable inland waters, lakes, rivers, streams and their tributaries; interstate waters and their tributaries; wetlands adjacent to the above (e.g. swamps, marshes, bogs, or other land areas); and isolated wetlands and lakes, intermittent streams, and other waters where degradation could affect interstate commerce. Section 404 permits (and possibly Section 10 permits) are required for stormwater activities that may impact natural wetlands.

Protection of wetlands in Georgia is also accomplished through comprehensive planning and ordinances at the local level through the Georgia Planning Act. The GPA establishes provisions for planning by local governments and authorizes the DNR to develop minimum planning standards for the protection of critical natural resources, including wetlands.

2.6.11 Coastal Management Program

The state Coastal Management Program (CMP) was recently developed to establish Georgia as a participant in the federal Coastal Zone Management Act (CZMA) of 1972. The goal of the CMP is to balance economic development in Georgia's coastal zone with preservation of natural, environmental, historic, archeological, and recreational resources. The program establishes a network of federal, state, and local agencies to address coastal issues. Activities under the program include permitting, planning, resource protection, and economic development activities. Requirements of the CZMA are designed to protect marshlands and include use of stormwater controls in critical areas near the coast to reduce the discharge of urban stormwater pollutants. The requirements are similar to those anticipated under the NPDES Phase II regulations.

2.6.12 Coastal Marshlands Protection Act

The Coastal Marshlands Protection Act (CMPA) manages certain activities and structures in marsh areas and requires permits for other activities and structures. The jurisdiction of the CMPA includes marshlands, intertidal areas, mudflats, tidal water bottoms, and salt marsh areas within estuarine areas of the state. The estuarine area is defined as all tidally influenced waters, marshes, and marshlands lying within a tide-elevation range from 5.6 feet above mean high-tide level and below.

A Marshlands Protection Permit administered through the DNR's Coastal Resources Division is required for any project that involves removing, filling, dredging, draining, or otherwise altering any marshlands. In cases where the proposed activity involves construction on state-owned tidal water bottoms, a Revocable License issued by the Coastal Resources Division may also be required.

2.7 Unregulated Communities

Any community that is not classified as a NPDES Phase I or Phase II MS4 community is considered an unregulated community. Qualifications for Phase I and Phase II communities are identified in Section 2.5. Unregulated communities are typically small or rural areas without the population (at least 100,000 people) to qualify as a Phase I community or sufficient urbanized area to qualify as a Phase II community. Phase I and Phase II communities are required to develop a comprehensive stormwater management program, which incorporates many recommendations and requirements from the Georgia Stormwater Management Manual (GSMM). While unregulated communities do not have the same requirements placed on them, they are certainly not immune to the negative effects of stormwater runoff, such as flooding and water quality degradation. By implementing a program to address both stormwater quantity and quality, unregulated communities can protect themselves and nearby communities from these hazards. Several aspects of the GSMM will be beneficial to unregulated communities:

- The better site design principles listed in Chapter 3 will help any community implement low impact development (LID) projects and policies.
- The standards for development described in Chapter 4 present a uniform way to guide and/or regulate growth and development in the community, in line with other communities in the state.
- The BMPs described in Volume 2, Chapter 4 represent the best available strategies for protecting water resources from the impacts of development.

CASE STUDY

Better Site Design and Low Impact Development in Clarkesville

The City of Clarkesville, Georgia is a small, fast-growing community interested in developing a green infrastructure plan. The city's municipal separate storm sewer system is not subject to state or federal requirements to address stormwater pollution. However, the city has proactively addressed stormwater quality and quantity through post-construction stormwater requirements and supporting the use of green infrastructure for stormwater management.

In April 2014, the U.S. Environmental Protection Agency (USEPA) announced the selection of 14 communities to receive $860,000 in green infrastructure technical assistance. The City of Clarkesville received technical assistance in the form of a Green Infrastructure Implementation Strategy. USEPA identified opportunities for improving the city's Zoning Ordinance to encourage implementation of green infrastructure by developers, property owners, and other parties. The following key opportunities were identified:

- Reduce street and parking dimensions
- Offer incentives for redevelopment
- Reduce setbacks
- Require phased disturbance of vegetated areas
- Require minimization of hydrologic alteration to wetlands
- Increase stream buffer width
- Require a Best Management Practice (BMP) Maintenance Plan for all stormwater facilities
- Develop additional stormwater performance standards for new development and redevelopment

By outlining goals, priorities, code improvements, project opportunities, and funding sources, the City of Clarkesville's strategy provides a model approach for small, unregulated communities to successfully pursue green infrastructure.



Figure 2.7-1 Clarkesville Green Infrastructure Implementation Strategy

References

American Planning Association. 2015. Planning and Community Health Center. American Planning Association.

American Public Health Association. 2013. "Improving Health and Wellness through Access to Nature". American Public Health Association.

Brown, Edward, Deb Caraco, and Robert Pitt. 2004. Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments. Center for Watershed Protection, Ellicott City, MD & University of Alabama, Tuscaloosa, AL.

Georgia Environmental Protection Division. 2013. *NPDES Construction Storm Water General Permits*. Georgia Environmental Protection Division.

Georgia Environmental Protection Division. *Storm Water.* Georgia Environmental Protection Division.

Georgia Environmental Protection Division. *Authorization to Discharge Under the National Pollutant Discharge Elimination System.* Georgia Environmental Protection Division.

Georgia Environmental Protection Division. 2013. *Georgia Water Quality Standards.* Georgia Environmental Protection Division.

Hirschman, David J., John Kosco. 2008. Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program. Center for Watershed Protection, Ellicott City, MD.

Novotney, Michael and Rebecca Winer. 2008. Manual 9: Municipal Pollution Prevention/Good Housekeeping Practices. Center for Watershed Protection, Ellicott City, MD.

Radeloff, V. C., R. B. Hammer, S. I. Stewart, J. S. Fried, S. S. Holcomb, and J. F. McKeefry. 2005. *The Wildland Urban Interface in the United States.* Ecological Society of America.

Schueler, T. R., P. A. Kumble, and M. A. Heraty. 1992. A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Department of Environmental Programs.

U.S. Environmental Protection Agency. Stormwater Phase II Final Rule Fact Sheet Series. U.S. Environmental Protection Agency, Washington D.C.

3. Better Site Design

3.1 Introduction to Better Site Design

Addressing stormwater management begins with the site planning and design process. Development projects can be designed to reduce their impact on watersheds when efforts are made to conserve natural areas, reduce impervious cover, and better integrate stormwater treatment. By implementing a combination of these nonstructural approaches, collectively known as Better Site Design (BSD), it is possible to reduce the amount of runoff and pollutants generated by a site and provide for some nonstructural on-site treatment and control of runoff. The goals of Better Site Design include:

- Preventing stormwater impacts rather than mitigating them
- Managing stormwater (quantity and quality) as close to the point of origin as possible and minimizing collection and conveyance
- Utilizing simple, nonstructural methods for stormwater management that are lower cost and lower maintenance than structural controls
- Creating a multifunctional landscape
- Using hydrology as a framework for site design

Terminology can be confusing with stormwater management concepts. As discussed in Section 1.5, "Low-Impact Development" (LID), "Green Infrastructure", and "Better Site Design" (BSD) have similar and overlapping goals. All of these terms refer to goals of replicating natural hydrology at development sites, preserving key natural resources, and treating stormwater close to its source with distributed and often vegetated practices. This manual uses LID as the overarching term for these goals and practices, and the focus of this chapter is BSD, referring to a group of generally non-structural and policy-related practices that direct development to appropriate areas, preserve natural features that aid in water management, and minimize impervious cover. The publication "Better Site Design: A Handbook for Changing Development Rules in Your Community" from the Center for Watershed Protection (1998b) provides additional guidance on implementing BSD practices.

Better Site Design is also related to the concept of "smart growth". While BSD refers to how development is conducted at the scale of an individual site or neighborhood, smart growth is a concept that operates at a broader, community-wide scale, and is more concerned with where development takes place. Smart growth directs a community's development to areas with existing infrastructure (e.g., infill and redevelopment), while avoiding new growth (or sprawl) in the countryside. Smart growth can be the backbone of a community's land use strategy, and is addressed in this chapter as a tenet of community planning.

Table 3-1: Benefits of BSD for Various Parties, as Compared to Conventional Development
Developers: • Provides flexibility in design options • Allows for more sensible locations for stormwater facilities • Facilitates compliance with wetland and other regulations • Allows for reduced development costs, especially for stormwater infrastructure
Local Government: • Improves quality of life for residents • Facilitates compliance with wetland and other regulations • Assists with compliance for NPDES MS4 permits, TMDL requirements, etc. • Increases local property tax revenues due to higher home values • Can allow for development in communities otherwise limited by sewer capacity
Property Owners: • Increases property values • Creates more pedestrian-friendly neighborhoods • Provides open space for recreation • Results in a more attractive landscape • May reduce car speed on residential streets • Promotes neighborhood designs that provide a sense of community • Reduces water and energy demands
Environment: • Protects sensitive forests, wetlands, and wildlife habitats • Protects the quality of local streams and lakes • Generates reduced loads of stormwater pollutants • Allows more recharge of groundwater supply • Reduces erosion and sedimentation during construction and for the life of the development • Reduces noise and air pollution • Reduces urban heat island • Reduces atmospheric carbon dioxide

Table 3-1 outlines some of the benefits of using BSD for various parties involved in the development process.

Better Site Design aims to protect and conserve natural areas, reduce impervious cover, and integrate stormwater management with site design. These principles can provide notable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads. Also, they can reduce development costs and increase property values (MacMullin and Reich, 2007; Winer-Skonovd et al., 2006; US EPA, 2007). BSD techniques are applied most readily on new residential and commercial development projects. In addition, many of the techniques are applicable to redevelopment or infill scenarios as part of a smart growth strategy. While some of these principles can be applied easily by a developer, others may require changes in local regulations (see Section 3.2).

CASE STUDY

Southface Eco Office, Atlanta, Georgia

The award-winning Southface Eco Office, located in downtown Atlanta, is a three-story commercial structure that serves as an office, training and demonstration facility. At 10,100 square feet, it is similar in size to many commercial buildings, making it a strong example for what can be achieved in energy-, water- and resource-efficiency within the commercial building sector. It is also one of the most sustainable office facilities in the world, using 84 percent less water and 53.3 percent less energy than a comparable, code-built facility.

The following Better Site Design and LID practices were used on the Southface property: water efficient landscaping, permeable pavement, a vegetated swale, underground and rainwater cisterns, shared parking, and a green roof.

The Eco Office is fully instrumented so that performance can be measured on a continuous basis. This performance information is available online at http://www.buildingdashboard.com/clients/southface/ and provides real-time and historical data on daily gallons of rainwater captured, consumed, and saved and current rainwater levels in the building's cisterns, local weather conditions, and more (www.southface.org).



Figure 3.1-1 Southface Eco Office
(Source: www.siteselection.com)



Figure 3.1-2 South Face Eco Office Green Roof
(Source: www.vertical-theory.com)

3.2 How to Make Your Local Development Codes Consistent with BSD Principles

Many communities across the country have found that their own local "development rules" (e.g., subdivision ordinances, zoning ordinances, parking lot and street design standards) prevent BSD techniques from being applied during the site planning and design process (CWP, 1998b). These communities have found that their own codes and ordinances are responsible for the wide streets, expansive parking lots, and large lot subdivisions that are crowding out the very natural resources they are trying to protect. Examples include the minimum parking ratios that many communities require for retail or commercial development and zoning restrictions that limit conservation development designs.

Some of the policy instruments that need to be reviewed for compatibility with the BSD principles include:

- Zoning Ordinances and Procedures
- Subdivision Codes
- Stormwater Management/Drainage Criteria
- Tree Protection/Landscaping Ordinances
- Buffer and Floodplain Regulations
- Erosion and Sediment Control Ordinances
- Grading Ordinances
- Street Standards/Road Design Manuals
- Parking Requirements
- Building and Fire Regulations and Standards
- Septic/Sanitary Sewer Regulations
- Local Comprehensive Plans

Obviously, it is difficult to make use of the recommended BSD techniques when local development codes restrict their use. It takes some time to work through the process of evaluating and eliminating these restrictions. Therefore, until these revisions have been completed and barriers to the use of BSD have been removed, site planning and design teams are encouraged to consult with the local development review authority to identify any local restrictions and work on potential solutions.

Table 3-2 provides a set of example questions that can be used to review a community's local development codes and ordinances with the goal of streamlining implementation of BSD. The questions are organized by general BSD categories. The questions included in Table 3-2 are just examples of the types of questions that need to be asked. A more comprehensive analysis of local development regulations, with more concrete, in-depth questions should be conducted with the Codes and Ordinance Worksheet available in the Better Site Design manual (CWP, 1998b), See http://www.cwp.org/online-watershed-library/ and search page for "Codes and Ordinance Worksheet" or a similar tool, such as EPA's Water Quality Scorecard (http://www.epa.gov/sites/production/files/2014-04/documents/water-quality-scorecard.pdf).

Table 3-2 Questionnaire for Reviewing Local Regulations for Compatibility with BSD Principles

CATEGORY 1: COMMUNITY PLANNING (SECTION 3.3.1)	
Community Planning, Infill and Redevelopment, Smart Growth	• Does the community have incentives or other regulatory or non-regulatory means to promote infill and redevelopment in areas already served by infrastructure? • In general, is it more or less difficult for developers to build in already-developed areas versus greenfields?
CATEGORY 2: SITE PLANNING and DESIGN (SECTION 3.3.2)	
Natural Resources Inventory	• Is a natural resources inventory required or incentivized as part of the preliminary design? • Does the community have a land conservation, open space, or green space plan with which individual development sites can integrate? • Are there any incentives to developers or landowners to preserve land in a natural state (density bonuses, conservation easements, or lower property tax rates)?
Conservation of Natural Features	• Is there a stream buffer ordinance in the community that provides for greater buffer requirements than the state minimums? • Do the buffer requirements include lakes, freshwater and tidal wetlands, or steep slopes? • Do the buffer requirements specify that at least part of the buffer be maintained with undisturbed vegetation? • Does the community restrict or discourage development in the 100-year floodplain? • Does the community restrict or discourage building on steep slopes?
Development Design	• Does the local permitting agency provide pre-application meetings, joint site visits, or technical assistance with site plans to help developers best fit their design concepts to the topography of the site and protect key site resources? • Are there development requirements that limit the amount of land that can be cleared in a multi-phase project? • Does the community allow and/or promote Planned Unit Developments (PUD's), which give the developer or site designer additional flexibility in site design? • Are open space or cluster development designs allowed? • Are the submittal or review requirements for open space designs greater than those for conventional development? • Are flexible site design criteria (e.g. setbacks, road widths, lot sizes) available for developers who utilize open space or cluster design approaches? • Does a minimum percentage of the open space have to be managed in an undisturbed natural condition?

Tree Conservation and Tree Canopy	• Does the community have a tree or tree canopy cover protection ordinance? • Is a minimum percentage of a parking lot required to be landscaped and/or planted with trees?
Management of Open Space, Sustainable Landscaping	• Does the community have enforceable requirements to establish associations that can effectively manage open space? • Is there adequate guidance for the managers of open space (e.g., homeowners' associations) on how to select and manage vegetation in a sustainable manner?
CATEGORY 3: REDUCING IMPERVIOUS COVER (SECTION 3.3.3)	
Reducing Roadway and Right-of-Way Width and Length	• Do road and street standards promote the most efficient site and street layouts that reduce overall street length? • What is the minimum pavement width allowed for streets in low density residential developments?
Alternative Roadway Components	• What is the minimum radius allowed for cul-de-sacs? • Can a landscaped island be created within a cul-de-sac? • Are alternative turnarounds such as "hammerheads" allowed on short streets in low density residential neighborhoods? • Can "open-section" roads be utilized under certain conditions as an alternative to curb and gutter?
Reducing Paved Parking and Walking Areas	• What are the minimum parking ratios for various development types? • If mass transit is provided nearby, are parking ratios reduced? • What is the minimum parking space size? • What percentage of parking spaces are required to have smaller dimensions for compact cars? • Is the use of shared parking arrangements promoted? • Are there any incentives to developers to provide parking within structured decks or ramps rather than surface parking lots? • Are there provisions or incentives for shared driveways, reduced setbacks to allow for shorter driveways, and/or use of permeable materials for driveways? • Are sidewalk layouts (both sides vs. one side), widths, and material
Reducing Building Footprints	• Does the community provide options for taller buildings and structures which can reduce the overall impervious footprint of a development?

Revising local development codes can seem overwhelming when one considers all of the questions in **Table 3-2**. However, these efforts can be scaled to the community's capabilities and level of interest. The effort can be done in a comprehensive fashion or incrementally with an eye towards achieving key priorities. **Table 3-3** portrays three generalized levels of effort for code review, based on actual case studies on communities that have undertaken the process. Note that the categories represent a continuum, and hybrid or phased approaches are also possible. The table also lists anticipated staff time and costs for each level; however, those will vary between communities. For assistance with code and ordinance updates, see the James River Association's Code and Ordinance Manual, which provides example ordinance language for many Better Site Design principles: http://jrava.org/what-we-do/codes-and-ordinance-manual.pdf

Table 3-3 Different Levels of Effort to Revise Local Codes for Compatibility with BSD

Level of Effort	Type of Code Review	Description
Low	High priority code changes to ensure consistency with stormwater management program	• Relatively quick code housekeeping to identify and rectify inconsistencies and conflicts between stormwater management program/ordinance and other development codes, such as zoning, subdivision, and public safety. • Steer away from larger changes that are likely to be controversial, such as new stream buffer requirements or use of BMPs on individual lots. • Aim to have process complete within 6 months. • Approximate figure for code review: 75 – 100 hours, including code review, report, and meetings. Assume $8,000 - $10,000* if done by consultant. • Additional time and resources would be necessary to actually make the code changes, public involvement for code change meetings, etc.
Moderate	Thorough code review to ensure consistency with stormwater management program and Better Site Design principles	• Involves comprehensive code review by internal staff or consultant to identify broader topics to make codes more consistent with stormwater management. • Code recommendations should be prioritized so that 7 to 10 of the highest priority changes can be made, with longer range plan to make additional changes. • Aim to have process complete within 1 year, including stakeholder review (e.g., focus group) and public input. • Approximate figure for code review: 150 – 200 hours, including code review, report, and meetings. Assume $17,000 - $20,000* if done by consultant. • Additional time and resources would be necessary to actually make the code changes, public involvement for code change meetings, etc. • See example code changes from **Northern Shenandoah Valley Code Review** case study.

Table 3-3 Different Levels of Effort to Revise Local Codes for Compatibility with BSD

Level of Effort	Type of Code Review	Description
High	Full roundtable process to achieve broad stakeholder involvement and consensus on code changes	• Full stakeholder process involving comprehensive code review and stakeholder committees to vet and discuss the merits of various code changes. Individual committees may include: (1) roads and parking, (2) lot development, (3) natural resources management, and (4) stormwater. • Likely requires assistance from consultant. • Ideally results in consensus document of recommended code changes. More robust process can handle some issues that require more local discussion and debate. • Aim to have process complete within 2 to 3 years. • Approximate figure for code review: 600 – 750 hours, including code review, report, committee meetings, and consensus document. Assume $80,000 - $100,000* if done by consultant. • Additional time and resources would be necessary to actually make the code changes, public involvement for code change meetings, etc. • See CWP Roundtable case study below.

*Cost ranges approximated from Center for Watershed Protection code review project budgets between 2009 and 2012.

CASE STUDY

High Level of Effort Code and Ordinance Review: Full BSD Roundtable

Richland County, SC, completed a Site Planning Roundtable in 2009 (CWP, 2009). The roundtable process is a collaborative, consensus-building initiative designed to convene local government agencies, the development community, engineering and planning firms, and groups interested in environmental and conservation issues. The goal is to identify local hurdles to and opportunities for implementing Better Site Design and planning techniques, and to then build consensus across a diverse group of stakeholders on necessary local ordinance modifications to allow for them. The Site Planning Roundtable process in Richland County was modeled after the National Site Planning Roundtable (CWP, 1998a), the 22 Better Site Design Principles (CWP, 1998b) and four basic objectives:

- Reduce overall site impervious cover
- Preserve and enhance existing natural resources
- Integrate stormwater management
- Retain a marketable product

The first step was a thorough codes analysis based on results from: the Richland County Codes and Ordinances Worksheet (COW); an in-depth review of existing codes, ordinances, policies and regulations; and interviews conducted with developers, engineers, and County staff. The COW asks a series of questions organized around the Better Site Design Principles, which are based and scored on national benchmarks for Better Site Design. This analysis, completed by the Roundtable facilitators, provided a concise summary of the regulatory barriers to implementing Better Site Design in the county and served as the foundation for subcommittee discussions.

Subsequent to the code review, a kick-off meeting and site design exercise was conducted with all of the stakeholder groups, so that participants could gain an understanding of BSD principles. This was followed by a field trip to a development site that has several good examples of BSD applications.

Stakeholder committees were then convened to review current development practices involving four major categories: 1) Residential Streets and Parking Lots, 2) Lot Development, 3) Natural Resource Management, and 4) Stormwater Management. The committees met for approximately 5 months through face-to-face meetings and conference calls. At the conclusion of the committee process, participants prepared a consensus document, which contains a variety of recommendations and action items. These actions will require follow-through from partners to see that the recommendations of the consensus document are implemented to successfully improve protection of Richland County's water resources, natural resources, and quality of life.

CASE STUDY

Moderate Level of Effort Code and Ordinance Review: Northern Shenandoah Valley (Virginia) Code Review

The Northern Shenandoah Valley Regional Commission received a grant to assist their member jurisdictions (five counties) with reviewing their development codes in preparation for upcoming state-wide stormwater regulations. The purpose of the project was to quickly identify local code elements that would be in direct conflict with the stormwater regulations (Tier 1), as well as other code sections that could be changed to complement the stormwater program, such as implementation of BSD (Tier 2). A modified Codes and Ordinance checklist was developed based on these two tiers of review, and the actual code review and analysis was conducted by the Center for Watershed Protection. The result was a prioritized list of code changes. Table 3-4 illustrates examples of the types of code changes recommended for one of the Northern Shenandoah counties.

Table 3-4 Code Changes Recommended for Northern Shenandoah Valley Counties

Tier 1. Required Action for Stormwater Program Implementation	
Actions that are part of adopting a local stormwater program in accordance with the state stormwater regulations.	
Topic	**Recommendation**
Plan Submittal and Review	• The county code should be updated to include the required elements of a stormwater management plan consistent with the revised state manual. • The existing stormwater maintenance provisions will need to be modified and/or transferred to the new stormwater regulations.
Tier 2. Complementary Code Changes for Consistent Stormwater Implementation	
Code changes that are complementary and would promote BSD and low-impact development (LID).	
Topic	**Recommendation**
Stormwater Practices on Lots	• Authorize LID in other zoning districts besides open space cluster developments.
Open Space/Common Area Within Subdivisions	• Add "stormwater treatment as compatible with other purposes" to one of the uses of open space.
Plan Submittal and Review	• Ensure that stormwater management practices are specifically included in the requirement for performance bonds. • Consider combining erosion and sediment control ordinance with post-construction stormwater ordinance.
Subdivision Street Standards	• Consider allowing the use of above-ground stormwater practices in the right-of-way if part of an overall stormwater system. • Remove curb and gutter requirement for subdivision streets if another system preferable for stormwater can be verified to be adequate.
Natural Resources Inventory	• Require or provide incentives for a natural resources assessment as the initial part of the plan development review process (i.e. pre-submission/pre-application requirement for site plans, preliminary subdivision plats, etc.) and use this information in the review of proposed projects to limit the impacts on natural resources.
Parking Requirements	• Reduce the size of parking stalls to 9' by 18'. Currently county code requires 10' by 20'. • Reduce parking space minimums for commercial and office uses to 4 for every 1,000 square feet of building space. Currently county code requires 5 parking spaces for every 1,000 square feet. • Encourage or require the use of alternative pervious surfaces for required parking/overflow parking

CASE STUDY

Stakeholder Involvement: Green Infrastructure Requirements in Atlanta

In 2013, the City of Atlanta amended its Post-Development Stormwater Management Ordinance to require green infrastructure on new and redevelopment projects, including requiring runoff reduction for the first one (1) inch of rainfall. Given the significance of these changes, Atlanta City staff determined that it was critical to implement a strong stakeholder involvement and education strategy in conjunction with the proposed changes. Early in the process, staff launched numerous parallel efforts to ensure a smooth ordinance adoption, educate City leadership and future applicants, train plan review staff, prepare for compliance and enforcement, and anticipate inspection and maintenance issues. In all, it took just over a year to formalize a first draft of the proposed ordinance changes and an additional 10 months to conduct outreach, receive stakeholder input, and enact revisions prior to officially starting the legislative process.

Prior to drafting any changes to the ordinance, staff met with several prominent local engineering groups to find out which parts of the ordinance needed improvement and gain feedback on ideas that the City was interested in proposing. With this information, the Ordinance Review Team (comprised of Watershed Management and legal staff) drafted the changes and briefed other City groups that may be affected, such as Office of Planning, Office of Buildings, Department of Public Works, and the Office of Sustainability.

The City then organized a Technical Stakeholder Group consisting of civil engineers who are familiar with the City's requirements and processes, as well as non-profit organizations like the Chattahoochee Riverkeeper that advocate for clean water protection. They conducted two roundtable discussions with this group, during which they received feedback and suggestions on how the ordinance could be improved. After many of these revisions were made, they began an outreach campaign to spread the word to as many stakeholders as possible, including development groups, environmental groups, government agencies, and many others.

The city received valuable feedback from these organizations and made several revisions prior to submitting the new ordinance to City Council. With regard to satisfying all parties involved, City staff members worked diligently to provide a balanced approach to the new requirements and were open to many of the specific changes that were suggested. While all stakeholders did not agree on all of the issues, this collaborative effort proved to be the key to gaining support from many of the groups involved.

Source: Rayburn, C., S. Rutherford. 2014. Implementing Green Infrastructure: Atlanta's Post-Development Stormwater Ordinance City of Atlanta Department of Watershed Management.

3.3 Better Site Design Principles

Each sub-section in **Section 3.3** focuses on a specific category of BSD principles. Each section begins with a summary profile sheet that includes a brief description of the BSD principle(s) in that category and a list of the key benefits of those BSD techniques. Following each profile sheet are specific recommendations for how communities can incorporate each BSD principle into their development process. Some sections also include information on how a local government can adopt codes and/or regulations to support Better Site Design in their communities, as well as case studies to serve as examples of communities in and beyond Georgia that have successfully adopted BSD principles.

Table 3-5 provides an overview of the BSD development principles addressed in this chapter.

Table 3-5 Better Site Design Principles Discussed in Section 3.3

Section	Description
3.3.1 Community Planning	
3.3.1.1 Community Planning, Infill and Redevelopment	• Developing within existing urbanized areas on or between previously developed land that is currently underutilized, such as degraded parking lots or shopping centers.
3.3.2 Site Planning and Design	
3.3.2.1 Natural Resources Inventory	• Identifying natural features and resources on a site prior to designing development layout.
3.3.2.2 Conservation of Natural Features	• Strategies that can be used by local governments to enforce or provide incentives for conservation of natural features.
3.3.2.3 Development Design	• Site development designs that minimize clearing and grading and emphasize use of available buildable areas in the most space-efficient way.
3.3.2.4 Tree Conservation and Tree Canopy	• Local government codes that promote the preservation of trees/tree canopy cover and native vegetation during construction and post-construction phases of development.
3.3.2.5 Management of Open Space, Sustainable Landscaping	• Methods to effectively manage open space and vegetation within a development.
3.3.3 Reducing Impervious Cover and the Development Footprint	
3.3.3.1 Reducing Roadway and Right-of-Way Width and Length	• Strategies to reduce impervious cover by making streets narrower while still meeting transportation objectives.
3.3.3.2 Alternative Roadway Components	• Alternatives to large cul-de-sacs and curb-and-gutter stormwater conveyance.
3.3.3.3 Reducing Paved Parking and Walking Areas	• Reducing the footprint of paved parking lots, driveways, and sidewalks to reduce imperviousness.
3.3.3.4 Reducing Building Footprints	• Reducing footprint size of commercial buildings and residences by using alternate or taller buildings while maintaining the same floor to area ratio (the ratio of building square footage to lot size).

3.3.1 Community Planning

Community planning works to improve the welfare of people and their communities by creating more convenient, equitable, healthful, efficient, and attractive places for present and future generations. Infill development and redevelopment focus growth in already developed areas. Incentives, reduced fees, and required provisions are a few tools that communities can use to encourage the redevelopment of existing impervious surfaces. The following section looks at both regional and community-scale strategies that can help reduce unnecessary land disturbance and incorporate "smart growth" to create more environmentally-sound and attractive neighborhoods.

Encouraging infill development, redevelopment, and smart growth starts at both the community and regional levels. On a community level, local governments can use planning techniques including instituting an infill development/redevelopment program, reviewing and revising local codes, and utilizing tools provided by state and federal programs to encourage these types of projects. In addition, several excellent resources mentioned in this section are geared toward local governments to help them implement these types of planning efforts.

3.3.1.1 COMMUNITY PLANNING, INFILL, AND REDEVELOPMENT

Description: By using land more efficiently, Georgia communities can protect natural resources from development impacts while creating vibrant neighborhoods and open space for recreational activities. Encouraging infill and redevelopment is one of the best ways to use land more efficiently. **Infill development** usually refers to building on vacant parcels within existing urbanized areas already containing transportation and utility infrastructure. **Redevelopment** refers to development that occurs on previously developed land that is currently underutilized, such as degraded parking lots or shopping centers.



Figure 3.3-1 Atlantic Station – Brownfield Infill Development
(Source: http://intownbethann.com/areas/atlantic-station/)



Figure 3.3-2 Alpharetta City Center – Redevelopment Project
(Source: Alpharetta City Center)

KEY BENEFITS

- Preserves valuable environmental areas
- Reduces urban sprawl
- Can help reduce the amount that people drive, improving air quality and reducing greenhouse gas emissions, when it occurs near existing transit infrastructure, employment centers, and other destinations.
- Reduces costs by avoiding the need for increased infrastructure and support operations
- Incorporates "smart growth" opportunities

CASE STUDY

Atlantic Station, Atlanta, GA

Atlantic Station in Atlanta, Georgia offers a wonderful example of a brownfield redevelopment project. By converting an under-utilized steel mill into a mixed-use, transit-oriented community, a "live, work, play environment" was created. When the redevelopment is complete, it will consist of six million square feet of Class A office space; 3,000 to 5,000 residential units; two million square feet of retail and entertainment space, including restaurants and movie theatres; 1,000 hotel rooms; and 11 acres of public parks. Atlantic Station protected over 1,000 acres of greenfield from being developed and influenced several other neighborhood development projects (De Sousa, 2013)

BENEFITS OF INFILL DEVELOPMENT AND REDEVELOPMENT

Encouraging infill development and redevelopment is one of the best ways to use land more efficiently and reduce sprawl. In general, infill development and redevelopment preserve valuable environmental areas and reduce urban sprawl since development is more compact and centered in a town or city corridor. Ultimately, costs to the community can be reduced by avoiding the need for increased infrastructure and support operations, such as fire stations, hospitals, police, and other city services in outlying areas (BMC, 2009). Infill and redevelopment also offer the opportunity to incorporate "smart growth" into the community. Smart growth refers to building urban, suburban and rural communities with housing and transportation choices near jobs, shops, and schools. This approach supports local economies and protects the environment (SGA, 2015). Some other benefits to consider are listed below.

Infill Development

- Can reduce development pressure on outlying areas, helping to protect lands that serve important ecological functions.
- Can reduce the amount that people drive, improving air quality and reducing greenhouse gas emissions, when it occurs near existing transit infrastructure, employment centers, and other destinations.

Redevelopment

- Allows a community the opportunity to bring an existing site into compliance with current stormwater requirements.
- Repurposes under-used, abandoned, and/or contaminated sites, which can improve the environment while providing multiple community benefits (DCA, 2015).
- Reduces runoff from existing properties and provides direct water quality improvements.
- Provides an opportunity to upgrade aging infrastructure, such as sewer and stormwater pipes, that are deteriorated and causing water impairments (Ellis, 2014).



Figure 3.3-3 Atlantic Station in Atlanta, Georgia

OBSTACLES TO INFILL DEVELOPMENT AND REDEVELOPMENT

Infill development can present barriers that should be evaluated prior to moving forward with the development process. As is the case with brownfields (land previously used for industrial or commercial purposes), the expansion, redevelopment, or reuse of some sites may be complicated by the potential presence of a hazardous substance, pollutant, or contaminant (EPA, 2011). Past land use contamination should be researched and considered.

Georgia has a Brownfield Redevelopment Program that provides oversight for voluntary cleanups, a Hazardous Site Reuse and Redevelopment Act, and a Brownfields Tax Incentive Law. All of these are intended to encourage and help developers with the hurdles associated with brownfield cleanup.

In addition to site contamination, regulatory barriers such as zoning, land development regulations, and fire and building codes should be considered. Since these codes are usually written for greenfield sites, they often require more frontage, lot area, setbacks, or buffers than will fit on the typical infill lot. This can result in developers having to pursue multiple variances to develop a site (DCA, 2015).

INSTITUTING AN INFILL DEVELOPMENT/ REDEVELOPMENT PROGRAM

An effective program would include the following elements:

- Identification of areas of the community where this type of development is desired.
- Guidelines for the types of infill development / redevelopment that is appropriate for each of these areas. These guidelines will typically regulate the density, size, and architectural design of new infill development.
- Incentives to developers
- Improvements to public facilities and services to support these types of development
- Changes in existing regulations (DCA, 2015)



Figure 3.3-4 Alpharetta, Georgia is a suburb approximately 25 miles north of Atlanta. Downtown Alpharetta was lacking a pedestrian- and family-friendly environment before Alpharetta City Center was constructed. The 25-acre site consisted of city hall, small office buildings, and parking lots. Now, the site consists of a five-acre park, a Town Green area, and several pocket parks. When complete, Alpharetta City Center will be a vibrant blend of commercial, residential, and community uses.

HOW LOCAL CODES CAN BE AMENDED TO SUPPORT THESE PRACTICES:

Local Level

Local development codes often need to be revised to encourage infill development and redevelopment. Most codes are geared towards "greenfield" development rather than infill development or redevelopment. The codes that typically need to be reviewed are:

Zoning ordinances

- Subdivision codes
- Street standards or road design guidelines
- Parking requirements
- Minimum setback requirements
- Site coverage limits
- Height limitations
- Form-based development codes (codes based on physical form rather than use) (Hirschman, 2008)

Table 3-6 Local Code Changes to Encourage Infill and Redevelopment

Topic	Typical Local Code Conflicts	How Conflicts Can Be Resolved
Land Use Restrictions	Relying on single use districts (as with conventional zoning) to manage local land uses will prevent developers from implementing creative design ideas that involve a mix of land uses.	Add provisions for planned unit developments (refer to GQGP quality growth tool: Planned Unit Developments) or mixed-use districts (refer to GQGP quality growth tool: Mixed-Use Zoning) to your local land use regulations. See also Section 3.3.3.4 for Planned Unit Developments and other development design strategies.
Minimum Setback Requirements	Setback requirements are usually too large to fit a typical infill site.	Add a separate set of setback requirements for infill development and redevelopment projects.

Source: ARC Smart Growth Audit

Atlanta Regional Commission (ARC) Smart Growth Audit: A smart growth audit can help local governments review their growth policies and implementation measures in a systematic manner. This tool describes the concept of a smart growth audit and provides considerations and methods on how to implement a smart growth audit in your community. Although references are made to state-level and regional applications of smart growth audits, this tool focuses on how to conduct smart growth audits for local governments (ARC, 2015).

REGIONAL LEVEL

On a regional level, the following planning techniques can be utilized to encourage infill development and redevelopment including directing growth to already developed areas, creating regional plans to identify and protect natural resources, and working with local governments to review and revise codes and ordinances.

- Direct growth to already developed areas
  - » Financial incentives and prioritized capital funding to direct growth to already developed areas or to areas targeted for development.
  - » Local government incentives, such as density bonuses and accelerated permitting processes, for infill development and redevelopment projects.
  - » Reduced impact fees for infill development based on less demand for new infrastructure.
  - » Differentiating sewer and water connection fees would allow municipalities and utility authorities to offer discounts for development in desired areas.
  - » Capital or financing from local governments for infrastructure improvements (upgrades to water, sewer, road, sidewalk, etc.) in identified growth areas.
  - » Tax Increment Financing districts to encourage redevelopment (a public-private partnership tool used to promote economic development by earmarking property tax revenue from future increases in assessed values to pay for current infrastructure development).
  - » Stormwater management requirement provisions that reduce on-site management requirements for projects that decrease total imperviousness on previously developed sites, or offering off-site compliance alternative.
  - » More restrictive zoning, utility access, stormwater requirements, and other provisions outside of growth boundary or at the edge of a city to restrict development and to preserve rural character (Nevue, 2009).
- Create regional plans to identify and protect natural resources
- Work with local governments to review and revise codes and ordinances

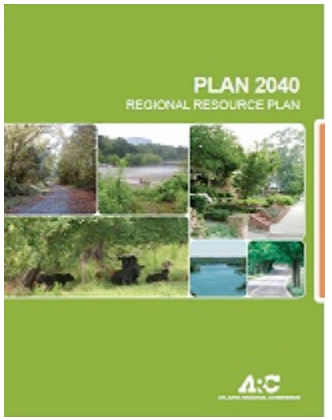


Figure 3.3-4 Pursuant to Rules of the Department of Community Affairs (DCA), the **Atlanta Regional Commission (ARC)** must prepare and adopt a Regional Plan, which includes a plan for the protection and management of regional resources and a review of activities potentially impacting these resources. In addition to the work that ARC has done with mapping the Region's Greenspace Inventory and developing a Green Infrastructure Toolkit, the Regional Resources Plan furthers the work being done on the local, regional, state and federal levels to preserve environmental resources, historic sites, and unique cultural landscapes. (ARC, 2015)

CREATING REGIONAL PLANS TO IDENTIFY AND PROTECT NATURAL RESOURCES:

According to the rules of the Georgia Department of Community Affairs, all regional commissions in the state are required to prepare and update a "Regional Agenda. The Regional Agenda includes the region's vision for the future as well as the strategy for achieving this vision. This gives regional commissions the opportunity to create a list of regional issues and opportunities identified for further action, an implementation program for achieving the regional vision, and an evaluation and monitoring plan to ensure the regional plan is accomplishing the desired results. For example, the Atlanta Regional Commission (ARC) has created a Regional Resource Plan that has included the following Environmental Protection Principles:

- Conserving and protecting environmentally-sensitive areas and increasing the amount and connectivity of greenspace
- Continuing to enhance stewardship of water resources throughout the region
- Promoting energy-efficient land development and infrastructure investments that foster the sustainable use of resources and minimize impacts to air quality
- Encouraging appropriate infill development, redevelopment, and adaptive reuse of the built environment to maintain the regional footprint and optimize the use of existing investments

As shown above, ARC has included infill development and redevelopment into its Regional Resource Plan. Regional commissions can use these plans to coordinate the activities and planning efforts of local governments, land trusts, and environmental protection groups in the region (ARC, 2015).

Infill development and redevelopment can be encouraged throughout a community by local governments and regional commissions incorporating the planning techniques discussed above. By utilizing infill development and redevelopment, impacts to natural resources can be reduced by directing growth to already developed areas. Smart growth initiatives can be incorporated to create more "live, work, play" atmospheres.

HELPFUL RESOURCES

Georgia Environmental Protection Division Brownfield website: http://epd.georgia.gov/brownfield

Georgia Redevelopment Fund Program: http://www.dca.state.ga.us/communities/downtowndevelopment/programs/redevfund.asp

Green Infrastructure Center: www.gicinc.org

Smart Growth America. "What Is Smart Growth?" Smart Growth America. N.p., 2015.

U.S. Environmental Protection Agency Smart Growth Implementation Assistance website: http://www2.epa.gov/smartgrowth/smart-growth-implementation-assistance

U.S. Environmental Protection Agency (EPA). 2006. This is Smart Growth. Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2014. *Smart Growth and Economic Success: Strategies for Local Governments.* Washington, D.C.

3.3.2 Site Planning and Design

The land development process can significantly alter the natural landscape by converting previously undisturbed areas into more intensive land uses. During site development vegetation and topsoil may be removed, natural drainage features may be altered, and valuable natural resources may be converted into building sites. Better site planning and design techniques seek to minimize impervious cover, conserve more natural areas, and use pervious areas more effectively to treat stormwater runoff.

The site planning and design techniques described in the following sections evaluate the footprint of a proposed development project and illustrate the relationship between proposed impervious surfaces and the existing natural conditions. The techniques place value on the environmental benefits of the natural resources at a site and incorporate protection strategies into the overall design of a project to preserve existing natural features. Protecting natural resources early in the planning process allows them to be utilized for many functions, such as infiltration, flow attenuation, groundwater recharge, flood storage, runoff reduction, nutrient cycling, air and water pollution reduction, habitat diversity, and thermal impact reduction. In addition, some of the techniques can also have a direct positive impact on property values and provide an economic incentive to safeguard the natural features of a site before development.

The following Site Planning and Design techniques are included in Section 3.3.2:

3.3.2 Site Planning and Design	
3.3.2.1 Natural Resources Inventory	• Identifying natural features and resources on a site prior to designing development layout.
3.3.2.2 Conservation of Natural Features	• Strategies that can be used by local governments to enforce or provide incentives for conservation of natural features.
3.3.2.3 Development Design	• Site development designs that minimize clearing and grading and use available buildable areas in the most space-efficient way.
3.3.2.4 Tree Conservation and Tree Canopy	• Local government codes that promote the preservation of trees/tree canopy cover and native vegetation during construction and post-construction phases of development.
3.3.2.5 Management of Open Space, Sustainable Landscaping	• Methods to effectively manage open space and vegetation within a development.

3.3.2.1 NATURAL RESOURCES INVENTORY

Description: The first step in the Better Site Design process is to identify existing natural features and resources that can be used in protecting water resources by reducing stormwater runoff, providing runoff storage, reducing flooding, preventing soil erosion, promoting infiltration, and removing stormwater pollutants. This can be done at the small watershed scale as part of an open space or green infrastructure plan, or at the site scale as an early step in the land development (or redevelopment) process.

Ideally, these two scales can be coordinated so that site-scale inventories are part of larger, community efforts. However, even in the absence of a larger community-wide plan, site-scale natural resources inventories are a critical part of the development process. The natural resources inventory should be completed during the site assessment phase of the overall site planning and design process. An example of a natural resources inventory map is shown in Figure 3-6. Some of the features that should be delineated in a natural resources inventory are listed in Table 3-7.

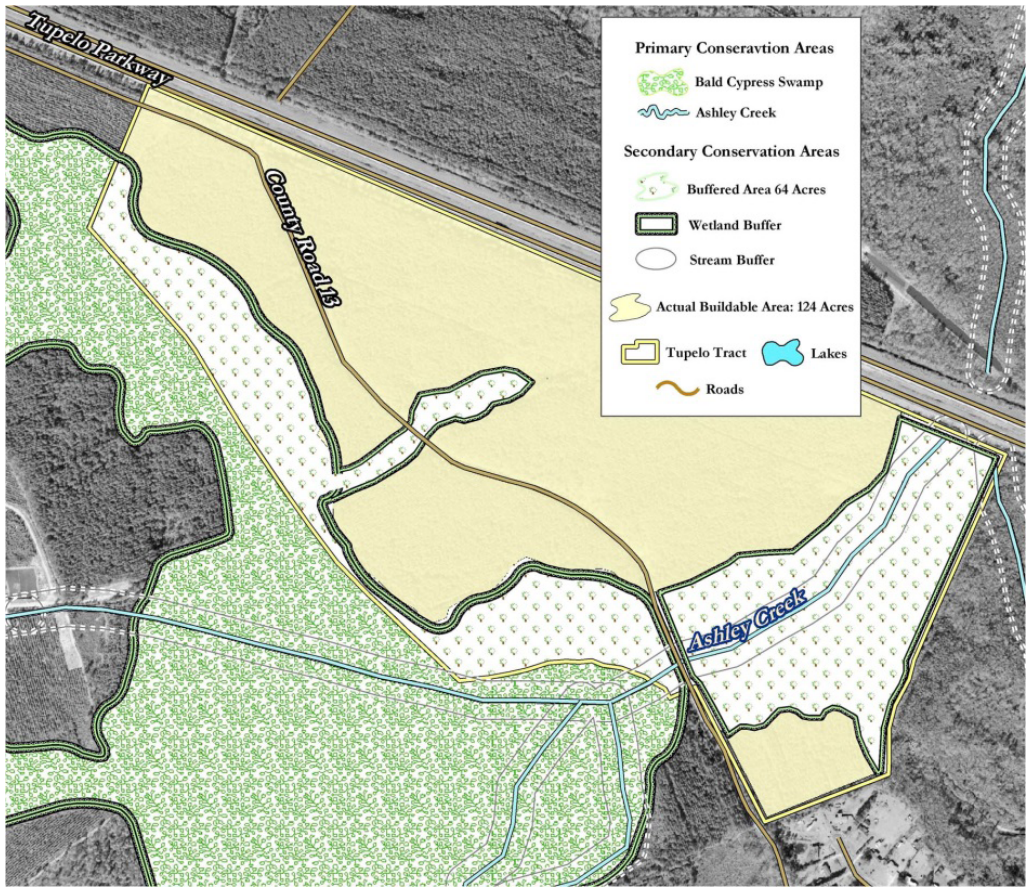


Figure 3.3-6 Delineation of Primary and Secondary Conservation Areas
(Source: GDNR, 2006)

KEY BENEFITS

- Guides layout of the buildable area
- Guides creation of the stormwater management concept plan
- Serves as a basemap to accomplish other Better Site Design objectives

SPECIFIC RECOMMENDATIONS:

Table 3-7 makes a distinction between Primary and Secondary conservation areas. Primary areas are top priority areas for protection, and Secondary areas are landscape features that support and expand protection of the primary areas. Secondary features should also be identified in the natural resources inventory and incorporated into the site design to the extent possible.

Mapping

Although a lot of the information needed to complete the natural resources inventory must be gathered through site reconnaissance and surveying, some of it may be available directly from the local, state, and federal agencies, or from the Internet. In addition to local sources of data, helpful resources include:

- Georgia Department of Natural Resources, Wildlife Resources Division
- National Wetland Inventory (NWI) Maps – show the wetland geographic extent
- Wetlands-At-Risk Protection Tool (WARPT)
- U.S. Geological Survey's National Gap Analysis Program – species ranges and distribution for conservation planning

A comprehensive list of internet sites that act as clearinghouses for Geographic Information System (GIS) data and other spatial data, along with additional information about completing a site assessment and natural resources inventory, is provided in Green Growth Guidelines (GDNR, 2006).

Table 3-7 Features to Include in Natural Resources Inventory

Primary Conservation Areas (WRD, 2005)	Secondary Conservation Areas (GADNR, 2006)
Aquatic Resources • Rivers and Streams • Floodplains • Freshwater Wetlands • Tidal Rivers and Creeks • Waterway Buffer Zones	**Site Characteristics and Constraints** • Natural Drainage Divides • Natural Drainage Patterns • Natural Drainage Features (e.g., Swales, Basins, Depressional Areas) • Erodible Soils • Steep Slopes (i.e., areas with slopes greater than 15%, or steeper in hilly or mountainous areas of the State) • Trees and Other Existing Vegetation (see Section 3.3.2.4)
Terrestrial Resources • Regionally-significant forest lands, savannas, and other unique vegetation communities, especially contiguous areas that provide habitat and wildlife corridors • Identified wellhead protection areas	**Other Natural Resources** • Other Groundwater Recharge Areas • Specimen Trees (CWP, 2009) • Unique natural features (CWP, 2009)
Other Natural Resources • Shellfishing Areas • High Priority Habitat Areas • Areas Providing Habitat for Threatened and/or Endangered Species	

HOW LOCAL REGULATIONS CAN BE AMENDED TO SUPPORT THIS PRACTICE:

In order to ensure that developers conduct a natural resources inventory prior to creating the site development design, local governments should make it a mandatory part of the development review process (as described in Table 3-8). This can be a requirement for all development plans or for discretionary reviews, such as special use permits or rezoning applications. See Standard #1 in Section 4.2.

The specific features required in the natural resources inventory should be included in the locality's plan review checklist. The natural resources inventory would be a separate engineering design sheet within the plan set listing the location of the natural resources. Pre-application meetings and plan submittal checklists can help communicate and coordinate the process. Local codes may also be revised to give the planning department or planning board the authority to require more or less protections on particular sites based on the natural resources existing on those sites.

HELPFUL RESOURCES

Georgia Green Growth Guidelines: A Low Impact Development Strategy for Coastal Georgia: http://coastalgadnr.org/cm/green/guide

National Wetland Inventory (NWI) maps: http://www.fws.gov/wetlands/

Wetlands-At-Risk Protection Tool: http://www.wetlandprotection.org/

U.S. Geologic Survey's National Gap Analysis Program: http://gapanalysis.usgs.gov/

Table 3-8 Example Process for Conducting a Natural Resource Inventory (CWP, 2009)

1.	**Locality conducts a desktop analysis using existing GIS data: locate wetlands, floodplains, steep slopes, water bodies, etc. This provides a preliminary analysis of what is on the site and includes a jurisdictional determination and tree protection plan.**
2.	Developer would hire a qualified professional to conduct full field site inventory based on what was identified during desktop analysis.
3.	**Optional: Locality and developer conduct a natural resources field visit.**
4.	The locality field checks the completed natural resources inventory as needed.
5.	The natural resources inventory would then go into the development review process.

3.3.2.2 CONSERVATION OF NATURAL FEATURES

Description: The site designer should ensure that conservation areas shown in the natural resources inventory (see Section 3.3.2.1) are protected in the development design. These features should remain undisturbed before, during, and after construction. The identification and subsequent preservation and/or restoration of these natural resources reduce the negative impacts of the land development process "by design". This section describes strategies that can be used by local governments to enforce or provide incentives for protection of natural features designated for conservation.



Figure 3.3-7 Conservation Area in Midway, GA
(Source: GDNR, 2006)

KEY BENEFITS

- Preserve priority conservation areas
- Preserve a portion of the site's natural predevelopment hydrology
- Preserve a portion of the site's natural character and aesthetic features
- Increase the value of the developed property
- Use vegetated areas as nonstructural stormwater filtering and infiltration zones
- Reduce urban heat island effect
- Improve opportunities for outdoor recreation
- Improve air quality
- Preserve wildlife habitat
- Carbon sequestration and storage

SPECIFIC RECOMMENDATIONS:

The conservation strategies described in Table 3-9 may require local code changes and/or changes to site plan submittal requirements for new development.

Table 3-9 Strategies for Conserving Natural Features on Development Sites

Topic	Strategy	Description
Protect Aquatic Buffers	Prohibit Development	• Prohibit development, ideally within 100 feet of streams, wetlands, and shorelines.
	Specify Buffer Criteria	• Minimum buffer width • Minimum requirements for vegetative cover • Allowable uses of buffer area • Re-vegetation required if vegetation currently does not exist • Program/mechanism to inform new property owners
Protect Floodplains	Prohibit Development	• Ideally, the entire 100-year floodplain should be avoided for clearing or building activities, and should be preserved in a natural undisturbed state where possible. Floodplain protection is complementary to riparian buffer preservation.
Protect Steep Slopes	Avoid Grading	• Require that slopes of 15% or greater are marked on development plans and avoid excess clearing and grading of those areas. Prohibit land development activities in areas that have slopes greater than 25% unless necessary for roadway or utility construction.
Protect Soils	Avoid Disturbing Erodible Soils	• Avoid grading erodible soils. Locate buildings and other impervious surfaces in areas with tight soils with the lowest infiltration rates (e.g., hydrologic soil group C and D soils).
Protection During Construction	Label on Plans	• Ensure that any natural features to be protected and/or conserved are clearly delineated on clearing and grading (erosion control) plans.
	On-Site Fencing	• Require that natural features to be protected and/or conserved are blocked off by temporary construction fencing prior to the start of land development activity.
Zoning	Overlay Zoning	• A technique to "overlay" more protective standards over areas needing special protection. Examples are drinking water supply watersheds, wellhead protection areas, areas subject to flooding, and watersheds for critical resources, such as wetlands and special recreational areas. The overlay zone typically designates allowable land uses and performance standards for stormwater management.
Legally Enforceable Instruments	Deed Restriction	• A written instrument that affects the title of a property by restricting development in perpetuity. Recorded where deeds are recorded.
	Conservation Easement	• Similar to a deed restriction. Some conservation easements are set up to expire after a certain number of years, while others are designated to remain in perpetuity. Landowners with conservation easements are often eligible for tax deductions.
	Maintenance Agreement	• Recorded document signed by a land-owner agreeing to protect and maintain conservation areas. These are often signed by landowners who receive cost-share funds for conservation practices.

In order to make protection of on-site natural features more attractive to developers and landowners, local governments can also consider providing incentives, such as those shown in Table 3-10. Local governments that want to encourage better protection of natural resources from development may find that a combination of more stringent development rules and incentives for conservation is the most successful approach.
:

Table 3-10 Recommended Strategies for Incentivizing Conservation of Natural Features

Strategy	Description
Provide Stormwater Credits for Natural Area Conservation	Volume 2, Section 2.3 **describes a credit that reduces the runoff reduction volume or TSS removal requirements for developments that conserve natural areas on a site.**
Transfer of Development Rights (TDR)	TDR programs set up development rights markets whereby some landowners in rural or sensitive watersheds can sell their development rights to landowners in areas where growth, infill, and redevelopment are encouraged.
Purchase of Development Rights (PDR)	A program typically funded by local government that pays landowners to not convert farmland and/or sensitive natural areas to development. PDR programs are particularly targeted to areas or watersheds where rural character and natural resources should be protected.
Density Compensation	In exchange for preserving natural features in a development site plan, developers are allowed to build at a higher density. This is sometimes called Conservation Development, Cluster Development, or Open Space Development. For protecting water resources, a particular emphasis may be placed on riparian buffers, forest protection, and open space areas that capture and disperse runoff. A maximum and minimum allowable density should be established by the locality (see also Section 3.3.2.3).
Permit Process Incentives	Local governments can offer incentives such as reduced permit fees, faster permit processes, and/or exemptions from permitting requirements when natural resources are protected in a development plan.
Property Tax Reduction	Landowners are charged a lower property tax rate in exchange for establishing conservation easements for sensitive natural features on their property.

CASE STUDY

City of Chattahoochee Hills Transfer of Development Rights Program

The City of Chattahoochee Hills, Georgia defined a goal of retaining its rural and natural character through a Comprehensive Land Use Plan. To help achieve this goal, the city adopted a transfer of development rights (TDR) ordinance to protect its rural and natural areas such as farmland and forests. Under a TDR program, properties identified as priority green space are protected. Priority green space represents the values of farmland protection, watershed protection, and cultural, historic and scenic vista protection expressed by the community. The Chattahoochee Hills Conservancy (CHC) works with property owners of identified priority green space to establish a conservation easement on their property that gives up the right to develop the land. A conservation easement is a legal document that becomes part of the deed in which the property owner pledges not to develop a defined portion of the land. In exchange, the development rights are bought by developers to increase the development density in designated growth areas to the maximum allowable density as defined in the zoning ordinance. The CHC completed two transactions to purchase TDRs as a pilot project to establish procedures. Through this pilot project, the CHC holds TDRs covering 22 acres on two parcels.

http://www.chatthillcountry.org/dev_rights

CASE STUDY

Forest Conservation in DeKalb County

Through the conservation efforts of the Briarlake Community Forest Alliance, a grass roots non-profit organization, the 21-acre forest at Briarlake Road and Amberwood Drive is now a community park. The wooded property, which includes at least 60 trees with trunk diameters over 30 inches (as well as many smaller trees and understory vegetation), was slated for potential development. Even with preliminary plans for a conservation development, with clustered homes on a smaller portion of the property, some believed that too much damage would be done to the forest, and the natural stormwater management benefits the forest provides would be lost. Rather than allow the land to be developed, the DeKalb County Department of Recreation, Parks, and Cultural Affairs purchased the land to create a public park and ensure that the forest would be preserved. Planning for how to manage the park, and development of a Friends of the Park organization is now underway.

http://briarlakecommunityforest.org/

3.3.2.3 DEVELOPMENT DESIGN

Description: In order to avoid sensitive natural features, site designers may need to use creative development designs that minimize clearing and grading and use available buildable areas in the most space-efficient way. This section describes several lot location and design techniques that allow for avoiding conservation areas. This type of development design flexibility may be a prerequisite for the implementation of the other Better Site Design strategies noted in Section 3.3.2. In essence, this and the Natural Resources Inventory (see Section 3.3.2.1) form the backbone of the site planning and design techniques.

Figure 3-8 below illustrates an example whereby development at a higher density with a space-efficient design can actually reduce overall impervious cover and disturbed area within a small watershed, as long as protection mechanisms are in place for the non-developed areas (see Section 3.3.2.2).

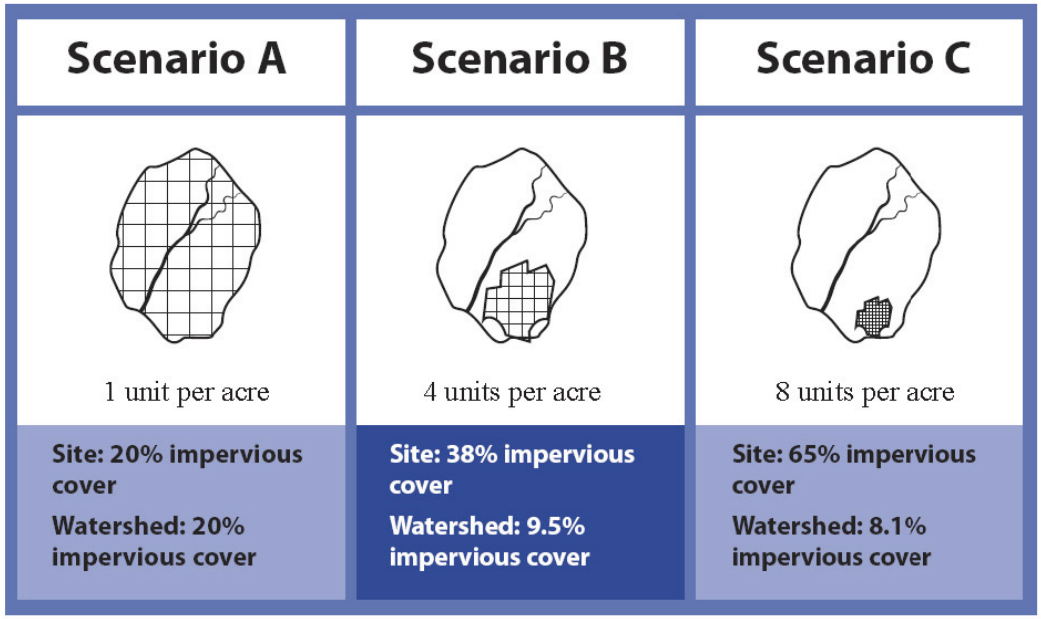


Figure 3.3-8 This illustration, adapted from the U.S. EPA publication "Protecting Water Resources with Higher Density Development", shows how increasing density at the site level decreases impervious cover for the watershed. (Source: Ellis et al., 2014)

KEY BENEFITS

- Maximize land conservation while retaining same number of dwelling units as traditional lot layout
- Preserve contiguous open spaces for recreational use and/or habitat protection
- Reduce area of clearing and grading needed during construction
- Reduce sprawl
- Use vegetated areas as nonstructural stormwater filtering and infiltration zones

SPECIFIC RECOMMENDATIONS:

Table 3-11 Development Design Recommendations

Topic	Strategy	Description
Flexibility on Lot Size and Density	Open Space / Conservation / Cluster Development	A development pattern used to concentrate structures and impervious surfaces in a small portion of a site, leaving room for larger conservation areas and managed open spaces elsewhere on the site. Smaller lot sizes and alternative lot designs are typically used to "cluster" structures and other impervious surfaces within these development projects (see Figure 3-9). Communities might be seeking this type of design to support walkability, transit station access, reduced infrastructure costs, and/or for water resource protection. Compact designs can be used in any development setting from ultra-urban retrofits to rural village centers. (Hirschman and Kosco, 2008)
	Smaller Street Design	Skinnier and shorter street specifications can facilitate denser lot layouts as needed in cluster developments. Many state departments of transportation are issuing "context-sensitive" alternatives for street design that include narrow streets and consider multiple transportation modes. For transportation planners, the narrow streets are aimed at slower speeds and neighborhood design models (see also Sections 3.3.3.1 and 3.3.3.2).
Lot Dimensions and Layout	Alternative Lot Dimensions	Allow zipper lots, angled z-lots, and other irregular lot shapes (see Figure 3-10) in order to facilitate denser development.
	Planned Unit Development (PUD)	Type of development approval that allows deviations from development standards such as: • Modifying lot size and width requirements • Reducing building setbacks and frontages from property lines • Altering parking requirements • Increasing building height limits (see also Section 3.3.3.4)
	Reduce Setbacks and Frontages	Reduce front yard building setback to 20 feet to reduce the required length of driveways and sidewalks (see Figure 3-11 below). Reduce side yard setbacks to 25 feet or less and frontage length to 80 feet or less to allow for denser development and shorter road lengths.

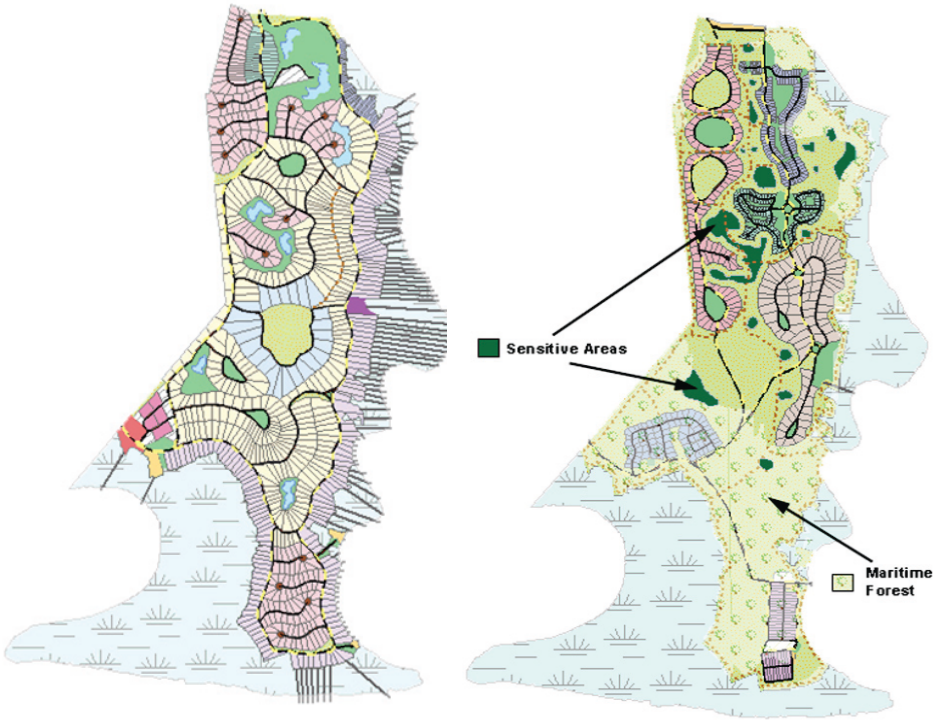


Figure 3.3-9 Conventional development with large lots throughout the site (left) vs. Conservation development style that preserves more open space (right) with the same number of lots.
(Source: GDNR, 2006)

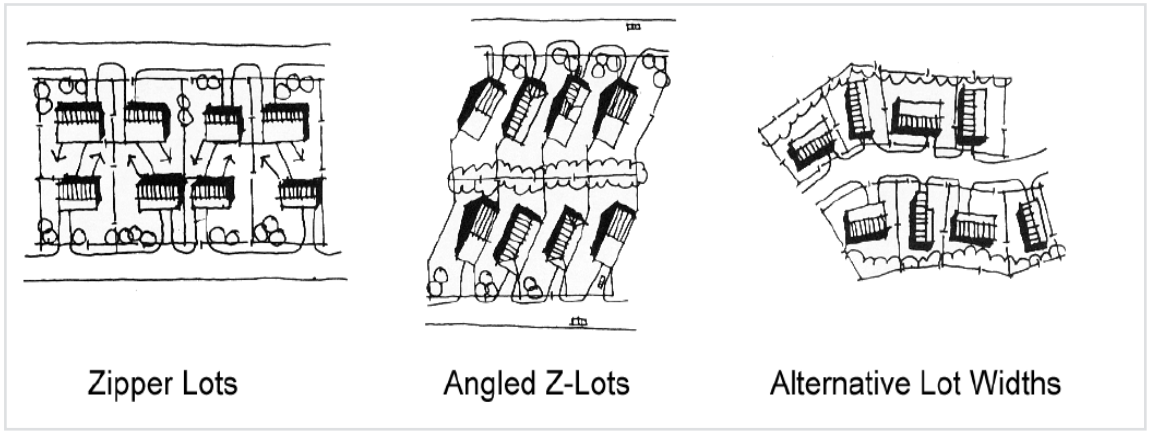


Figure 3.3-10 Alternative Lot Designs
(Source: Center for Watershed Protection, 1998b)

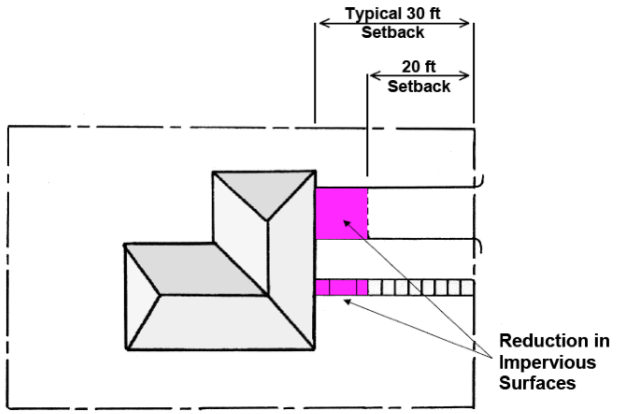


Figure 3.3-11 Reduced front yard setbacks results in the creation of less impervious cover on development sites. (Source: CWP, 1998b)

How Local Codes Can Be Amended to Support This Practice:

It is important to note that, although all of the Better Site Design techniques listed in Table 3-12 are recommended, their use may be restricted by local codes and ordinances. Therefore, until these revisions have been completed and barriers to the use of BSD techniques have been removed, developers and their site planning and design teams are encouraged to consult with the local development review authority to identify any local restrictions on the use of these techniques.

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Table 3-12 Local Code Changes to Support Alternative Development Designs

Topic	Typical Local Code Conflicts	How Conflicts Can Be Resolved
Flexibility for development design, lot sizes, layouts, setbacks, etc.	Zoning and subdivision codes can be prescriptive to the extent that alternative designs cannot be approved. There may be "one-size-fits-all" zoning and performance standards for all zoning districts.	• Consider the big picture of how alternative development design can complement and support an open space or green infrastructure plan (see Section 3.3.1) or broader-scale natural resources inventory. • Consider planned unit development, transfer of development rights, and other tools for specified zoning districts to enhance density within designated growth areas , restrict impervious cover, and/or protect natural resources within rural or natural resource areas.

CASE STUDY

Fox Hollow Development – James Island, SC

Located on James Island, South Carolina, Fox Hollow is a 2.65 acre low impact development that protected the trees, wetlands, and topography of the site. Unlike conventional development, where mass grading is common, at Fox Hollow the land has been highly conserved – only enough land for the 9 houses and roadway were cleared. Narrow streets and driveways reduce impervious cover in the development. Rather than relying on pipes, a bioswale system conveys stormwater and bioretention cells replace stormwater ponds. The site has a density of 4.22 homes/acre with 0.52 acres of open space consisting of park, bioretention and wetlands. Named "Best New Community of 2013" by the Charleston Homebuilders Association, Fox Hollow was specifically recognized for its low impact development approach (Ellis et al. 2014).



Figure 3.3-12 Site plan for Fox Hollow (Ellis et al, 2014)

3.3.2.4 TREE CONSERVATION AND TREE CANOPY

Description: Trees provide numerous well-documented benefits and are important contributors to the overall quality and viability of the environment. Trees reduce stormwater runoff through rainfall interception by the tree canopy, by releasing water into the atmosphere through evapotranspiration, by promoting infiltration of water through the soil, and by storage of water in the soil and forest litter (Figure 3-13). Georgia Forestry Commission's State of the Urban Forest Report states that infiltration rates for forested areas are 10-15 times greater than for equivalent areas of turf and grass, and a healthy forest can absorb as much as 20,000 gallons of water in an hour. The report also indicates that in Atlanta alone, the stormwater retention capacity of the urban forest is worth about $86 million a year (Georgia Forestry Commission, 2012).

Local government codes can promote the preservation of trees and native vegetation during both the construction and post-construction phases of development. Tools that can be used for tree conservation include:

- Forest conservation ordinances
- Landmark (champion) tree preservation language in local codes
- Setting canopy goals at the site and local level
- Open space development practices
- Planting vegetation in rights-of-way and public areas
- Clearing and grading planning to protect trees at a site

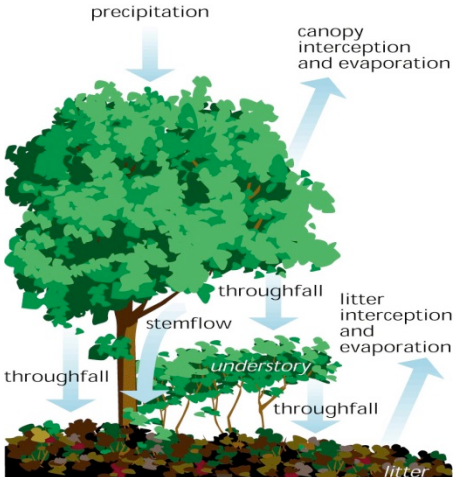


Figure 3.3-13 Schematic of a Tree's Hydrologic Cycle (Source: FISRWG)



Figure 3.3-14 Tree that Owns Itself Athens, GA (Source: Wikipedia)

KEY BENEFITS

- Provide reduction of stormwater runoff volume through canopy interception and water uptake
- Moderate summer air and water temperatures
- Increase value of property
- Improve regional air quality
- Reduce stream channel erosion
- Improve soil and water quality through nutrient uptake
- Provide habitat for terrestrial and aquatic wildlife
- Improve aesthetics and recreational opportunities
- Carbon sequestration and storage

SPECIFIC RECOMMENDATIONS:

Some of the following recommended actions for protecting trees and forest are the responsibility of the developer, while others require local government policies and action.

- Design structural elements such as roads and utilities to minimize soil disturbance and take advantage of natural drainage patterns.
- Create an inventory of landmark trees and forest preservation areas prior to developing the site plan, as part of the Natural Resources Inventory.
- Designate trees of a certain size, species, age, historical significance, ecological value, aesthetics, or location as landmark trees.
- Protect landmark trees by designating an area of no disturbance around each tree
- Promote the Site Design Credit for Natural Area Conservation (see Volume 2, Section 2.3) to encourage tree retention during site development
- Adopt a forest conservation ordinance that specifies the minimum percentage of existing forest or a tree size threshold that must be retained at a site.
- A tree replacement plan should be submitted and approved before any protected trees are removed. Protected trees that have been approved for removal should be replaced at a higher ratio of trees gained to trees lost (e.g., 3:1).
- Set minimum green space and tree canopy preservation percentages after an evaluation of existing tree resources.
- Adopt a Tree Protection Ordinance that: (1) specifies it is unlawful to remove a tree without a permit, (2) requires replacement of any removed trees that are larger than 24 inches diameter at breast height (dbh), and (3) sets a size limit to prevent certain healthy trees from being removed.
- Ensure adequate protection practices are required during site construction (such as the placement of temporary fencing around trees, and the prohibition of materials storage within the tree root zone) and that no impervious material is placed within the dripline of preserved trees.
- Consider implementing a tree point system to evaluate site plans and ensure that both the number of trees and the quality of the trees for each site are assessed. See the City of Savannah's Landscape and Tree Ordinance Compliance Manual for an example point system.

How Local Codes Can Be Amended to Support This Practice:

Local governments play an important role in protecting forests during and after construction by ensuring that appropriate ordinances are enforced to adequately protect trees and forest areas. Many of the actions recommended above require additions or revisions to local codes and ordinances. Table 3-13 lists several code changes that communities can make if their codes are currently "silent" on or in conflict with tree and forest protection.

Table 3-13 Local Code Changes to Encourage Tree Conservation and Planting

Topic	Typical Local Code Conflicts	How Conflicts Can Be Resolved
Forest/Tree Conservation	No codes exist promoting tree retention during site development	Adopt a Forest/Tree Conservation Ordinance in local land development regulations that specifically addresses the link between a functional landscape and the protection of trees at a site
Landmark Trees	No protection is afforded to trees of significant value	Establish criteria in the ordinance (or accompanying regulations) for size, age, and/or type of trees that must receive special protection. Define penalties associated with unauthorized damage or removal of an individual tree that meets the criteria.
Landscaping requirements	Landscaping code does not specify the type of vegetation to be used or does not allow for adequate spacing of trees	Landscape ordinances can provide guidance on: number of trees per parking space; species selection; plant spacing; setbacks from buildings, pavement, and utilities; planting plan development; and maintenance schedules.

CASE STUDY

Oak Terrace Preserve, North Charleston, SC

Oak Terrace Preserve is a 55-acre sustainable redevelopment project located in Park Circle, North Charleston. The redevelopment project provided green sustainable features in home construction in addition to pocket parks, public space, an LID stormwater management system, and an extensive tree preservation program. An important aspect incorporated into the project was the protection of its tree resources. Prior to development, Oak Terrace Preserve was home to over 600 trees, many of them grand trees with 24-inch or larger diameters, including oaks, magnolias, and additional old-growth trees that are rarely found in a new community. Tree preservation and management was a top priority. A certified arborist performed a tree survey and assessment before construction. During site construction activities, fencing protected the trees and their critical root zone. The certified arborist's continued involvement on-site was a major factor for successful tree protection



Figure 3.3-15 One of the mature oak trees protected in Oak Terrace Preserve

3.3.2.5 MANAGEMENT OF OPEN SPACE, SUSTAINABLE LANDSCAPING

Description: Development that encourages open space design also has an opportunity to use that open space to help manage stormwater and reduce runoff. The retention of open space in a natural condition (i.e., native vegetation) helps to infiltrate rainfall, thereby reducing runoff volume and the need for structural stormwater practices at a development site.

Communities should also explore reliable methods to assure that the responsibility for open space management can be met within a development. The two primary options are to create a community association (with an annual assessment to property owners for management purposes) or to shift the responsibility to a third party, such as a land trust or park authority, by means of a conservation easement. The latter technique is especially useful in developments that have high quality conservation areas retained in open space.



Figure 3.3-16 EcoScapes Sustainable Landscaping Demonstration Garden at UGA Marex Brunswick Station
(Source: University of Georgia)

KEY BENEFITS

- More effective treatment of stormwater
- Open space managed in natural condition has a reduced annual maintenance cost
- Reduced demand for irrigation and use of potable water supplies
- Fewer chemical inputs and less pollution in runoff.
- Improve site aesthetics which may result in higher property values
- Carbon sequestration
- Reduce urban heat island
- Improve recreational opportunities

SPECIFIC RECOMMENDATIONS:

When existing open space and natural landscaping areas are designated for permanent protection on a development plan, it is important to ensure that they will remain intact and functional for the long-term. This requires assurances that they will not be impacted for future development and that they will be maintained properly. The following list includes recommended methods to establish long-term designation and management of such open spaces.

- Ensure that consolidation of open space is maximized to provide the largest natural areas possible.
- Spell out allowable uses for open space areas in local codes or maintenance agreements.
- Require that a minimum percentage of the open space be managed in an undisturbed natural condition, preferably with low-maintenance native vegetation. The University of Georgia Cooperative Extension has guidance on native landscaping appropriate for a site.
- Prohibit the installation of any plant species that is listed as an invasive species by the Georgia Invasive Species Task Force.
- Establish limits for lawn areas in favor of other natural groundcovers or vegetation.
- Be sure to have a reliable method for ensuring management of open space through enforceable requirements to establish associations that can effectively manage open space.
- Provide assistance to developers and/or real estate agents to develop and transfer information to homebuyers and homeowners' associations concerning maintenance of on-site water quality practices, the purpose of stormwater management facilities, proper management of conservation areas, etc.
- Identify and document existing stream buffers, forest conservation areas, and other natural features that may be located in designated open space areas. Use signage as a communication tool about the open space areas and protection objectives (signs reading "designated for protection", "do not dump yard waste or litter", etc.).
- Landscaping should be designed to remain functional and attractive during all seasons of the year through a thoughtful selection of deciduous, evergreen, flowering, and non-flowering plant varieties.
- Prominent natural features of the landscape, such as mature trees and surface waters, should be retained and incorporated into the landscape plan where possible.
- LEED Standards (Leadership in Energy and Environmental Design) for new construction call for outdoor space greater than or equal to 30% of the total site area (including building footprint). A minimum of 25% of that outdoor space must be vegetated or have an overhead vegetated canopy. Turf grass does not count as vegetation.

Sustainable Landscaping

In addition to preserving existing open spaces, developments have an opportunity to establish new areas of vegetation and habitat. There are many factors to consider when creating a sustainable, low impact landscape. The Sustainable Sites Initiative, a collaborative project of the American Society of Landscape Architects, Lady Bird Johnson Wildflower Center, and the United States Botanic Garden, seeks to establish and encourage sustainable practices in landscape design, construction, operations, and maintenance. The following table describes some design, construction, and maintenance factors to assess the sustainability of a landscape design.

Table 3-14 Summary of Sustainable Landscaping Practices*

Criteria	Suggested Landscaping Practices
Site Selection	• Protect floodplain functions • Preserve wetlands • Preserve threatened or endangered species and their habitats • Select brownfields or other vacant properties for redevelopment • Select sites within existing communities • Maintain natural, undisturbed areas
Site Design – Water	• Control and manage known invasive plants found on site • Use appropriate, non-invasive plants and native plants • Create a soil management plan • Minimize soil disturbance in design and construction • Preserve or restore appropriate plant biomass on site • Preserve or restore appropriate plant communities native to the ecoregion • Use vegetation to minimize building heating and cooling requirements • Reduce urban heat island effects • Reduce the risk of catastrophic wildfire
Site Design – Materials Selection	• Reuse salvaged materials and plants • Use recycled content materials • Use regional materials • Support sustainable practices in plant production and materials manufacturing
Site Design – Human Health and Well-Being	• Protect and maintain unique natural, cultural, and historical places, such as shell rings, Carolina bays, tabby structures, and cemeteries • Provide views of vegetation and outdoor spaces for mental restoration
Construction	• Restore soils damaged by previous development • Reuse or recycle vegetation, rocks, and soil generated during construction
Operations and Maintenance	• Compost organic matter generated during site operations and maintenance

*Adapted from the Sustainable Sites Guidelines and Performance Benchmarks, 2009

How Local Codes Can Be Amended to Support This Practice:

Local development codes should ensure that open space is well planned and that clear performance criteria for open space consolidation, maintenance, allowable uses, and future management are carefully crafted. This includes ensuring that common open space and natural conservation areas are managed by a responsible party able to maintain the areas in a natural state, in perpetuity. Typically, the conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements. Management of open space areas can be taken on by a Homeowner Association or a local land trust, for example, to monitor the site and enforce its boundaries. The option to designate maintenance should be specifically allowed in local ordinances.

CASE STUDY

Sustainable Landscape Management Policy – DeKalb County, GA

DeKalb County's Sustainable Landscape Management Policy endorses environmentally responsible and sustainable landscaping management practices for the protection of the county's water supply and the enjoyment of these resources by DeKalb residents. All newly constructed and existing county facilities and grounds employ sustainable landscaping practices including the use of drought tolerant, locally-adapted plants and the use of Integrated Pest Management (IPM).

Table 3-15 Local Code Changes to Support Management of Open Space

Topic	Typical Local Code Conflicts	How Conflicts Can Be Resolved
Sustainable Landscaping	The use of alternate landscaping practices can actually be restricted by current planting requirements in ordinances	Communities should develop and adopt a Sustainable Landscaping section in their land development regulations that specifically addresses the link between a functional landscape and the protection of water resource quality, which spells out requirements and objectives based on land use type and activity.
Definitions of Open Space	Code is "silent" on what can be officially designated as open space on a development plan	Specify the types of features that can (e.g., stream buffers, contiguous forest, floodplains) and cannot (e.g., lawn) be designated as open space. This is especially important for developments that are given special credit for preserving open space.
Allowable Uses of Open Spaces	Acceptable uses for open space areas are not defined in local codes and may prevent efforts to address runoff	Add definitions for eligible and ineligible uses for open space areas (e.g., recreation).

3.3.3 Reducing Impervious Cover and the Development Footprint

Impervious surfaces like asphalt and concrete generate the greatest amount of stormwater runoff, and the pollutant loads are higher coming off impervious surfaces than pervious surfaces like lawns or other vegetated areas. Designing development and redevelopment with the goal of minimizing pavement and building surfaces is an excellent way to mitigate runoff and promote healthy waterways. The design is heavily influenced by municipal ordinances.

The policy guidelines here are generally recommended, but it is important to recognize that individual circumstances may not support application of these tenets. For example, fire code and fire engine access requirements influence roadway design and will take priority over recommendations guided by Better Site Design where there is conflict. To minimize potential conflicts and foster mutual understanding and agreement, stakeholder roundtable discussions are highly recommended; often long-standing concepts can be reexamined and new, progressive, purposeful consensus can be achieved (see Section 3.2).

Much of the information presented here is adapted or taken from the National Association of City Transportation Officials (NACTO) and their Urban Street Design Guide (NACTO, 2015), the collected works of the American Association of State Highway and Transportation Officials (AASHTO), primarily A Policy on Geometric Design of Highways and Streets (AASHTO, 2004), and the Center for Watershed Protection's Better Site Design: A Handbook for Changing Development Rules in Your Community (CWP, 1998b).

The role of local government

A local government's codes and regulations can guide development and transportation design in such a way that the volume of stormwater runoff is reduced and water quality is improved. This also serves other community goals, such as economic development, safety, aesthetics, and land use objectives. Reducing impervious cover can also reduce the urban heat island effect, and may result in lower construction and maintenance costs.

The following Better Site Design techniques for reducing impervious surfaces are included in Section 3.3.3:

3.3.3 Reducing Impervious Cover and the Development Footprint		
3.3.3.1 Reducing Roadway and Right-of-Way Width and Length	1.	Strategies to reduce impervious cover by making streets narrower while still meeting transportation objectives.
3.3.3.2 Alternative Roadway Components	**2.**	**Alternatives to large cul-de-sacs and curb-and-gutter stormwater conveyance.**
3.3.3.3 Reducing Paved Parking and Walking Areas	3.	Reducing the footprint of paved parking lots, driveways, and sidewalks to reduce imperviousness.
3.3.3.4 Reducing Building Footprints	4.	Reducing footprint size of commercial buildings and residences by using alternate or taller buildings while maintaining the same floor to area ratio.

3.3.3.1 REDUCING ROADWAY AND RIGHT-OF-WAY WIDTH AND LENGTH

Description: One of the more obvious ways to reduce impervious cover is to make streets narrower and shorter, while still meeting transportation objectives. "Skinny" streets have many benefits, not only for reducing runoff, but to enhance aesthetics, safety, pedestrian orientation, and neighborhood character. Communities that have adopted skinny street practices have found that while there are policy issues and obstacles to navigate, most can be resolved with a focus on stakeholder input and a clear vision.



Figure 3.3-17 Narrow streets reduce impervious cover area.

KEY BENEFITS

- Less stormwater runoff
- Lower flow velocities (less erosion potential)
- Less expensive to construct and maintain roads
- Safer (due to lower speeds)
- Lower heat island effect

SPECIFIC RECOMMENDATIONS:

Table 3-16 shows recommended street widths based on the volume of traffic and parking needs expected for a given street. The acronym "AADT" stands for annual average daily traffic, a common method in transportation planning of measuring expected vehicle use and designing roads based on that level of traffic. If the designer knows the number of residences served by a street, but not AADT, a general rule is 10 AADT per household, though this number may be lower depending on other transportation modes available and general connectivity of the area.

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Table 3-16 Street Width Recommendations, Based on Traffic Volume and Parking Needs

Width	Condition
10-12'	Residential access alley (no parking)
18-20'	Up to 400 AADT, parking/queueing one side Up to 1000 AADT, no parking
26-28'	Up to 400 AADT, parking/queueing on both sides Up to 1000 AADT with parking on one side (two lanes, no queueing necessary)

Note: Street width options are influenced by housing density and need for on-street parking, and may vary. These are recommended widths, prioritizing reduction of impervious surfaces.

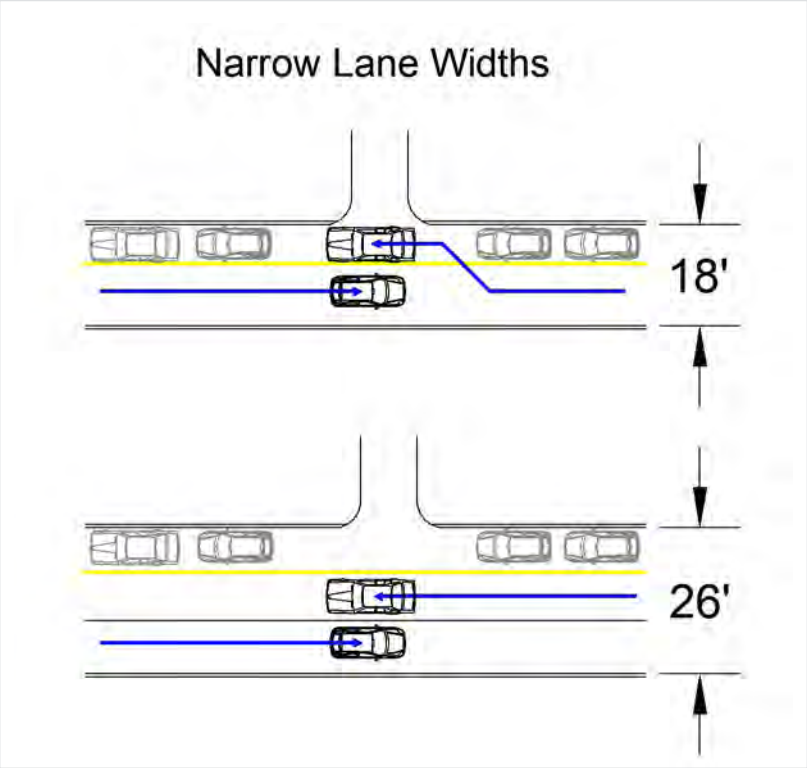


Figure 3.3-18 Examples of narrow road configurations. Top: one drive lane and one parking/queueing lane; Bottom: two drive lanes and one parking lane

Table 3-17 Considerations for Narrow Streets (CWP, 1998b)

- Maximum vehicle width is 8.5' per USDOT. Note: this is the body width, exclusive of rear-view mirrors, etc.
- Roadway can be as narrow as 18' wide with parking on one side* and still pass fire engines or other emergency vehicles. This is a 7' parking/queueing lane, and 11' drive lane. *Travel in both directions requires occasional queueing, where one vehicle pulls to the side to allow another to pass in the opposite direction.
- Roadway can be as narrow as 26' wide to have parking and traffic queueing on both sides.
- The slight increase in accident risk associated with narrower drive lanes is easily offset by the associated lower risk and severity due to a slight reduction in speed limit.
- Most vehicles are significantly narrower than 8.5'.

[Example: Connecticut Avenue through Chevy Chase, MD (inside the Washington, D.C. Capital Beltway) has 8' lane widths on a 6-lane road with AADT counts between 35,000 and 50,000. The speed limit was lowered slightly (to 30 mph) to account for the narrower road width, and the presence of multiple lanes and median strip allows an oversized vehicle to traverse the road if and when necessary.]

Table 3-18 provides lane width guidance from the American Association of State Highway and Transportation Officials (AASHTO), based on the type of roadway and geographic location

Table 3-18 Acceptable Lane Widths for Various Roadway Types (AASHTO, 2004)

Type of Roadway	Rural		Urban	
	Feet	Meters	Feet	Meters
Freeway	12	3.6	12	3.6
Ramps (1-lane)	12-30	3.6-9.2	12-30	3.6-9.2
Arterial	11-12	3.3.-.3.6	10-12	3.0-3.6
Collector	10-12	3.0-3.6	10-12	3.0-3.6
Local	9-12	2.7-3.6	9-12	2.7-3.6

Many agencies are hesitant to allow narrower streets, due to various safety and logistical concerns. Table 3-19 addresses some of the common concerns about narrow roadways and some facts that may help to relieve those concerns.

Table 3-19 Perceptions vs. Realities about Narrow Streets (CWP, 1998b)

Perception	Reality
Narrow streets interfere with the ability to clear and stockpile snow.	FACT: "Narrow" snowplows are available. Snowplows with 8' width, mounted on a pick-up truck are common. Some companies manufacture alternative plows on small "Bobcat" type machines. FACT: Snow stockpiles on narrow streets can be accommodated if parking is restricted to one side of the street.
Narrow streets will cause traffic congestion.	FACT: Narrow streets are generally appropriate only in residential areas that experience less than 500 AADT. Design criteria based on volume generally provide safe and efficient access in residential areas.
Narrow streets do not provide enough room for on-street parking.	FACT: Parking can be accommodated through the use of queuing streets with only one travel lane. FACT: Most communities require some off-street parking accommodation in residential subdivisions. Olympia, Washington requires two parking spaces per dwelling unit. On-street parking is used for visitor parking or other vehicles, such as boats.
Narrow streets can cause pedestrian/vehicle accidents.	FACT: In a study of over five thousand pedestrian and bicycle crashes, a narrow roadway was a factor in only two cases. Unsafe driving speed, on the other hand, contributed to 225 accidents. FACT: Narrower street widths reduce the speed at which vehicles can drive, which reduces the severity of pedestrian/vehicle accidents.
Narrow streets do not provide access for maintenance and service vehicles.	FACT: Trash trucks require only a 10.5' travel lane, with a standard truck width of approximately 9'. In residential neighborhoods, trash collection often occurs simultaneously on both sides of the street; cars must wait for trash trucks to pass regardless of street width. FACT: Half ton mail trucks, smaller than many privately owned vehicles, are generally used in residential neighborhoods. Hand delivery of mail or single point of mail delivery for multiple houses is also an option. CASE STUDY: School buses are typically eight feet wide (nine feet from mirror to mirror). Both Prince Georges County and Montgomery County, MD require only a 12' driving lane for bus access. Furthermore, school buses usually do not drive down every street, but instead meet children at bus stops on larger roads.

Reducing Right-of-Way Width

A complementary strategy for narrow streets is to reduce the width of the overall right-of-way (ROW). The right-of-way is the total land area that contains all of the cross-sectional features of the roadway, including pavement width, curbing, buffers, sidewalks, utilities, drainage, and grading (RI DEM and CRMC, 2011).

- The ROW width affects many stormwater-related conditions.
- Reducing the ROW width can reduce the area of vegetation that must be cleared regularly, thereby preserving existing trees and reducing the impact on water resources.

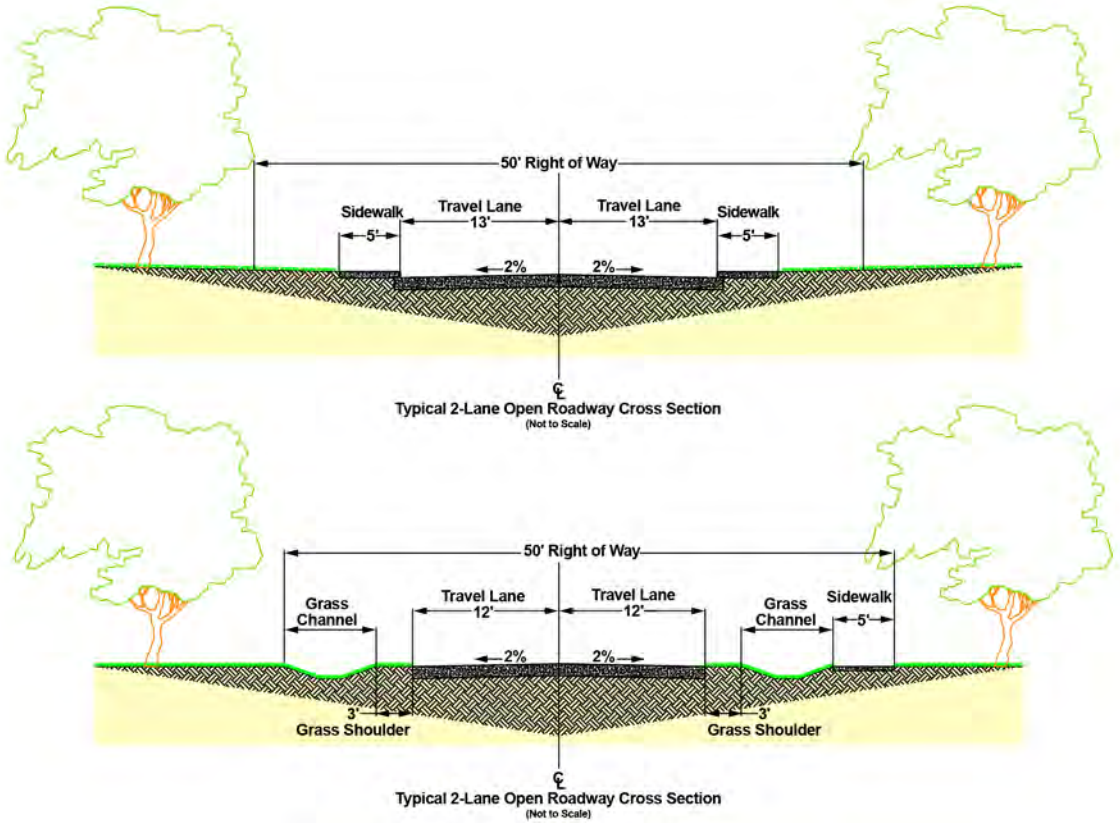
The Institute of Transportation Engineers (ITE) guidelines recommend a minimum ROW width of 50 feet for low density development and 60 feet for medium and high-density developments (ITE, 1997). Therefore, ROWs between 50 and 60 feet in width are common. However, the standard 50 to 60 foot width can be excessive in many situations. While a wide ROW does not necessarily create more impervious cover, it can work against Better Site Design principles. The wider ROW subjects a greater area to clearing and grading during road construction, and also consumes land that could be used for development. The ROW should only be wide enough to contain the necessary elements as shown in Figure 3-19. Generally, widths of 24 to 52 feet are sufficient (Ellis, 2014).

How Local Codes Can Be Amended to Support This Practice:

Rather than writing codes to establish minimum widths under certain conditions, establishing maximum widths that can be overridden only with special exceptions or circumstances will help achieve lower impervious area quantities in new development scenarios. National codes and standards actually allow somewhat surprising reductions compared to what is normally seen. For example, the U.S. Fire Administration allows a road as narrow as 18' wide, while many low-volume residential streets are 24-36' wide or wider.

For best stormwater runoff conditions, require designs to use the minimum required width to accommodate travel, parking, and emergency, maintenance and service vehicles – based on annual average daily trips (AADT).

Figure 3.3-19 Right-of-way cross sections. Both roadways have a 50-ft ROW. The top cross-section shows how a typical road produces excessive impervious cover with 26 feet of pavement and sidewalks on both sides of the street. The bottom cross section demonstrates a design with roadside swales, narrower travel lanes, and a single sidewalk (Source: Center for Watershed Protection).



CASE STUDY

Conservation Incentive: Laurel Oak Grove, James Island, SC (Ellis et al, 2014)

Laurel Oak Grove was successfully able to integrate several Better Site Design techniques and LEED certification into affordable housing. When complete, Laurel Oak Grove will have 22 houses (13 in Phase I and 9 in Phase 2) situated on 6.3 acres with approximately half of the property in preserved open space. The basis of the site design is clusters of houses at a higher density surrounding communal features, such as courtyards. The City of Charleston has a special zoning ordinance for this type of development for the purpose of "permitting unique developments that utilize flexible design that is sensitive to natural areas, provides quality open space, decreases stormwater runoff by reducing impervious surfaces, reduces the cost of infrastructure, and provides a mixture of lot sizes and housing options." Homeowner association dues will be used to pay for maintenance of common areas, but homeowners also receive 20 hours of educational classes about the green features of their homes and landscapes.

In addition to high density lots and conserved open space, the site also minimizes impervious surfaces. The 3-ft wide sidewalks are narrower than the typical 5-ft widths. Houses do not have individual driveways; parking is situated along the perimeter of the roadway. The parking spaces are gravel, and are limited to two per house. The asphalt road allows for resident access to parking and houses on one side of the property; a gated, gravel access road for utilities and emergency vehicles was provided on the back side.

The soils on site have a high infiltration rate, allowing for shallow infiltration basins and perforated underdrains as the main components of the stormwater management system. The narrow (20' wide) asphalt roadways are bordered by flat ribbon curbs, which allow stormwater to flow to pervious gravel parking areas. Gravel trenches and perforated underdrain pipes are underneath the gravel parking areas so that stormwater runoff will flow through the rock, into the underdrain, and into the infiltration basins. Under saturated soil conditions, the water passes from the infiltration basins into overflow catch basins and into an underground piping system that discharges into low lying, undeveloped areas of the property. The infiltration basins serve a secondary purpose as attractive, vegetated common space features for the homeowners and are centrally located.



Figure 3.3-20 Laurel Oak Grove Road Narrowing Plan.

3.3.3.2 ALTERNATIVE ROADWAY COMPONENTS

Description: Cul-de-sacs in residential areas account for a significant amount of impervious area and typically serve small numbers of homes. Using different configurations for turnarounds can reduce this contribution greatly. Either landscaping to the extent practical, or replacing the traditional cul-de-sac with something else, will help achieve the benefits associated with lower impervious areas. Similar to a center island in a cul-de-sac, longitudinal landscaped islands along roadways can reduce stormwater runoff and improve treatment, and often make great locations for tree pits or grass swales.

Standard curb-and-gutter systems serve a few purposes: acting as safety measures, helping to keep vehicles from running off the road, and conveying stormwater runoff directly into storm sewers. As an alternative to traditional curb-and-gutter, open drainage channels (e.g., grass swales, dry swales) both reduce volumes and flow rates, while also treating runoff and improving water quality.



Figure 3.3-21 Cul-de-sac with vegetated island (left) and narrow road with grass swale (right).

KEY BENEFITS

- More attractive
- Less stormwater runoff
- Lower flow velocities (less erosion potential)
- Less expensive to construct and maintain
- Lower heat island effect

SPECIFIC RECOMMENDATIONS

Reducing Right-of-Way Width

Cul-De-Sacs and Turn-Arounds

Residential neighborhood road layouts often require some form of turn-around. A cul-de-sac is the most prevalent type of turn-around, and usually takes the form of a large, round, paved area. Although they most often serve only a small number of homes, cul-de-sacs tend to be exceedingly large. Alternatives to the large bulb (such as those shown in Figure 3-22 and Table 3-20) can greatly reduce impervious area, provide adequate access for vehicles, and be much more visually appealing.

One option for the cul-de-sac of standard size is to add a center island as a sunken stormwater practice (Option 1 in Figure 3-22). By grading the cul-de-sac toward the center rather than the edges, a center island with a bioretention basin can collect runoff and reduce the need for curb and gutter (see next section on curb and gutter). As shown in Figure 3-23, the bioretention must have an underdrain and/or overflow connected to the storm drain infrastructure, otherwise excessive ponding may cause a hazardous condition on the road (see detailed specifications in Volume 2, Section 4.2).

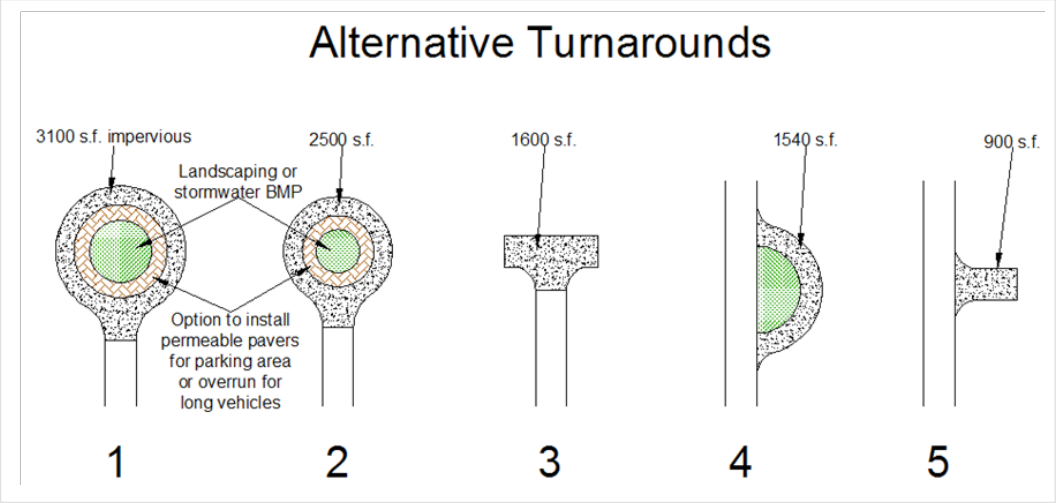


Figure 3.3-22 Alternative turn-around options, and their approximate impervious surface areas

Table 3-20 Impervious Area Associated with Various Turn-Around Options.

Option	Impervious area, as drawn
1. 42' radius cul-de-sac, with landscaped island and pervious paver parking/overhang lane	3100 square feet
2. 35' radius cul-de-sac, w/island and pervious lane	2500 square feet
3. "Tee" or "Hammerhead" turn-around	1600 square feet
4. Loop road	1540 square feet
5. "L" alternative to hammerhead	900 square feet

Smaller cul-de-sacs, such as Option 2 in Figure 3-22, may be an issue for emergency/service vehicles. The AASHTO design vehicle single-unit truck has a minimum design turning radius of 42', and a minimum inside radius of 28.3' (AASHTO, 2004). Pump truck fire engines and ambulances fall into this category. While many of these vehicles will have smaller turning radii, the "least common denominator" is the generic design vehicle. The fire marshal may have an overriding standard necessitating a larger diameter cul-de-sac. If so, it is recommended to have a discourse to determine the extent to which the center island and pervious lane can be implemented.

Round cul-de-sacs are popular turn-arounds in residential developments, but alternatives potentially create less impervious area. Tee-shaped turn-arounds, also known as "hammerheads" (Option 3), are especially suitable for short streets and require only a moderate amount of pavement area. Loop roads (Option 4) work well where there is a place for a wider right-of-way, but still use less impervious area than a cul-de-sac. The L-shaped turnaround (Option 5) works similarly to a hammerhead, but requires the least amount of pavement out of all the options.

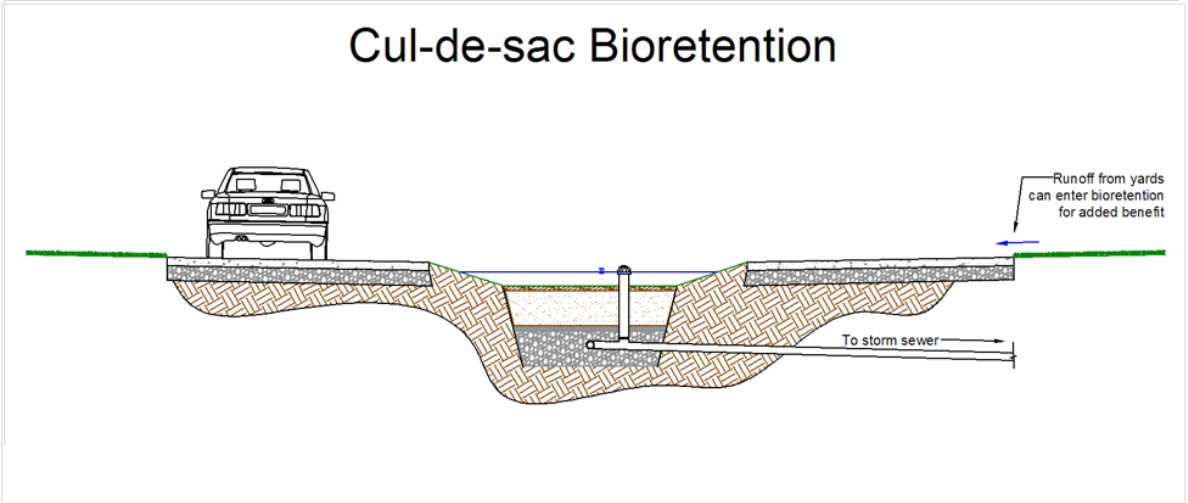


Figure 3.3-23 Bioretention option for cul-de-sac center "island". These can capture runoff from the cul-de-sac and adjacent yards, but must have an overflow device connected to a storm sewer or other outfall.



Figure 3.3-24 Cul-de-sac bioretention at E. Rivers Elementary School in Atlanta.

Curb and Gutter Stormwater Conveyance

The traditional curb-and-gutter system is space-efficient, but only functions to convey stormwater away from roads. In contrast, grass channels, swales, and other vegetated stormwater conveyances (Figure 3-25) built alongside streets or in medians provide several functions simultaneously:

- Stormwater conveyance
- Stormwater treatment
- Impervious area reduction (as compared to curb and gutter)
- Act as a shoulder when necessary for emergency vehicles or parking

How Local Codes Can Be Amended to Support These Practices:

Local governments can make changes to street design specifications and codes in order to allow and encourage the use of turnarounds that create less impervious area and the use of vegetated conveyances that provide more treatment of stormwater. Many communities have local design codes that require the use of round cul-de-sacs and curb-and-gutter. Therefore, the first code changes needed are those that provide flexibility to developers on these requirements. Local design codes can also set maximum sizes for cul-de-sacs, based on the number of homes served, as a way to avoid the creation of excessively large cul-de-sacs. Rebates or other incentives for retrofitting already-built cul-de-sacs and roads can reduce existing impervious area.

Establishing these codes in collaboration with other stakeholders will likely require deliberation with a variety of agencies and groups. The local fire marshal's office, for example, usually has specific guidelines governing vehicle access requirements. Discussions between emergency service providers, transportation engineers, and local government officials can potentially lead to reduced sizing requirements for cul-de-sacs and acceptance of alternative turn-around options with less impervious cover. The City of Portland, Oregon is one city that successfully established codes supporting narrow streets and alternative turnarounds, accommodating fire engines while reducing impervious surfaces.



Figure 3.3-25 Road with grass swales instead of curb-and-gutter

CASE STUDY

Jordan Cove Watershed Project Case Study, Waterford, CT (Clausen, J, 2007)

Long Island Sound is an impaired estuary due to low dissolved oxygen (hypoxia), toxic contaminants, pathogen contamination, floatable debris, and habitat degradation. Jordan Cove is a small estuary composed of a long (1.75 miles) narrow (300 feet) neck feeding into an inner cove (100 acres) and then an outer cove (390 acres) before flowing into the Long Island Sound.

The Jordan Cove Urban Watershed Section 319 National Monitoring Program Project was a ten-year study designed to determine the water quantity and quality benefits through the development of an urban subdivision using pollution prevention BMPs. Stormwater runoff from three watersheds – "control", "traditional", and "BMP" – was monitored as part of the study. The traditional watershed was developed using 'traditional' subdivision requirements. The BMP watershed was developed using a best management practice approach before, during, and after construction. The runoff from these two watersheds was compared to an existing control watershed. Ultimately, the goal was to show that, by using a BMP approach, pre-development hydrologic conditions can be maintained during and after residential development.

The BMP watershed incorporated several pollution prevention measures as part of its design. A main feature was the replacement of a traditional 28-foot asphalt road with curbs and gutters with a 20-foot wide concrete paver road and grassed bioretention swales. A bioretention cul-de-sac that allows for detention and infiltration of runoff was constructed in lieu of a conventional paved area. Individual bioretention gardens were incorporated into each lot to detain roof and lot runoff. Several alternate driveway surfaces were installed, including asphalt, concrete pavers, and gravel. Houses were constructed in a cluster layout with reduced lawns, low-mow areas, and no-mow areas.

A comparison of imperviousness among the watershed indicates that the BMP watershed has less impervious area than the traditional watershed. The percentage of acreage taken up by roads and driveways is also lower for the BMP watershed than the traditional watershed. Table 3-21 on the following page shows various costs of BMPs as compared to the traditional watershed. In general, BMPs added development costs. Added costs became apparent during the planning and approval stages of the project. Designing the BMPs required more time by the design engineer, which translated into additional costs for each lot.

CASE STUDY (CON'T)

Jordan Cove Watershed Project Case Study, Waterford, CT (Clausen, J, 2007) (con't)

By the end of the 10-year monitoring process, it was clear that traditional residential development has significant adverse impacts on runoff quality and quantity. During the construction phase in the traditional watershed, runoff volume increased twofold. That increase in flow continued during the post-construction period. However, these typical hydrologic alterations were not found in the BMP watershed. On the contrary, a reduction of stormwater runoff was observed. This reduction can be attributed to both excavation of all basements in a relatively short time and proper location of earthen berms to retain and infiltrate stormwater onsite. Decreases in runoff continued in the BMP watershed during the post-construction period. Thus, the BMP watershed project was successful in maintaining predevelopment discharge rates.

Table 3-21 Cost Comparisons of Traditional Development and BSD Development
(Source: Jordan Cove Actual Costs, Clausen, J. 2007)

Activity	Traditional	BMP
Cul-de-sac Bioretention	$1,275	$2,183
Driveway (asphalt)	$2,800/lot	$7,896/lot
Driveway (paver)	N/A	$7,896/lot
Erosion and sediment control	$322/lot	$625/lot
Plantings	$500/lot	$650/lot
Planning and design	$401/lot	$808/lot
Road and curb	$23,494	$102,500
Rain gardens	$0	$575/lot
Stormwater collection	$7,700	$3,600

3.3.3.3 REDUCING PAVED PARKING AND WALKING AREAS

Description: Paved parking areas are only useful some of the time, but are always there. Even at peak traffic times, there is often unused parking. Reducing the footprint of paved parking, and reducing the imperviousness by using alternative construction methods, can significantly reduce stormwater runoff and pollution transport. This is true for industrial, commercial, and residential areas, though greater benefits can be achieved when implementing shared or alternative parking arrangements on commercial sites.



Figure 3-26 Pervious parking lot (left) and shared driveway (right).

KEY BENEFITS

- More space available for purposes other than parking
- Encourages public and mass transit, and alternative modes of transportation
- Less stormwater runoff
- Lower flow velocities (less erosion potential)
- Lower heat island effect

SPECIFIC RECOMMENDATIONS:

Parking space requirements can drive the construction of a lot of excessive impervious cover (see Table 3-22), while actual parking needs are almost always lower than minimum code requirements.

Local governments should investigate their current parking space requirements to see if they may be in excess of what is realistically needed at various types of businesses. They can take into account both local and national experience to see if lower ratios are warranted and feasible in their communities. If so, they may consider reducing the requirements for the minimum number of parking spaces according to business type, land use, or activity. They should also consider enforcing maximums in order to curb excess parking space construction.

Parking Ratios

- Increase minimum ratio of compact or sub-compact parking spaces to conventional size spaces
- Add/increase number/ratio of alternative mode parking – motorcycle, bicycle, electric, carpool, vanpool, car-share vehicles, etc.

Parking Codes

- Adjust ratios and numbers of parking spots by use type, and also by available transportation type. Where mass transit is available, require less parking. Where pedestrian and bicycle transportation offer good connectivity, require less parking.

Table 3-22 Conventional Minimum Parking Ratios (Source: ITE, 1987; Smith, 1984; Wells, 1994)

Land Use	Parking Requirement		Actual Average Parking Demand
	Parking Ratio	Typical Range	
Single family homes	2 spaces per dwelling unit	1.5–2.5	1.11 spaces per dwelling
Shopping center	5 spaces per 1000 ft^2 GFA	4.0–6.5	3.97 per 1000 ft^2 GFA
Convenience store	3.3 spaces per 1000 ft^2 GFA	2.0–10.0	N/A
Industrial	1 space per 1000 ft^2 GFA	0.5–2.0	1.48 per 1000 ft^2 GFA
Medical/ dental office	5.7 spaces per 1000 ft^2 GFA	4.5–10.	4.11 per 1000 ft^2 GFA

GFA = Gross floor area of a building without storage or utility spaces.

Table 3-23 Examples of How Cities Incentivize and Facilitate Lower Parking Requirements

Community	Description of Program
Olympia, WA	Allows reduction in required parking in concert with public transportation
Loudoun County, VA	Allows a reduction of up to 20% of the required parking for any use, building or complex within 1,000 feet of any regularly scheduled bus stop
Chicago, IL	Offers reduction in required parking for buildings connected to underground transit stations*
Hartford, CT	Reduces minimum required parking in return for developer carpool and transit incentives*
Montgomery County, MD	Reduces minimum parking requirements in proximity to rail stations*
Phoenix, AZ	Allows parking requirement relaxations in proximity to bus transit*
Orlando, FL	Allows payments to support a transportation management program in lieu of on-site parking*

*Source: Federal Transit Administration, 1997

Parking Lots

- Use permeable pavement materials if possible (pavers, pervious concrete, porous asphalt).
- Any overflow or extra parking areas should be made of pervious pavement materials, or vegetation (grass, etc.) (Figure 3.3-26).
- Encourage shared parking arrangements with other businesses for overflow or even routine parking.
- When feasible, use vertical parking structures to take advantage of the comparatively smaller footprint – they can make economic sense where land costs are very high.
- Parking structures can be expensive on a per space basis, but they have additional benefits:
  - » Less space devoted to parking
  - » Reduced heat island effect
  - » Reduced runoff
  - » Lower costs associated with stormwater management

Driveways

- Residential driveways are often unnecessarily long, large, and are typically impervious.
- Driveways can be well-suited to permeable pavement/pavers or two "runner strips" for the wheels, with permeable surfaces (or even an infiltration area) between the strips.
- In residential developments with garages, it is possible to use one driveway access for two or more homes' parking.

Sidewalks

- Sidewalks are not always necessary on both sides of the street. If access is needed on both sides, crosswalks can be provided.
- Sidewalks are often suitable for pervious material.
- Impervious sidewalks should drain to pervious areas, such as yards or grass channels (rather than into the street or curb/gutter).



Figure 3.3-26 Permeable overflow parking area



Figure 3.3-27 Parking lot bioretention in Johns Creek, GA.

Table 3-24 Perceptions vs Reality for Sidewalks (CWP, 1998b)

1. Sidewalks on only one side of the street are unsafe.	FACT: A recent survey showed that 7.7% of pedestrian accidents occurred on roads with single sidewalks and 7.3% of such accidents occurred on roads with double sidewalks. Roads without sidewalks at all are by far the most hazardous to pedestrians, with 83.5% of pedestrian accidents.
2. Roads without sidewalks on both sides are a legal liability.	FACT: Careful design and policy implementation protects governments and professionals from undue liability.
3. The ADA requires sidewalks on both sides of the street.	FACT: The ADA requires at least one accessible route from public streets, parking areas, and passenger loading zones along a route that generally coincides with that of the general public. There are no specific restrictions on roadway sidewalks.
4. Local government officials do not want to hear complaints from residents regarding sidewalk placement.	FACT: Most complaints occur when sidewalks are installed after the development has been built and occupied, and not during initial construction.
5. Residents want sidewalks on both sides of the street.	FACT: There is no appreciable market difference between houses that are directly served by sidewalks (i.e., the sidewalk is on the same side of the street) and houses not directly served (i.e., sidewalk is on the opposite side of the street). Some residents do prefer to have access to a sidewalk in front of their property, while others prefer no sidewalks. These types of preferences are logically resolved at the time buyers purchase the property.

CASE STUDY

Minimizing Parking: City of Greenville, SC (Ellis et al, 2014)

Smaller lots make better use of available land, improve water quality, and save money. Upstate Forever, Furman University, and the City of Greenville conducted a study of commercial parking lots to determine the optimal number of parking spaces for different uses. Researchers used aerial photography and on-the-ground monitoring of 120 commercial parking lots during peak and non-peak hours. The study concluded that there was an excess of off-street parking, with up to 65% of parking spaces empty during peak hours.

Based on the findings from the study, the City of Greenville adjusted its parking requirements. For example, the parking requirement for a medical facility was reduced from 5 spaces per 1,000 square feet to 1.7 spaces per 1,000 feet. The change resulted in a reduction of 3.3 spaces per 1,000 square feet and represents approximately $6,000-$18,000 in cost savings for the developer. Under the current code, developers have two options: 1) install the minimum parking spaces required in the new policy or 2) use low-impact development (LID) practices to manage the stormwater generated by parking spaces over the minimum requirement. Upstate Forever is working with the City of Greenville to create a third alternative in which developers would pay a fee in-lieu if they do not use LID. This new revenue stream will fund local clean water projects.

Table 3-25 Findings from Parking Study, City of Greenville, SC

Business Type	Peak Parking Occupancy	Excess Parking
Grocery Stores	35%	65%
Other Restaurants	39%	61%
Discount/Dept. Stores	45%	55%
Pharmacies	45%	55%
Medical Facilities	52%	48%
Offices	58%	42%
Drive-thru Restaurants	58%	42%
Shopping Centers	63%	37%
Health Clubs	74%	26%

HELPFUL RESOURCES

American Association of State Highway and Transportation Officials (AASHTO). 2004. **Green Book: A Policy on Geometric Design of Highways and Streets.** 5th Edition. American Association of State Highway and Transportation Officials (AASHTO). Washington, DC.

Transportation Research Board. 2008. *Multimodal Level of Service Analysis for Urban Streets*. National Cooperative Highway Research Program, Report 616. Washington, D.C.

Transportation Research Board. 2010. *The Highway Capacity Manual.* Washington, DC.

Victoria Transport Policy Institute (VTPI). 2009. *Pedestrian and Bicycle Planning Guide to Best Practices.* Victoria, British Columbia.

3.3.3.4 REDUCING BUILDING FOOTPRINTS

Description: The impervious footprint of commercial buildings and residences can be reduced by using alternatively designed or taller buildings while maintaining the same floor-to-area ratio.

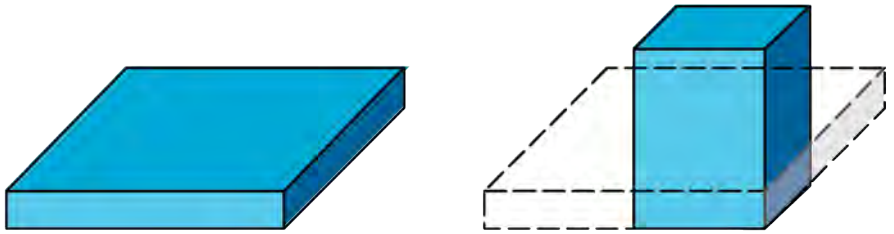


Figure 3.3-28 Building up rather than out can reduce the amount of impervious cover

KEY BENEFITS

- Reduces impervious cover
- Minimizes land disturbance
- Limits clearing and grading
- Carbon sequestration
- More efficient use of valuable urban land
- Reduces urban heat island

SPECIFIC RECOMMENDATIONS:

Encourage site designers to create taller building designs that have smaller impervious footprints by:

- Creating incentives or requirements for buildings with smaller footprints instead of large single-story structures.
- Creating a floor-to-area ratio (FAR) bonus for taller buildings that have a smaller impervious footprint.

How Local Codes Can Be Amended to Support This Practice:

Local development codes can support this practice in the following ways:

- Offer incentives that encourage local communities to increase density
- Consider variances to reduce lot size requirements
- Consider variances to reduce setback requirements
- Reduce height restrictions and increase FARs



Figure 3.3-29 Building up rather than out can reduce the amount of impervious cover

Table 3-26 Local Code Changes to Support Reducing Building Footprints

Topic	Typical Local Code Conflicts	How Conflicts Can Be Resolved
Lot Size Requirements	Lot size requirements usually accommodate larger building footprints.	Add a separate set of lot size requirements to encourage smaller building footprints.
Minimum Setback Requirements	Setback requirements usually accommodate larger building footprints.	Add a separate set of setback requirements that encourages smaller building footprints.
Height Restrictions	Height restrictions usually encourage more horizontal building construction.	Consider variances for height restrictions to encourage more vertical construction, rather than horizontal. Offer floor-to-area ratio bonuses (see specific recommendations).

References

American Association of State Highway and Transportation Officials. 2001. *A Policy on Geometric Design of Highways and Streets (Fourth Edition)*. American Association of State Highway and Transportation Officials (AASHTO), Washington, DC.

American Association of State Highway and Transportation Officials. 2004. *Green Book: A Policy on Geometric Design of Highways and Streets (Fifth Edition).* American Association of State Highway and Transportation Officials (AASHTO), Washington, DC.

American Society of Landscape Architects. 2009. *The Sustainable Site Initiative: Guidelines and Performance Benchmarks.* American Society of Landscape Architects (ASLA), Lady Bird Johnson Wildflower Center at The University of Texas at Austin.

Atlanta Regional Commission. 2015. *Community Choices Smart Growth Toolkit*. Atlanta Regional Commission (ARC), Atlanta, Georgia.

Bob Moore Construction. 2009. *Overcoming the Unique Challenges of Infill Developments to Deliver a Gold LEED for Core & Shell Project.* Bob Moore Construction (BMC), Arlington, TX.

Cappiella K., T. Wright, and T. Schueler. 2006. *Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites.* Center for Watershed Protection (CWP), Ellicott City, MD.

Center for Watershed Protection. 1998. *Consensus Agreement on Model Development Principles to Protect Our Streams, Lakes, and Wetlands.* Center for Watershed Protection (CWP), Ellicott City, MD.

Center for Watershed Protection. 1998. *Better Site Design: A Handbook for Changing Development Rules in your Community.* Center for Watershed Protection (CWP), Ellicott City, MD.

Center for Watershed Protection. 2009. *Recommended Development Principles for Richland County, South Carolina Consensus of the Site Planning Roundtable*. Center for Watershed Protection (CWP), Ellicott City, MD.

City of Flowery Branch. *Article 8, Planned Unit Development District Zoning Ordinance City of Flowery Branch.* City of Flowery Branch, GA.

City of Savannah. 2012. *Landscape and Tree Ordinance Compliance Manual.* Savannah, GA.

City of Smyrna. 2003. *Article II. Tree Conservation and Replacement.* City of Smyrna Tree Conservation and Replacement Ordinance, Smyrna, GA.

Clausen, John C., 2007. *Jordan Cove Watershed Project – Final Report.* Department of Natural Resources Management and Engineering College of Agriculture and Natural Resources. University of Connecticut.

De Sousa, Christopher, Lily-Ann D'Souza. 2013. *Atlantic Station, Atlanta, Georgia: A Sustainable Brownfield Revitalization Best Practice.* UIC Institute for Environmental Science and Policy, Chicago, IL.

Ellis, K., C. Berg, D. Caraco, S. Drescher, G. Hoffmann, B. Keppler, M. LaRocco, and A.Turner. 2014. *Low Impact Development in Coastal South Carolina: A Planning and Design Guide.* ACE Basin and North Inlet – Winyah Bay National Estuarine Research Reserves.

The Federal Interagency Stream Restoration Working Group. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices.* The Federal Interagency Stream Restoration Working Group (FISRWG).

Federal Transit Administration. 1997. *Parking Supply Management.* Federal Transit Administration. Washington, D.C.

Georgia Department of Community Affairs. 2005. *A Guide to Using Georgia's Urban Redevelopment Act.* Georgia Development of Community Affairs (DCA). Atlanta, GA.

Georgia Department of Community Affairs. 2015. *Infill Development Program.* Georgia Department of Community Affairs (DCA). Atlanta, GA.

References (con't)

Georgia Department of Natural Resources. 2006. *Green Growth Guidelines: A Low Impact Development Strategy for Coastal Georgia.* Georgia Department of Natural Resources, Brunswick, GA.

Georgia Department of Natural Resources Wildlife Resources Division. 2005. *A Comprehensive Wildlife Conservation Strategy for Georgia.* Georgia Department of Natural Resources Wildlife Resources Division, Social Circle, GA.

Georgia Forestry Commission. 2012. Georgia: The State of the Urban Forest Report 2012. Georgia Forestry Commission, Alamo, GA.

Georgia Land Conservation Program. *Georgia Conservation Tax Credit 2012.* Georgia Department of Natural Resources, Social Circle, GA.

Hirschman, David J., John Kosco. 2008. Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program. Center for Watershed Protection, Ellicott City, MD.

Institute of Transportation Engineers. 1987. *Parking Generation (Second Edition)*. Institute of Transportation Engineers, Washington, DC.

Institute of Transportation Engineers. 1997. *Guidelines for Residential Subdivision Street Design.* Institute of Transportation Engineers (ITE), Washington, DC.

MacMullin, Ed and Sarah Reich. 2007. *The Economics of Low-Impact Development: A Literature Review.* ECONorthwest, Eugene, OR.

Mero, Ted. 2013. *The Living Landscape.* Mary Ann Liebert, Inc. New Rochelle, NY.

National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, International City/County Management Association, and Rhode Island Sea Grant. 2009. *Smart Growth for Coastal and Waterfront Communities*. National Oceanic and Atmospheric Administration (NOAA), Silver Spring, MD.

U.S. Environmental Protection Agency (EPA), Washington, DC. *International City/County Management Association (ICMA)*, Washington, DC. Rhode Island Sea Grant, Narragansett, RI.

Nevue Ngan Associates, Eisen|Letunic, Van Meter Williams Pollack LLP, ICF International. 2009. *Stormwater Management Handbook: Implementing Green Infrastructure in Northern Kentucky Communities*. ICF International. Fairfax, Va. Nevue Ngan Associates. Portland, OR.

Rayburn, Cory, Susan Rutherford. 2014. *Implementing Green Infrastructure: Atlanta's Post-Development Stormwater Ordinance.* City of Atlanta Department of Watershed Management, Atlanta, GA.

Rhode Island Department of Environmental Management (RI DEM) and Coastal Resources Management Council (CRMC). 2010. RI Stormwater Design and Installation Standards Manual. Rhode Island Department of Environmental Management (RI DEM), Providence, IR. Coastal Resources Management Council (CRMC), Wakefield, RI.

Rhode Island Department of Environmental Management (RI DEM) and Coastal Resources Management Council (CRMC). 2011. *Rhode Island Low Impact Development Site Planning and Design Guidance Manual.* Rhode Island Department of Environmental Management (RI DEM), Providence, RI. Coastal Resources Management Council (CRMC), Wakefield, RI.

Smart Growth America. 2015. *What Is "Smart Growth?"*. Smart Growth America. Washington, DC.

Smith, Thomas. 1984. *Flexible Parking Requirements. Planning Advisory Service Report No. 377.* American Planning Association, Chicago, Illinois.

Wells, C. 1994. *Impervious Surface Reduction Technical Study. Draft Report.* City of Olympia Public Works Department. Washington Department of Ecology.

University of Georgia Cooperative Extension. 2007. *Best Management Practices for Landscape Water Conservation*. Bulletin 1329.

University of Georgia Cooperative Extension. 2009. *Environmentally Friendly Landscape Practices.* Circular 967.

References (con't)

U.S. Environmental Protection Agency (EPA). 2006. *Protecting Water Resources with Higher Density Development.* U.S. Environmental Protection Agency. Washington, DC.

U.S. Environmental Protection Agency (EPA). 2015. *Smart Growth and Economic Success: Investing in Infill Development.* U.S. Environmental Protection Agency (EPA). Washington, DC.

U.S. Environmental Protection Agency (EPA). 2015. *Brownfields Definition.* Environmental Protection Agency (EPA). Washington, DC.

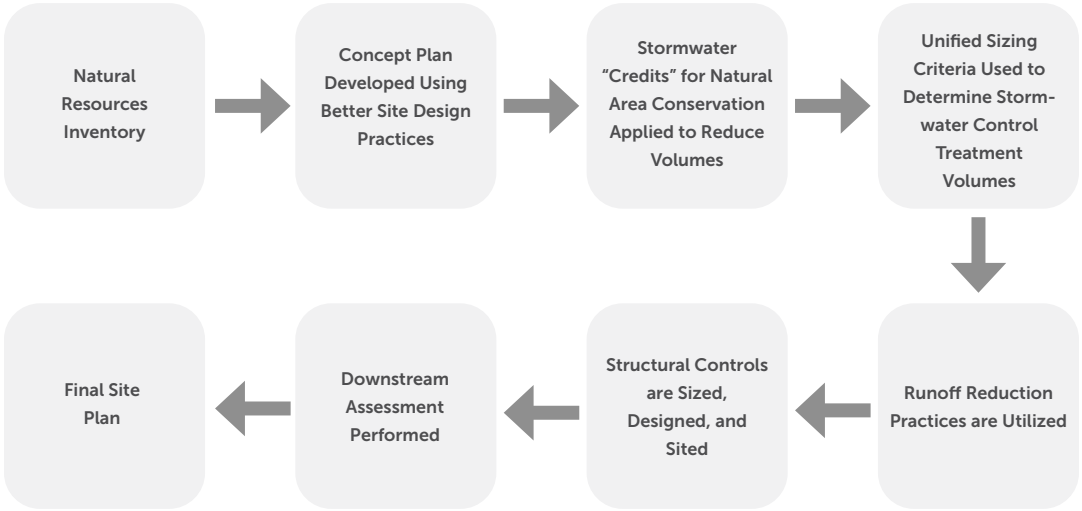
Westerfield, R., D. Pulis. 2009. *Environmentally Friendly Landscape Practices.* University of Georgia Cooperative Extension. Athens, GA.

Winer-Skonovd, R., D. Hirschman, H.Y. Kwon and C. Swann. 2006. *Synthesis of Existing Cost Information for LID vs. Conventional Practices*. Center for Watershed Protection. Ellicott City, MD.

4. Implementing Stormwater Management Requirements for Development

4.1 Overview

Description: Requirements and standards for controlling runoff from development are critical to addressing water quantity and quality impacts of post-construction urban stormwater. In addition, they are a required component of NPDES municipal stormwater programs. The unified stormwater sizing criteria represent comprehensive rules for various storm events in Georgia.



KEY CONSIDERATIONS

The key concepts for addressing the effects of development on storm-water include:

- Natural Resources Inventory
- Stormwater Better Site Design
- Stormwater Credits for Natural Area Conservation
- Unified Stormwater Sizing Criteria
- Runoff Reduction Practices
- Guidance on Structural Stormwater Controls
- Downstream Assessments
- Stormwater Management Site Plans

Adoption of a comprehensive and integrated set of stormwater management requirements for new development and redevelopment projects is one of the key components of a comprehensive local stormwater management program. Performance requirements and standards for controlling runoff from development are critical to addressing both the water quantity and quality impacts of post-construction urban stormwater and are a required component of NPDES municipal stormwater programs.

Stormwater management standards must also be supported by a set of design and management tools, through an integrated design approach for implementing structural and nonstructural stormwater controls. The following elements of a local toolbox for addressing development activities are described in this chapter:

- **Natural Resources Inventory** – Prior to the start of any land disturbing activities (including any clearing and grading activities), acceptable site reconnaissance and surveying techniques should be used to complete a thorough assessment of the natural resources, both terrestrial and aquatic, found on a development site. Some of these natural resources may be protected by federal and state regulations and/or local zoning rules.
- **Stormwater Better Site Design** – The first step in addressing stormwater management begins with the site planning and design process. The goal of better site design is to reduce the amount of runoff and pollutants that are generated from a development site and provide for some non-structural on-site treatment and control of runoff by implementing a combination of approaches collectively known as stormwater better site design practices. These include maximizing the protection of natural features and resources, developing a site design which minimizes impact, reducing overall site imperviousness, and utilizing natural systems for stormwater management.
- **Stormwater Credits for Natural Area Conservation** – One better site design practice, conservation of natural areas, includes an additional stormwater credit. If a natural area is conserved (with a conservation easement or other similar mechanism), the runoff reduction volume and/or water quality volume will be reduced. This credit is intended to provide developers and site designers with an incentive to conserve natural areas that can reduce the volume of stormwater runoff and minimize the pollutant loads from a site. The credit directly translates into cost savings for the developer by reducing the size of structural stormwater control and conveyance facilities.
- **Unified Stormwater Sizing Criteria** – An integrated set of design criteria for stormwater quality and quantity management that addresses the entire range of hydrologic events. These criteria allow site engineers to calculate the stormwater control volumes required for runoff reduction volume and/or water quality volume, downstream channel protection, and overbank and extreme flood protection.
- **Runoff Reduction Practices** – Runoff reduction practices are stormwater management practices that are used to disconnect impervious and disturbed pervious surfaces from the storm drain system, thereby reducing post-construction stormwater runoff rates, volumes, and pollutant loads. Since runoff reduction practices actually eliminate stormwater runoff (and the pollutants associated with it), rather than simply treating or detaining runoff, they can contribute to all of the Unified Stormwater Sizing Criteria, while providing many additional benefits.
- **Guidance on Structural Stormwater Controls** – When runoff reduction practices are insufficient, this Manual recommends a set of structural stormwater controls that can be used to meet stormwater management water quantity and quality goals.
- **Downstream Assessments** – Peak flow downstream assessments can be required to ensure that a proposed development is not adversely impacting downstream properties after the stormwater management requirements have been addressed. These assessments can also potentially be used to waive the need for detention for overbank and extreme flood control.
- **Stormwater Management Site Plans** – Communities should require the preparation of a stormwater management site plan for development activities. A stormwater site plan is a comprehensive report that contains the technical information and analysis to allow a local review authority to determine whether a proposed new development or redevelopment project meets the local stormwater regulatory requirements.

Figure 4.1-1 illustrates how these design tools would be used in the development process to address local stormwater management requirements.

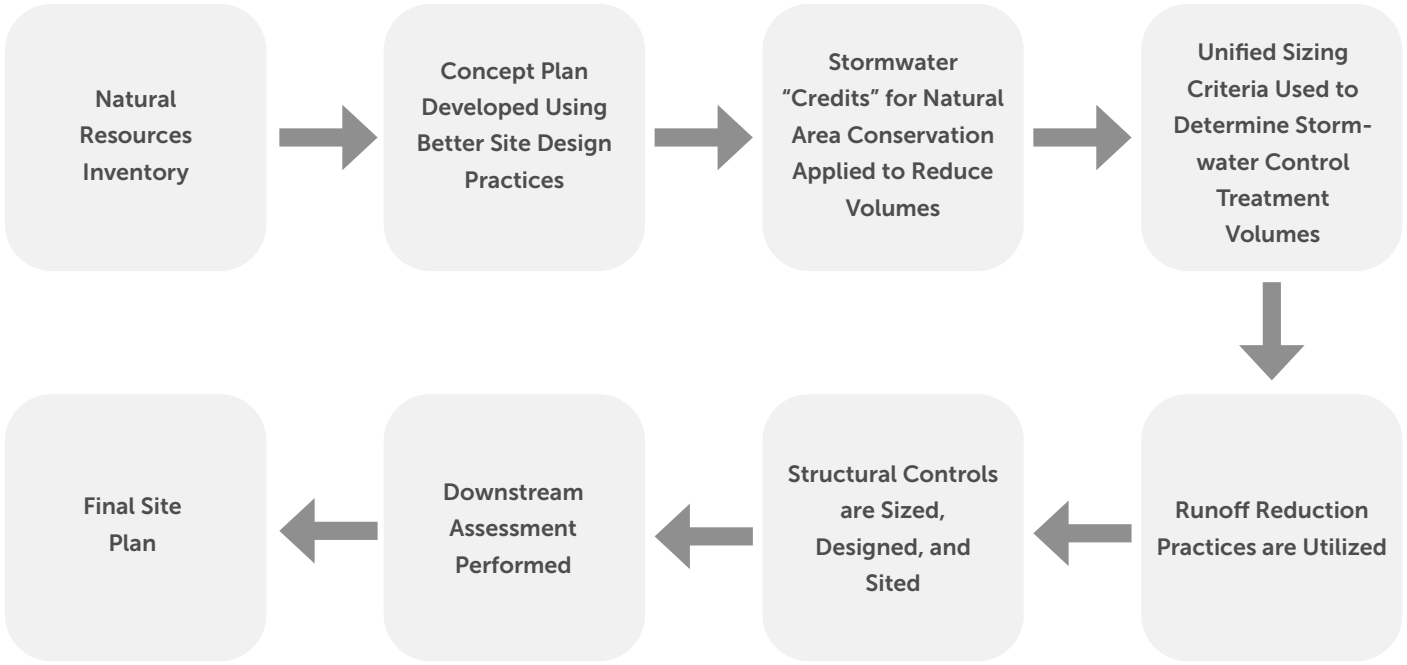


Figure 4.1-1 Typical Stormwater Management System Design Process

Better Site Design, Runoff Reduction, and the Unified Stormwater Sizing Criteria

The Unified Stormwater Sizing Criteria, which are incorporated into the Standards for Development described in Section 4.2 represent comprehensive rules for various storm events in Georgia. Rules regarding the quality of runoff are applied to small storm events (1.2"), while rules regarding the quantity and rate of runoff are applied to larger storm events (specifically, the 1-year, 25-year, and 100-year return intervals).

Some stormwater practices are best suited to address runoff quality, while others are best suited to address runoff quantity. However, better site design and runoff reduction practices address both simultaneously. As discussed in Chapter 3, by reducing the impervious cover associated with a development, better site design techniques reduce the amount of runoff being generated by a development in the first place. Runoff reduction practices, on the other hand, eliminate some of the runoff after it is generated. Instead of treating or detaining the runoff like a typical water quality practice, or detaining it like a typical water quantity practice, they remove it – removing the pollutants along with it. Runoff reduction practices remove runoff through a variety of processes. Infiltration (sending runoff into the ground) may be the most common means, but it is not the only one. Runoff reduction can also be achieved through evaporation, transpiration, or rainwater harvesting and reuse. Through these processes, runoff reduction practices both improve water quality, and reduce the water quantity that must be managed for larger storm events.

Taken together, better site design and runoff reduction practices provide many other benefits as well:

- Maintain Pre-Development Site Hydrology: By reducing stormwater runoff volumes and rates, post-development site hydrology is kept closer to pre-development site hydrology (the site operates much more like a natural system).
- Reduced Combined Sewer Overflow Events: Better site design and runoff reduction practices help reduce the magnitude and frequency of combined sewer overflow events.
- Urban Heat Island Mitigation: The trees, shrubs and other vegetation associated with better site design and runoff reduction practices create shade, reflect solar radiation and emit water vapor, all of which create cooler temperatures in urban environments and help mitigate the impacts of urban heat islands.
- Reduced Energy Demand: Trees, shrubs and other vegetation help lower ambient air temperatures and, when incorporated on and around buildings, help insulate buildings from temperature swings, decreasing the amount of energy used for heating and cooling.

U.S. Environmental Protection Agency (US EPA). 2008. "Environmental Benefits of Green Infrastructure." Managing Wet Weather with Green Infrastructure. Accessed: June 27, 2008.

4.2 Standards for Development

Description: A comprehensive set of performance standards for stormwater management should be incorporated into community development and redevelopment requirements.

KEY CONSIDERATIONS

The following twelve (12) standards are recommended performance requirements for new development or redevelopment sites:

- Standard #1 – Natural Resource Inventory
- Standard #2 – Better Site Design Practices for Stormwater Management
- Standard #3 – Runoff Reduction
- Standard #4 – Water Quality
- Standard #5 – Stream Channel Protection
- Standard #6 – Overbank Flood Protection
- Standard #7 – Extreme Flood Protection
- Standard #8 – Downstream Analysis
- Standard #9 – Construction Erosion and Sedimentation Control
- Standard#10 – Stormwater Management System Operation and Maintenance
- Standard #11 – Pollution Prevention
- Standard #12 – Stormwater Management Site Plan



4.2.1 Introduction

This section presents a comprehensive set of performance standards for stormwater management for development and redevelopment activities. These standards provide Georgia communities with an integrated approach to address the water quality and quantity problems associated with stormwater runoff due to urban development. When adopted by Georgia communities, these standards will help maintain the quality and quantity of their community waters. They are designed to assist local governments in complying with regulatory and programmatic requirements for various state and Federal programs, including the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit program and the National Flood Insurance Program under FEMA.

These standards should be incorporated into a community's development requirements and supported by the plan review process, as well as inspection, tracking, and maintenance procedures. Where appropriate, they may be modified to meet local or watershed-specific stormwater management goals and objectives.

The goal of stormwater management requirements for areas of new development and redevelopment is to reduce the negative impacts of post-construction stormwater runoff on the watershed such as deteriorating water quality, reduced base flows, stream entrenchment, stream bank instability, and erosion. A reduction in negative impacts can be achieved by (1) maximizing the use of site design and nonstructural methods to reduce impervious cover and the generation of runoff and pollutants; (2) managing and treating stormwater runoff though the use of structural stormwater controls; and (3) implementing pollution prevention practices to limit potential stormwater contaminants. The stormwater management standards presented here incorporate these concepts and cover the entire cycle of development, from site planning through long-term maintenance of stormwater management facilities.

4.2.2 Applicability

It is recommended that the stormwater management standards listed below be required for any new development or redevelopment site that meets one or more of the following criteria:

1. New development that includes the creation or addition of 5,000 square feet or greater of new impervious surface area, or that involves land disturbing activity of 1 acre of land or greater.
2. Redevelopment that includes the creation or addition of 5,000 square feet or greater of new impervious surface area, or that involves land disturbing activity of 1 acre or more.
3. Any commercial or industrial new development or redevelopment, regardless of size, with a Standard Industrial Classification (SIC) code that falls under the NPDES Industrial Stormwater Permit program, or is a hotspot land use as defined below.

Since runoff from smaller developments can cause water quality and quantity impacts as well, an individual community may choose to adopt more stringent area criteria, especially if it determines that a significant amount of development in the community falls below these thresholds. In addition, a community may choose to apply stormwater management standards on a case-by-case basis to smaller developments.

Definitions

New development is defined as land disturbing activities, structural development (construction, installation or expansion of a building or other structure), and/or creation of impervious surfaces on a previously undeveloped site.

Redevelopment is defined as structural development (construction, installation, or expansion of a building or other structure), creation or addition of impervious surfaces, replacement of impervious surfaces not as part of routine maintenance, and land disturbing activities associated with structural or impervious development on a previously developed site. Redevelopment does not include such activities as exterior remodeling.

Previously developed site is defined as a site that has been altered by paving, construction, and/or land use that would typically have required regulatory permitting to have been initiated (alterations may exist now or in the past).

A *hotspot* is defined as a land use or activity on a site that produces higher concentrations of trace metals, hydrocarbons, or other priority pollutants than are normally found in urban stormwater runoff. Examples of hotspots include gas stations, vehicle service and maintenance areas, industrial facilities such as salvage yards (both permitted under the Industrial General Permit and others), material storage sites, garbage transfer facilities, and commercial parking lots with high-intensity use.

The goals and policies of individual communities should determine the specific definition of *pre-development*. It is recommended that pre-development be defined as "natural, undisturbed conditions." This can be simplified to a set type of vegetative condition, such as "woods in good condition," if appropriate. However, where redevelopment incentives are desired, or where flooding concerns do not currently exist, pre-development may be defined as the condition of the site immediately prior to the implementation of the proposed project.

Exemptions

In order to avoid excessive regulation on individual residential lots, maintenance and repair efforts, and environmental projects, the following development activities are recommended to be exempted from the stormwater management standards:

1. Individual single family residential lots (single family lots that are part of a subdivision or phased development project should not be exempt from the standards);
2. Additions or modifications to existing single-family structures;
3. Duplex residential units that do not meet the criteria listed above.
4. Land disturbing activity conducted by local, state, authority, or federal agencies, solely to respond to an emergency need to protect life, limb, or property or conduct emergency repairs;
5. Land disturbing activity that consists solely of cutting a trench for utility work and related pavement replacement that maintains the original grade; and
6. Land disturbing activity conducted by local, state, authority, or federal agencies, whose sole purpose is to implement stormwater management or environmental restoration.

As noted above, since runoff from smaller developments can cause water quality and quantity impacts as well, an individual community may choose not to adopt these exemptions. The City of Atlanta, for example, currently requires that stormwater management measures be utilized for any new home or addition that is greater than 1,000 square feet of impervious surface. See the Case Study in Section 4.4.4.

Additional Requirements

New development or redevelopment in critical or sensitive areas, or as identified through a watershed study or plan, may be subject to additional performance and/or regulatory criteria. Furthermore, these sites may need to utilize or restrict certain structural controls in order to protect a special resource or address certain water quality or drainage problems identified for a drainage area. For example, in Coastal Georgia, areas that discharge into designated shellfish harvesting areas are recommended by the Coastal Stormwater Supplement to adopt Special Criteria including increasing runoff reduction criteria to the 1.5" storm and provide a minimum 50-foot aquatic buffer.

4.2.3 Stormwater Management Standards

It is recommended that the following stormwater management performance standards be adopted for new development or redevelopment sites falling under the applicability criteria above. It is further recommended that these twelve (12) standards be adopted in whole to create a comprehensive stormwater management approach. However, an individual community may choose to adopt some of the standards rather than the entire set, or modify individual standards, depending upon its regulatory requirements and specific local approach to stormwater management. Specific required criteria for communities covered by a Municipal Separate Storm Sewer System (MS4) permit are delineated in the permit.

STANDARD #1 – NATURAL RESOURCE INVENTORY

Prior to the start of any land disturbing activities (including any clearing or grading activities), acceptable site reconnaissance and surveying techniques shall be used to complete a thorough assessment of the natural resources, both terrestrial and aquatic, found on a development site. The site's critical natural features and drainage patterns shall be identified early in the site planning process. The natural resources inventory shall be used to identify and map the natural resources on site, as they exist prior to the start of any land disturbing activities. The identification, and subsequent preservation and/or restoration of these natural resources, through the use of better site design practices, helps reduce the negative impacts of the land development process "by design".

Resources to be identified and mapped during the natural resources inventory, include, at a minimum (as applicable):

- Topography and Steep Slopes (i.e., Areas with Slopes Greater Than 15%)
- Natural Drainage Divides and Patterns
- Natural Drainage Features (e.g., swales, basins, depressional areas)
- Wetlands
- Water Bodies
- Floodplains
- Aquatic Buffers
- Shellfish Harvesting Areas
- Soils
- Erodible Soils
- Groundwater Recharge Areas
- Wellhead Protection Areas
- Trees and Other Existing Vegetation
- High Quality Habitat Areas
- Protected River Corridors
- Protected Mountains
- Karst Areas

All relevant resources shall be shown on the Stormwater Site Plan (Standard #12).

STANDARD #2 – BETTER SITE DESIGN PRACTICES FOR STORMWATER MANAGEMENT

All site designs shall implement a combination of approaches collectively known as stormwater better site design practices to the maximum extent practicable. Through the use of these practices and techniques, the impacts of urbanization on the natural hydrology of the site and water quality can be significantly reduced. The goal is to reduce the amount of stormwater runoff and pollutants that are generated, provide for natural on-site control and treatment of runoff, and optimize the location of stormwater management facilities. Better site design concepts can be viewed as both water quantity and water quality management tools, and can reduce the size and cost of structural BMPs.

Site designs shall preserve the natural drainage and treatment systems and reduce the generation of additional stormwater runoff and pollutants to the maximum extent practicable. More information on Better Site Design is provided in Chapter 3.

The use of certain better site design practices that provide water quality benefits allows for a reduction (known as a "credit") of the water quality volume. The applicable design practices and stormwater site design credits are covered in Volume 2, Section 2.3.

STANDARD #3 – RUNOFF REDUCTION

Runoff reduction practices shall be sized and designed to retain the first 1.0 inch of rainfall on the site to the maximum extent practicable. Runoff reduction practices are stormwater BMPs used to disconnect impervious and disturbed pervious surfaces from the storm drain system, thereby reducing post-construction stormwater runoff rates, volumes, and pollutant loads. Since runoff reduction practices actually eliminate stormwater runoff (and the pollutants associated with it), rather than simply treating or detaining runoff, they can contribute to several of the other performance standards, while providing many additional benefits. If the entire 1.0 inch of rainfall can be retained onsite using runoff reduction methods, the community may choose to waive the water quality treatment volume in Standard #4. If the entire 1.0-inch runoff reduction standard cannot be achieved, the remaining runoff from the 1.2-inch rainfall event must be treated by BMPs to remove at least 80% of the calculated average annual post-development TSS loading from the site per Standard #4 Water Quality.

Runoff reduction percentages are assigned to applicable BMPs that reduce the amount of stormwater required for treatment, and subsequently reduce the other stormwater management volumes, incentivizing their use. Runoff reduction practices inherently reduce TSS and other pollutants to provide water quality treatment (i.e. 100% pollutant removal for stormwater retention, infiltration, evaporation, transpiration, or rainwater harvesting and reuse). This standard is quantified and expressed in terms of engineering design criteria through the specification of the runoff reduction volume (RR_V), which is equal to the runoff generated on a site from 1.0 inches of rainfall. Individual runoff reductions specific to each practice are described in detail in Volume 2, Chapter 4.

While runoff reduction practices provide important water quality benefits, as described in Chapter 2, certain conditions, such as karst topography, soils with very low infiltration rates, high groundwater, or shallow bedrock, may lead a community to choose to waive or reduce the runoff reduction requirement. Alternatively, these conditions can be addressed on a site-specific basis. If the RR_V of 1.0 inches of rainfall cannot be achieved, adequate documentation should be provided to the local development review authority to show that no additional runoff reduction practices can be used on the development site.

CASE STUDY

City of Atlanta's Runoff Reduction Requirement

In February 2013, the City of Atlanta amended its Post-Development Stormwater Management Ordinance to require green infrastructure on new and redevelopment projects in the city. One of the most significant revisions to the ordinance was a volume-based runoff reduction requirement. Commercial and single family residential developments must capture the first 1.0" of runoff and reduce this volume onsite using infiltration, evapotranspiration, and/or harvesting the rainwater and reusing it in irrigation or indoor plumbing systems. This new standard replaces the previous water quality requirement of capturing and removing 80% of the total suspended solids from the first 1.2" of runoff on commercial sites.

In order to implement the runoff reduction standard, the City adopted the Coastal Stormwater Supplement (CSS) of the Georgia Stormwater Management Manual (Blue Book). The CSS (2009) includes these runoff reduction BMPs and provides design parameters and a specified credit system for implementation. Because these practices both clean and reduce the volume of runoff, quantifiable credit is given to satisfy both runoff reduction and attenuation requirements, reducing the size of detention ponds or underground vaults.

Source: Rayburn, Rutherford, Implementing Green Infrastructure: Atlanta's Post-Development Stormwater Ordinance, City of Atlanta Department of Watershed Management, 2013.

STANDARD #4 – WATER QUALITY

Stormwater management systems shall be designed to retain or treat the runoff from 85% of the storms that occur in an average year, and reduce average annual post-development total suspended solids loadings by 80%. Averaged from rainfall events across the state of Georgia, this equates to treating storm events of 1.2 inches or less, as well as the first 1.2 inches of runoff for all larger storm events.

Communities may choose to waive the water quality treatment volume from this standard if 100% of the 1.0 inch runoff reduction volume is achieved. If the entire 1.0-inch runoff reduction standard cannot be achieved, the remaining runoff from the 1.2-inch rainfall event must be treated by BMPs to remove at least 80% of the calculated average annual post-development TSS loading from the site.

This standard is quantified and expressed in terms of engineering design criteria through specification of the water quality volume (WQ_v), which is equal to the runoff generated on a site from 1.2 inches of rainfall. The WQ_v must be treated to the 80% TSS removal performance goal.

This standard assumes that BMPs will be designed, constructed and maintained according to the criteria in this Manual. Stormwater discharges from land uses or activities with higher or special potential pollutant loadings may require the use of specific structural practices and pollution prevention practices. A detailed overview of BMPs is provided in Volume 2, Chapter 4.

STANDARD #5 – STREAM CHANNEL PROTECTION

Stream channel protection shall be provided by using all of the following three approaches: (1) 24-hour extended detention storage of the 1-year, 24-hour return frequency storm event; (2) erosion prevention measures, such as energy dissipation and velocity control; and (3) preservation of the applicable stream buffer. Stream channel protection requirements are further described in Volume 2, Section 2.2.4.2.

The first method of providing stream bank protection is the extended detention of the 1-year, 24-hour storm for a period of 24 hours using BMPs. It is known that the increase in runoff due to development can dramatically increase stream channel erosion. This standard is intended to reduce the frequency, magnitude and duration of post-development bankfull flow conditions. The volume to be detained is also known as the channel protection volume (CP_v). The use of nonstructural site design practices and runoff reduction BMPs that reduce the total amount of runoff may also reduce CP_v by a proportional amount (See Volume 2, Section 3.1.7.5 for calculations that incorporate the runoff reduction volume into larger storm events).

This requirement may be waived by a local jurisdiction for sites that discharge directly or through piped stormwater drainage systems into larger streams, rivers, wetlands, lakes, estuaries, tidal waters, or other situations where the reduction in the smaller flows will not have an impact on stream bank or channel integrity.

The second stream bank protection method is to implement velocity control, energy dissipation, stream bank stabilization, and erosion prevention practices and structures as necessary in the stormwater management system to prevent downstream erosion and stream bank damage. Energy dissipation and velocity control methods are discussed in Volume 2, Section 5.5.

The third method of providing for stream channel protection is through the establishment of riparian stream buffers on the development site. Stream buffers not only provide channel protection but also water quality benefits and protection of streamside properties from flooding. It is recommended that 100-foot buffers be established where feasible. Additional stream buffer guidelines are presented in Volume 2, Section 2.3.

STANDARD #6 – OVERBANK FLOOD PROTECTION

Overbank flood protection shall be provided by controlling the post-development peak discharge rate to the pre-development rate (natural or existing condition, as applicable) for the 2-year through the 25-year return frequency storm events. Overbank flood protection requirements are further described in Volume 2, Section 2.2.4.3.

The use of nonstructural site design practices and runoff reduction BMPs that reduce the total amount of runoff will also reduce $Q_{p2\text{-}25}$ by a proportional amount (See Volume 2, Section 3.1.7.5 for calculations that incorporate the runoff reduction volume into larger storm events).

This standard may be adjusted by a local jurisdiction for areas where all downstream conveyances and receiving waters have the natural capacity to handle the full build-out 25-year storm through a combination of channel capacity and overbank flood storage without increasing flood stages above pre-development flood levels (natural or existing condition, as applicable).

STANDARD #7 – EXTREME FLOOD PROTECTION

Extreme flood protection shall be provided by controlling and/or safely conveying the 100-year, 24-hour storm event (denoted Q_f). This is accomplished either by (1) controlling Q_f through BMPs to maintain the existing 100-year floodplain, or (2) by sizing the on-site conveyance system to safely pass Q_f and allowing it to discharge into a receiving water whose protected floodplain is sufficiently sized to account for extreme flow increases without causing damage. In this case, the extreme flood protection criterion may be waived by a local jurisdiction in lieu of provision of safe and effective conveyance to receiving waters that have the capacity to handle flow increases to maintain 100-year level.

The use of nonstructural site design practices and runoff reduction BMPs that reduce the total amount of runoff will also reduce Q_f by a proportional amount (See Volume 2, Section 3.1.7.5 for calculations that incorporate the runoff reduction volume into larger storm events).

Existing and future floodplain areas shall be preserved to the extent possible. Extreme flood protection requirements are further described in Volume 2, Section 2.2.4.4.

STANDARD #8 – DOWNSTREAM ANALYSIS

Due to peak flow timing and runoff volume effects, some structural practices fail to reduce discharge peaks to pre-development levels downstream from the development site. A downstream peak flow analysis shall be provided to the point in the watershed downstream of the site or the stormwater management system where the area of the site comprises 10% of the total drainage area. This is to help ensure that there are minimal downstream impacts from the developed site. The downstream analysis may result in the need to resize BMPs, or may allow the waiving of some unnecessary peak flow controls altogether. The use of a downstream analysis and the "ten-percent" rule are discussed in Volume 2, Section 3.1.9.

STANDARD #9 – CONSTRUCTION EROSION AND SEDIMENTATION CONTROL

Erosion and sedimentation control practices shall be utilized during the construction phase of development or during any land disturbing activities.

All new development and redevelopment sites must meet the regulatory requirements for land disturbance activities under the Georgia Erosion and Sedimentation Control Act and/or the NPDES General Permit for Construction Activities. This involves the preparation and implementation of an approved erosion and sedimentation control plan, including appropriate best management practices, during the construction phase of development. Further guidance on practices for construction site erosion and sedimentation control can be found in the latest version of the *Manual for Erosion and Sediment Control in Georgia*.

Better site design practices and techniques that can reduce the total amount of area that needs to be cleared and graded should be implemented wherever possible. It is essential that erosion and sedimentation control be considered and implemented in stormwater concept plans and throughout the construction phase to prevent damage to natural stormwater drainage systems and previously constructed best management practices and conveyance facilities.

STANDARD #10 – STORMWATER MANAGEMENT SYSTEM OPERATION AND MAINTENANCE

The stormwater management system, including all best management practices and conveyances, shall have an operation and maintenance plan to ensure that it continues to function as designed. See Section 5.2 and Volume 2, Appendix E for more information on stormwater operation and maintenance.

All new development and redevelopment sites are to prepare a comprehensive operation and maintenance plan for the on-site stormwater management system. This is to include all of the stormwater management system components, including drainage facilities, BMPs, and conveyance systems. To ensure that stormwater management systems function as they were designed and constructed, the operation and maintenance plan must provide: (1) a clear assignment of stormwater inspection and maintenance responsibilities; (2) the routine and non-routine maintenance tasks to be undertaken; (3) a schedule for inspection and maintenance; and (4) any necessary legally binding maintenance agreements.

STANDARD #11 – POLLUTION PREVENTION

To the maximum extent practicable, the development or redevelopment project shall implement pollutant prevention practices and have a stormwater pollution prevention plan.

All new development and redevelopment sites are to consider pollution prevention in the design and operation of the site, and prepare a formal stormwater pollution prevention plan if circumstances warrant it. Specific land use types and hotspots may need to implement more rigorous pollution prevention practices. The preparation of pollution prevention plans and the full set of pollution prevention practices are covered in Volume 3 of this Manual.

STANDARD #12 – STORMWATER MANAGEMENT SITE PLAN

The development project shall prepare a stormwater management site plan for local government review that addresses Standard #1 through Standard #11.

All new development and redevelopment sites will require the preparation of a stormwater management site plan for development activities. A stormwater site plan is a comprehensive report that contains the technical information and analysis to allow a local review authority to determine whether a proposed new development or redevelopment project meets local stormwater regulatory requirements. See Section 4.3 and other local stormwater regulatory requirements for specific guidance.

4.3 Stormwater Management Site Plans

Description: A stormwater management site plan is a comprehensive plan used to show compliance for all applicable stormwater management requirements. The stormwater management site plan is the key document in the site plan review process and used to ensure that a development has been designed and will be constructed as required. It also provides important details and certifications for the long-term ownership, operation, and maintenance of stormwater BMPs on a site.

KEY CONSIDERATIONS

- The stormwater management site plan should be signed and sealed by a qualified design professional.
- A typical stormwater management site plan should include the following components:
  1. Natural Resources Inventory
  2. Existing Conditions Hydrologic Analysis
  3. Post-Development Hydrologic Analysis
  4. Stormwater Management System
  5. Downstream Analysis
  6. Erosion and Sediment Control Plan
  7. Landscaping Plan
  8. Operations and Maintenance Plan
  9. Evidence of Acquisition of Applicable Permits
  10. Waiver Requests (if applicable)

- The site plan review should be performed by a qualified local government staff person or consultant. The review may consist of the following steps:
  1. Pre-consultation Meeting and Joint Site Visit
  2. Review Stormwater Concept Plan
  3. Review Preliminary Stormwater Site Plan
  4. Review Final Stormwater Site Plan
  5. Pre-construction Meeting
  6. Construction Inspections
  7. Ongoing Maintenance Inspections



4.3.1 Introduction

To encourage and ensure that local stormwater guidelines and requirements are implemented, communities should implement a formal site plan preparation, submittal, and review procedure that facilitates open communication and understanding between the involved parties.

A stormwater management site plan is a comprehensive report containing the technical information and analysis to allow a community to determine whether a proposed new development or redevelopment project meets the local stormwater regulatory requirements. This section discusses the typical contents of a stormwater management site plan and the recommended review and consultation checkpoints between local government staff and the site developer.

The procedures and guidelines for the preparation of a site stormwater plan should be explicitly stated in a local ordinance. The ordinance, in turn, may refer to a design guidance document for additional detail. Ideally, site stormwater plans are developed with open lines of communication between the developer (and developer's engineer) and the plan reviewer. Stormwater plans are more than just the preparation of a document and maps. Instead, stormwater plans should be thought of as a process that occurs over the planning and development cycle and continues after build-out via regular inspection and maintenance of the stormwater management system.

4.3.2 Contents of a Stormwater Management Site Plan

The following elements are required components for a local stormwater management site plan. This stormwater management site plan shall be signed and sealed by either a professional engineer or landscape architect registered in the State of Georgia. Flood studies for and floodplain or flood prone areas, and hydrologic and hydraulic analysis and design calculation which are performed for the design of a dam as defined in the Gwinnett County Stormwater Management Manual shall be certified by a registered professional engineer in the State of Georgia.

Based on a community's prerogative, small-scale projects could be allowed to prepare a site plan that includes a defined subset of the elements outlined below.

1. Natural Resources Inventory
   - Natural Drainage Divides
   - Natural Drainage Features (e.g., swales, basins, depressional areas)
   - Wetlands
   - Water Bodies
   - Floodplains
   - Aquatic Buffers
   - Shellfish Harvesting Areas
   - Soils
   - Erodible Soils
   - Steep Slopes (i.e., Areas with Slopes Greater Than 15%)
   - Groundwater Recharge Areas
   - Wellhead Protection Areas
   - Trees and Other Existing Vegetation
   - High Quality Habitat Areas
2. Existing Conditions Hydrologic Analysis
   - A topographic map of existing site conditions (minimum 2-foot contour interval recommended) with the basin boundaries indicated
   - Acreage, soil types, and land cover of areas for each sub-basin affected by the project
   - All perennial and intermittent streams and other surface water features
   - All existing stormwater conveyances and structural control facilities
   - Direction of flow and exits from the site
   - Analysis of runoff provided by off-site areas upstream of the project site
   - Infiltration rates of existing soils
   - Analysis of the offsite properties shall anticipate future development in addition to addressing existing conditions.
   - Methodologies, assumptions, site parameters, and supporting design calculations used in analyzing the existing conditions and site hydrology
3. Natural Conditions Hydrologic Analysis (where applicable)
   - In communities where pre-development is defined as natural conditions rather than existing conditions, or where natural conditions are a more appropriate hydrologic standard, such as discharges to impaired streams or floodprone areas,

a natural conditions hydrologic analysis will be necessary. The natural conditions hydrologic analysis should include all of the elements described for Existing Conditions Hydrologic Analysis above.

- In some cases, the existing topography may not be representative of natural conditions, and the hydrologic analysis should be modified for leveling or grading that has occurred.
- A set type of vegetative condition such as "woods in good condition" may be used in the natural conditions hydrologic analysis

4. Post-Development Hydrologic Analysis
   - A topographic map of developed site conditions (minimum 2-foot contour interval recommended) with the post-development basin boundaries indicated
   - Total area of post-development impervious surfaces and other land cover areas for each sub-basin affected by the project
   - Unified stormwater sizing criteria runoff calculations for water quality, channel protection, overbank flooding protection, and extreme flood protection for each sub-basin
   - Location and boundaries of proposed natural feature protection areas
   - Documentation and calculations for any applicable site design credits that are being utilized
   - Analysis of the offsite properties shall anticipate future development in addition to addressing existing conditions.
   - BMPs shall be designed using predevelopment flows based on existing conditions for all off-site areas and include all existing on-site lakes and detention.
   - Methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology
   - Calculations shall be provided showing how all times of concentration or lag times were computed, both for pre- and post-developed conditions. Likewise, adequate support must be provided for all composite runoff coefficients or curve numbers used.
   - If a computer program is used for hydrologic and hydraulic analysis and design, including generating and routing hydrographs, the output from the program shall be summarized in the Storm Water Management Site Plan.
   - Evaluate if site plan created concentrated flows where none had occurred previously.

5. Stormwater Management System
   - Drawing or sketch of the stormwater management system including the location of non-structural site design features and the placement of existing and proposed structural stormwater controls. This drawing should show design water surface elevations, storage volumes available from zero to maximum head, location of inlets and outlets, location of bypass and discharge systems, and all orifice/restrictor sizes.
   - Narrative describing that appropriate and effective structural stormwater controls have been selected
   - Cross-section and profile drawings and design details for each of the structural stormwater controls in the system. This should include supporting calculations to show that the facility is designed according to the applicable design criteria.
   - Hydrologic and hydraulic analysis of the stormwater management system for all applicable design storms (should include stage-storage or outlet rating curves, and inflow and outflow hydrographs)
   - Documentation and supporting calculations to show that the stormwater management system adequately meets the unified stormwater sizing criteria
   - Drawings, design calculations, and elevations for all existing and proposed stormwater conveyance elements including stormwater drains, pipes, culverts, catch basins, channels, swales, and areas of overland flow

6. Downstream Analysis
   - Supporting calculations for a downstream peak flow analysis using the ten-percent rule necessary to show safe passage of post-development design flows downstream

7. Erosion and Sedimentation Control Plan
   - Must contain all the elements specified in the Georgia Erosion and Sediment Control Act and local ordinances and regulations

- Sequence/phasing of construction and temporary stabilization measures
- Temporary structures that will be converted into permanent stormwater controls

8. Landscaping Plan
   - Arrangement of planted areas, natural areas and other landscaped features on the site plan
   - Information necessary to construct the landscaping elements shown on the plan drawings
   - Descriptions and standards for the methods, materials and vegetation that are to be used in the construction
9. Operations and Maintenance Plan
   - Description of maintenance tasks, responsible parties for maintenance, funding, access, and safety issues
10. Evidence of Acquisition of Applicable Permits
11. Waiver Requests (if applicable)

4.3.3 Procedure for Reviewing Stormwater Site Plans

Section 2.4 of Volume 2 describes the general procedure for the preparation of a stormwater site plan. The following steps are intended to provide communities with a review process and checkpoints that complement the procedure from the site developer's perspective:

12. Pre-consultation Meeting and Joint Site Visit
13. Review Stormwater Concept Plan
14. Review Preliminary Stormwater Site Plan
15. Review Final Stormwater Site Plan

Additional steps to ensure compliance with the stormwater management site plan include:

16. Pre-construction Meeting
17. Construction Inspections
18. Ongoing Maintenance Inspections

STEP 1. PRE-CONSULTATION MEETING AND JOINT SITE VISIT

The most important action that can take place at the beginning of the development project is a pre-consultation meeting between the local review authority and the developer team to outline the stormwater management requirements and other regulations, and to assist developers in assessing constraints, opportunities, and potential for stormwater design concepts.

This recommended step may help to establish a constructive partnership through the development process. A joint site visit, if possible, can yield a conceptual outline of the stormwater management plan and strategies. By walking the site, the two parties can identify and anticipate problems, define general expectations, and establish boundaries of natural feature protection and conservation areas. A major incentive for pre-consultation is that permitting and plan approval requirements will become clear at an early stage, increasing the likelihood that the approval process will proceed more quickly and smoothly.

The site developer should be made familiar with local stormwater management and development requirements and design criteria that apply to the site. These may include:

- Design and performance standards for stormwater management
- Design storm frequencies
- Conveyance design criteria
- Floodplain criteria
- Buffer/setback criteria
- Wetland provisions
- Watershed-based criteria
- Erosion and sedimentation control requirements
- Maintenance requirements
- Need for physical site evaluations (infiltration tests, geotechnical evaluations, etc.)

This guidance could be provided at the pre-consultation meeting and should be detailed in various local ordinances (subdivision codes, stormwater and drainage codes, etc.). This information could be contained in a set of checklists, which would be provided to the developer. Appendix B includes example checklists outlining the necessary steps to prepare preliminary and final stormwater management site plans.

Current land use plans, comprehensive plans, zoning ordinances, road and utility plans,

watershed or overlay districts, and public facility plans should all be consulted to determine the need for compliance with other local and state regulatory requirements. Opportunities for special types of development (e.g., clustering) or special land use opportunities (e.g., conservation easements or tax incentives) should be investigated. There may also be opportunities to partner with the site developer for the creation of greenways or open space parks.

CASE STUDY

City of Atlanta Stormwater Concept and Consultation Meeting

For certain types of developments, the City of Atlanta requires that a stormwater concept plan and consultation meeting be held early in the design process. At this meeting, the project's engineer and City of Atlanta staff discuss the post-development stormwater management measures necessary for the proposed project and assess constraints, opportunities, and ideas for better site design, low impact development, and runoff reduction techniques early in the design process. This consultation meeting must be held prior to submittal of an application for a building permit (BB) or land disturbance permit (LD).

Per the City of Atlanta's Post Development Stormwater Management Ordinance, the project's engineer must present a Stormwater Concept Plan to City of Atlanta staff for the following activities:

- New commercial development (greenfield) that involves the creation of any impervious cover;
- Commercial redevelopment that includes the creation, addition, or replacement of 500 square feet of impervious cover or more;
- Commercial development or redevelopment that disturbs one acre of land or more; and,
- Commercial demolition projects that leave in place more than 500 square feet of impervious cover.

The city's Stormwater Concept Plan and Consultation Meeting Record is available here: https://www.atlantawatershed.org/greeninfrastructure/stormwater-concept-plan-requirements-and-meeting-record/?showMeta=2&ext=.pdf

STEP 2. REVIEW STORMWATER CONCEPT PLAN

During the concept plan stage the site designer will perform most of the layout of the site, including the preliminary stormwater management system design and layout. The stormwater concept plan allows the design engineer to propose a potential site layout and gives the developer and local review authority a "first look" at the stormwater management system for the proposed development. The stormwater concept plan should be submitted to and approved by the local plan reviewer before detailed preliminary site plans are developed.

It is extremely important at this stage that stormwater design is integrated into the overall site design concept in order to best reduce the impacts of the development, as well as provide for the most cost-effective and environmentally sensitive approach.

STEP 3. REVIEW PRELIMINARY STORMWATER SITE PLAN

The preliminary plan ensures that local requirements and criteria are being complied with and that opportunities are being taken to minimize adverse impacts from the development.

The preliminary stormwater management site plan should consist of maps, narrative, and supporting design calculations (hydrologic and hydraulic) for the proposed stormwater management system, and should include the following elements:

- Existing Conditions Hydrologic Analysis
- Natural Conditions Hydrologic Analysis (where applicable)
- Post-Development Hydrologic Analysis
- Stormwater Management System
- Downstream Analysis

It should be demonstrated that appropriate and effective stormwater controls have been selected and adequately designed. The preliminary plan should also include, among other things, street and site layout, delineation of natural feature protection and conservation areas, soils data, existing and proposed topography, relation of site to upstream drainage, limits of clearing and grading, and proposed methods to manage and maintain conservation areas (easements, maintenance agreements/responsibilities, etc.)

STEP 4. REVIEW FINAL STORMWATER SITE PLAN

1. The final stormwater management site plan adds further detail to the preliminary plan and reflects changes that are requested or required by the local review authority. The final stormwater site plan should include all of the revised elements from the preliminary plan as well as the following items:

- Erosion and Sedimentation Control Plan
- Landscaping Plan
- Operations and Maintenance Plan and Agreement (see Section 5.2 and Appendix D)
- Evidence of Acquisition of Applicable Local and Non-local Permits
- Waiver Requests

This process may be iterative. The reviewer should ensure that all submittal requirements have been satisfactorily addressed and permits, easements, and pertinent legal agreements (maintenance agreements, performance bond, etc.) have been obtained and/or executed.

The completed final stormwater site plan should be submitted to the local review authority for final approval prior to any construction activities on the development site. Approval of the final plan is the last major milestone in the stormwater planning process. The remaining steps are to ensure that the plan is installed, implemented, and maintained properly.

STEP 5. PRE-CONSTRUCTION MEETING

This step ensures that the contractor, engineer, inspector, and plan reviewer can be sure that each party understands how the plan will be implemented on the site. A pre-construction meeting should occur before any clearing or grading is initiated on the site. This is the appropriate time to ensure that natural feature protection areas and limits of disturbance have been adequately staked and adequate erosion and sediment control measures are in place.

STEP 6. CONSTRUCTION INSPECTIONS

Project sites should periodically be inspected during construction by local agencies to ensure that conservation areas have been adequately protected and that stormwater control and conveyance facilities are being constructed as designed. Inspection frequency may vary with regard to site size and location; however, monthly inspections are a good target. In addition, it is recommended that some inspections occur after larger storm events (e.g., 0.5 inches and greater). The inspection process can prevent later problems that result in penalties and added costs to developers. Example construction inspection forms are included in Appendix C.

An added benefit of a formalized and regular inspection process is that it should help motivate contractors to internalize regular maintenance of sediment controls as part of daily construction operations. If necessary, a community can consider implementing a penalty system, whereby fines can be assessed and/or stop work orders issued.

A final inspection is needed to ensure that all construction conforms to the intent of the approved design. Prior to issuing an occupancy permit and releasing any applicable bonds, the review authority should ensure that: (1) temporary erosion control measures have been removed; (2) stormwater controls are unobstructed and in good working order; (3) permanent vegetation cover has been established in exposed areas; (4) any damage to natural feature protection and conservation areas has been restored; (5) conservation areas and buffers have been adequately marked or signed; and (6) any other applicable conditions are being met.

Record drawings of the structural stormwater controls and drainage facilities should also be acquired by the community, as they are important in the long-term maintenance of the facilities. The review authority should keep copies of the drawings and associated documents to develop a local stormwater control inventory and data storage system. With geographic information systems (GIS) becoming more widely used, much of these data can be stored electronically.

STEP 7. ONGOING MAINTENANCE INSPECTIONS

Ongoing inspection and maintenance of a project site's stormwater management system is often the weakest component of stormwater plans. It needs to be clearly detailed in the stormwater site plan which entity has responsibility for operation and maintenance of all structural stormwater controls and drainage facilities. Often, the responsibility for maintenance is transferred from the developer and contractor to the owner. Communication about this important responsibility is usually inadequate; therefore, communities may need to consider ways to notify property owners of their responsibilities. For example, notification can be made through a legal disclosure upon sale or transfer of property or public outreach programs may be instituted to describe the purpose and value of maintenance.

Ideally, preparation of maintenance plans should be a requirement of the stormwater site plan preparation and review process. A maintenance plan should outline the scope of activities, schedule, and responsible parties. Vegetation, sediment management, access, and safety issues should also be addressed. It is important that the maintenance plan contains the necessary provisions to ensure that vegetation establishment occurs in the first few years after construction. In addition, the plan should address testing and disposal of sediments that will likely be necessary.

Periodic inspections of stormwater management facilities should be conducted by an appropriate local agency, but these inspections should not replace the more frequent inspections required of the BMP owner. Where chronic or severe problems exist, local governments should have the authority to remedy the situation and charge the responsible party for the cost of the work. This authority should be well established in an ordinance.

4.4 Different Development Types

Description: There are many different types of development, and some types may not fit as well into the typical site plan review process. Different development types bring different stormwater challenges, and need to be addressed accordingly.

KEY CONSIDERATIONS

Development types discussed in this section that may require special consideration include:

- Subdivisions
- Linear Development
- Redevelopment
- Single Family Homes
- Planned Unit Developments (PUDs)



There are many different types of development that impact natural site features and runoff patterns. By revising local codes, communities may be able to help conserve these site features and reduce the amount of impact a development has on the existing hydrology and topography. The Atlanta Regional Commission (ARC) offers a Community Choices Toolkit (http://atlantaregional.com/local-government/implementation-assistance/best-practices), which provides information for local officials on the choices available to them to create and sustain quality communities and takes many of the types of development discussed in this section into account.

In addition to having tailored ordinance language, communities should be prepared to address the different stormwater challenges that may be unique to each particular development type. The following offers a basic overview of the typical development categories and some of the more common challenges to implementing effective stormwater strategies.

4.4.1 Subdivision

A subdivision is a large parcel of residential, commercial, or industrial zoned land divided into smaller parcels, or lots, for the purpose of developing and selling the individual lots. In the Georgia Construction General Permit Program, this is referred to as a Common (Plan of) Development, which is a contiguous area where multiple, separate, and distinct construction activities will be taking place at different times on different schedules under one plan of development.

Residential Subdivisions

For some single-family detached residential subdivisions, the original owner or developer also serves as the home builder and will construct the primary infrastructure (i.e., roads, utilities, and other common improvements), including stormwater management facilities, in concert with the home construction, allowing for gradual and sequential construction, stabilization, and occupancy. However, the more common approach is for the original owner/developer to construct the primary infrastructure and sell the lots to be developed individually by others. This latter approach will not typically follow a sequential construction pattern and is often more difficult to manage in terms of erosion and sediment control and stormwater management implementation and oversight.

In all cases, the erosion and sediment control plan and the post-construction stormwater management plan for residential subdivisions should be developed for the entire plan of development. The Natural Resources Inventory (NRI) and the Stormwater Concept Plan (SCP) should be reviewed carefully, with a focus on any proposed phasing of construction or stormwater practice implementation.

Industrial/Commercial Subdivisions

The development of an industrial or commercial subdivision may be very different. While the site may be developed in a similar manner to a residential subdivision, with mass grading of all lots together, sometimes, the primary access road and utility infrastructure is built and the lots are left untouched, or minimally disturbed, as may be needed for ancillary improvements. This allows the individual purchasers or tenants to develop a site plan customized for their intended use. However, the NRI should identify all the relevant features for the entire plan of development. The NRI should be utilized to configure the individual lot lines so as to minimize potential future impacts and for alignment of the primary access road. Likewise, the SCP should establish the strategy for managing the stormwater runoff from the roadway and, if applicable, conceptually identify potential strategies for the future development of the individual lots.

In some cases, the owner/developer of a commercial or industrial subdivision will benefit from an economy of scale and construct a stormwater management plan for full build-out of the subdivision. This will allow for a more efficient plan review and initial construction inspection, but the subsequent ESC plan review for individual parcel construction should be cognizant of the potential disturbed acreage in the contributing drainage area to the stormwater controls.

Stormwater Strategies for Residential Subdivisions

Applying and enforcing the application of distributed stormwater BMPs in a subdivision development can be challenging. Since traditional residential subdivisions have many different owners and potentially on-going construction, it can be difficult to be sure adequate stormwater measures are being implemented appropriately. Ideally a subdivision layout would maintain natural site features as amenities and identify the most advantageous topography and soils for locating stormwater BMPs. Figure 4.4-1 represents a combined NRI and a SCP for a large mixed-use development. Based on the NRI, the SCP identifies the locations of high, medium, and low density development zones. The SCP also identifies ideal locations for the primary 'subdivision-scale' stormwater controls. Figure 4.4-2 represents the conceptual layout.

Generally, the NRI offers an opportunity to maximize cost-effectiveness of the stormwater strategy, and the development as a whole, by informing the overall layout of the development. The next step is to develop a SCP for each development zone in order to identify the degree to which the development achieves the goals of Standard #2: Better Site Design Practices for Stormwater Management, Standard # 3: Runoff Reduction, and Standard #4: Water Quality. The SCP for each development zone should include preliminary sizing computations to ensure that the stormwater practice locations are adequate for the development.

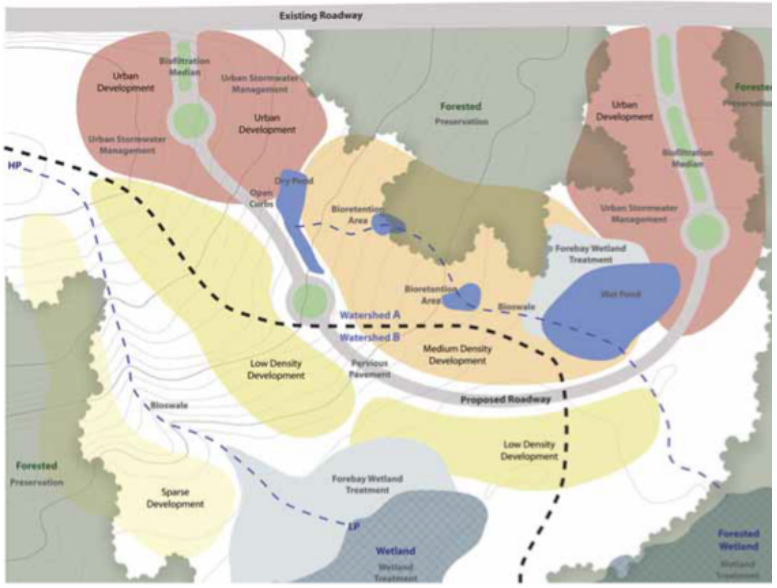


Figure 4.4-1 Schematic of a Water Quality Treatment Plan
(Source: Central, LA Municode)



Figure 4.4-2 Final Water Quality Treatment Plan
(Source: Central, LA Municode)

In order to review the SCP, communities should establish basic standards for acceptable better site design and water quality practices within residential subdivisions. Not all better site design strategies are consistent with local ordinances (cluster development, reduced front yard setbacks, reduced road widths, etc.). See Section 3.2 for more information about aligning local ordinances with Better Site Design Principles.

Likewise, not all water quality practices are compatible with residential subdivisions. For example, maintenance-intensive or underground practices can be difficult to manage on residential sites. Communities should establish provisions to guide the selection of subdivision-scale and micro-scale stormwater practices based on lot size (i.e., 1/2-acre lots versus 1/8-acre lot subdivisions), the presence of a Home Owners Association for establishing a single entity responsible for ongoing inspection and maintenance, and neighborhood-wide covenants related to the protection of stream buffers, proper pollution prevention, and management of open space, among other concerns. These documents are critical to long-term maintenance of stormwater infrastructure. Proper review of these documents and acceptance by the developer and future owners should be established early in the review process.

4.4.2 Linear Projects

Linear development projects can include roads and highways, railroad tracks, and utility corridors, such as gas and electric transmission lines. Linear development projects are different enough that the Georgia Department of Natural Resources developed a sector specific NPDES construction general permit: Infrastructure Construction General Permit. These projects can represent numerous design challenges for both ESC and SWM:

- The right-of-way for these infrastructure corridors is highly constrained. Public acquisition processes limit the purchase or taking of right-of-way to only that which is necessary for the primary transportation goal (meaning acquiring additional right-of-way for ancillary features such as stormwater management practices can be difficult and expensive).
- The alignment of these corridors is not flexible. Either specific topographic or public safety considerations can force the selection of the least unfavorable alignment, rather than the one that meets all the design goals;
- Alignments can form a 'levy' or diversion system, intercepting off-site areas of sheet flow and creating concentrated flow from the combined on-site and off-site drainage where it discharges from the right-of-way. Defining the specific stormwater requirements can become complicated.
- Alignments can cross several watersheds and sub-watersheds creating very complex conveyance and treatment design strategies.



Figure 4.4-3 Bioretention Area in a Subdivision
(Source: US EPA)

Early coordination through the environmental permitting processes will typically direct these linear alignments towards minimizing impacts to regulated waters of the U.S. and private property. However, this process will likely establish design performance goals rather than the design itself, especially on new location highway projects. Primary and limited access collector widening projects and urban infrastructure upgrades are much more common and more difficult to address due to severely limited space.

Designers and plan reviewers should utilize the pre-consultation SCP process to identify and assess these challenges early in the design process to ascertain the efficacy of linear LID to the extent practicable. The Georgia Department of Transportation (GDOT) Manual on Drainage Design for Highways (http://www.dot.ga.gov/PS/DesignManuals) provides design guidance for linear applications of filter strips, grass channels, enhanced swales, infiltration trenches, bioslopes, sand filters, bioretention basins, and open-graded friction course BMPs. Where these practices cannot achieve full compliance, designers should consider supplemental off-site mitigation options as a viable compliance option. (Section 5.7).

4.4.3. Redevelopment

Many jurisdictions actively encourage redevelopment with tax breaks, reduced impact fees, and other monetary incentives to revitalize abandoned or underutilized urban lands. Redevelopment of existing urban lands is preferred over the 'greenfield' development that expands the urban area footprint into rural areas. The desire to retrofit these redeveloping sites with stormwater controls requires a delicate balance to avoid creating a disincentive for redevelopment.

Designers and plan reviewers should utilize the pre-consultation and SCP process to identify and assess stormwater treatment options. In some cases, reductions in impervious cover can help satisfy stormwater management requirements. Designers may also evaluate the most readily managed portion of the site for treatment in order to reduce costs, rather than treating the specific area of new impervious cover. Designers should also consider off-site mitigation as a viable compliance option.

Ultimately, financial or other incentives to encourage redevelopment should take precedence over exemptions or variances to environmental protection ordinances. Other avenues to encourage redevelopment include:

- Establishing a formal infill development/redevelopment program to ensure that developers and property owners are aware of incentives, such as:
  - » Financial incentives and prioritized capital funding or financing for infrastructure improvements (water, sewer, and transportation upgrades, etc.) in identified growth areas;
  - » Housing density bonuses and accelerated permitting process for infill and redevelopment projects;
  - » Reduced impact fees for infill development based on less demand for new infrastructure;
  - » Establishment of Tax Incremental Financing districts to encourage redevelopment; and
  - » More restrictive zoning, utility access, stormwater requirements, and other provisions outside of growth boundary or at the edge of a city to restrict development and preserve rural character (Nevue, 2009).
- Reviewing and revising local codes to eliminate unnecessary site infrastructure upgrades to the extent practicable; and
- Utilizing and promoting financial incentives provided by state and federal programs to encourage redevelopment and revitalization.

More information on the advantages, opportunities, and strategies for local adoption of infill development and redevelopment and planning policies is provided in Chapter 3 of the Manual.



Figure 4.4-4 Linear Bio-swale
(Source MDSHA)

4.4.4. Single Family Homes

Single family home construction that is not part of a common plan of development is usually exempt from stormwater management requirements. However, the cumulative effect of many new homes and/or large additions can result in changes to the hydrologic conditions of a developing area. Some guiding principles can be applied to individual building permits to help property owners and general contractors minimize impacts as well as the potential for ongoing drainage problems:

- Provide educational materials with building permits to clearly illustrate proper implementation of pollution prevention and ESC measures;
- Ensure adequate grading and drainage around the house foundation and other improvements without creating concentrated flow, which can include the use of level spreaders or impervious disconnection at downspouts; and
- Review soil conditions and make property owners aware of permeable soils for directing downspout and sheet flow, or the implementation of rain gardens, dry wells, permeable pavers, and other BMPs.



Figure 4.4-5 Residential Rain Barrel
(Source: www.energyearth.com)

CASE STUDY

City of Atlanta Single-Family Development Requirements

In February 2013, the City of Atlanta amended its Post-Development Stormwater Management Ordinance to require green infrastructure on new and redevelopment projects in the City. Atlanta's ordinance is unique in terms of its applicability to single-family development.

The City's previous requirements allowed 99% of homes to be constructed in existing neighborhoods without any form of stormwater management. The City now requires new homes and large additions (>1,000 ft^2 of impervious surface) to manage the first 1.0" of runoff on their site using green infrastructure.

With the help of a consultant, the City developed a guidance document, Green Infrastructure for Single Family Residences, which specifies the types of stormwater practices that can be utilized on an individual lot, allows the user to size the practice using easy to read sizing charts and provides tear-off detail sheets that show a step-by-step construction sequence for the given practice. The practices include routing runoff from the roof to a simplified rain garden, dry well, modified French drain, cistern, or natural buffer.

The guidance document is available here: https://www.atlantawatershed.org/greeninfrastructure/atlanta-residential-gi-nov-2012022013/?showMeta=2&ext=.pdf

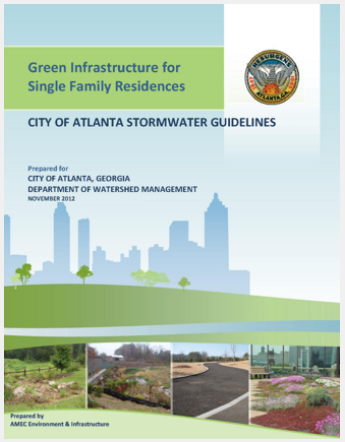


Figure 4.4-6 City of Atlanta's Green Infrastructure for Single Family Residences Manual

Source: Rayburn, Rutherford, Implementing Green Infrastructure: Atlanta's Post-Development Stormwater Ordinance, City of Atlanta Department of Watershed

4.4.5. Planned Unit Development

According to the American Planning Association, a planned unit development (PUD) is a large, integrated development adhering to a comprehensive plan and located on a single tract of land or on two or more tracts of land that may be separated only by a street or other right-of-way. Establishing PUD districts can enable the building of innovative new developments, while preserving natural features and open spaces.

PUDs offer a comprehensive approach to the design of large scale developments, as opposed to the conventional lot-by-lot approach typically allowed in community zoning codes and regulations. Unlike conventional development, a PUD allows developers to by-pass standard zoning and development regulations in exchange for site-specific design and development innovations, such as clustered lots, mixed land uses, conservation of open spaces, and natural resource preservation (Ellis, 2014).

These considerations offer a potentially unlimited list of options to creatively and holistically manage stormwater. Specific strategies can be applied to different areas or phases of the development. Regional or subdivision-scale practices can be supplemented with micro-scale practices distributed throughout the development on outparcels or individual lots.

The zoning approval process for PUDs typically involves many rounds of negotiation. Any commitments regarding stormwater management made during these negotiations, including any restrictive covenants or shared responsibilities for the stormwater infrastructure, should be clearly documented and passed forward to the stormwater program plan review staff. The pre-consultation and SCP process should incorporate these provisions into the final construction drawings, accompanied by detailed HOA and common area restrictive covenants and maintenance agreements.

CASE STUDY

Planned Unit Development: Palmetto Bluff, SC (Ellis et al, 2014)

Palmetto Bluff, South Carolina is a sea island with expansive frontage on the May, Cooper, and New Rivers. For most of the last century, Palmetto Bluff has been managed and enjoyed as a private wildlife and forest preserve. The property has been carefully master-planned to grow into a complete, balanced, and controlled community within a coastal setting. Its size makes possible the creation of a series of inter-related, yet distinctive, settlements and natural preserves. The combination of its location and varied natural features makes this a unique community.

Palmetto Bluff has been designed to preserve the land's beauty, vastness, and rich landscape, while taking advantage of the views and island setting to create a strong sense of place. Owners, along with their architect and landscape architect, are encouraged to work together from the initial phases of design to ensure that all aspects of the design are consistent with specific design objectives, such as implementing sustainable building systems, site development, materials, and construction techniques in all development. Reducing consumption of materials and energy, reducing waste, and making intelligent choices about how a building is used benefits both Palmetto Bluff as a community and the sensitive sea island landscape as a whole. Palmetto Bluff is committed to the implementation of Sustainable and Low Impact Design concepts, such as reducing the house's "footprint" on the land, implementing energy and water conservation measures, reuse and recycling of building materials, and preservation of the existing forest and river marsh frontage.

The text for the Palmetto Bluff Planned Unit Development is based on the Beaufort County Zoning and Development Standards Ordinance 90/3 with the following amendments:

- River Protection Overlay District
  - » The buffer width was changed from fifty (50) feet to an average of one hundred (100) feet, with a minimum of eighty (80) feet.
  - » Development setbacks changed from fifty (50) feet to an average of one hundred (100) feet, with a minimum of eighty (80) feet. Additionally, streets and roads to access land within the PUD can penetrate the buffer provided stormwater runoff is treated.
- Site Design and Development Standards
  - » In the planned resort, residential and commercial development parking requirements were changed for the following uses. The assumption underlying the change was that a substantial number of visitors would arrive by public transportation, thus requiring fewer spaces than the current requirements.
    - Auditorium and Theaters: 0.2 spaces for each spectator seat.
    - Automobile Service Station: One (1) space for each vehicle stored or parked, plus one (1) space for each employee.
    - Bank: One (1) space for each two-hundred square feet (200 sf) of gross floor space, plus one (1) space for each two (2) employees.
    - Church: One (1) space for each six (6) seats in the main assembly room.

References

City of Atlanta. 2013. *Stormwater Concept Plan and Consultation Meeting Record.* City of Atlanta, Atlanta, GA.

Ellis, K., C. Berg, D. Caraco, S. Drescher, G. Hoffmann, B. Keppler, M. LaRocco, and A.Turner. 2014. *Low Impact Development in Coastal South Carolina: A Planning and Design Guide.* ACE Basin and North Inlet – Winyah Bay National Estuarine Research Reserves.

Nevue Ngan Associates, Eisen|Letunic, Van Meter Williams Pollack LLP, ICF International. 2009. *Stormwater Management Handbook: Implementing Green Infrastructure in Northern Kentucky Communities.* ICF International. Fairfax, Va. Nevue Ngan Associates. Portland, OR.

Rayburn, Cory, Susan Rutherford. 2014. *Implementing Green Infrastructure: Atlanta's Post-Development Stormwater Ordinance.* City of Atlanta Department of Watershed Management, Atlanta, GA.

5. Elements of Stormwater Management Programs

5.1 Site Plan Review and Enforcement

Description: A formal stormwater management site plan review process is important to ensure that local stormwater guidelines and requirements are implemented.

KEY CONSIDERATIONS

Roles of Interested Parties in the Site Plan Review Process:

- Local Program Authority – Establish post-construction stormwater management requirements, develop and facilitate an effective stormwater design and plan review process, and evaluate program regularly.
- Design Engineer – Understand local requirements and communicate design options and life-cycle implications to client and local program authority.
- Local Plan Reviewer – Ensure that stormwater management plans meet the standards and specifications of applicable permits and ordinances.

The Site Plan and Construction Review Process should include the following:

1. Design and Review Materials
2. Pre-Design or Pre-Submittal Consultation Meeting
3. Stormwater Management Concept Plan
4. Final Stormwater Management Design and Construction Plans and Computations
5. Land Disturbing Permit and Transfer Project to Inspection and Maintenance Personnel
6. Pre-Construction Meeting
7. Construction Inspection and As-Built Record Drawings



5.1.1 Introduction

To encourage and ensure that local stormwater guidelines and requirements are implemented, communities should implement a formal stormwater management site plan submittal and review procedure. The basic steps in the review process should be outlined and the appropriate contact information for purposes of communicating approval, or disapproval when necessary, with corresponding written comments should be identified.

A stormwater management site plan is a comprehensive report that contains the technical information and analysis to allow a community to determine whether a proposed new development or redevelopment project meets local stormwater regulatory requirements. The introduction of Better Site Design (BSD) and low impact development (LID) practices that reduce impervious surface and infiltrate as part of the stormwater management strategy complicate the design review and change the methods in which land-disturbing activities are undertaken. Typical development projects often fit the landscape to the development, but with implementation of BSD and LID, the goal is the opposite – fit the development to the natural landscape. The conceptual approach to designing with BSD and LID should occur at the earliest stages of the design and review process, including zoning applications and preliminary plan approvals.

This section discusses the recommended roles and responsibilities of the local government staff plan reviewer and the applicant (or more likely the applicant's designated agent – the design engineer), as well as consultation checkpoints through the plan review process.

5.1.2 Roles of the Local Program, the Local Plan Reviewer, and the Design Engineer

The technical criteria, performance goals, accepted best management practices (BMPs), and associated hydrologic and hydraulic computational methods upon which the stormwater management plan must be based should be explicitly spelled out or adopted by reference in the local ordinance. However, the design steps, calculations, and modeling tools that the design engineer utilizes for demonstrating compliance may vary from engineer to engineer and/or from site to site. Complex commercial projects may utilize a robust package of integrated design and CADD software, while small single family lot subdivisions or similarly simple developments may use of a more modest design package.

In either case, it is the role of the local program to establish and communicate clear expectations and minimum design criteria. It is the role of the design engineer to understand the local requirements and work with his or her client to incorporate these into the site and stormwater management design strategy with the necessary documentation and clearly communicate the strategy to the plan reviewer. And finally, it is the role of the plan reviewer to ensure that all the required elements of the design and construction drawings are present and that they collectively demonstrate compliance with the standards and specifications in the ordinance and design manual.

The following should be considered general guidance to help the local program authority, design engineer, and plan reviewer navigate the various responsibilities necessary for bringing a project from the preliminary planning stage to construction.

The Role of the Local Program Authority:
To facilitate effective stormwater design and plan review processes, the local program authority should consider the following recommendations:

- Set clear and concise goals for integrating better site design and low impact development strategies into stormwater management designs.
- Establish processes for stormwater management strategies to be incorporated early in the planning process (e.g., zoning, preliminary plan) and carried forward through subsequent steps in the development approval process.
- Establish routine pre-design, pre-submittal process to review the site conditions and discuss opportunities for conserving natural resources, minimizing impervious surface, and using LID best management practices.

- Develop standard procedures for applicants to propose innovative designs for challenging sites. Development projects will often present unique conditions that could not have been foreseen in the development of specific design standards. A review process that establishes minimum performance goals and recommended steps for demonstrating compliance will often encourage innovative and effective design strategies.
- Sponsor periodic combined training workshops for plan review staff and the local design community to foster communication and understanding of the different site design issues and challenges, and support a better understanding of acceptable implementation strategies.
- Develop design, submittal, and review checklists to foster consistency in the design documentation and review process. Example site plan review checklists can be found in Appendix B.

More detailed information for site plan review is available in *Managing Stormwater in Your Community Chapter 7, The Stormwater Plan Review Process* (CWP, 2008).

The Role of the Design Engineer:

- Understand local requirements and represent his or her client's interests in developing a compliant stormwater management strategy that minimizes adverse post-development stormwater runoff impacts from the development.
- New stormwater management objectives and performance goals, such as better site design and runoff reduction, are being added to the traditional site planning process. The design engineer should strive to understand these objectives, identify consistencies with his or her client's site design objectives, and incorporate them into the overall site plan.
- Meet with the local plan reviewer prior to beginning design in order to discuss site constraints and opportunities for implementing BSD and LID practices. Do not rely on plan review comments to identify best fit strategies or specific requirements.

Communicate design options and life-cycle implications to the client and the local plan review authority. Some LID strategies can be relatively inexpensive to build and may or may not represent an ongoing maintenance responsibility for the post-construction owner of the property. Alternatively, other BMPs may be expensive to build but the shared responsibility of maintenance can be relatively minor. In all cases, the engineer should ensure that their client is aware of these options and develop appropriate long-term maintenance documentation to be included in the design submittal.

- Conduct site visits to verify field conditions.
- In most cases the design requirements include a soils investigation, depth to groundwater, wetlands, and other formal site assessments. However, the design engineer should also visit the site and verify any pre-developed conditions related to site hydrology, vegetation, topography, and any other conditions relevant to the stormwater design. Consider site designs that maintain a portion of the site in a natural, undisturbed condition, particularly environmentally sensitive landscapes such as wetlands and stream buffers.
- Clearly communicate the design and supporting computations to the plan reviewers. Stormwater management designs can be complex with LID practices in series (or "treatment train") with structural stormwater treatment practices and/or peak rate detention practices. These designs require that reductions in runoff volume, pollutant loads (in some watersheds), and peak rate of flow be tracked through multiple drainage areas and stormwater practices. Engineers should consider the use of a design narrative, node diagrams, and other documentation strategies to facilitate review of the design.
- In general, design engineers should follow the Fundamental Canons of the Professional Engineer, especially:
  - » Hold paramount the safety, health, and welfare of the public; and
  - » Perform services only in areas of their competence.

Further, the National Society of Professional Engineers' Professional Obligations encourages engineers to "adhere to the principles of sustainable development in order to protect the environment for future generations."

"Sustainable development" is the "challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management, while conserving and protecting environmental quality and the natural resource base essential for future development." National Society of Professional Engineers Code of Ethics; http://www.nspe.org/resources/ethics/code-ethics

The Role of the Local Plan Reviewer:
The role of the local plan reviewer can be summed up as that of ensuring that stormwater management plans meet the standards, specifications, and performance criteria in the ordinance, applicable permits, and design manual, and that BMPs are being properly applied to the project site.

- Determine if the stormwater management plan adequately addresses the standards and specifications in the ordinance and design manual.
- Understand the requirements and the difference between requirements and guidelines.
- Offer suggestions where appropriate, but do not re-design the plan.
- Ask questions: Stormwater plans and computations can be complex. Plan reviewers may not recognize the thought process and intent of design elements or the computational methods, especially given the numerous hydrologic and hydraulic software packages available.
- Reserve the right to get smarter: Comments on the first submission may lead to new comments on the second submission, or it may be that not everything was noted on the first review. In either case, reviewers should strive to identify all comments on the first review, but should not be restricted to assessing first review comments only in subsequent plan submissions.
- Attend the pre-construction meeting with the contractor, engineer, and inspector to ensure that each party understands the essential elements of the stormwater management plan, including locations for LID installation and conserved natural areas that should not be disturbed.

5.1.3 Site Plan Review Process

The recommended standards of the stormwater management plan can be found in Section 4.2. The detailed review of the plan and computations will determine if the design adequately meets local stormwater management technical requirements. This section provides a recommended stepwise process for reviewing plans and computations to ensure compliance, while also fostering multi-disciplinary and innovative design strategies (discussed in more detail in Section 5.1.4).
All plan submittal stages should include a Submittal Completeness Checklist to ensure that the submittal package is reviewable. This is not a determination of the adequacy of the design in meeting the requirements, but rather it is used to confirm that all required parts of a complete stormwater management design are included. All stages of plan review should also include written documentation of comments. This can be in the form of an itemized list of questions or comments, or a marked-up plan set.

1. Design and Review Materials
The regulated community should have the same plan review checklists as the plan reviewers, including the following:

- Submittal application or transmittal form with applicant information;
- Checklists – including Design, Submittal Completeness, and Review checklists – for each stage of the review process (see Section 4.3.2 for Contents of a Stormwater Management Site Plan);
- Review process and schedule information; and
- Contact information for relevant personnel.

2. Pre-Design or Pre-Submittal Consultation Meeting

- The regulatory criteria and ordinance language rarely accounts for all varieties of site conditions and development scenarios encountered in the land development process. This is especially true if the project will consist of multi-disciplinary and/or innovative compliance strategies. A pre-design meeting with a site visit allows the design team to identify site-specific issues and review potential design strategies with the local plan review personnel. In general, this step will lead to better designs and preliminary understanding of the expectations, which in turn results in a faster review and approval process.

3. Stormwater Management Concept Plan

The stormwater concept plan articulates the basic design strategy to the design and review team. Similar to the Pre-Design Consultation Meeting, this is a critical step for plans that will include multi-disciplinary and/or innovative compliance strategies, as it allows the opportunity to coordinate with staff who might be reviewing other components of the site plan or subdivision plat. The local plan review staff can provide preliminary feedback before the applicant spends time and resources preparing more complex engineered plans and computations.

A general checklist of recommended items should include preliminary hydrologic computations (e.g., impervious area anticipated, preliminary pre- and post-runoff volumes). This can be especially important if multiple stormwater practices will be utilized in series or treatment train; the design engineer can provide basic node diagrams or other graphics to help convey the strategy.

4. Final Stormwater Management Design and Construction Plans and Computations

This stage includes several items that should be identified in the Final Design Submittal Completeness Checklist (plan review application and fees, project narrative, stormwater management and erosion and sediment control construction drawings, hydrologic and hydraulic computations, draft stormwater management practice maintenance agreements, certification statement (Professional Engineer, or registered Landscape Architect or Land Surveyor as appropriate), etc.

This is likely an iterative process; however, with a pre-design consultation meeting and a concept plan review, two review cycles should be sufficient. The submittal completeness checklist should require a sufficient number of plans and computations to route a review plan set to the appropriate sister agencies (i.e. the transportation, water, and sewer departments) and all review letters should be consolidated into a single transmittal response.

5. Land Disturbing Permit and Transfer Project to Inspection and Maintenance Personnel

Issuance of a local land disturbing permit should be predicated on all local approvals having been obtained, including erosion and sediment control (if review and approval is independent of the stormwater design review). Also, final documentation or proof of other permits, (Army Corps of Engineers Section 404 and/or state stream and wetland permits, NPDES construction general permit, stream buffer variance (if applicable), etc.), should be provided.

In addition, any construction bonds or surety for erosion and sediment control, BMP construction, and any other improvements should be calculated based on the approved plans and posted.

Finally, stormwater BMP inspection and maintenance agreements, maintenance access easements, and conservation easements (if applicable), as reviewed and approved during the plan review process, must be signed and recorded.

The last step is to verify that all the appropriate information is transferred to the Inspection and Maintenance Teams:

- Project information: name of project, location, file or tracking number, file location
- Plan reviewer contact information
- Information from stormwater plan: number, type of practices (structural and nonstructural), and location
- Copy of any stormwater credits applied to site
- Copy of plat showing drainage and access easements and any deeds of easement
- Copy of recorded long-term inspection and maintenance agreement denoting responsible party
- Performance bond form and computation sheet
- Copy of other relevant permits (streams, wetlands, floodplains, and dam safety)

6. Pre-Construction Meeting

The pre-construction meeting ensures that each party (contractor, engineer, inspector, and plan reviewer) understands how the plan will be implemented on the site. A pre-construction meeting should occur before any clearing or grading is initiated. The local inspection team should meet with the 'site operator' and the designated 'certified personnel' to discuss the project and ensure that natural feature protection areas and limits of disturbance have been adequately staked and that sufficient erosion and sediment control measures are in place before any land disturbance occurs (other than that needed for implementation of erosion control measures).

The inspection team should also review the requirements for stormwater BMP construction and establish critical milestones that will require inspections. For example, infiltration BMPs must be protected from compaction and sedimentation during construction of other portions of the site. Additional information regarding inspections is provided in Section 5.1.5.

7. Construction Inspection and As-Built Record Drawings

Once construction begins, construction inspections should be performed periodically to confirm that required stormwater management plan elements are properly located and constructed. Once construction is complete, "as-built" documentation should be submitted so the county has a record of all stormwater BMPs on the site (construction inspection is discussed further in Section 5.1.5).

5.1.4 Multidisciplinary Approach to Stormwater Management

Stormwater management treatment objectives have evolved significantly from the early years of peak rate control for flood protection through the range of targeted design storms for natural channel protection, and into the recent years of targeted stormwater runoff pollutant removal. The current regulatory epoch is focused on all of these goals through runoff volume reduction as the surrogate treatment objective and replicating the pre-development hydrologic cycle on development sites as the performance goal. These strategies will require a multi-disciplined approach to site design starting at the earliest stages of the development process. For example, a landscape architect may be better able to assist with some better site design principles and vegetation-based BMPs, such as bioretention.

The various better site design strategies that can be considered self-crediting through the resulting reduction in impervious cover include:

- Cluster or compact development that leaves portions of the property undisturbed
- Local subdivision street acceptance (roadway design, pavement width, curb and gutter section versus open section, sidewalks, etc.)
- Reduced parking requirements
- Reduced building setbacks
- Impervious cover limitations

These impervious cover reduction strategies are typically contingent upon locally administered zoning, subdivision, and other land use ordinances (additional information on these can be found in Chapter 3).

Other site design strategies may serve as BMPs; however, multi-disciplinary design and plan review/approval steps may be warranted for the following:

- Vegetated buffers
- Natural area conservation
- Stream buffers
- Improved soils management

The first step in the review process is to determine if any additional documentation of agreements, special conditions, and other correspondence that originated from the earliest days of the project is required. For example, documentation of conservation easements to maintain land set aside from development in perpetuity should be documented and included for review as necessary. These early process stages are where site design elements are introduced as ways of ensuring compliance with local resource protection initiatives above and beyond stormwater management requirements.

5.1.5 Enforcement

An enforcement program consists of regular inspections during construction as well as periodic (ongoing) operation and maintenance inspections at regular intervals after construction. Ensuring that the post-construction stormwater practice is built correctly (in accordance with the approved plans) and that the contributing drainage area is stabilized is critical to the initial and long-term performance of the practice. This section focuses on construction inspections, and Section 5.2 addresses the periodic (ongoing) operation and maintenance inspection program.

Stormwater BMP construction inspections ensure that:

- The approved erosion and sediment control plan is implemented and effective;
- Structural and non-structural stormwater practices are built in accordance with the approved stormwater management plan;
- Better site design and LID strategies are properly implemented (e.g., areas of the site shown on the plan to be preserved are not disturbed during construction);
- As-built record drawings include inspection documentation of critical milestones of BMP construction; and
- Final permanent stabilization is achieved, such that the stormwater BMPs are functional prior to releasing bonds or terminating the permit (this final inspection should also verify the removal, as appropriate, of any remaining erosion control measures, that conservation areas and buffers have been protected and adequately marked or signed, etc.).

BMP construction inspection frequency may vary with regard to the particular type of BMP. Some BMPs, particularly those with underground elements, will require more frequent inspections, while surface BMPs will require fewer. It is also recommended that some inspections occur after larger storm events (e.g., ¼" or ½" and greater). The inspection process can prevent later problems that result in penalties and added costs to developers.

Local ordinances will dictate the frequency of local erosion and sediment control inspections, while the frequency of self-inspections conducted by the site operator's designated certified personnel is dictated by the construction permit. General guidance on erosion and sediment control inspections conducted by local program inspectors and required self-inspections conducted by the site operator's designated certified personnel can be found in the Manual for Erosion and Sediment Control in Georgia.

The complexity of BSD and LID strategies in terms of timing of construction makes for a very complex erosion and sediment control plan. Multiple site design strategies that must be installed after the contributing drainage areas are stabilized require careful phasing of site grading and stabilization efforts to control runoff on-site while transitioning to final conditions. An important goal of local program inspections and self-inspections is to ensure compliance with the sequence of construction. The sequence of construction is critical for ensuring that site conditions are adequate for the staged installation of multiple permanent Post-Construction BMPs. The erosion and sediment control plan should include specific requirements governing the construction of the stormwater BMPs (e.g., transitional drainage pattern and stabilization requirements) and conversion to the final layout once the practice has been completed.

BMP construction inspections should also be coordinated to the extent possible to allow inspection at the critical milestones of construction. These will vary by BMP, but generally include the following:

- Grading for post-construction BMPs
- Modifications to embankments, risers, and spillways
- Construction of forebays or pretreatment cells
- Placement of underdrain systems
- Testing and installation of soil or filtering media
- Planting, final grading, and final stabilization

Basic Stormwater Construction Inspection Checklists that can be customized to meet local requirements can be found in Appendix C.

The inspection team should review the proposed BMPs with the site operator and/or certified personnel at the pre-construction meeting and coordinate contact information and lead times to facilitate quick response when critical construction milestones are approaching. The inspection team should encourage contractors to take photographs before, during, and after construction to help document the process and provide evidence that BMPs have been properly constructed. The inspection process should also include:

- Clear communication of any corrective actions required to address deficiencies in BMP construction;
- The time allotted for the completion of the corrective action; and
- Follow-up inspection documenting that the action has been successfully completed.

The effectiveness of the construction inspection process will be an important factor in the long-term performance and community acceptance of better site design and low impact development strategies. Documentation of inspections and any corrective actions required should be maintained in the project file.

As-built plan submittals represent the final tool a local enforcement program has to ensure that all BMPs were constructed properly on a site. Upon completion of a project, and before a certificate of occupancy is granted, the applicant should be required to certify that the completed project is in accordance with the approved stormwater management plan. The plan should show the final design specifications for all stormwater management facilities and practices and be certified by a Professional Engineer.

When the bond is released, or a certificate of occupancy is granted, the updated owner's contact information should be required of the developer so that the long-term maintenance program can properly update their files. Without updated contact information it is extremely difficult for the local government to ensure the BMP is properly maintained.

5.2 Operation and Maintenance

Description: A comprehensive long-term BMP inspection and maintenance program is essential to ensuring that the water quality and peak flow reduction benefits achieved from BMP installation are maintained over time.

KEY CONSIDERATIONS

- A community needs to consider what level of involvement they plan to have in the maintenance of privately-constructed BMPs.
- The types of BMPs constructed in a community will greatly affect future maintenance needs.
- Maintenance needs can be reduced or simplified through thoughtful design of BMPs.
- The requirements and components of the inspection and maintenance program should be identified with clear legal authority in a local ordinance.



5.2.1 Introduction

One of the most important measures of a successful stormwater program is the total lifecycle cost effectiveness of the accepted stormwater practices. The question is not whether a local stormwater system maintenance program is necessary; rather, the question is how the community's maintenance program will be budgeted, staffed, and administered, and who has responsibility for scheduling and conducting inspections, carrying out routine maintenance, and funding corrective and/or non-routine maintenance. Local governments have been implementing stormwater programs for many years now, providing numerous examples of the benefits of addressing these long-term operations and maintenance questions proactively. Incorporating long-term maintenance provisions into each of three phases of local stormwater management program implementation will help to achieve the desired water quality benefits at the lowest life-cycle cost for property owners and local governments:

1. **Local ordinance and design guidance.** The local ordinance and accompanying stormwater Best Management Practice (BMP) design guidance should clearly emphasize the long-term inspection and maintenance features that ensure maximum performance and lifecycle cost effectiveness of the BMPs (i.e., addressing issues related to complex construction phasing, adequate erosion control while vegetation is established, and requiring maintenance related accommodations in the BMP design).
2. **Local construction inspection program.** Successful construction of what can be a complex design strategy depends on the ability of contractors to understand the design and to orchestrate BMP construction phasing and timing amid all the other moving parts of a construction site (i.e., small structural and non-structural BMPs being implemented only after the contributing drainage areas have been stabilized). The local construction inspector is therefore a critical part of ensuring long-term performance through compliance with the approved plans and properly performing BMPs.
3. **Local long-term inspection and maintenance program.** The long-term inspection and maintenance program ensures that the cost and effort to design and construct the stormwater strategy yields the intended long-term water quality benefits. The local program should utilize multiple avenues to engage property owners and encourage (and enforce when necessary) compliance with owner-inspection and routine maintenance requirements, while also performing the responsibilities reserved for the local program.

This section covers the local government long-term inspection and maintenance program, which is the third leg of a cost-effective local stormwater program.

Challenges and concerns related to the implementation of a stormwater system inspection and maintenance program have not changed. While stormwater management strategies and BMP designs have evolved to recognize the importance of LID and runoff reduction, communities must still make decisions concerning which parts of the stormwater management infrastructure should be the local government's responsibility and which parts, if any, can be successfully delegated to the private property owner. When these questions are not addressed and communicated to the community, maintenance is often neglected, and the drainage and stormwater system can gradually fall into disrepair until flooding or another form of system failure forces a reaction (that likely costs orders of magnitude higher than regular maintenance).

The challenges associated with the development and implementation of an effective maintenance program include (CWP 2006):

- Lack of definition of the 'stormwater system'
- Lack of an awareness of 'ownership' and accompanying maintenance responsibilities
- Lack of funding
- Inability to track responsible parties
- Lack of dedicated inspection staff
- Designs that are not conducive to easy maintenance

- Lack of compliance and enforcement authority
- Lack of simple tests to determine BMP effectiveness
- Varying set of regulations applied to the BMPs, based on the permitting date.

While any one or a combination of these challenges can quickly undermine the implementation of a maintenance program, the most important item is the initial definition, inventory, and map to serve as the foundation for development of a successful program. Knowledge of the existing system and the qualifying characteristics of the future system becomes the basis for identifying and assigning long-term roles and responsibilities for the maintenance program and level of service.

5.2.2 Low Impact Development Maintenance

As discussed in Chapter 1, there is a growing body of evidence that the traditional stormwater management strategies (i.e., peak flow attenuation) may not be as effective in protecting receiving stream channels and aquatic resources as was once believed. These traditional strategies combined with traditional urban drainage conveyance systems (curb and gutter, drainage inlets, pipes, etc.) do not address impacts associated with increased volume, duration, and frequency of peak discharges from urban areas or the loss of stream baseflow and groundwater recharge. Alternatively, LID that encourages infiltration and runoff volume reduction through distributed small-scale stormwater management practices is generally considered to be more protective of water quality and receiving stream health (NAS, 2008).

A challenge for local programs is identifying how to address long-term inspection and maintenance of this new type of infrastructure. This challenge is compounded by the application of these strategies for residential development. Traditional inspection and maintenance program requirements are too cumbersome for community-wide application of distributed small-scale practices. The reflex reaction to this potential expansion of the administrative burden of traditional BMP tracking and inspection protocols is to restrict LID as part of the compliance strategy, especially when proposed on residential developments with small-scale BMPs distributed throughout the development, including individual lots.

Low impact development will increase the number of BMPs above what would be expected from traditional strategies. The perception is that the increase in the number of practices will translate into a corresponding increase in the inspection and maintenance resources needed to administer the program, thereby creating a barrier to implementation of LID (Houle et al. 2013).

However, it is important to note that LID practices are small and generally less complex than traditional centralized (subdivision) scale BMPs and should therefore require less time to perform routine inspections (i.e., a lay-person's observations of general landscaping and standing water). Alternatively, a traditional centralized BMP may require qualified inspections of (1) the embankment for stability and seepage; (2) the riser/outlet for structural integrity; (3) the riser-barrel (principal spillway) connection for water tightness; (4) the outlet for signs of scour; and (5) the overall storage volume area for excessive sedimentation.

Likewise, routine maintenance of LID may be more frequent in order to support the often highly visible locations, but this maintenance is generally less complex, consisting of routine landscaping and trash removal activities versus the often reactive maintenance required of traditional centralized structures. This is often a hypothetical debate based on anecdotal experience with failed stormwater systems. However, LID and distributed small-scale stormwater strategies are shown to be cost-effective: a recent study (Houle et al. 2013) compared the maintenance burden as measured by cost and personnel hours of LID and traditional practices and determined that:

1. LID practices have lower annualized maintenance costs based on acres treated (see Figure 5.2-1); and
2. LID practices have lower marginal maintenance costs in terms of mass pollutant load reductions: ranging from $4–$8/kg/year TSS removed for porous asphalt, a vegetated swale, bioretention, and a subsurface gravel wetland, to $11–$21/kg/year TSS removed for a wet pond, a dry pond, and a sand filter system.

LID practices not only represent a viable treatment strategy for compliance on new development projects, but also can be very practical for stormwater retrofitting of large residential areas for total maximum daily load (TMDL) compliance. As local program plan reviewers and construction inspection personnel gain experience with these strategies, there will be lessons learned and improved efficiencies in the administration and implementation of inspection and enforcement programs on residential lots.

In general, the challenges, complexities, and administrative burden of an inspection and maintenance program geared toward small-scale distributed BMPs are related to data management, which can be addressed through improved information technology and assertive community outreach programs.

5.2.3 Components of an Inspection and Maintenance Program

The stormwater drainage infrastructure of many urban areas consists of varying sizes of concrete pipes, channels, and other features that were designed to effectively convey the peak runoff away from built infrastructure – roads, sidewalks, parking lots, and commercial and residential structures. These systems have been and continue to be designed, to the extent practical, to be durable and relatively easy to maintain; minimum hydraulic design criteria ensure that the flow velocity keep the system clear of debris and the system, in general, has a long design life.

In more recent years, stormwater management systems have been designed to perform in an almost opposite manner: detaining peak flows in order to protect downstream receiving stream channels from damage associated with increases in peak discharge from new impervious cover. These flow attenuation facilities include large storage volumes and flow control structures that are designed to require minimal maintenance (flow controls with trash racks that shed debris, outlet channel armoring to minimize scour, etc.). Periodic vegetation management has become an accepted element of maintenance. Removal of sediment, structural repairs to the flow control structure, and/or geotechnical investigations of the embankment occur so infrequently that owners often have no first-hand experience with the responsibilities associated with ownership of these facilities.

Most recently, design treatment objectives and performance goals have evolved further to include varying scales of LID. This 'watershed' change in the stormwater management paradigm adds a new and beneficial level of stormwater infrastructure performance. However, the added water quality benefits come with a tradeoff. With smaller, more distributed BMPs, there will now be considerably more stormwater infrastructure subject to the inspection and maintenance program.

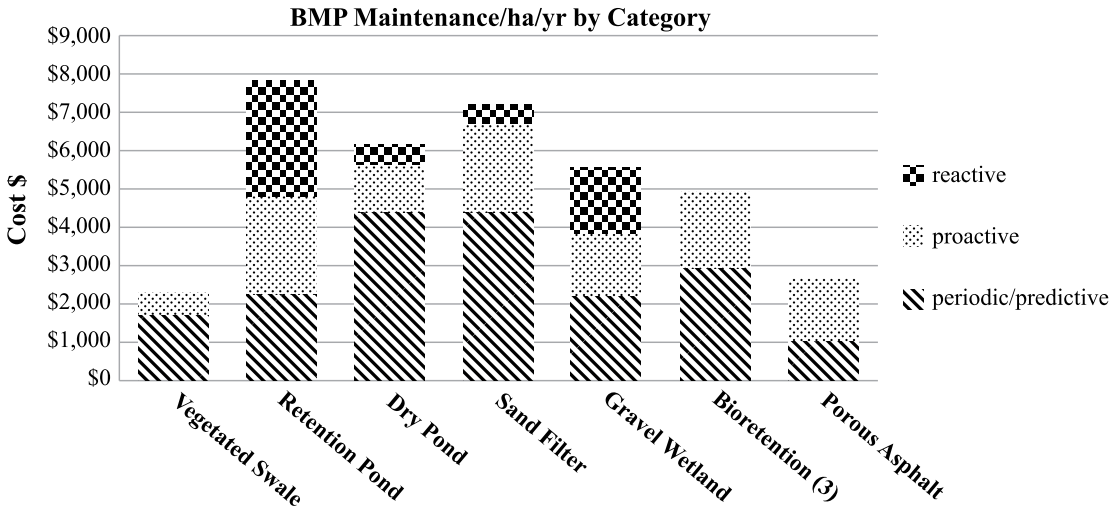


Figure 5.2-1 Annualized maintenance costs per BMP type per hectare of impervious cover (Houle et al, 2013).
Note: 1 hectare = 2.47 acres

5.2.3.1 STORMWATER SYSTEM LEVEL OF SERVICE

The extent of local program responsibility for the condition and performance of the stormwater system is generally referred to as Level of Service (LOS). A maintenance LOS is defined by the types of services the local program will provide to different parts of the drainage system. For example, within the right-of-way and in critical areas highly susceptible to flood damages, the maintenance LOS might include periodic inspection, priority cleaning, and the highest level of emergency response. This LOS may translate to providing a similar degree of service to the upstream stormwater management retention and detention structures. In similar right-of-way areas not susceptible to flooding, the level of service for maintenance might be much lower, with a corresponding lower degree of inspection responsibilities for the upstream retention and detention structures.

The LOS concept translates readily to drainage conveyance infrastructure. This concept is more complicated when the stormwater infrastructure includes on-site dual purpose BMPs for stormwater quality and flow attenuation. Responsibility for on-site stormwater management systems is typically assigned to the property owner through use of recorded maintenance agreements or another mechanism. The conveyance of that stormwater off-site, onto the neighboring property and beyond, either in a pipe or surface conveyance, is typically part of the public drainage conveyance infrastructure within an easement or public right-of-way. As should be expected, if a local program adopts a low LOS with minimal responsibilities it should anticipate increasing complaints and possibly a growing backlog of unmet maintenance needs associated with these upstream practices.

The development of MS4 permits, TMDL requirements, and other water quality focused regulatory permit programs has created a basis for local programs to consider a water quality LOS. The extent to which a local program will conduct periodic inspections to ensure that BMPs are properly maintained by the of owners of the on-site stormwater BMPs is now a programmatic requirement that is initiated at the outset of the land development process. The extent to which the local program decides to maintain neglected BMPs documented in an inspection becomes a policy decision related to the selected LOS. The decision is driven by (1) public safety and welfare and, in some cases, (2) regulatory permit compliance. In other words, the locality may be in violation of their program responsibility to ensure that water quality standards are met when these facilities are not maintained and decide to raise their selected LOS to more aggressively ensure maintenance is being performed (see Section 5.2.4: Maintenance Program Responsibility).

5.2.3.2 INSPECTIONS

Inspections can be categorized as regular or routine inspections, and periodic (oversight) inspections.

Routine Inspections

Routine inspections are usually performed by the BMP owner and conducted on a regular schedule based on the specific BMP type and level of activity or traffic in the contributing drainage area (high traffic sites may require more frequent inspections). The following are some general guidelines for routine inspections:

- The proposed schedule of routine inspections can be modified as experience identifies site-specific conditions and pollutant loading.
- Routine inspections can also include 'drive-by' inspections after measureable rainfall events. A programmatic decision may identify target rainfall depths as BMP-specific triggers for inspections (i.e., large storms for flow attenuation structures).
- Credentials of inspectors conducting routine inspections may vary by BMP type.
  - » Large impoundment structures with embankments, hydraulic control structures, principal and emergency spillways, etc. should be conducted by a qualified licensed engineer (or another comparably qualified individual).
  - » Underground vaults, filters, etc., should be inspected by a qualified licensed engineer (or another comparably qualified individual). These systems may require special equipment or confined space certification.

» *Homeowner BMPs* (located on individual residential lots) are generally simple with the primary pollutant removal pathways consisting of filtering through vegetation, soil media infiltration/extended filtration, and/or shallow surface volume, with few structural components. These systems can be periodically inspected and documented by property owners.

Periodic (Oversight) Inspections

Periodic (oversight) inspections are conducted by the designated local program personnel or a hired contractor and are intended to verify that the routine maintenance is being performed as stated in the Maintenance Agreement and, where applicable, to verify that routine inspections are being conducted and recorded. These periodic inspections are generally conducted on a schedule as part of the local stormwater program and stormwater permit compliance review, and should include inspection forms and photographs.

5.2.3.3 MAINTENANCE

Maintenance activities can be divided into two types: scheduled (routine) maintenance and corrective maintenance.

Scheduled (Routine) Maintenance

Scheduled (routine) maintenance tasks are those that are typically accomplished on a regular basis by the owner or owner's representative and can generally be scheduled without referencing inspection reports or requiring special equipment (depending on the stormwater practice). The minimal maintenance items should be listed in the design specifications and recorded maintenance agreement, and will usually include frequently scheduled maintenance items. such as trash removal, or grass mowing in the summer months, as well as less frequent items, such as removal of woody vegetation from embankments and removal of sediment from forebays.

Corrective Maintenance

Routine inspections or the process of performing routine maintenance will periodically reveal the need for more extensive maintenance efforts, such as removal of more sediment than is typically done with hand tools or a significant corrective action (i.e. structural repair of an inflow pipe end section or riser structure). This is generally how the inspection and routine maintenance process should work; however, this also makes it difficult to plan or budget for these activities. Reviewing the routine inspection and maintenance documentation along with accompanying photographs should provide a general sense of the likely corrective maintenance needs.

Also, similar to the scheduled maintenance, there are regular long-term maintenance needs associated with some BMPs that have a predicted schedule, albeit with a very broad range (i.e. wet pond major sediment dredging/removal schedule of 10 to 20 years). This range is very dependent on conditions in the contributing drainage area; instances of ongoing construction activity or large pervious areas may shorten this range significantly. Likewise, high density commercial or residential areas may generate very little sediment, with the likely alternative of requiring more frequent trash removal.

5.2.4 Maintenance Program Responsibility

There are many possible approaches to assigning responsibilities for stormwater maintenance. Three basic approaches are presented here:

- Limited Local Responsibility;
- Expanded Local Responsibility; and
- Comprehensive Local Responsibility.

It should be noted that aside from Homeowner BMPs the local program authority should utilize right-of-entry easements and the recorded maintenance agreements to reserve the right to enter a property to perform corrective or routine maintenance after proper notification of the owner, where it is determined that public safety and welfare may be at risk. The formula for evaluating the LOS for a maintenance program will be different for each locality; however, the decision to quickly perform maintenance will often result in beneficial public relations. Examples include instances of embankments in disrepair that could result in adjacent property damage and 'dry' BMPs that are holding water, causing vector-borne disease concerns. The local program can file a lien or utilize other mechanisms to recover costs.

Having this ultimate responsibility for the safety and welfare of the public may be a challenge for local program decision-makers considering the application and maintenance of various BMPs. For example:

A residential subdivision with a homeowner's association owns a stormwater pond located out of sight and out of mind of the residents, who have little understanding of the purpose of the pond and how it operates and even less funding available to repair and maintain it. Based on the potential impact to the public, should the local program:

1. **Pursue enforcement and require the homeowner's association to perform required maintenance?** This action will likely result in years of inactivity since there is no simple means to compel a homeowner's association to take action. Meanwhile the safety issue remains in place.

OR

2. **Perform the maintenance overhaul and then file a lien against the individual properties to recover costs?** Filing a lien will require liens on each residence and will only be collected upon the sale of the individual property (there may be other legal avenues to collect the money, however, there are no simple processes when it comes to recovering expenses). The local program has expended the funds to perform maintenance, and will possibly spend much more in legal costs trying to collect.

OR

3. **Take over future maintenance responsibilities of the basin and perform the complete overhaul?** This is the same as option 2 without the recovery of costs, and with the addition of future maintenance. Localities that have pursued this third option generally do so in recognition of the savings associated with repairing or bringing a BMP up to current standards, and conducting 'preventive' scheduled inspections and routine maintenance in the future.

This is clearly a difficult question to answer, with no perfect solution. The best approach is to avoid the situation in the first place where possible, by clearly defining maintenance responsibilities (see Section 5.2.4.1), making a concerted effort to communicate maintenance responsibilities to the public (see Section 5.2.4.2), and encouraging BMP designs that reduce the maintenance burden overall (see Section 5.2.6).

5.2.4.1 ASSIGNING INSPECTION AND MAINTENANCE RESPONSIBILITY

The following provides a brief explanation of three basic approaches for assigning local program responsibility (numerous other combinations or hybrid approaches are possible):

Limited Local Responsibility

Limited local responsibility is exactly what it sounds like: the local program is only responsible for the BMPs and stormwater system infrastructure that they own; that is, systems within the public right-of-way or on publicly owned land (schools, local parks, etc.). Adopting this approach means the local program would have no involvement with any stormwater systems on private property, except for possible regulatory enforcement action or in response to a threat to public safety, as noted above. However, in order to minimize the occurrence of enforcement actions, the local program will have to exert the initial effort to educate homeowners on the presence and purpose of their BMPs, and engage them in a discussion of possible homeowner association funding mechanisms to address current and/or future maintenance.

Expanded Local Responsibility

Expanded local responsibility means that in addition to maintaining and operating publicly owned stormwater systems, the local program has determined that it should maintain and operate some of the private portions of the system. This approach could be chosen in an attempt to prevent the problems of neglected BMPs that will likely become the local program's responsibility anyway.

The challenge with this approach is the establishment of a very objective process for taking over private BMPs. Taking over the greatest health and safety risks in some ways creates an incentive for owners to neglect their BMP, due to the expectation that the local program will take over. One option considered by several jurisdictions is local program acceptance of the routine inspection and periodic corrective maintenance responsibilities on all single-family residential development BMPs (no commercial or industrial BMPs, LID or otherwise), while designating all the routine maintenance (grass cutting or other routine activities as designated by the maintenance plan) to the owner. This includes only structural 'centralized' BMPs on out parcels or within easements (no Homeowner BMPs). This approach is in response to the challenges that typical HOAs face in generating sufficient funding to contract qualified resources for inspections or corrective maintenance. It is anticipated that the application of local program expertise in conducting periodic inspections will help keep the long-term costs of periodic corrective maintenance to a minimum by addressing issues before they require costly structural repairs.

Comprehensive Local Responsibility

A comprehensive local responsibility approach would fold the inspection and maintenance responsibilities for all stormwater systems within its jurisdictional boundaries into the local program. This approach has been gaining some supporters in watersheds with TMDLs, potentially providing the local program with a long list of potential retrofit opportunities. The primary obstacle to this approach is funding. However, the implementation of a stormwater utility becomes an easier sell to the community because there is no question as to the utility services that will be provided.

It is important to note that the Comprehensive and Expanded Local Responsibility options should exclude the Homeowner BMP category, and should only include those BMPs that manage runoff from multiple lots or the public right-of-way, which are located on out parcels and/or within easements. Also, to the extent practicable, routine maintenance responsibilities, such as grass cutting and periodic debris removal, should remain with the owners.

5.2.4.2 COMMUNICATING PROGRAM RESPONSIBILITIES TO THE PUBLIC

Once decisions have been made as to the assignment of maintenance responsibilities, the local program should utilize available resources to communicate these decisions to the public. In the modern world of communication there should never be a case where the owners of a stormwater BMP are unaware of their ownership and assigned responsibility. The documentation associated with purchasing a home, including the required HOA agreements and restrictive covenants for new developments, combined with the ongoing expansion of social media and other forms of public education and outreach offer numerous opportunities to reach and educate the public.

There have been several case studies on effective messaging and formatting of public education and outreach in response to MS4 permit programs. The goal of the local program should be to ensure that the community understands the roles, responsibilities, and long-term benefits of the selected maintenance program. The following are some basic considerations in communicating various responsibilities to the public:

- Communicate policy decisions along with the program goals and community characteristics upon which they are based in explicit language;
- Cover all aspects of the program; don't assume that all parties will recognize implied responsibilities;
- Utilize easement agreements, maintenance agreements, and similar documentation to clearly outline rights and responsibilities where applicable; don't assume that public outreach can replace the need for enforceable agreements;
- Develop a maintenance guidebook and other technical documentation to allow the development and design community to provide consistent messaging; and
- Incorporate appropriate messaging and communication skills into staff training to help them more effectively communicate responsibilities to the public during routine and periodic inspections.

5.2.4.3 INSPECTION AND MAINTENANCE STAFF RESOURCES

Local programs should evaluate the scale of the stormwater system, level of service, and designated local program responsibility (limited vs. comprehensive) to estimate the resources needed to fulfill the basic responsibilities:

- Periodic inspection of post construction BMPs (based on the required or desired inspection frequency);
- Routine inspections of publicly owned stormwater facilities;
- Routine maintenance of publicly owned stormwater facilities; and
- Periodic corrective maintenance of publicly owned facilities.

Evaluating the capacity of in-house staff to conduct BMP inspections and maintenance, or decisions on expanding the role of other department personnel responsible for operating and managing utilities, buildings, and roads, along with the option of using private contractors, represents a complex process beyond the scope of this manual. However, there will be cases where the amount of development, scale of the jurisdiction and local staff, or other limiting factors will make the decision relatively straightforward (with the option of changing that decision as circumstances or experience in implementing the program change). The use of qualified private contractors may be more efficient than hiring new staff and purchasing equipment while trying to establish a stormwater program. Similarly, localities may elect to enter into an agreement with the water and sewer utility, a neighboring jurisdiction, or transportation agency to share maintenance responsibilities and maximize economies of scale in the use of equipment and personnel.

5.2.5 Legal Authority

Adoption of an MS4 permit has increased the role of the stormwater management program into functions that may be spread across many local government divisions, programs, and local ordinances. Requirements for the inspection and maintenance program should be identified with clear legal authority. The following offers some suggestions for utilizing local ordinances and legal agreements to minimize legal and other challenges to the local program.

5.2.5.1 LOCAL ORDINANCE PROVISIONS

All requirements for the inspection and maintenance program should be included in a local ordinance or, where applicable, in a separate formal policy document. Having these provisions formally documented will simplify the process of communicating with the development community and the public in general. Further, the process of incorporating these provisions into an ordinance ensures that the governing political body is fully aware of the requirements and can help support the program staff when questions or complaints are elevated to that level.

The following represent items that should be adopted by ordinance:

- Purpose and Intent: The local ordinance will likely include language that, among other things, it is intended to 'protect, maintain, and enhance the public health, safety, and general welfare'. This section should include a clear statement regarding the establishment and ongoing implementation of long-term inspection and maintenance program roles and responsibilities.
- **Applicability:** Establish a hierarchy if any language in the ordinance is deemed to be in conflict with other local provisions. This is especially useful when complex zoning, subdivision, and other development standards are in place and conflicts may not be apparent during the development of the stormwater inspection and maintenance program.
- **Stormwater Program Department Responsibilities:** As noted above, the role of the local stormwater program has grown. The specific roles and responsibilities of the local inspection and maintenance program should be itemized in very clear terms with further narrative or criteria included in the appropriate sections.
- **Definitions:** Include the various stormwater system component definitions that may be referenced in the inspection and maintenance program section or policy document.

- **Variances:** It is hard to determine all of the potential situations or site conditions that may arise related to land development. Requests for variances to stormwater technical criteria are very common. Once the inspection and maintenance program has been defined and there is even the slightest possibility of conditions that may justify a variance of any kind to that program (which is impossible to rule out), this section should include a process by which requests should be made, who is responsible for reviewing and decision-making, and, if possible, the parameters that will be used in making those decisions.

- **Technical Criteria and Design Standards:** Include any additional design standards that may be applicable to facilitating long-term inspection and maintenance. As it is more likely that the ordinance will only reference the technical criteria (design storms, calculations, etc.), rather than the full design standards for the BMPs, be sure that the desired maintenance provisions are considered a requirement and not simply a 'good idea'.

- **Plan Submittal Requirements, Review, and Approval Procedures:** Include requirements for access easements, maintenance agreements and plans, etc., tailored for specific BMPs. These provisions should be reviewed during the plan review process for accuracy, and recorded prior to either plan approval or other milestones in the project construction prior to permit termination and/or project occupancy.

- **Inspections:** What is the role of the inspector and what does the inspector's authority include? An inspection section should address erosion and sediment control, BMP construction, and post-construction inspections separately, delineating the authority of the inspector in terms of right of access for purposes of inspection, sampling of stormwater, etc.

- **Enforcement:** Identify levels of enforcement for the violation of an inspection and maintenance agreement, including the administrative steps for communicating the initiation and prosecution of enforcement actions, such as notice of violation, establishment of a time frame and designation of remedial actions necessary, and the level of penalties, including civil and criminal penalties. Additional language should address the local program's rights to address immediate danger to the public health, safety, or general welfare because of unsafe conditions or improper maintenance, including explicit language for the recovery of costs.

- **As-built Plans (Record Drawings):** Establish minimum requirements of as-built drawings compiled by a licensed professional engineer to document that the BMP was built in accordance with the approved plans. This represents a difficult task for a Professional Engineer that was not present during the construction of the BMP. Inspection checklists applicable to the specific BMP being built should include 'milestone' inspections when the licensed Professional Engineer should document compliance with subsurface construction elements, such as underdrains, compaction (or scarifying) of sub soils, riser barrel connections, etc. This individual will then be able to complete the as-built survey of required surface features and certify compliance with the plans.

- **Inspection and Maintenance Responsibilities:** Explicit inspection and maintenance roles and responsibilities of the owner and local program personnel should be itemized, along with any provisions related to development type (commercial, industrial, residential, etc.). This includes any specific qualifications of inspectors, documentation format (checklist) requirements, record keeping, and reporting. This section should reference the enforcement section and any other applicable 'failure to maintain' provisions.

5.2.5.2 INSPECTION AND MAINTENANCE AGREEMENTS

Whenever stormwater BMPs are identified on a stormwater plan and utilized for compliance with ordinance requirements, regardless of being structural or non-structural, the inspection and maintenance requirements must be explicitly stated, implemented, and when necessary, enforced. For example, a permit or maintenance agreement could specify that the local government accepts responsibility for inspecting and maintaining the stormwater system's structural components, including the periodic removal of debris and accumulated sediments. However, vegetative and aesthetic maintenance would still be performed (or contracted) by the owner. Some key aspects of these permits or maintenance agreements is the clear delineation of responsibilities, such as:

- As-Built documents, including designed property access to the BMP for inspections and maintenance;
- Identification of who will perform routine inspection duties and how often;
- Listed routine maintenance duties that are to be performed by the owner, such as mowing, debris removal, and replanting of vegetation;
- Defined roles for the local government, possibly including routine inspections and/or corrective maintenance or modifications to the system;
- Identification of enforcement provisions in the local ordinance and a statement of recourse for failure to perform the agreed upon responsibilities; and
- Requirements for documentation and/or reporting frequency (i.e., annually), along with an attached inspection form (a standardized format will help in utilizing a database system for tracking records).

An inspection and maintenance agreement should be developed specifically for each BMP. This is important for educating the property owner, but also for eliminating the question of enforceability when inspections and/or routine maintenance are not being performed. Consider some of the typical routine inspection elements for a stormwater detention basin, which should be performed by a qualified individual (i.e., licensed Professional Engineer with appropriate certifications):

- Inspection of the embankment for stability and seepage
- Inspection of the riser for structural integrity
- Inspection of the riser-barrel (principal spillway) connection for water tightness
- Inspection of the emergency spillway for signs of scour
- Inspection of the basin volume for excessive volume loss due to sedimentation

In contrast, consider the inspection of an LID or Homeowner BMP:

- Inspection of raingarden (drains properly within 24 hours of rainfall)
- Inspection of raingarden storage volume (standard dimensions)
- Inspection of positive drainage from raingarden away from the house foundation
- Inspection of plants (health, control of invasive species, removal of weeds)

An example Maintenance Agreement is provided in Appendix D.

5.2.6 Inspection and Maintenance by Design

Maintenance must be considered throughout each component of the entire stormwater program. The long-term inspection and maintenance components can represent the largest investment of program resources, thereby making it critical to look for opportunities to incorporate policies and procedures that lead to a cost-effective program. As noted previously, this includes inserting maintenance related design and construction elements into the local ordinance, BMP design standards, and policies, and ensuring that these provisions are upheld during construction.

The following are tips on how to tailor design and construction procedures to minimize long-term maintenance needs. It should be noted that most of this guidance refers to centralized or subdivision scale BMPs, and that Homeowner BMPs should be considered separately.

- **BMP Selection:** The selection of BMPs is often driven by the performance credit or compliance value; that is: what is required in order to achieve compliance with the local program performance goals. This may include treatment trains of multiple BMPs where the order of BMPs in the treatment train can influence the overall compliance and construction costs. Unfortunately, the designer and/or developer of the project may not be responsible for long-term maintenance and is therefore considering the construction costs over the long-term costs. One example is the use of an underground treatment system such as a sand filter or proprietary device. This may be appropriate in a commercial setting where space is limited and the owner can establish a maintenance contract with a qualified contractor; however, these systems represent a significant maintenance burden in a residential setting where any one of several surface BMPs would be more cost-effective for the eventual owner(s) of the practice(s).

Guidance on long-term maintenance often categorizes BMPs by a relative maintenance burden of High, Medium, or Low. This is helpful as a quick reference, but the local program should establish additional guidance and conditions for BMP approval based on the type of development and BMPs that require simpler and/or less costly maintenance. Emphasizing nonstructural BMPs, such as conservation of natural areas, restoration of riparian areas, and disconnection of impervious surfaces, can help reduce the maintenance burden for residential property owners (whether these are Homeowner BMPs or community scale BMPs). Further, designing both structural and non-structural BMPs as components of greenways, walking trails, recreation areas, parks, streetscapes, and courtyards gives them more visibility and, therefore, a higher likelihood of receiving maintenance.

- **BMP Specific Maintenance Plans and Maintenance Agreements:** Maintenance plans and maintenance agreements should be included with the construction drawings and reviewed prior to plan approval to ensure that they reflect the specific BMPs, their locations, and anticipated ownership of the BMPs. The maintenance plan should identify responsible parties, and both the plan and the maintenance agreement should include a list and schedule for routine and periodic structural maintenance. Also, the maintenance plan and agreement should outline the legal mechanisms in place that guide or govern long-term maintenance responsibilities (i.e., access easements, subdivision restrictive covenants, and/or deed restrictions). Maintenance Checklists can assist with typical maintenance tasks for specific types of BMPs.

- **Runoff Pretreatment:** The local program BMP design specifications, plan review, and construction inspection should require and emphasize the need for runoff pretreatment upstream of all inflow points into the BMP. Proper pretreatment preserves the primary BMP pollutant removal pathway over time by sequestering larger sediment particles, trash, and organic debris. Pretreatment practices include forebays, vegetated filter strips, stone filter strips (for higher velocities), and grass channels. These practices should be located such that they are easy to access for routine inspections and maintenance.

Multiple pretreatment practices may be appropriate for high traffic development sites utilizing infiltration or filtration BMPs. Refer to the individual BMP design specifications in Volume 2, Chapter 4 for the appropriate types and sizing rules of pretreatment practices.

- **Permanent Maintenance Access:** Providing permanent maintenance access includes both the access easement and the means by which maintenance equipment can access the BMP. Providing an easement over slopes too steep to navigate, or to a limited area of the BMP, will discourage if not prevent proper maintenance.

Ponds and wetlands should have access routes, with adequate width (12-foot minimum is common) and appropriate slopes (no steeper than 15% is recommended) to allow maintenance vehicles to enter and turn around, and be extended as needed to allow access to inflow locations (refer to pretreatment), outlet structures, and any other structures, such as diversion manholes or bypass structures. These roads can be constructed of reinforced turf or other pervious material so as to avoid further stormwater impacts.

- **Innovative Control Structures:** The design specifications for all BMPs should include appropriate guidance on how to achieve the intended runoff treatment for the scale of the BMP. The design of dewatering structures has evolved from establishing a minimum size of the control orifices to discourage clogging to more creative approaches. For example, the developed landscape includes numerous examples of stormwater extended detention basins and wet ponds that include a minimum 3-inch diameter orifice, since that was considered necessary to pass the expected trash and debris to avoid clogging (often referred to as the 'Budweiser' rule), even if it meant the rate of discharge exceeded the minimum allowed rate. So while maintenance was definitely being considered in the design, the goal of avoiding a maintenance burden trumped the desired water quality benefits.

The alternative has been to develop innovative strategies that create sufficient capacity to avoid clogging while also restricting discharge. A common example is the perforated pipe buried in gravel, set at the design outlet invert elevation, with a control orifice or weir in the control structure. The perforations combine to create a large flow area that will continue to allow discharge even as sediment begins to reduce the porosity of the gravel. This allows for a much longer maintenance cycle than simply placing a small orifice at the outlet invert of the control structure. The tradeoff is that the gravel diaphragm must be periodically maintained, requiring appropriate resources and equipment. Another example is the micro-pool outlet with an inverted (reverse slope) outlet pipe. The lower elevation of the pipe is set above the micro-pool bottom to allow for the accumulation of sediment that will likely migrate towards the outlet.

Design specifications for each BMP should provide appropriate examples of outlet structure configurations. Designers are encouraged to be creative in solving this inherent design challenge: restrict the design discharge so as to promote water quality without clogging the outlet and creating unsafe (overtopping) conditions during storm events, or nuisance conditions (standing water) after storm events, while also preserving the desired maintenance cycle.

- **Maintenance By-Pass:** If, based on the scale of the BMP, it is expected that a maintenance activity will take several days or longer, the design should include provisions for routing a targeted design peak discharge around the BMP. This can include a pump well or other structure near the inflow points. This is a very site- and BMP-specific feature, which should be considered for large detention basins and ponds.

- **Stable Conveyance Systems:** After the contributing drainage area to a BMP has been adequately stabilized (usually after one or two growing cycles), the sediment loading to the BMP should be relatively low. Since sediment is the primary cause of clogging and maintenance, this should mean that the heavy maintenance burden gradually decreases over time, leaving the more readily performed (and lower cost) vegetation management as the primary activity. Unfortunately, in cases where there is a network of open channel conveyances serving the contributing drainage area, this load can increase dramatically if the conveyances begin to erode.

Open channels, especially grass channels, can be an effective part of a treatment train, even if only for pre-treatment. Therefore, in addition to including inspection of the contributing drainage area and conveyance systems for bare spots and/or erosion, the design specifications for the conveyances should include provisions for minimizing flow velocities. Where applicable, this can also include check dams and/or forebays for sequestering sediment in an easy to access location (similar to the inflow forebay).

- **Sediment Markers and Benchmarks:** Benchmarks or graded markers can be established for tracking and monitoring BMPs. For example, graded markers can be placed in forebays, or permanent pools of ponds and wetlands, to consistently measure the depth of sediment during inspections. Sediment clean-out markers should always be used in underground vaults and in the sediment chambers of sand filters.

- **Plan for Sediment Disposal:** Removing sediment and debris is a common maintenance item for many types of BMPs. Minor debris removal is relatively simple, but removing large quantities of sediment can be an involved and costly undertaking. Design features should enhance access, as described above, and include features that simplify removal efforts. For example, a pond drain is an important design feature that allows maintenance crews to drain ponds or wetlands before removing accumulated sediment.

Sediment removal costs can be site-specific and dependent on disposal plans since it can be expensive to dispose of saturated sediment. This is not due to issues of toxicity, but rather the challenge of how and where to dispose of the material. The 'how' requires water-tight dump trucks to prevent the discharge of liquid in transit. The 'where' is related to the reluctance of landfills to accept wet material that can add to leachate concerns and the reluctance of waste water treatment plants to accept solid materials that burdens the treatment process.

A possible solution is to establish a dewatering area in the vicinity of the BMP. This includes appropriate grades so the sediment doesn't migrate back into the BMP, as well as stabilization guidance for re-stabilizing the area after the dried material is hauled to the landfill or other approved location. This strategy relies on having available space. Where this is not realistic, the maintenance plan should acknowledge the likely expense of dredging and sediment disposal.

5.3 Geographic Information Systems (GIS)

Description: A Geographic Information System (GIS) is a computer-based database system that allows a user to visualize, query, analyze, and interpret geographical data. GIS can be an important tool for a stormwater management program, assisting with tracking BMP locations and drainage area characteristics, organizing stormwater infrastructure data, and many other tasks.

KEY CONSIDERATIONS

The main functions of GIS typically include:

- Data Input
- Data Conversion
- Query and Analysis
- Data Display
- Output
- Visualization

Example uses for GIS include:

- Mapping surface features such as land uses, soils, watershed boundaries, etc.
- Managing stormwater assets and information
- Automating tasks such as measuring areas of watersheds, plotting floodplain boundaries, etc.
- Evaluating water quality impacts
- Forecasting future land use or land cover conditions.



5.3.1 Introduction

A Geographic Information System (GIS) is a computer-based database system that allows a user to visualize, query, analyze, and interpret data to understand relationships, patterns, and trends. The system is designed to utilize spatial or geographical data as a collection of thematic layers or databases that can be linked together by geo-referencing a series of coordinates. GIS uses location as the key index variable to manipulate data and combine datasets to produce a wide variety of individual maps that effectively convey relationships between geographic elements and events related to stormwater management, such as topography, rainfall, and hydrography. GIS has proven invaluable for solving many real-world stormwater problems, from tracking complaints to master planning applications and infrastructure management. GIS is also a fundamental tool of asset management systems, and is used extensively by MS4s to schedule and track inspection and maintenance of the MS4's structural controls.

A GIS-based data inventory not only helps monitor existing stormwater management practices but also guides planning officials in analyzing vulnerable areas, retrofitting existing facilities, and identifying potential locations for implementing new stormwater best management practices (BMPs). Some sample base data that is helpful for assessing stormwater management potential is listed in Table 5-1.

Table 5-1 Sample Data Layers for Stormwater Management Assessment

- Surface Parking Lots
- Sidewalks
- Road Widths
- Building Footprints
- Impervious Surfaces
- Trees and Tree Canopy
- Curve Numbers
- Watershed Boundaries
- Streams
- Stream Banks
- Floodplains
- Stormwater Network, including ditches, catchbasins, ponds, stormwater lines, etc.
- Water Distribution Networks
- Wetlands
- Existing Best Management Practices (BMPs)
- High Water Marks
- Riparian Buffer Status
- Orthophoto
- Contours
- Land Uses
- Soils

Table 5-2 Advantages of Using an Integrated GIS/Database Management System (DBMS) to Track Stormwater Assets

Can track inventory and lifetime history of stormwater assets, including the history of inventory, preventative maintenance, and condition assessments
Visualize stormwater infrastructure assets
Collect service requests with web-based citizen access, easily create work orders to address issues in a timely manner, and track the lifecycle and costs of each request
Create schedules configured against a single stormwater inlet or your entire system, and manage stormwater preventative maintenance schedules from your mobile device
Store video and inspection comments for stormwater infrastructure and other assets to review deterioration and determine requirements for repair and replacement
Monitor real-time statistics and extract work order, assets, and other stormwater system data into a spreadsheet for use in compatible third-party applications, presentations, or reports

5.3.2 GIS Components

A functional GIS integrates four key components:

- Hardware: Desktop or laptop computers and digitizing equipment are the primary hardware components of a typical local GIS system.
- Software: GIS software provides the functionality and tools needed to input, store, analyze, display, and output geographic information.
- Data: Generally the most costly part of a GIS is data development. Some geographic data and related tabular data can be collected in-house or purchased from commercial data providers. Many government agencies, including metropolitan planning organizations (MPOs), federal administrations, and city and county departments, maintain GIS datasets for their jurisdictions, which are typically available for public use. GIS software can integrate tabular data, image (raster) files, and electronic drafting (CAD) data to build information into the GIS database.
- Users: GIS technology is of limited value without trained operators who understand the data, system, organization, and how to apply resources to achieve the desired results.

5.3.3 GIS Functions

General purpose geographic information systems essentially perform six processes or tasks:

Data Input

Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology can sometimes automate this process fully for projects using scanning technology, though some jobs may require manual digitizing using a digitizing table. Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from a number of different sources including the Georgia GIS Data Clearinghouse at https://data.georgiaspatial.org/login.asp.

Data Conversion

It is likely that some needed data may not be in the correct format or proper map projection to use with your system. Most GIS software has the ability to do this conversion, but in some cases this is better done by a contractor who specializes in data conversion. Be careful with third party data; it is imperative that you understand the source, quality, age, accuracy, and limitations of all datasets. This and other information about a dataset are often provided in Federal Geographic Data Committee (FGDC) metadata that accompanies the dataset.

Query and Analysis

Once there is a functioning GIS containing geographic information, it can be used to answer questions such as:

- Who owns the land parcel being flooded?
- What is the distance between two stream locations?
- Which homes are located in the updated floodplain?
- How will the new development impact downstream properties?
- What types of infrastructure give us the most complaints and where are they located?

GIS provides both simple point-and-click query capabilities and sophisticated spatial analysis tools to provide timely information to stormwater managers and analysts. GIS technology can also be used to analyze geographic data to look for patterns and trends and undertake "what if" scenarios. Most modern geographic information systems have many powerful analytical tools including:

- Size Analysis – Provides specific information about a feature (e.g., What is the area and perimeter of a parcel?)
- Proximity Analysis – Determines relationships between objects and areas (e.g., Who is located within 100 feet of the streambank?)
- Overlay Analysis – Performs integration of different data layers (e.g., What is the SCS curve number for this sub-watershed considering soils and land use?)
- Network Analysis – Analyzes the connectivity of linear features and establishes routes or direction of flow (e.g., Which pipes feed into this junction box?)
- Raster Analysis – Utilizes a raster model to address a number of hydrologic issues (e.g., What does the 3-D model of this watershed look like? Where does the water flow?)

Data Display, Output and Visualization

Geographic information systems excel at allowing users to create rich and detailed maps, graphs and other types of output which can help local staff, elected officials, and the general public visualize and understand complex problems and large amounts of information. These maps and charts can be integrated with reports, three-dimensional views, photographic images, and multimedia presentations.

5.3.4 Use of GIS in Stormwater Management

Types of Uses

GIS can be useful to a community in a wide variety of stormwater-related applications:

- GIS can be used for the mapping of surface features, land uses, soils, rainfall amounts, watershed boundaries, slopes, land cover, etc.
- GIS integration with a database management system (DBMS) can be used to help manage a stormwater system inventory and information about facility conditions, storm sewer networks, inspection and maintenance scheduling, and problem areas.
- GIS can be used to automate certain tasks, such as measuring the areas of subwatersheds, plotting floodplain boundaries, or assessing stormwater utility fees.
- GIS can be used to evaluate water quality impacts and answer cause and effect questions, such as the relationship between various land uses and in-stream pollution monitoring results.
- "What if" analyses can be undertaken with GIS. For example, various land use scenarios and their impacts on pollution or flooding can be tried in various combinations to determine the best management solutions or the outcome of current decisions. When tied to hydrology, hydraulics, and/or water quality models, this type of analysis becomes a powerful tool to assess the impacts of new development on downstream properties.
- GIS databases can provide public officials, consultants, and citizens with immediate answers and ready information. For example, inventory, complaints, and other information about stormwater infrastructure (including pictures) can be placed in a database tied to geographic location.
- Complex problems or changes over time, such as water quality improvements, can be easily visualized in maps and graphs generated by GIS systems.
- GIS maps can be used to inform and influence citizens and political leadership concerning a course of action or a project's viability.

Implementation Issues

Communities often make enormous expenditures on data, hardware, software, and databases, but spend too little resources on planning, staff familiarization, training, graphical user interface (GUI), and applications development. The end result is an unusable system accessible by only a few who have the resources to learn the system, hire competent staff, and develop applications. It is generally better to target GIS implementation to certain needs and quickly roll-out applications that work for these needs, even prior to the complete development of the database and overall system.

Proper implementation of GIS applications for stormwater management involves planning for stormwater-only applications and integration of these applications with other potential users within the municipality.

5.3.5 Other Related Technologies

GIS is closely related to several other types of information systems, and can be used with these other information tools, including:

- CAD—Computer-Assisted Design (CAD) systems evolved to create designs and plans of buildings and infrastructure. The systems are designed to do very detailed drafting and drawing, but have only limited capability to attach data fields to the electronic drawing. As a result these systems do not have the capability to perform spatial analysis. Fortunately these drawings can be input to GIS, saving significant time on digitizing. Once in GIS, attribute data can be added to the graphic features.
- DBMS—Database Management Systems (DBMSs) specialize in storage and management of all types of data, including geographic data. DBMSs are optimized to store and retrieve data and many geographic information systems rely on them for this purpose. They do not typically have the analytic and visualization tools that are common to GIS.
- SCADA—SCADA stands for Supervisory Control and Data Acquisition System. These systems combine the ability to monitor information (rainfall, stream flow, flood level, etc.) remotely through telemetry. SCADA systems can also execute commands to do such things as open gates or close valves from a distance. Examples of the use of SCADA include automating stormwater pump station operation, alarms for flood warning, and lowering of traffic control barrier arms during high water periods. SCADA systems can be combined with GIS to create comprehensive tracking systems.

5.4 Asset Management

Description: Asset management is a process employed to track stormwater infrastructure needs and efficiently allocate resources to promote strategic preventative maintenance and timely repairs. Stormwater programs can use asset management and tracking to help address a number of issues, including aging infrastructure, failure analysis, NPDES and TMDL compliance, inspection and maintenance, reporting requirements, and inadequate funding.

KEY CONSIDERATIONS

A stormwater infrastructure tracking system is an integral part of the stormwater management program, which should:

- Provide detailed knowledge of stormwater practice locations and conditions;
- Provide prioritization of maintenance and replacement activities based on the risk and consequences of failure;
- Supply information for long-term conditions and performance of BMPs, which can help the design of future BMPs;
- Help estimate pollutant removal rates on a watershed (or MS4-wide) basis; and
- Support the Illicit Discharge Detection and Elimination (IDDE) program.



5.4.1 Introduction

Asset Management is a process of maintaining and managing assets once they are acquired or built to maximize value while providing an expected level of service. In general, asset management allows a local government to optimize asset life while focusing maintenance efforts on the most critical assets. This allows a program to improve decision-making by tracking infrastructure needs and efficiently allocating resources to promote strategic preventative maintenance and timely repairs.

Stormwater programs can use asset management and tracking to address a number of issues, such as aging infrastructure, failure analysis, NPDES and TMDL compliance, inspection and maintenance, reporting requirements, and inadequate funding. Stormwater assets are typically identified as system components with a physical and functional role (e.g., manholes, catch basins, pump stations, stormwater piping and conveyances, ponds, and outfalls). Asset management in this context means creating an inventory of existing infrastructure with location, establishing a baseline rating for the condition of the components, and then developing a system to track operations and maintenance and issue alerts when repairs are necessary. Asset management can also provide a basis to identify long-term funding needs as stormwater infrastructure begins to reach the end of its functional life, with replacement prioritized based on risk and consequences of failure.

5.4.2 Stormwater Infrastructure Tracking System

The stormwater infrastructure tracking system is a map-based database that tracks the location and condition of BMPs, outfalls, conveyance structures, and other stormwater infrastructure attributes. This tracking system should include a field inspection and survey program for stormwater infrastructure. The tracking system is integral to the stormwater program for the following reasons:

- Detailed knowledge of stormwater practice location and condition is needed to ensure ongoing maintenance.
- Long-term condition and performance of specific BMPs and BMP design elements can help to inform the future BMP design process.
- BMP condition can reflect the effectiveness of the program.
- Integration of BMP data with land use data can be used to develop models that estimate pollutant removal on a watershed- or MS4-wide basis
- As a supplemental benefit, mapping of outfalls and infrastructure will support the Illicit Discharge Detection and Elimination (IDDE) program.

Because a stormwater infrastructure inventory program can be an ambitious and costly undertaking, it can be phased over time. For instance, the program can start with newly installed BMPs and major outfalls, followed by older BMPs, minor outfalls, and conveyance elements.

An important part of the inventory, in addition to the location and type of BMP, is an assessment of the physical and regulatory condition of the system, including the following:

- BMP type and location
- Contributing drainage area statistics
- Control structure type and design elevations
- Location of outfall and receiving stream
- BMP and conveyance stability and functionality
- The regulatory condition
  - » Located within easement
  - » Covered by maintenance agreement
  - » Maintenance access
  - » Proper maintenance being performed
- Previous inspections
  - » Inspection dates
  - » Maintenance dates
  - » Specific maintenance tasks performed
  - » Digital photographs

All data entered into the database should be verified and updated over time through field inspections. For example, the quality of the location data can be enhanced through the use of hand-held global positioning system (GPS) units during ongoing operation and maintenance activities, as well as when new stormwater infrastructure elements are added.

The specific data collected during field inspections can be used to determine what percentage of practices meet particular stormwater practice performance goals, such as:

- Sediment forebays should be no more than half full of sediment.
- Vegetation should cover at least 80% of the surface area of bioretention and wetland BMPs.
- Emergency spillways should be clear of debris and obstructions.
- Open channels should be stable (not eroding) and free of sediment deposits.
- Catch basin sediment should not comprise more than 25% of the space below pipe inverts.

These data are also used as triggers for when maintenance should be performed by the municipality or other responsible party. The authority and ability to track stormwater infrastructure maintenance work can help ensure regular compliance with a maintenance plan.

In parallel with physical infrastructure mapping, the MS4 needs a readily available, accurate, and preferably digital mapping layer of any easements and property boundaries. These data help in determining which practices have adequate maintenance access, and they help in identifying situations where a new agreement with a private property owner is needed to conduct regular inspections and maintenance.

5.4.3 Land Use and Land Cover Tracking

The ultimate effectiveness of a program needs to be evaluated in the context of changing land use. Many of the codes and policies implemented as a part of a post-construction stormwater program, such as implementation of LID or open space design techniques, can directly affect future land use. Consequently, updating basic land use layers in GIS is critical to understanding the actual benefits of the program.

Baseline data, including a good measure of impervious cover, land use, land cover, and developed areas, should be developed early in the process. These data should then be overlaid with zoning data or another estimate of future land use. Taken together, these data can help identify sensitive watersheds, as well as areas of potential growth.

Ultimately, these data help to inform decisions about redevelopment policies, zoning, and stormwater criteria. They also help the community to understand realistic pollutant reduction goals in the context of existing land use and future development pressures. Finally, these land use layers help the MS4 identify areas for potential stormwater retrofits.

These basic land use and land cover data can be supplemented with additional data that can help the MS4 better understand habitats and pollutant loading potentials. Some examples include stream, wetland, or forest assessments that identify high-value resources, or locations of stormwater hotspots that identify key pollutant load sources. Another example is a green space inventory, in which a community inventories landscape scale features that help manage stormwater and would aggravate stormwater problems if development is allowed there, including floodplains, stream buffers, and wetlands.

Land use and land cover data should be continuously updated to the extent possible. A plan review tracking system can be a direct source of information, as long as the existing and current land uses are accurately recorded for each development plan. As these data are updated, the MS4 can periodically reevaluate progress toward watershed-wide goals identified at the program's onset.

5.4.4 Reporting

Asset management in this context is about ensuring that mechanisms are in place so data generated by the system is communicated to the proper departments and agencies. These reports can be generated weekly, monthly, or yearly based on need. Weekly reports would be used for tracking inspection and maintenance demand, while monthly reports might be designed to track NPDES, TMDL, or state required goals.

CASE STUDY

DeKalb County Asset Management

DeKalb County is responsible for inspection and maintenance of over 150,000 public stormwater assets, 20% of which must be inspected every year, according to their MS4 permit. These inspections include permanent control structures (catch basins, pipe conduits, ditches, ponds, etc.), dry weather outfall inspections for illicit discharges, highly visible pollutant source businesses, industrial facilities that are required to have an NPDES permit, and privately maintained detention ponds. In the past, all inspection and maintenance records were prepared on paper and manually entered into the County database. With help from a consultant, the County is switching to a geographically linked asset management system – a web-based program that incorporates ArcGIS to help with stormwater asset inspections, inventory updates, and reporting. With this program, inspectors will be able to access and document inspections in real-time, rather than returning to the office to look up data or manually enter records into a database. The result is expected to be a significant improvement in inspector efficiency and productivity.

Source: Kurz, J.S., Proceedings of the 2013 Georgia Water Resources Conference, held April 10–11, 2013, at the University of Georgia

CASE STUDY

Coweta County Asset Inspection Program

Industrial and commercial growth has put significant pressure on Coweta County's infrastructure in the past 20 years. In that time, the population has more than doubled, to 130,000.
"The growth in all aspects of our community has resulted in us just trying to keep up with infrastructure," Coweta County stormwater resources manager Brice Martin said. "The big thing is keeping up with our assets and trying not to outpace ourselves. We don't want to get to the point where we have a lot of infrastructure going in and we are not able to keep up with it."
In just the past two years, something else doubled: daily infrastructure inspections. Coweta County recently became part of the Metropolitan North Georgia Water Planning District, resulting in stricter regional mandates, including inspecting all urbanized infrastructure and at least 10 percent of assets in unincorporated areas.

To keep up with the new annual inspection requirement, the County invested in better mobile device capabilities. Rather than relying on a device that required daily downloads and uploads to and from the County's GIS system, the County converted to a tablet-based system that would automatically download and upload GIS information over the internet. The improved system has led to a doubling of inspector productivity – from 50 inspections per day to over 100.

Source: Double Time in Georgia: Coweta County Public Utility District Moves Twice as Fast with ArcGIS on iPad. 2014. Esri News for Water & Wastewater.

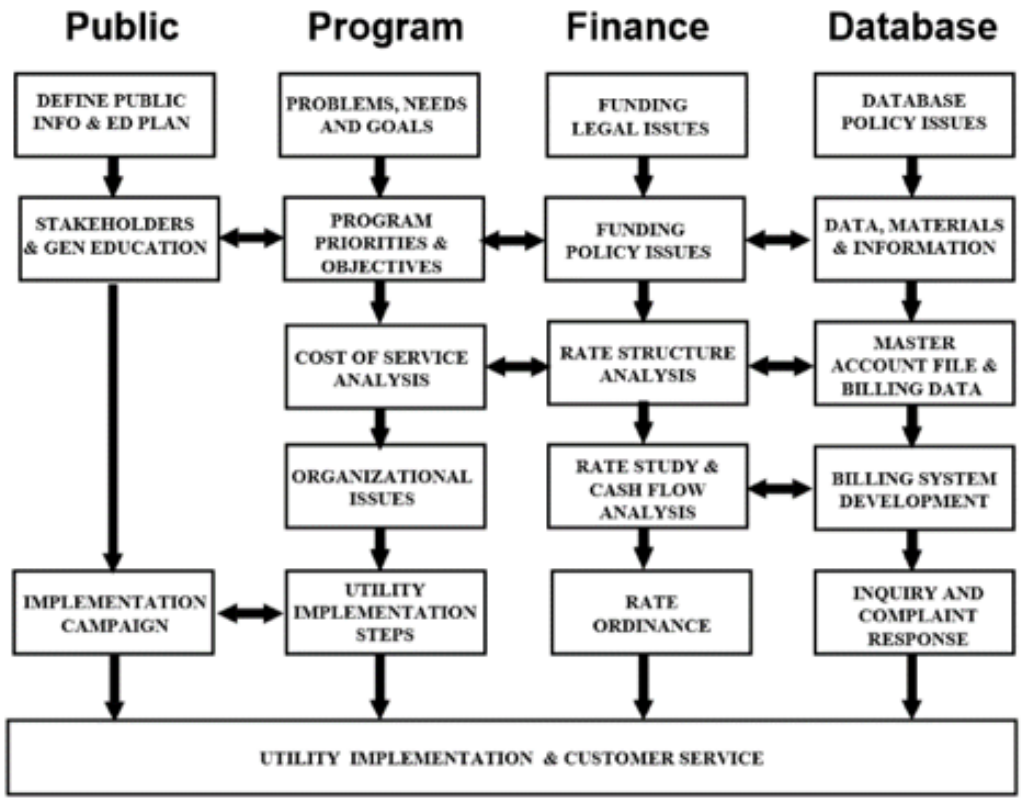
5.5 Funding

Description: Adequate funding is an essential part of a stormwater management program. While General Fund monies may be the most common funding approach, many other effective strategies exist.

KEY CONSIDERATIONS

Funding strategies covered in this section include:

- General Fund
- Stormwater Utilities
- Grant and Loan Programs
  - » Clean Water State Revolving Fund (CWSRF)
  - » Section 319(h) Georgia's Nonpoint Source Implementation Grant
  - » Department of Community Affairs (DCA) Water First
  - » National Flood Insurance Program (NFIP) Community Rating System (CRS)
  - » Coastal Incentive Grant (CIG) Program
- Other Funding Sources
  - » General Obligations Bonds
  - » Development Impact Fees
  - » Special Assessments/Tax Districts



5.5.1 Introduction

Adequate funding of local stormwater management program activities is perhaps one of the most critical, yet difficult, aspects of establishing a comprehensive stormwater management program. The best-designed stormwater management program will flounder without sufficient community support and a stable and sufficient funding source. Funding is required for the formation and ongoing operation of a local stormwater program. With regard to long-term operation of the program, the key funding issues are: (1) how much money is required to fund the program annually and (2) how to support the program with a consistent and dedicated funding base. An effective and ongoing program that includes planning, engineering, plan review, capital improvements, maintenance, and enforcement activities will typically require more resources than what is available from general appropriations.

In Georgia, general revenues from property taxes are typically the main funding source for local stormwater management activities. However, there are a number of alternative funding methods for stormwater management programs, including the sale of bonds, development impact fees, the formation of local improvement districts, and the creation of stormwater user fee systems (also known as stormwater utilities). Each funding approach has its advantages and limitations. These methods are discussed below and should be assessed as to potential revenue, suitability, and public acceptance.

5.5.2 General Fund

General appropriations are a traditional way of funding most government programs and services. The strongest advantage of general funding is that it represents a stable funding source from local taxes. The disadvantage is that stormwater activities must compete with other local programs and activities for limited funds. A government that elects to use its general fund may subject its stormwater operations to budget deliberations each fiscal year.

5.5.3 Stormwater Utilities

A stormwater user fee system is a financing option that provides a stable and dedicated revenue source for stormwater management. User fees for stormwater management present an alternative to increased taxes or impact fees for the support of local program operations and maintenance, as well as funding of other stormwater program activities. In a stormwater user fee system, stormwater infrastructure and programs are considered a public service or utility, similar to wastewater and water programs that are funded on a similar basis. As with water and wastewater rates, stormwater fees are assessed on users of the system based on average conditions for groups of customers with similar service requirements. Typically, fees are based on some measure of a property's impervious area. Rates may be assessed in charges per either equivalent dwelling unit (EDU) (e.g., "x" dollars per EDU per month) or unit area (e.g., "x" dollars per 100 square feet per month). Alternative methodologies include the use of a runoff factor or coefficient based on the type or category of land use, a flat fee per customer, or a combination of any of these methods.

A stormwater utility operates similarly to water, sewer, or fire districts, which are funded through service fees and administered separately from the general tax fund, ensuring stable and adequate funding for these public services. Stormwater utilities have existed for a number of years in several states, but have only recently been used in Georgia.

A stormwater utility can provide a vehicle for:

- Consolidating or coordinating activities and responsibilities that were previously dispersed among several departments and divisions;
- Generating funding that is adequate, stable, and equitable (as it is borne by the user on the basis of the user's demand placed on the stormwater system), and dedicated solely to stormwater management; and
- Developing programs that are comprehensive, cohesive, and consistent year-to-year.

Generally a community enacts two ordinances to create a stormwater utility, one to establish the various components of the utility and the other to determine the rate structure. Forming the utility through two separate ordinances allows the flexibility to alter the rate structure without having to revise the ordinance governing the basic structure of the utility. The first ordinance may also include a statement of the goals of the utility. The second ordinance tries to structure the service charges to create a logical and equitable relationship between the quantity of stormwater leaving a property, the benefits received from the stormwater system, and the amount assessed.

The stormwater utility rate should be designed to defray the costs of the service provided by the municipality. It is important that there is an equitable relationship between the amount of stormwater generated by a given property, the benefit received by the ratepayer, and the corresponding fee assessed. Generally, case law suggests that a rate will be deemed valid where: (1) the revenue generated benefits for the payers primarily, if not exclusively; (2) revenue is only used for the projects for which it was generated; (3) the revenue generated does not exceed the costs of the projects; and (4) the rate is uniformly applied among similarly situated properties.

Below are several features that should enhance a stormwater utility's chances of surviving any legal challenge:

- Operation as a separate public utility (similar to a water or power utility)
- Detailed findings explaining why the project is needed to protect public health, safety, and welfare
- Revenues from fees are segregated and managed as a separate fund
- Fees are proportionate to the burden placed on the system by class of property
- Credits can be implemented
- Findings and resultant fees are based on a professional analysis
- An appeal process is provided

Though they are not without significant administrative, political, and potential legal hurdles, stormwater utilities are worth considering as a potential funding source for local stormwater management activities.

The Georgia Stormwater Utility Dashboard is a useful tool to explore and compare stormwater utility fees for the many Georgia communities that have already adopted one. http://www.efc.sog.unc.edu/reslib/item/ga-stormwater-utility-dashboard

For more information on stormwater utilities and other stormwater funding mechanisms, see the National Association of Flood and Stormwater Management Agencies' Guidance for Municipal Stormwater Funding: http://www.epa.gov/sites/production/files/2015-09/documents/guidance-manual-version-2x-2_0.pdf

CASE STUDY

Stormwater Utilities in Georgia

In 2012, the Environmental Finance Center at the University of North Carolina, Chapel Hill performed a survey of existing stormwater utilities in the State of Georgia. At the time, there were a total of 44 stormwater utilities in existence. Key facts and observations from the survey included:

- Populations served by utilities range from 2,900 people in Avondale Estates to over 800,000 in Gwinnett County.
- Monthly fees for residential customers range from $0.10 to $6.00, with a median rate of $4.00.
- 34 of the 44 utilities offer a credit for installation of stormwater BMPs.

More information can be found in the report Approaches to Stormwater Management: Stormwater Utilities and Green Infrastructure http://www.efc.sog.unc.edu/sites/www.efc.sog.unc.edu/files/White%20Paper_Stormwater%20Overview%20for%20Rincon_GA_v6.pdf

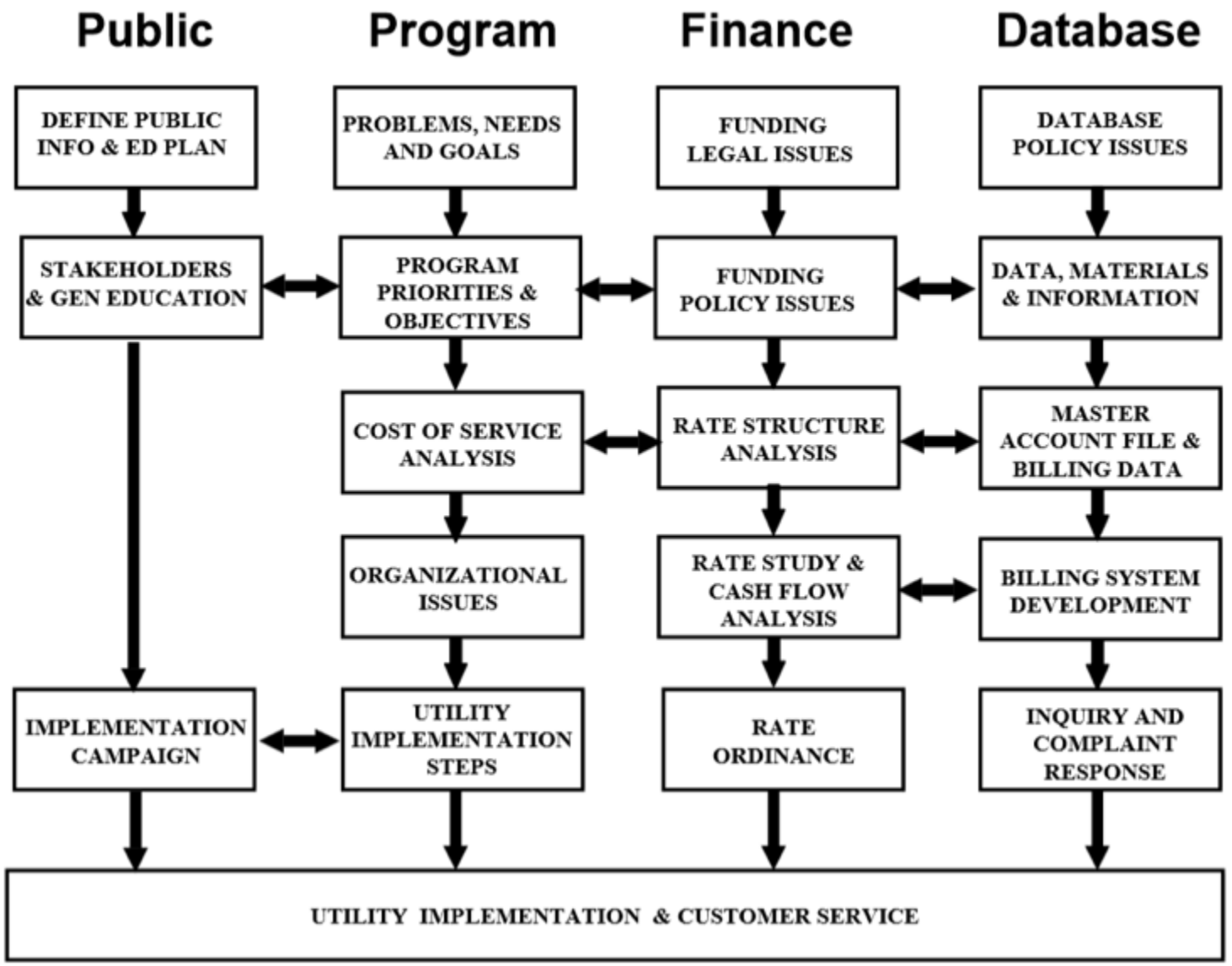


Figure 5.5-1 Utility Implementation Approach from *Guidance for Municipal Stormwater Funding*.

5.5.4 Grant and Loan Programs

The following loan and grant programs provide credits and incentives to communities that incorporate green infrastructure/LID practices into their projects and regulations. Some of these programs apply only to government entities, while others apply to actual projects. The websites given for each program can be referenced for more information.

The Clean Water State Revolving Fund (CWSRF)

The Clean Water State Revolving Fund (CWSRF) is a federal loan program administered by the Georgia Environmental Finance Authority (GEFA) that provides funding for pollution prevention projects. Green infrastructure projects consisting of site- and neighborhood-specific practices, such as bioretention, trees, green roofs, permeable pavements, and cisterns are eligible for funding. Reference the GEFA website for more information: http://gefa.georgia.gov/clean-water-state-revolving-fund

Section 319(h) Georgia's Nonpoint Source Implementation Grant

Under Section 319(h) of the Clean Water Act, the U.S. Environmental Protection Agency (USEPA) awards a Nonpoint Source Implementation Grant to the Georgia Environmental Protection Division (GAEPD) to fund projects in support of Georgia's Nonpoint Source Management Program. Funding is distributed via a competitive process to projects that will lead to direct reductions in pollutant loads and measurable water quality improvements.

Eligible applicants include: public agencies, such as local, regional, or state governments; authorities that operate service or delivery programs (e.g., sewer, water); regional commissions; agricultural conservation councils; and school and university systems. State law prohibits non-governmental organizations from receiving Section 319(h) funds directly; but, these organizations are encouraged to form partnerships with public agencies to develop or implement projects. Stormwater projects are reviewed to determine whether or not they are specifically required in MS4 permits. This funding cannot be used to implement MS4 permits. More information regarding the grant can be found at: http://epd.georgia.gov/section-319h-georgias-nonpoint-source-implementation-grant

Department of Community Affairs (DCA) WaterFirst

The WaterFirst Community Program is a voluntary partnership between local governments, state agencies, and other organizations working together to increase the quality of life in communities through wise management and protection of valuable water resources. This proactive approach to water resources requires local governments to make the connection between land use and water quality, and think beyond political boundaries to recognize the inextricable links created by shared water resources. The intended result of the program is the achievement of excellence beyond the current water regulations in seven major categories:

- Watershed Assessment
- Stormwater Master Planning
- Wastewater Treatment and Management
- Water Supply Planning
- Water Supply Protection
- Water Conservation
- Water Reclamation and Reuse

Participation benefits include resources, tools, and support to help meet water management goals and state-wide recognition for being environmental stewards. In addition to the Participation Benefits, designated communities receive:

- A 1% interest rate reduction for Georgia Environmental Finance Authority water-related loans;
- Annual eligibility for DCA Community Block Development Grants for water related projects;
- Priority for EPD 319 Grant funding; and
- State-wide recognition, including road signage and authorization to use the WaterFirst trademarked logo.

More information on the WaterFirst program can be found at: http://www.dca.state.ga.us/development/PlanningQualityGrowth/programs/WaterResourcesTechnicalAssistance.asp

National Flood Insurance Program (NFIP) Community Rating System (CRS)

The National Flood Insurance Program's (NFIP) Community Rating System (CRS) was implemented in 1990 as a voluntary program for recognizing and encouraging community floodplain management activities exceeding the NFIP's minimum standards. Any community that is in full compliance with the NFIP's minimum floodplain management requirements may apply to join CRS.

As a result of joining the CRS, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from community actions meeting the three goals of the CRS:

1. Reduce flood damage to insurable property;
2. Strengthen and support the insurance aspects of the NFIP; and
3. Encourage a comprehensive approach to floodplain management.

The CRS uses a method that is similar to fire insurance rating to determine flood insurance premium reductions for residents. Most communities enter the program at a CRS Class 9 or 8 rating, which entitles residents in Special Flood Hazard Areas (SFHAs) to a 5% discount on their flood insurance premiums for a Class 9, or 10% discount for Class 8. Each CRS Class improvement produces a 5% greater discount on flood insurance premiums for properties in the SFHA. More information about the CRS program can be found at: https://www.fema.gov/national-flood-insurance-program-community-rating-system

Coastal Incentive Grant (CIG) Program

The Coastal Incentive Grant (CIG) Program is a competitive pass-through sub-grant program made possible by a grant to the Georgia Department of Natural Resources (GDNR) from the National Oceanic and Atmospheric Administration (NOAA) through congressional funding pursuant to the Coastal Zone Management Act. Each year, the Georgia Coastal Management Program (GCMP) allocates a portion of its federal funding to the CIG Program. This program supports the objective of the GCMP: balancing economic development in Georgia's coastal area with preservation of natural, environmental, historic, archaeological and recreational resources for the benefit of Georgia's present and future generations.

These sub-grants may be awarded to qualified county and municipal governments, regional commissions, state-affiliated research or educational institutions, or state agencies (except GDNR), provided the project takes place entirely within the eleven-county service area of the program. The CIG Program service area includes Brantley, Bryan, Camden, Chatham, Charlton, Effingham, Glynn, Liberty, Long, McIntosh, and Wayne counties.

More information about the CIG Program can be found at: http://coastalgadnr.org/cm/grants/cig

5.5.5 Other Funding Sources

5.5.5.1 GENERAL OBLIGATIONS BONDS

Debt financing of capital and operation and maintenance costs can be accomplished through issuing general obligation bonds, revenue bonds, or a combination of the two. A bond issue requires voter approval on a referendum ballot and is subject to local administrative policy in the form of debt ceilings. Most stormwater project debt has been financed through issuance of 15-year term bonds. These bonds are repayable from service charge proceeds, general revenues, and other sources (e.g. development fees), depending on the type of debt issued.

5.5.5.2 DEVELOPMENT IMPACT FEES

This funding source involves the assessment of a development impact fee on developers of new projects within a defined watershed or area. The project's total share of costs is determined not by the benefits received but by the impacts it creates in requiring new facilities and/or increased service levels. Development impact fees may be assessed as a permit or plan review fee. These are generally one-time fees, the revenues of which are used specifically to finance new stormwater facilities or other system components. While paid by the developer, these type of costs are typically passed on to the property owner(s).

A variation of the development impact or permit fee approach commonly used by small jurisdictions is the use of a private consultant to conduct plan reviews, construction inspections, and maintenance inspections. Using this scenario, the consultant would directly bill the developer for all services rendered. Ongoing maintenance inspections could be billed to the local jurisdiction. This type of arrangement typically results in a very low implementation cost to the community.

5.5.5.3 SPECIAL ASSESSMENTS/TAX DISTRICTS

A community may create special tax (or local improvement) districts to develop stormwater control systems. This approach is good in cases where capital improvements, land acquisition, special studies, and/or extraordinary maintenance benefits a specific area or number of properties within a jurisdiction. The result is that only those who benefit from the systems pay for them. Special districts function as quasi-municipal corporations created by law. As such, these districts have several funding options available: special taxes on property within the district area, development fees, user fees and, in some instances, debt financing. Creation of these districts requires voter approval. An alternative to creating these districts is to develop basin-specific user fees through a stormwater utility.

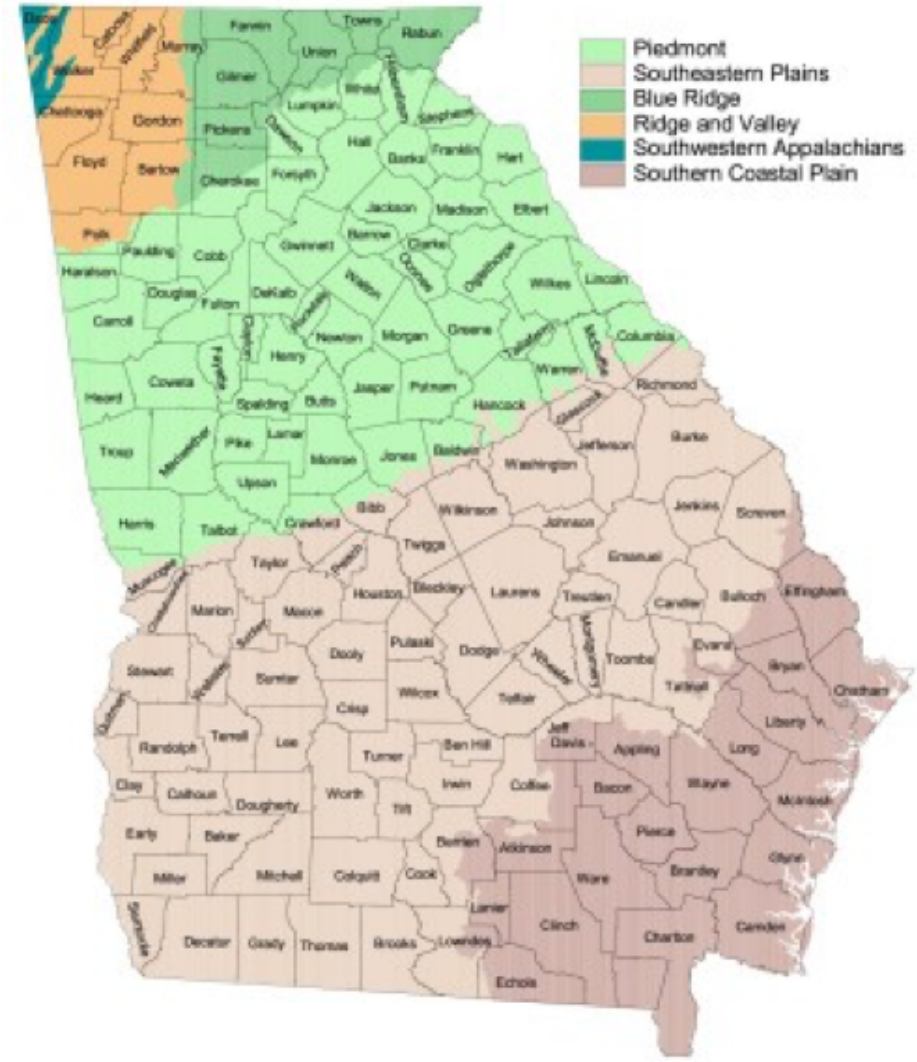
5.6 Adapting the Program to Meet Local Needs and Challenges

Description: Georgia communities vary significantly in terms of environment, as well as past and future growth conditions. Therefore, it is important for each community to customize its stormwater management program to meet its local needs and challenges.

KEY CONSIDERATIONS

There are several factors worth considering that may require local customization or modification of a local stormwater management program, including:

- Historic Rainfall and Flooding Concerns
- Climate Change
- Land Use Patterns and Zoning Requirements
- Anticipated Development and Population Growth
- Typical Terrain and Soil Conditions



5.6.1 Introduction

Adapting a stormwater management program to meet local needs and challenges is an important step that requires extensive planning and forethought. A community must consider environmental factors such as flooding and hurricanes, regional factors such as proximity to the coast and presence of karst, and future growth conditions and patterns. In addition, a community must determine the best approach for implementing and building political and public support for the program. The goal of this section is to provide an overview of the necessary steps for adapting a stormwater management program to meet the local needs and challenges of a community.

5.6.2 Environmental Factors

Identifying the location and magnitude of existing and/or potential stormwater-related problems including flooding, property damage, water quality impairment, streambank erosion, and habitat degradation is the first step in adapting a stormwater management program to the community.

Local governments should obtain geographical information to help determine which areas are contenders for new development and which areas should be avoided. The following information should be gathered to help with this process:

- Maps
  - » Watersheds
  - » Floodplains
  - » Soils
  - » Land use
  - » Land cover
  - » Water resources (rivers, lakes, wetlands, etc.)
  - » Source water protection areas
  - » Roads
- Precipitation
- Areas prone to flooding

When thinking about future conditions, climate change should be considered, since it could potentially affect the ways stormwater will be generated and treated in both the piedmont region and the coastal region. Climate change is anticipated to impact every aspect of the water cycle, and many of the underlying assumptions that stormwater managers use for runoff and storm system design might become outdated if these predictions become a reality. Changes in water elevation, storm intensity, and storm duration can impact the stormwater management program's LID placement, design variables (such as the design storm, water quality volume, and stormwater conveyance), and other considerations needed to account for changing climate and associated impacts. To review the predicted impacts of climate change on the State of Georgia, see the National Climate Assessment's Climate Change Impacts in the United States: http://nca2014.globalchange.gov/

Since there is still significant uncertainty regarding climate change's impacts on rainfall and stormwater management, it is difficult to recommend specific changes to BMP design standards. It is better to focus on broader LID design principles that build system resiliency for climate change, including designs and approaches that:

- Enhance storage and treatment in natural and vegetated areas;
- Use small-scale storage and treatment; and
- Provide conveyances that allow for a margin of safety for high flows.
- Provide greater stream and floodplain buffers and setbacks. (Ellis, et al)

Climate Variability and Stormwater Systems

Between 2006 and 2012, the Upper ACF Basin alone experienced four extreme weather events: the Drought of 2007-2008, which brought record-high temperatures and severe losses from local reservoirs; the September Flood of 2009, which caused widespread flooding and raised the Chattahoochee River to the 500-year flood level; the subsequent Winter Floods of 2009-2010; and the Drought of 2011-2012 (Beller-Sims et al, 2014, pg. C-1). With the expectation that similar extreme events will continue to occur in addition to shifting annual averages (C-4), communities, engineers, and scientists have increasingly recognized the role of climate variability in the long-range design of stormwater infrastructure and begun to pursue measures that create resilient systems capable of withstanding a range of potential climate conditions (1-3).

Stormwater management is an important element of a comprehensive climate adaptation strategy, and the climate action plans of Seattle, Miami-Dade County, New York City, and Chicago, among others, acknowledge the role of green infrastructure and other stormwater management practices to mitigate the broad effects of climate change (Seattle Office of Sustainability & Environment, Miami-Dade County, City of Chicago). These efforts are not restricted to large urban areas; jurisdictions of all size are implementing similar initiatives, including communities like Beaverton, Oregon, Dubuque, Iowa, and small coastal communities facing the immediate consequences of inaction (Resilient Communities for America, 2013).

Though there is some disagreement among climate studies regarding the exact nature of the localized climate impacts upon precipitation and hydrology across the state, communities and water utilities locally and nationally have begun to implement strategies to manage the risk of extreme events and, more broadly, future climate variability (US EPA, 2013, pg. 10). In 2013, the Metropolitan North Georgia Water Planning District (the District) undertook a utility climate resiliency study to assess the impact of climate variability upon water resources and infrastructure in the metropolitan Atlanta area (CDM Smith, 2015, pg. 1-1). The study used 108 projections from the CMIP5 ensemble of climate models to develop five representative scenarios of potential future climate conditions: hot/dry, hot/wet, warm/wet, warm/dry, and the central tendency. This approach allowed the District to evaluate a suite of potential futures that represent the uncertainty and variability of the available climate projections (2-3). Based on the projected climate outcomes, that study recommended a range of adaptation strategies for planners, designers, and managers of water, wastewater, and stormwater infrastructure systems. Other studies from the Georgia Institute of Water Resources, which predict more frequent droughts and extreme precipitation events across the ACF basin, support the need for resilient systems (Beller-Sims et al, 2014, pg. C-4).

The performance of stormwater conveyance systems is sensitive to changes in precipitation and peak flow. Particularly, an increase in the 24-hour storm depth or a decrease in the average recurrence interval (ARI) of precipitation events may overwhelm those systems designed with conventional design storm depths. Stormwater outfalls may also become submerged by floodwaters and high peak streamflow, cause backflow into the system, and ultimately create upstream flooding. Additionally, climate variability can lead to increased loadings of nonpoint source pollutants, which may affect the ability of stormwater systems to meet applicable water quality standards in the receiving water body (CDM Smith, 2015, 4-27). Prolonged or severe drought can impact the integrity of existing infrastructure, which can be compromised by roots seeking moisture during times of drought, and the performance of CSO systems constructed with the expectation of higher flows (Cromwell and McGuckin, 2010, pg. 25).

Some adaptation strategies have been identified to protect against the impact of climate variability and build resiliency in local stormwater conveyance systems. The District's study described some general actions to prepare for future climate variability:

- Increase the capacity of stormwater collection, conveyance, and storage systems;
- Incorporate green infrastructure to promote infiltration and reduce stormwater volumes;
- Conduct extreme precipitation event analyses with climate variability to understand the risk of impacts to the stormwater collection system;
- Monitor and inspect the integrity of existing infrastructure (5-12).

Climate Variability and Stormwater Systems - (Con't)

Decreasing return periods for storm events can significantly impact the performance of stormwater infrastructure. The District study predicted an increase in storm depths by -2 to 12% and peak streamflow by -2 to 11% around the Atlanta metropolitan area (CDM Smith, 2015, 4-19). In response, engineers can anticipate this change and provide greater protection by designing hydraulic structures for more extreme events (50-year storm vs. 25-year storm) and incorporating green infrastructure and infiltration practices in site and system designs. The uncertain impacts of climate change also support the use of environmental site design and the inclusion of green infrastructure to build capacity throughout the system and redirect flow from undersized conveyance systems. From a planning perspective, utilities and managers should monitor and track local climate data to identify changing conditions, evaluate the system's performance, and prioritize critical adaptations to best improve the system response (Ellis et al, 2014, pg. G-2). The usefulness of these strategies is not limited to the District or the ACF basin; they build resilience to a range of climate futures, independent of the geographic context.

Coastal communities are also uniquely vulnerable to the effects of tidal flooding and sea level rise. The existence of aging stormwater infrastructure and sea level rise pose a dual threat to coastal communities. For example, submerged outfalls can cause inundation in low-lying areas, even those located behind flood protection structures, and cause corrosion in pipes (Cromwell and McGuckin, 2010, pg. 21). Hard armoring and shoreline stabilization strategies can mitigate the effects of sea level rise upon inland structures. At-risk structures and proposed outfalls can be raised above the expected flooding level, and low-lying segments may be retrofitted with gates and pumps to prevent back up through the stormwater system (Keating and Habeeb, 2012, pg. 110). NOAA's Adapting to Climate Change: A Planning Guide for State Coastal Managers recommends a suite of strategies to regularly evaluate the system and build capacity for additional flooding to anticipate future need.

Other approaches that create resiliency, redundancy, and reliability are also recommended to be integrated in all areas of stormwater management, including planning, operations, and infrastructure to prepare for a range of possible climate futures that may feature both drought and extreme precipitation (Cromwell and McGuckin, 2010, pg. 18). The effects of climate change upon the design criteria of stormwater systems are complex, but early adoption of basic measures to build resiliency and an operations framework to proactively identify climate threats can mitigate the impact of variability across a broad range of climate futures. Simply, early preparation and recognition are key to protecting the future performance of stormwater systems.

References

Beller-Simms, N., E. Brown, L. Fillmore, K. Metchis, K. Ozekin, C. Ternieden, and K. Lackey. 2014. *Water/Wastewater Utilities and Extreme Climate and Weather Events: Case Studies on Community Response, Lessons Learned, Adaptation, and Planning Needs for the Future.* Project No. CC7C11 by the Water Environment Research Foundation: Alexandria, VA.

CDM Smith. 2015. *Utility Climate Resiliency Study.* Metropolitan North Georgia Water Planning District.

City of Chicago. 2010. *Chicago Climate Action Plan.* City of Chicago Climate Action Plan. http://www.chicagoclimateaction.org/filebin/pdf/finalreport/CCAPREPORTFINALv2.pdf.

Cromwell, John and Robyn McGuckin. 2010. *Implications of Climate Change for Adaptation by Wastewater and Stormwater Agencies.* Water Environment Federation Technical Exhibition and Conference 2010. pp. 1887-1915

Ellis, K., C. Berg, D. Caraco, S. Drescher, G. Hoffmann, B. Keppler, M. LaRocco, and A. Turner. 2014. *Low Impact Development in Coastal South Carolina: A Planning and Design Guide. ACE Basin and North Inlet – Winyah Bay National Estuarine Research Reserves, 462 pp.*

References - (Con't)

Keating, Larry and Dana Habeeb. 2012. *Tracking the Effects of Sea Level Rise in Georgia Coastal Communities.* Georgia Institute of Technology, School of City and Regional Planning.

Miami-Dade County. 2010. *Climate Change Action Plan.* Miami-Dade County GreenPrint. http://www.miamidade.gov/greenprint/pdf/climate_action_plan.pdf.

O'Neill II, James A. 2010. *Climate Change's Impact on the Design of Water, Wastewater, and Stormwater Infrastructure. Hydrology Days 2010.*

Resilient Communities for America. 2013. *Local Governments, Extreme Weather, and Climate Change.* Media Kit of the Resilient Communities for America Campaign. http://www.resilientamerica.org/wp-content/uploads/2013/06/RC4A_Cities_extreme_weather_climate_fact_sheet.pdf.

Seattle Office of Sustainability & Environment. 2013. *Seattle Climate Action Plan.* http://www.seattle.gov/Documents/Departments/OSE/2013_CAP_20130612.pdf.

US EPA. 2013. *Climate Ready Water Utilities Adaptation Strategies Guide for Water Utilities.* U.S. Environmental Protection Agency, Washington, DC, EPA/817/K-13/001.

5.6.3 Regional Factors

There are many regional factors that can affect the development of a stormwater management plan. The State of Georgia is made up of six ecoregions, each having its own geographical characteristics. Most stormwater management practices were originally developed for use in the Piedmont Region, however as shown in Figure 5.6-1 there are other regions, including the Southeastern Plains, Blue Ridge, Ridge and Valley, Southwestern Appalachians, and Southern Coastal Plain, which may require variations and modifications to these practices. Regional issues, such as coastal, karst, and watersheds containing water supply districts, all need to be considered when adapting a stormwater program to a community.

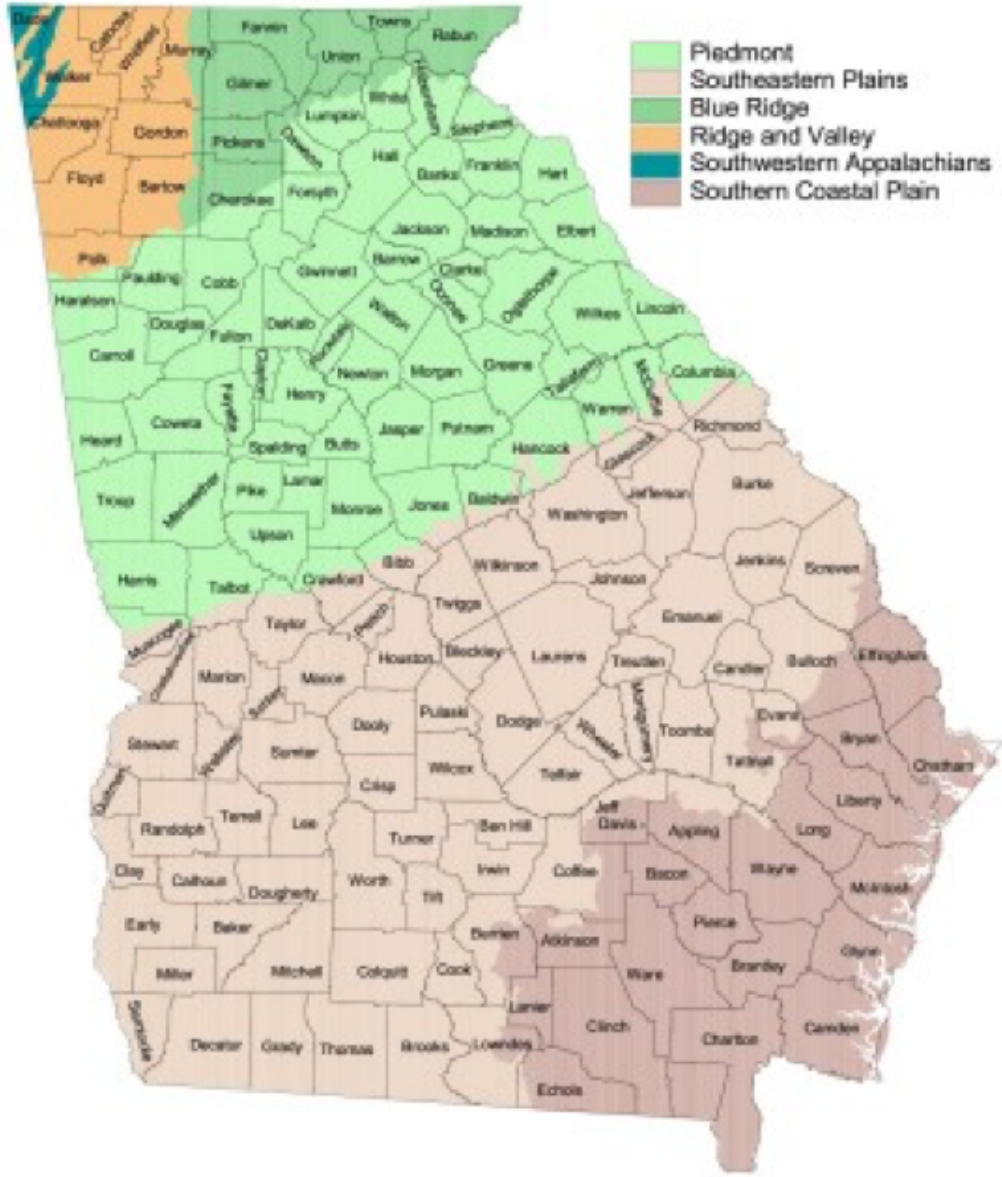


Figure 5.6-1 Georgia Ecoregions
(Source: Georgia DNR)

Coastal

Flat terrain, high water table, and various soil types are just a few physical features that must be considered in the coastal region. The surface water/groundwater interactions increase and the head available to treat the stormwater or move floodwaters through the watershed during intense tropical storms and hurricanes decreases due to the flat terrain present in the coastal region. Since the water table exists within a few feet of the surface, the movement of pollutants is increased through shallow groundwater causing a decrease in performance of stormwater management practices. Poorly-drained soils and well-drained soils can both be found in the coastal region. Since infiltration rates can vary greatly between each of these soil types, it is important to consider the effectiveness of certain stormwater BMPs.

Karst

Karst is a dynamic landscape composed of soluble bedrock that is associated with sinkholes, springs, caves, and a highly irregular soil-rock interface. Specific site and BMP design considerations are required in areas of karst geology. The best approach for the community is to create stronger comprehensive land use plans that direct new growth away from karst areas to more appropriate locations. In situations where an entire community is underlain by karst, it would be critical to implement geotechnical investigation requirements aimed at minimizing the impacts of land development on the natural drainage patterns. (1)

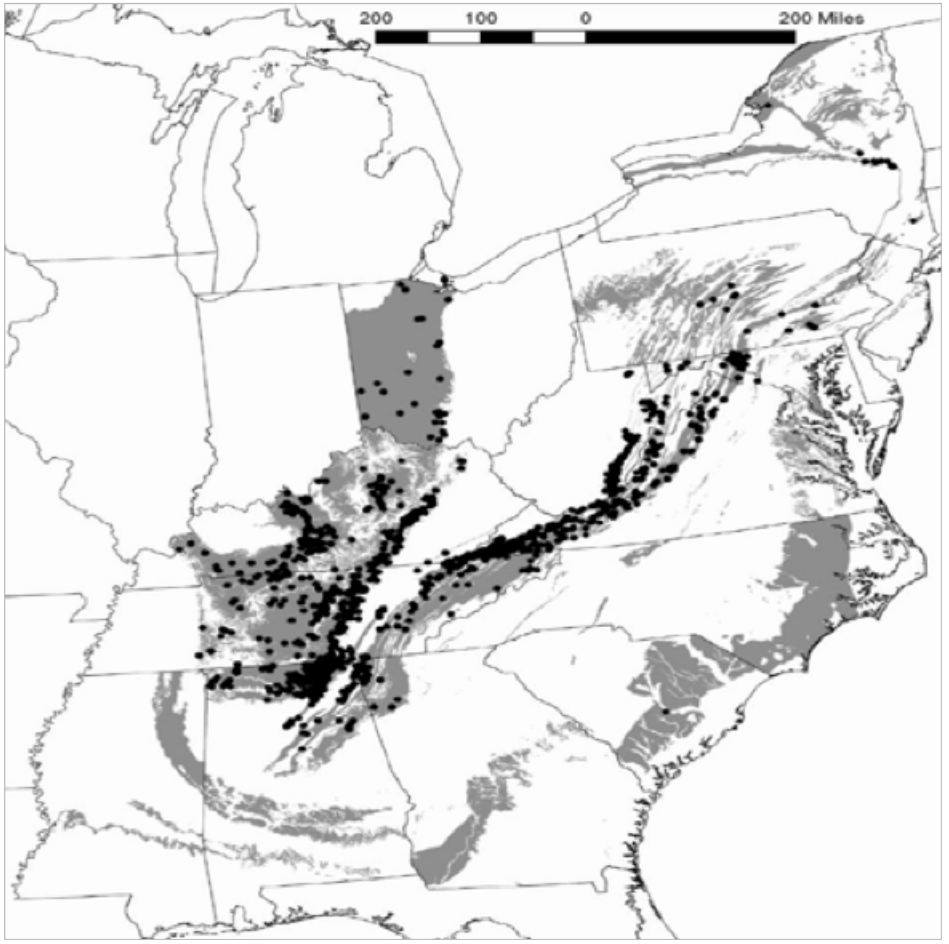


Figure 5.6-2 Karst Terrain Distribution: grey = karst, black = caves
(Source: CSN Technical Bulletin; Weary, 2005)

Water Supply Regions

When adapting the stormwater management program to your community, it is important to consider what watershed, or river basin, your community is located in and how the drinking water is supplied (see Figure 5.6-3). Much of the water supply in Georgia is supplied by surface waters from rivers and storage reservoirs. Care must be taken when directing growth and development of the community to these areas. In addition, stormwater management controls should be effective in protecting existing surface waters and storage reservoirs that supply this water. Low impact development practices that reduce sediment and other pollutants in water supply sources will also help reduce the cost of treating drinking water.

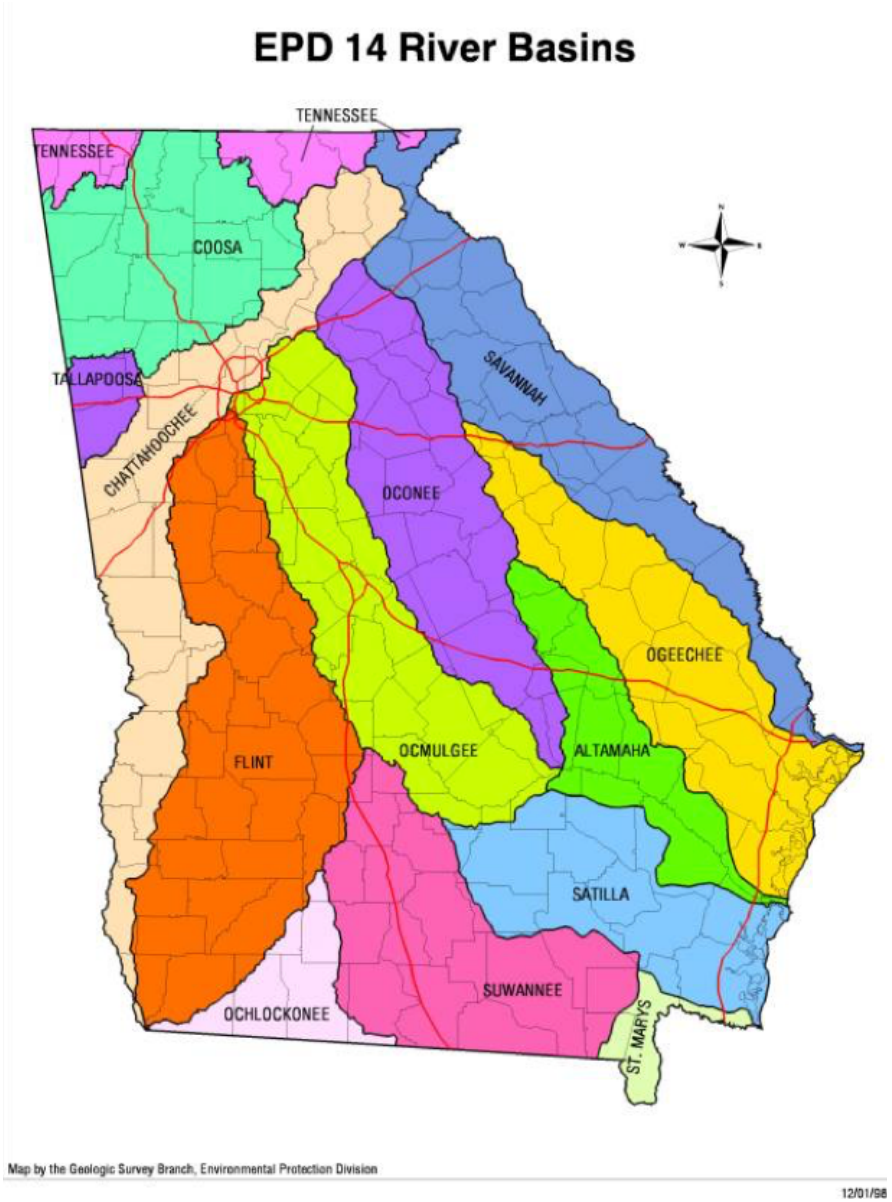


Figure 5.6-3 Georgia River Basins
(Source: Geologic Survey Branch, EPD, 1995)

5.6.4 Past Growth Conditions and Patterns

All types of land use pose their own challenges when it comes to implementation of stormwater BMPs, particularly LID practices. Past growth conditions and patterns of a community may affect which types of BMPs are easiest or most appropriate to implement. For example, in urban, heavily developed areas, land prices can be very high, making it difficult to find available space for large BMPs. On the other hand, in more suburban or rural areas finding available space may be less of a challenge, but other constraints, such as the presence of septic fields and wells, or a lack of drainage infrastructure for underdrain connection may exist. It is important to consider the existing development conditions when customizing a local stormwater management program. Rural areas may have the most to gain in adopting new runoff reduction stormwater management approaches, especially when combined with comprehensive planning to preserve critical landscapes for managing water supply and quality. Early planning to preserve floodplains, wide stream buffers, and biologically important habitats, like wetlands, will help local governments avoid future costly flooding and water quality impairments as they grow, develop, and create communities where people wish to live and work.

5.6.5 Future Growth Conditions and Patterns

Another important step for communities to consider is future growth conditions and patterns. As discussed in Chapter 3, implementing infill development and redevelopment in a community's land use regulations could encourage growth to be more centrally focused in city corridors, thereby reducing urban sprawl. Gathering current and historical information can help local governments identify areas for redevelopment and future growth. This information may include:

- Current population
- Anticipated population changes
- Current land use and zoning
- Proposed changes to land use
- Natural resources inventory
- Build-out analysis showing full development potential of existing zoning
- Impervious cover
- Construction projects (number, type, etc.)
- Transportation, utility, and infrastructure plans

5.6.6 Political and Public Support

The identification of stormwater-related problems or mandated requirements may lead to formal recognition by elected officials and establish a basis for developing the program. Program development should ideally be performed with a team from several departments to promote coordination and include the public in the process through the use of a stakeholder group.

All stormwater program goals should be based on problems that are clearly recognized as being important by the general public and that can be addressed through the basic powers and responsibilities of local government. Often a consensus-building approach is used to develop general program goals with citizen input. These goals often include the following general foundational responsibilities:

- Protect life and health
- Minimize property damage
- Ensure a functional drainage system
- Protect water quality
- Protect drinking water supplies
- Guide development
- Protect floodplain function
- Encourage economic development
- Protect and enhance the environment
- Improve quality of life

In order to gain public support for local stormwater management programs, citizens and the business community alike need to be educated and involved in the process. General education efforts can provide information about stormwater issues and pollution prevention practices. Educational efforts can include:

- Meetings and presentations
- Newsletters, fact sheets, and brochures
- Homeowner education materials
- Media campaigns
- Coordination with activist groups for program support

Further, programs like Georgia Adopt-A-Stream can involve local citizens in the cleanup and monitoring of local streams. The public can also be involved in the development of watershed plans and overall stormwater management policy.

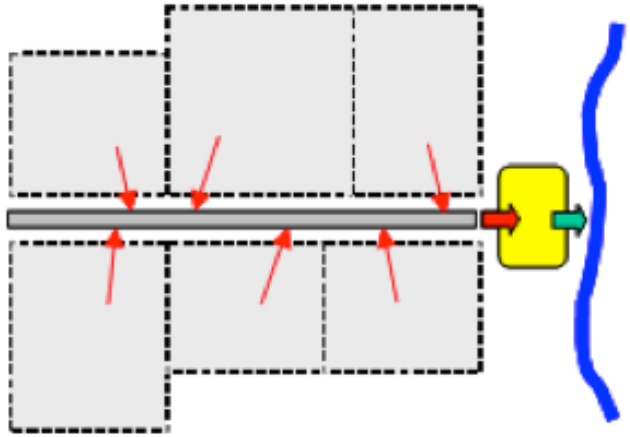
5.7 Watershed-Based Stormwater Planning

Description: Programs that offer alternatives to on-site stormwater management programs can provide flexibility to encourage development and redevelopment in areas where on-site stormwater management is cost-prohibitive or otherwise very difficult.

KEY CONSIDERATIONS

Alternatives to on-site stormwater management can include:

- Off-Site Mitigation, in which stormwater BMPs are constructed on a separate property, either as mitigation for forgoing on-site stormwater management, or as part of a regional stormwater management strategy.
- Fee-In-Lieu, in which a development pays a fee rather than constructing on-site stormwater management. The fees collected by the community are then used to pay for stormwater projects that have provided an equivalent level of protection.
- Offsets, Banking, and Trading, in which privately constructed stormwater BMPs may be used to offset developments that do not meet their stormwater regulations through selling or trading on a stormwater credit market.



Regional Structural Stormwater Control

5.7.1 Introduction

A guiding principle of low impact development (LID) is to manage and treat stormwater as close to the original source of runoff as possible. However, there are situations in which this is either not feasible, or not the most practical approach. This section discusses alternatives to on-site stormwater management, including off-site and regional stormwater practices, fee-in-lieu, and credit banking and trading.

This is a general overview with a few examples. For more thorough coverage of off-site and watershed-based compliance programs, examples, and sample documentation, consult additional resources, such as Guidance For Developing an Off-Site Stormwater Compliance Program in West Virginia (http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/permits/Documents/WV_Mitigation-FeeInLieu-Guidance_Final_Jan-2013.pdf) (CWP, 2012).

5.7.2 Advantages and Disadvantages of Alternative Approaches

When establishing alternative stormwater treatment options to on-site stormwater management, several considerations come into play. There are advantages and disadvantages to sub-watershed- or watershed-scale approaches for managing and treating stormwater. Generally, the advantages are associated with having increased options, and with the economy and efficiency of scale. Disadvantages are generally associated with administrative demands and constraints, as well as social and political perceptions and related difficulties.

Advantages

There are many cases where on-site stormwater management is either infeasible or impossible due to site or financial constraints. In ultra-urban environments, often development or redevelopment stormwater management criteria require significant space to implement, and can therefore become both difficult and expensive. Many regulatory guides allow exemptions to meeting the minimum criteria by using language like "if this cannot be achieved, treatment must be implemented to the maximum extent practicable," meaning that as much as possible must be done. This often carries with it the option to pay a fee for any on-site mitigation that cannot be achieved. This will be discussed later in Section 5.7.4 - Fee-In-Lieu. Allowing alternative mitigation provides for some equivalent of on-site mitigation to be achieved to a full extent, rather than the fullest practicable extent.

Another advantage for alternative mitigation is that it allows properties and areas to be used for water quality and quantity treatment that might have otherwise (a) lain dormant (like abandoned properties in urban areas) or (b) been developed in a way that contributes to negative impacts of increased runoff. For example, a parcel containing a dilapidated building that needs to be torn down could serve as the off-site location for structural stormwater practices installed to provide mitigation for runoff, offsetting the added runoff from a nearby parcel being developed or redeveloped.

Disadvantages

One potential concern is that the immediate or local impacts of stormwater runoff may not be resolved by treating stormwater elsewhere. For example, a site with certain runoff characteristics will in some way affect neighboring parcels. If the on-site runoff mitigation requirements are foregone in favor of some off-site treatment option, while the overall effect on the watershed may in fact be better than it would with full on-site treatment, the effects on the neighboring parcel are not affected by off-site mitigation. In addition, the other benefits of the on-site practice, such as habitat creation, green space addition, beautification, or air quality improvements may be lost. Often, regulations state that a certain portion of the required stormwater management practices be achieved on-site, with alternative compliance as an option for the remainder.

A second concern is that, administratively, there are more components involved in watershed-scale, or even neighborhood-scale mitigation options. With on-site treatment, there is essentially one owner of the practice, one BMP or BMP train, and the process for paying for, installing, maintaining, and repairing facilities is simpler. Once at the watershed scale, this relationship may include the site owner, potentially a neighborhood association, a locality, a municipality, and a separate utility or treatment provider. Potential conflict points include responsibility for maintenance, cost sharing and liability, and administrative burdens associated with larger scale efforts involving multiple stakeholders.

Difficulties Associated With Scope and Boundaries

When attempting to address water quality and/or quantity issues in a particular watershed, exact geographic boundaries can be difficult to delineate. As previously mentioned, even drawing the boundary for mitigation at the neighborhood scale, two parcels within that neighborhood may have issues between them as runoff from one affects another. This gets even more difficult when expanding to the watershed scale. For example, if nitrogen is a pollutant of concern in a river, and a total maximum daily load (TMDL) is established for controlling it, the boundaries constraining off-site mitigation relationships can get very tricky. A pound of nitrogen deposited at the head of a tributary to the river is not the same as a pound delivered at the confluence of the tributary and the river, since a significant amount of nitrogen would have been biologically processed and removed from the water if it had traveled the length of the tributary. Therefore, careful consideration is necessary to determine how and where mitigation projects can be located. To be effective, mitigation projects must be able to provide as much benefit as any on-site projects would have.

Political and administrative boundaries can be equally difficult to establish cleanly. Using another example, if a water quality workgroup determined that fecal coliform loads were of particular concern in a lake, the stakeholders would be involved in maintaining water quality. Therefore, a system that allowed a development in one of the stakeholder counties to treat stormwater elsewhere to offset on-site requirements might theoretically allow treatment somewhere in another one of the stakeholder counties, but the cross-county tracking and balancing could be cumbersome. It is possible, but a council with membership of the involved counties would need to be established so that they function as one collaborative entity. And to further complicate matters, for each goal – like a TMDL in a particular water body – there may need to be a governing body that is a collection of stakeholder entities.

If the alternative treatment system includes fee-in-lieu as an option, this can become more challenging, since it becomes difficult to assign portions of the cost liability to each of the entities associated with the larger system. A small-scale development in one stakeholder county might be able to pay a fee-in-lieu of on-site treatment, but would the fee go to that county, the larger council, or perhaps the operator of an online regional treatment facility closer to the lake? The answer to this question is to be answered by the group of municipalities and other administrative entities involved, and the process for establishing a system like this and making these determinations can be guided by some of the case studies offered in this section.

5.7.3 Off-Site Mitigation

Small scale off-site mitigation – sometimes called "in-kind" – is an option to install some controls or treatment on a site that is not where the development or redevelopment is occurring, perhaps on an individual site-development scale. Once geographic boundaries and constraints are established, this may be offered as an option with some qualifying conditions.

A typical approach in many communities is for a developer to finance, design, and construct stormwater controls at the individual parcel level, or the neighborhood level. Initially, the developer is responsible for all costs, operation, and maintenance. Most municipalities require inspection and maintenance agreements to solidify responsibility of the owners to maintain proper function of the practices. Once properties are sold to individuals, ownership of those agreements, the practices, and their maintenance is passed on. However, if the owners fail to maintain the stormwater controls, the local government is likely to become responsible for them, especially if the controls are in public right-of-way or communal land.

Some portion of stormwater management requirements must be met on-site. The remainder may be met by an alternative.	Example – Minimum on-site requirement: There is a 1" retention requirement for water quality, 75% *must* be managed on-site, and the remaining 25% may be managed using an alternative.
The alternative compliance methods allowed may not be required in a 1:1 ratio.	Example – Factor of Safety: There is a 1" retention requirement for water quality. If this cannot be met on-site, stormwater controls installed off-site must retain 1.2".

Table 5.7-1 Two common qualifying conditions for alternative stormwater management compliance

One alternative approach is to install strategically located regional stormwater control facilities in a sub-watershed, rather than on-site controls. Regional Stormwater Management Practice (RSMP) facilities are an option, pre- or post-construction. These are designed to handle stormwater runoff from multiple projects and/or properties through a local jurisdiction-sponsored program, where individual properties or developments may assist in financing the construction, operation and maintenance of the facility, and the requirement for on-site controls is either eliminated or reduced (see Figure 5.7-1). If future development is already planned, preemptively siting and installing RSMPs can be easier. If development is already complete, finding an appropriate location for an RSMP may be difficult, due to size and property ownership constraints.

There is always an ongoing cost to managing stormwater, whether it is at the site scale or the regional scale. With regional facilities, though the per-unit cost of construction, operation, and maintenance is reduced, it is still significant and ongoing. In many cases, a community must provide capital construction funds for a regional facility, including the costs of land acquisition. However, if a downstream developer is the first to build, the developer could be required to construct the facility and later be compensated by upstream developers for the capital construction costs and annual maintenance expenditures. Conversely, an upstream developer may have to establish temporary control structures if the regional facility is not in place before construction. Maintenance responsibilities generally shift from the homeowner or developer to the local government when a regional approach is selected. Many municipalities across the United States have established a stormwater utility or some other program to fund and implement stormwater controls.

Large-scale stormwater controls can be very cost effective. They can also be much more effective at removing pollutants of concern at the sub-watershed scale. However, an extremely effective and efficient RSMP may be better for the stream that eventually receives the discharge, but small tributaries upstream of that larger receiving stream might suffer due to lack of treatment or runoff reduction before discharge reaches them. It is important to ensure that improving one water body is not accomplished at the cost of harming another.

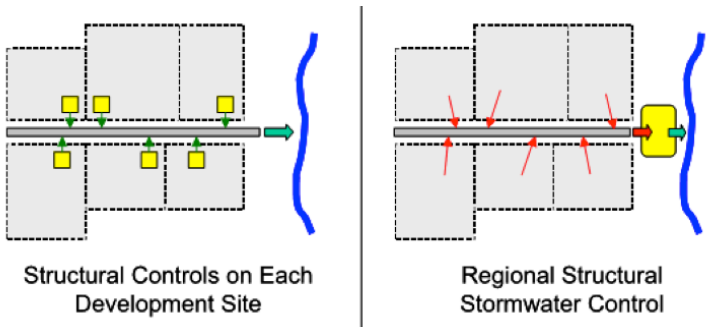


Figure 5.7-1 Difference between on-site and regional stormwater controls

CASE STUDY

Regional Stormwater Treatment in the St. Johns River

The St. Johns River watershed in northeast Florida has two regional stormwater treatment (RST) facilities, one in St. Johns County, and one in Putnam County. These RST facilities were funded by a cooperative effort, each costing approximately $3.8 million to construct. The goal of these facilities is to reduce nitrogen, phosphorus, and total suspended solids in the runoff being discharged into the St. Johns River. The tri-county agricultural area, including St. Johns, Putnam, and Flagler counties, produces a great deal of very nutrient-rich runoff from cropland, which contributes to algal blooms that may severely impact wildlife balance.

The Deep Creek West Regional Stormwater Treatment Area in St. Johns County, online since 2006, has a 15-acre wet pond and 38-acre constructed wetland in series to treat agricultural runoff, primarily from the upstream farmland. The Edgefield Regional Stormwater Treatment Area in Putnam County, online since 2007, consists of a 25-acre wet pond and 56-acre constructed wetland in series.
Source: http://floridaswater.com/lowerstjohnsriver/regionalstormwater.html

5.7.4 Fee-In-Lieu

Fee-in-lieu is, as the name suggests, a program where an entity with the responsibility of managing stormwater runoff pays a fee in lieu of physically managing the runoff. Based on the municipal-level cost of treatment, either in larger facilities, retrofit efforts, or non-structural or programmatic efforts, a representative cost of treating stormwater can be established, and that money can go to larger scale and more efficient practices being implemented. For example, a municipal separate storm sewer system (MS4) may be investing money in stream restoration and street sweeping to achieve their intended water quality goals. The fees they charge in a fee-in-lieu program will fund those broader efforts, selected for their watershed benefits. See Chattanooga, Tennessee's system example in the next subsection.

The similarity between these fee-in-lieu payments and the stormwater utility fees many local governments are now collecting is that they fund the same types of programs and efforts. A major difference is that the stormwater utility fees are being collected from existing residential, commercial, and industrial property owners within an MS4 boundary regardless of when the construction occurred.

5.7.5 Offsets, Banking, and Trading

Allowing off-site mitigation and compliance opens up the possibility of establishing an offset trading system. In a stormwater offset and banking system, one entity funds or builds stormwater management practices for purposes other than, or in addition to, meeting their stormwater management requirements, and can transfer or sell the credits to another entity that has difficulty meeting their own requirements on-site. Stormwater banking offers opportunities to reduce the costs of stormwater permit compliance and facilitate local water quality improvements. When coupled with local incentives, such a system can open up an inventory of properties that would not have otherwise been targeted for redevelopment or restoration.

Larger-scale or overbuilt practices can earn credits for any treatment beyond what is necessary or required. These credits can be "banked" (saved) or sold in a managed marketplace. For sites where on-site mitigation is difficult or expensive, credits can be purchased, often for less money than an on-site structural practice would cost. If payment in lieu of direct (on-site) mitigation is an option, those fees will set a cap for the credits in a free marketplace. For example, Chattanooga, Tennessee has a fee-in-lieu option that is volume-based and set at 1.5 times the estimated on-site construction cost for BMPs. Boundaries for trading need to be set, and will likely be formed by local water resource regulations. Typically, these will be watershed or sub-watershed scale boundaries.

CASE STUDY

Chattanooga, TN Fee-in-lieu

Credits are available to anyone who manages more than the minimum required volume at a 1:1 ratio. If 1,000 cubic feet of retention is required on a site, and a BMP is installed that retains 1,500 cubic feet, that installer can receive credit "coupons" for 500 cubic feet, and sell those. The estimated construction cost, according to Chattanooga, is $30 per cubic foot of retention. In addition, Chattanooga charges $45 per cubic foot as a fee-in-lieu. Thus, the owner of the 500 cubic feet of credits could sell or transfer those credits, but would not be able to receive more than $22,500 for them ($45 x 500 cubic feet). Most likely, the cost on the marketplace would be somewhere between $30 and $45 per cubic foot.

For more on Chattanooga's stormwater ordinance, visit their Credits and Incentives Manual.

CASE STUDY

Gwinnett County Wetland Mitigation Bank

For over 15 years, Gwinnett County has implemented a progressive watershed improvement program to evaluate and improve water quality in concert with a suite of other stormwater management practices. As part of this program, the county partnered with the Georgia Piedmont Land Trust to implement a stream and wetland restoration project downstream of Old Norcross Road on Sweetwater Creek in a highly urbanized area. The project included 2,000 feet of restored stream channel and restoration/creation of a total of 6 acres of wetlands.

Gwinnett County coordinated with the United States Army Corps of Engineers in order to use the restored segments of Sweetwater Creek and its tributaries and wetlands as a mitigation bank for use by Gwinnett County. The mitigation credits accrued from the project may be used by the county to offset unavoidable impacts to wetlands and waters of the United States. Revenue generated from the sale of credits will then be used to fund additional watershed improvements to improve and protect water quality conditions of streams throughout the County.

This unique urban mitigation banking model provides a true watershed approach by incorporating the Countywide Watershed Improvement Program to promote improvement of water quality and reduction of sediment/pollutant loads. Furthermore, development of a banking instrument for this project provides a strategy for addressing the needs of Gwinnett County by enhancing and protecting stream and wetland buffers, improving stormwater quality and volume control, stabilizing degraded stream channels and unstable stream banks, and acquiring land for preservation.

Source: Gwinnett County

CASE STUDY

Creedmoor, NC Stormwater Offset Mitigation

Creedmoor, North Carolina lies within the Falls Lake watershed of the Durham metropolitan area. In 2011, the North Carolina Department of Environment and Natural Resources (NCDENR) established new regulations for the Falls Lake watershed. Stormwater management is required for new development, with minimum on-site requirements of 30% for site areas less than one acre, and 50% site areas greater than one acre. The remainder of the stormwater management requirements may be met by either implementing or funding off-site offset measures. These off-site offsets must meet at least the baseline nutrient loading rate reductions that would otherwise be achieved on-site.
Mitigation or offset credits can be purchased from either the North Carolina Ecosystem Enhancement Program (NCEEP), or one of the Department of Water Quality (DWQ) approved mitigation banks. Mitigation must be provided and traded within the sub-watershed of interest; projects in the upper Falls Lake watershed must receive mitigation credits established within the upper Falls watershed, and not the lower Falls watershed, for example.

Sources: http://portal.ncdenr.org/web/wq/home?p_p_id=20&p_p_lifecycle=1&p_p_state=exclusive&p_p_mode=view&_20_struts_action=%2Fdocument_library%2Fget_file&_20_folderId=5060450&_20_name=DLFE-43717.pdf

http://www.durhamnc.gov/agendas_new/2011/cws20110815/289371_7934_403550.pdf

5.7.6 Conclusions

With several options and methods for managing stormwater, alternatives to on-site management are available and feasible. Off-site mitigation, mitigation fees, regional stormwater management practices, credit (or offset) banking and trading, or perhaps new and innovative programs are all options for managing stormwater runoff at the watershed scale. With big picture focus comes big opportunity; larger systems, despite their difficulties, can offer significant benefits when implemented properly. The information provided above is not intended to be an exhaustive review of all of the options or potential advantages and disadvantages for alternatives to on-site stormwater management. Communities should research the available options and select an approach that best meets their needs and goals.

In some states, a wastewater treatment plant (WWTP) that is not meeting its effluent water quality goals can purchase credits from another WWTP that is overachieving theirs. Similarly, most MS4s have limited public land on which to implement stormwater controls, and consolidating monies and efforts incentivizes private land owners with viable green infrastructure opportunities to do more than required and profit by doing so. Also, practices that are very expensive, such as stream restoration, have been shown to be very cost effective when compared on a cost per pound of pollutant removed basis. The initial capital threshold can be overcome when fees are paid in by those private land owners and developers that either cannot meet their on-site requirements, or would rather eliminate the risk associated with uncertain site constraints and timelines.

CASE STUDY

Savannah's Off-Site Credit Program

Introduction

In April 2011 Georgia's Department of Natural Resources Board codified the Coastal Stormwater Supplement (CSS) to the Georgia Stormwater Management Manual. This occurred at about the same time as Georgia EPD issued new Phase I MS4 NPDES permits for coastal Georgia communities. Revised MS4 permits required stormwater management practices at least as stringent as the CSS. Consideration of the Runoff Reduction Volume (RRv) described in the CSS was a significant new requirement for land development in Georgia's coastal MS4s. As the RRv also applies to redevelopment, it is a challenge for site plan reviewers and developers on city historic district projects. The City of Savannah's experience presents a good case study on providing the RRv and allowing historic district redevelopment to continue.

Description

Savannah's historic district is a defined area of downtown Savannah with specific zoning and development standards. This leads to several challenges with regard to stormwater management.

Zero setback zoning requirements in the Historic District impact the placement of buildings and parking lots. Zoning codes define the placement and extent of green space on parcels. Lot size and land cost further impact the availability of pervious surface to accommodate new green space and the RRv. Faced with redevelopment plans within the Historic District whose only option was to seek a variance of the RRv requirement, the City of Savannah chose to use the off-site credit provision of the Stormwater Management Ordinance. Savannah's ordinance derives from the Coastal Supplement's model ordinance and states:

> All stormwater management design plans shall include on-site stormwater management practices, unless arrangements are made with the Stormwater Management Director to manage post-construction stormwater runoff in an off-site or regional stormwater management practice. The off-site or regional stormwater management practice must be located on property legally dedicated to that purpose, be designed and sized to meet the post-construction stormwater management criteria presented in the City of Savannah Local Design Manual, provide a level of stormwater quality and quantity control that is equal to or greater than that which would be provided by on-site green infrastructure and stormwater management practices and have an associated inspection and maintenance agreement and plan (City of Savannah Municipal Code Div. II Sec. 4-11031).

To prepare to use the off-site credit provision of the Stormwater Management Ordinance, three steps were required:

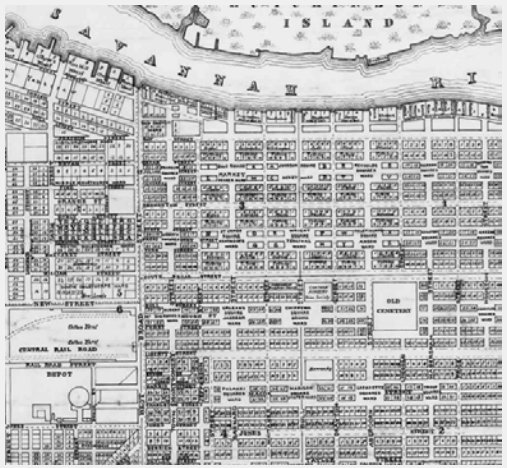


Figure 5.7-2 Property Map of downtown Savannah.

1. Provide and designate off-site GI/LID practices in the City right-of-way that meet the RRv requirement;
2. Update the Local Engineering Design Manual to include an application procedure for use of off-site credit; and
3. Amend the City Revenue Ordinance to allow the City to provide for a Stormwater Management Credit fee and accepting payment for provision of the off-site credit.

In addition, Georgia EPD sought an update to the City Stormwater Management Plan that presented the credits program, described under what circumstances the City would allow this approach, and summarized the City's method of accounting for credits available and used.

CASE STUDY - (CON'T)

Off-site GI/LID Program

In order to collect a fee-in-lieu for stormwater detention, (the City attorney advised that) existing detention structures would need to be in place. A City Streets Department program of brick street replacement with permeable pavement and a City detail for permeable paver construction existed. Off-site management practices within the City right-of-way that were available were sections of brick streets that met the City's permeable pavement standard. At its initiation roughly 3000 square feet of streets were in the "bank".

The Local Design Manual was updated with the following standard:

When GI/LID is provided within the City ROW or property owned by the City in the same drainage basin as the redevelopment, equivalent runoff reduction volume (RRv) can be applied as credit to meet the redevelopment criteria.

At the same time the City prepared the following guidelines and criteria for off-site practices:

- They must provide a level of stormwater quality and quantity control that is equal to or greater than that which would be provided by on-site green infrastructure and stormwater management practices.
- The off-site areas must be in the same drainage basin as the redevelopment.
- The developer's stormwater management plan must demonstrate how it complies with the redevelopment criteria, the local design manual, the City Stormwater Ordinance, and the Coastal Stormwater Supplement.
- Off-site compliance credit is only available for Runoff Reduction Volume or pervious area offsets, and must be applied for through the Application for Off-Site Runoff Reduction Volume Credit in Appendix H of the local design manual.
- A fee-in-lieu contribution to fund the construction of pervious pavement systems or other GI/LID practices in the public right-of-way to benefit redevelopment must be paid to the City before a "certificate of occupancy" can be issued.

A copy of the credit application is provided as Figure 5.7-3 in this case study.

Costs

The City's revenue ordinance was revised to establish the fee for purchasing credits to allow a developer to meet pervious surface requirements based on a square foot or cubic foot charge as follows:

$28.65 per square foot
$59.68 per cubic foot

The square foot charge allows a redevelopment to acquire square feet of pervious surface to meet the City's 20% pervious surface exemption from RRv for redevelopment. The cubic foot charge is for the RRv calculated for the project. Fees established by the City Revenue Ordinance included City permeable pavement installation cost and maintenance, to include resetting the pavers once and monthly street sweeping over a 20-year paver life.

Maintenance

GI/LID maintenance is critical to its efficiency and success at mitigating urban runoff's environmental impact. For green infrastructure in the city right-of-way, maintenance includes inspection for structural integrity and proper function, and regular cleaning. As a GI/LID practice, the MS4 permit requires documentation of inspection and maintenance with each year's NPDES Annual Report. Each green infrastructure project is identified in the City stormwater GIS inventory and scheduled for inspection as required. Regular inspection by the Streets Department also ensures the pavement's structural integrity. Savannah sweeps its historic district streets weekly and uses brush/vacuum sweepers. Their long-term effectiveness will be determined by the Stormwater Department's annual inspections.

CASE STUDY - (CON'T)

Applicant Information		
Name	Email:	
Primary contact:		Title:
Mailing Address		
City:	State:	Zip code:
Telephone number:		Cell number:
Project Site Information		
Location/Address:		Property size (acres)
Project name:		Plan number in ETRACK: ____-_____- Plan
Watershed/Downstream discharge point:		
Application is for off-site RRv _____ or impervious area off-set _____ (check one)		
Credit for off-site stormwater management is only available within city right-of-way or city-owned property.		
Eligibility of off-site Compliance: Documentation of Infeasibility of On-site Compliance		
Please check each eligibility criterion that applies to this site		
☐ Too small/no an area outside of the building foot print		
☐ Soil contamination or other subsurface or geologic condition that creates risks or hazards to infiltration of water into the ground		
☐ Site use that is inconsistent with capture and reuse of storm water (explain below)		
☐ A physical condition that prohibits use of storm water infiltration practice (like seawall, slip piles, walls)		
☐ Other significant site constraints (explain below):		
(explain)		
Water Volume Calculations		
Off-site RRv Calculation		**Off-site Pervious Surface Calculation**
Total off-site Runoff Reduction credit applied for: (cuft)		Total off-site pervious surface credit applied for: (sf)
RRC(off-site) [sf] = RRC (onsite) / 0.42		
Total off-site Runoff Reduction required:		Total off-site pervious surface required:
RRC(total) = RRC(off-site) + 0.20(RRC(off-site))		RRC(total) = RRC(off-site) + 0.20(RRC(off-site))
Total Cost of purchased Run-off Reduction Volume to be managed off-site = $_____		

Figure 5.7-3 Application for Redevelopment Runoff Reduction Volume Credit

References

Bacon, Lisa. Derry, William E., Grits, Michelle. 2001. *Technical Memorandum Compensatory Mitigation for Stormwater: An Evaluation of On-Site Mitigation Advanced Mitigation (Banking) and Environmental Credit Trading Approaches.* Washington Departments of Transportation and Ecology.

Bayon, R. Bloomgarden, E. Kaiser, C. Levine, L. Wachowicz, K. Valderrama, A. 2013. *Creating Clean Water Cash Flows: Developing Private Markets for Green Stormwater Infrastructure in Philadelphia*. Natural Resources Defense Council. Philadelphia, PA

Beller-Simms, N., E. Brown, L. Fillmore, K. Metchis, K. Ozekin, C. Ternieden, and K. Lackey. 2014. *Water/Wastewater Utilities and Extreme Climate and Weather Events: Case Studies on Community Response, Lessons Learned, Adaptation, and Planning Needs for the Future.* Project No. CC7C11 by the Water Environment Research Foundation: Alexandria, VA.

Berahzer, S.I. 2014. *Approaches to Stormwater Management: Stormwater Utilities and Green Infrastructure.* Environmental Finance Center, University of North Carolina at Chapel Hill.

CDM Smith. 2015. *Utility Climate Resiliency Study. Metropolitan North Georgia Water Planning District.*

Center for Watershed Protection (CWP). 2012. *Guidance for Developing an Off-Site Stormwater Compliance Program in West Virginia.* Center for Watershed Protection. Elliott City, MD.

Center for Watershed Protection. 2012. West Virginia Stormwater Management and Design Guidance Manual. West Virginia Department of Environmental Protection and CWP, Charlottsville, VA.

Chesapeake Bay Foundation. 2015. *The Economic Importance of the Bay*. Chesapeake Bay Foundation. Annapolis, MD.

City of Chattanooga. 2014. *Water Quality Program Credits and Incentives Manual.* City of Chattanooga. Chattanooga, TN.

City of Chicago. 2010. *Chicago Climate Action Plan.* City of Chicago Climate Action Plan. Chicago, Illinois.

City of Creedmoor. 2011. *Local Stormwater Program for New Development.* City of Creedmoor. Creedmoor, NC.

City of Durham. 2011. *Falls Reservoir Water Supply Nutrient Strategy: Stormwater Management for New Development.* City of Durham. Durham. NC.

City of Seattle. *"21.33.040 – Stormwater facility credit program."* Municode. n.d. Web 2015.

Ellis, K., C. Berg, D. Caraco, S. Drescher, G. Hoffmann, B. Keppler, M. LaRocco, and A.Turner. 2014. *Low Impact Development in Coastal South Carolina: A Planning and Design Guide*. ACE Basin and North Inlet – Winyah Bay National Estuarine Research Reserves.

Environmental Protection Division, *"Chattahoochee River Basin TMDL Reports."* Environmental Protection Division. n.d. Web. 2015.

ESRI News for Water & Wastewater. 2014. Double Time in Georgia: Coweta County Public Utility District Moves Twice as Fast with ArcGIS on iPad.

Hirschman, David J., John Kosco. 2008. Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program. Center for Watershed Protection, Ellicott City, MD.

Keating, Larry and Dana Habeeb. 2012. *Tracking the Effects of Sea Level Rise in Georgia Coastal Communities.* Georgia Institute of Technology, School of City and Regional Planning.

Kurz, J.S. 2013. Proceedings of the 2013 Georgia Water Resources Conference, held April 10–11, 2013. University of Georgia, Athens, Georgia.

References (con't)

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program,* 841 pp. doi:10.7930/J0Z31WJ2.

Miami-Dade County. 2010. *Climate Change Action Plan.* Miami-Dade County GreenPrint.

National Association of Flood and Stormwater Management Agencies. 2006. Guidance for Municipal Stormwater Funding.

National Society of Professional Engineers Code of Ethics. 2007. NSPE Code of Ethics for Engineers.

O'Neill II, James A. 2010. *Climate Change's Impact on the Design of Water, Wastewater, and Stormwater Infrastructure.* Hydrology Days 2010.

Seattle Office of Sustainability & Environment. 2013. *Seattle Climate Action Plan.*

Seattle Public Utilities. *"Stormwater Facility Credit Calculator."* 2011. PDF file.

Resilient Communities for America. 2013. Local Governments, Extreme Weather, and Climate Change. Media Kit of the Resilient Communities for America Campaign.

UNC Environmental Finance Center. *"GA Stormwater Utility Dashboard."* Environmental Finance Center. n.d. Web. 2013.

US EPA. 2013. *Climate Ready Water Utilities Adaptation Strategies Guide for Water Utilities.* U.S. Environmental Protection Agency, Washington, DC, EPA/817/K-13/001.

Appendix A: Contact Agencies for Stormwater Management Regulations and Programs

Contact Agencies for Stormwater Management Regulations and Programs

National Flood Insurance Act/Flood Disaster Protection Act

Contact Agency	Phone	Address
Federal Emergency Management Agency	770-220-5200	3003 Chamblee Tucker Road Atlanta, GA 30341

Website: https://www.fema.gov/region-iv-al-fl-ga-ky-ms-nc-sc-tn#RegionIVContactInformation

Contact Agency	Phone	Address
Georgia EPD – Floodplain Management Office	404-651-8496	2 Martin Luther King, Jr. Blvd. East Tower, Suite 1152, Atlanta, GA 30334

Website: https://epd.georgia.gov/

Georgia Safe Dams Act

Contact Agency	Phone	Address
Georgia EPD – Safe Dams Program	404-463-1511	2 Martin Luther King, Jr. Blvd. East Tower, Suite 1362, Atlanta, GA 30334

Website: https://epd.georgia.gov/

Municipal NPDES Stormwater Permit Program (Phase I and II)

Contact Agency	Phone	Address
Georgia EPD – Nonpoint Source Program	404-463-1464	2 Martin Luther King Jr. Drive Suite 1462 East, Atlanta, GA 30334

Website: https://epd.georgia.gov/

Industrial NPDES Stormwater Permit Program

Contact Agency	Phone	Address
Georgia EPD – Nonpoint Source Program	404-463-1464	2 Martin Luther King Jr. Drive Suite 1462 East Atlanta, GA 30334

Website: https://epd.georgia.gov/

Contact Agencies for Stormwater Management Regulations and Programs

NPDES Stormwater Permits for Construction Areas

Contact Agency	Phone	Address
Georgia EPD – Nonpoint Source Program	404-463-1464	2 Martin Luther King Jr. Drive,Suite 1462 East Atlanta, GA 30334

Website: https://epd.georgia.gov/

NPDES Municipal Wastewater Discharge

Contact Agency	Phone	Address
Georgia EPD – Wastewater Regulatory	404-463-1511	2 Martin Luther King Jr. Drive, Suite 1152 East Atlanta, GA 30334

Website: https://epd.georgia.gov/

Erosion and Sedimentation Act

Contact Agency	Phone	Address
1) Georgia Soil and Water Conservation Commission	706-552-4470	4310 Lexington Road (30605) P.O. Box 8024 (30603) , Athens, GA

Website: https://gaswcc.georgia.gov/

Contact Agency	Phone	Address
2) State Soil and Water Conservation Districts	(contact above for your district)	

Contact Agency	Phone	Address
3) Georgia EPD – Erosion and Sedimentation Control Unit	404-463-1464	2 Martin Luther King Jr. Drive Suite 1462 East, Atlanta, GA 30334

Website: https://epd.georgia.gov/

Contact Agencies for Stormwater Management Regulations and Programs

Total Maximum Daily Load (TMDL) Program

Contact Agency	Phone	Address
US EPA – Region 4	404-562-9900	Sam Nunn Atlanta Federal Center 61 Forsyth Street, SW , Atlanta, GA 30303-8960

Website: http://www.epa.gov/tmdl/forms/contact-us-about-impaired-waters-and-tmdls#reg4

Contact Agency	Phone	Address
Georgia EPD – TMDL Modeling & Developing Unit	404-463-1511	2 Martin Luther King Jr. Drive Suite 1152, East Tower, Atlanta, GA 30334

Website: http://www2.epa.gov/aboutepa/about-epa-region-4-southeast

River Corridor Protection

Contact Agency	Phone	Address
Georgia DCA – Office of Coordinated Planning	404-679-4940	60 Executive Park, South, NE Atlanta, GA 30329

Website: http://www.dca.ga.gov/

Metropolitan River Protection Act

Contact Agency	Phone	Address
Atlanta Regional Commission (ARC)	404-463-3100	40 Courtland Street, NE Atlanta, GA 30303

Website: www.atlantaregional.com

Georgia Planning Act (Water Supply Watersheds, Groundwater Recharge Areas)

Contact Agency	Phone	Address
Georgia EPD – Watershed Compliance	404-463-1511	2 Martin Luther King Jr. Drive Suite 1152 East, Atlanta, GA 30334

Website: https://epd.georgia.gov/

Contact Agencies for Stormwater Management Regulations and Programs

Groundwater Management / Wellhead Protection Program

Contact Agency	Phone	Address
Georgia EPD – Watershed Compliance	404-463-1511	2 Martin Luther King Jr. Drive Suite 1152 East, Atlanta, GA 30334

Website: https://epd.georgia.gov/watershed-protection-branch-technical-guidance

Source Water Assessment Program

Contact Agency	Phone	Address
Georgia EPD – Source Water Protection Unit	404-656-2750	2 Martin Luther King Jr. Drive Suite 1362 East Atlanta, GA 30334

Website: https://epd.georgia.gov/watershed-protection-branch-technical-guidance

Coastal Management Program and Coastal Marshlands Protection Act

Contact Agency	Phone	Address
Georgia DNR – Coastal Resources Division	912-264-7218	1 Conservation Way Brunswick, GA 31520

Website: http://coastalgadnr.org/

Section 404 of Clean Water Act and Section 10 Rivers and Harbors Act

Contact Agency	Phone	Address
US Army Corps of Engineers, Savannah District (for Central and Coastal Areas of State)	912-652-5279	100 W Oglethorpe Avenue Savannah, GA 31401
US Army Corps of Engineers, Atlanta Office (for North Area of State – top half of state)	678-422-2720	1590 Adamson Parkway The Plaza, Suite 200, Morrow, GA 30260

Website: http://www.usace.army.mil/Missions/CivilWorks/RegulatoryProgramandPermits.aspx

Georgia Land Conservation Program

Contact Agency	Phone	Address
Georgia Environmental Finance Authority	404-584-1000	233 Peachtree Street NE, Harris Tower, Suite 900 Atlanta, Georgia 30303

Website: http://gefa.georgia.gov/georgia-land-conservation-program

Appendix B: Stormwater Management Site Plan Review Checklists

Example Checklist for **Preliminary** Stormwater Management Site Plan Preparation and Review

1. Applicant information
   - ❏ Name, legal address, and telephone number
2. Common address and legal description of site
3. Vicinity map
4. Narrative describing proposed project and post-construction stormwater management measures.
5. Existing and proposed mapping and plans (recommended scale of 1" = 50' or greater detail) which illustrate at a minimum:
   - ❏ Existing and proposed topography (minimum of 2-foot contours recommended)
   - ❏ Perennial and intermittent streams
   - ❏ Mapping of soils from USDA soil surveys
   - ❏ Boundaries of existing vegetation and proposed limits of clearing and grading
   - ❏ Location and boundaries of natural feature protection and conservation areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks, etc.)
   - ❏ Location of existing and proposed roads, buildings, parking lots and other impervious areas
   - ❏ Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
   - ❏ Preliminary estimates of unified stormwater sizing criteria requirements
   - ❏ Preliminary identification and calculation of stormwater site design credits
   - ❏ Preliminary selection and location of structural stormwater controls
   - ❏ Location of existing and proposed conveyance systems such as storm drains, inlets, catch basins, channels, swales, and areas of overland flow
   - ❏ Flow paths
   - ❏ Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
   - ❏ Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings
6. Hydrologic and hydraulic analysis including:
   - ❏ Existing conditions hydrologic analysis for runoff rates, volumes, and velocities showing methodologies used and supporting calculations
   - ❏ Proposed (post-development) conditions hydrologic analysis for runoff rates, volumes, and velocities showing the methodologies used and supporting calculations
   - ❏ Hydrologic and hydraulic analysis of the stormwater management system for all applicable design storms
   - ❏ Preliminary sizing calculations for structural stormwater controls including contributing drainage area, storage, and outlet configuration
   - ❏ Preliminary analysis of potential downstream impact/effects of project, where necessary
7. Preliminary erosion and sediment control plan that at a minimum meets the requirements outlined in the Manual for Erosion and Sediment Control in Georgia
8. Preliminary landscaping plans for structural stormwater controls and any site reforestation or revegetation
9. Preliminary identification of waiver requests

Example Checklist for **Final** Stormwater Management Site Plan Preparation and Review

1. **Applicant information**
   - ❑ Name, legal address, and telephone number
2. **Common address and legal description of site**
3. **Signature and stamp of registered engineer/ landscape architect and designer/owner certification**
4. **Vicinity map**
5. **Narrative describing proposed project and post-construction stormwater management measures.**
6. **Existing and proposed mapping and plans (recommended scale of 1" = 50' or greater detail) which illustrate at a minimum:**
   - ❑ Existing and proposed topography (minimum of 2-foot contours recommended)
   - ❑ Perennial and intermittent streams
   - ❑ Mapping of soils from USDA soil surveys as well as the location of any site-specific borehole investigations that may have been performed
   - ❑ Boundaries of existing vegetation and proposed limits of clearing and grading
   - ❑ Location and boundaries of natural feature protection and conservation areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks, etc.)
   - ❑ Location of existing and proposed roads, buildings, parking lots and other impervious areas
   - ❑ Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
   - ❑ Estimates of unified stormwater sizing criteria requirements
   - ❑ Identification and calculation of stormwater site design credits
   - ❑ Selection and location of structural stormwater controls
   - ❑ Location of existing and proposed conveyance systems such as storm drains, inlets, catch basins, channels, swales, and areas of overland flow
   - ❑ Flow paths
   - ❑ Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
   - ❑ Location and dimensions of proposed channel modifications, such as bridge or culvert crossings
7. **Hydrologic and hydraulic analysis including:**
   - ❑ Time of concentration; pre- and post-development flow path
   - ❑ Existing conditions hydrologic analysis for runoff rates, volumes, and velocities showing methodologies used and supporting calculations
   - ❑ Proposed (post-development) conditions hydrologic analysis for runoff rates, volumes, and velocities showing the methodologies used and supporting calculations
   - ❑ Proposed (post-development) conditions hydraulic analysis for water quality BMPs
   - ❑ Hydrologic and hydraulic analysis of the stormwater management system for all applicable design storms
   - ❑ Final sizing calculations for structural stormwater controls including contributing drainage area, storage, and outlet configuration
   - ❑ Stage-discharge or outlet rating curves and inflow and outflow hydrographs for storage facilities
   - ❑ Final analysis of potential downstream impact/ effects of project, where necessary
   - ❑ Dam safety and breach analysis, where necessary
8. **Representative cross-section and profile drawings and details of structural stormwater controls and conveyances which include:**
   - ❑ Existing and proposed structural elevations (e.g., invert of pipes, manholes, etc.)
   - ❑ Design water surface elevations
   - ❑ Structural details of structural control designs, outlet structures, embankments, spillways, grade control structures, conveyance channels, etc.
9. **Applicable construction specifications**
10. **Erosion and sediment control plan that at a minimum meets the requirements outlined in the Manual for Erosion and Sediment Control in Georgia**
11. **Landscaping plans for structural stormwater controls and any site reforestation or revegetation**
12. **Operations and maintenance plan that includes:**
    - ❑ Name, legal address and phone number of responsible parties for maintenance activities
    - ❑ Description and schedule of maintenance tasks
    - ❑ Description of applicable easements
    - ❑ Description of funding source
    - ❑ Access and safety issues
    - ❑ Procedures for testing, removal, and disposal of sediments, if required
13. **Evidence of acquisition of all applicable local and non-local permits**
14. **Waiver requests**
15. **Evidence of acquisition of all necessary legal agreements (e.g., easements, covenants, land trusts, etc.)**

Appendix C: Stormwater Construction Inspection Checklists

Stormwater Management Construction Inspection Report for:

Bioretention Basin; Bioslopes; Dry Wells; Infiltration Trenches; Organic Filters; Regenerative Stormwater Conveyance; Sand Filters; and Stormwater Planters/Tree Boxes

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Site Preparation: Have erosion and sediment controls been properly installed according to approved plans?				
Is stormwater runoff being diverted around the facility?				
Has the contributing drainage area been fully stabilized?				
Is the area free of heavy equipment or items that can cause compaction?				
Subgrade Preparation: Is subgrade suitable? (free of debris, standing water, properly graded)				
Has compaction of the soils been avoided (for infiltration-based practices)?				
BMP Geometry: Are the BMP footprint and depth correct as shown on the plans?				
Filter Fabric: If called for in the plans, has the filter fabric been installed on the sides of the BMP only according to the specifications?				
Underdrain: If called for in the plans, has the underdrain been installed at the proper location and elevation?				
Are clean-outs installed as called for in the plans?				

Stormwater Management Construction Inspection Report for: (con't)

Bioretention Basin; Bioslopes; Dry Wells; Infiltration Trenches; Organic Filters; Regenerative Stormwater Conveyance; Sand Filters; and Stormwater Planters/Tree Boxes

Inspection Items	Yes	No	N/A	Remarks
Are perforated/non-perforated sections of underdrain installed correctly?				
Is the observation well/outflow drain built according to plans and clean?				
Have the necessary precautions been taken to minimize clogging potential during construction?				
Media Layer(s): Do the stone, sand, mulch, and/or other planting media meet specifications? (attach certification)				
Have the media layers been installed to the design depths?				
Surface: Is the surface free of sediment, fines, and areas of clogging?				
Embankment: Is suitable fill material used for construction of the embankment/berm?				
Vegetation: Does the vegetation meet the plan requirements (if called for), and is it in good health?				
Do the plants meet the planting plan?				
Is the proper mulch depth present?				
Pretreatment: Are the pretreatment facilities installed according to the approved plans?				
Inlets and Overflow: Are inlet and overflow diameters/measurements correct according to the plans?				
Are inlet and overflow inverts at the correct elevation?				
Final Inspection: Can water infiltrate/filter properly into the BMP?				
Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Downspout Disconnects; Site Reforestation/Revegetation; Soil Restoration; and Vegetated Filter Strips

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Site Preparation: Have erosion and sediment controls been properly installed according to approved plans?				
Do site excavation and grading conform to the plans?				
Contributing Drainage Area: Does the impervious area draining to the receiving pervious area match the plans?				
Site Geometry: Does the pervious area match the dimensions and slopes shown on the plan?				
Level Spreader: If called for on the plans, is the level spreader constructed at the proper elevation?				
Vegetation: Does the pervious area vegetation comply with the approved planting plan and specifications?				
Do the topsoil mixture, soil amendments, and/or soil compaction comply with the plans (if required)?				
Final Inspection: Have the contributing impervious area and the receiving pervious area been stabilized?				
Can water flow properly into the receiving pervious area (if called for on the plans)?				
Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Dry Detention Basins; Dry Extended Detention Basins; Multi-Purpose Detention Basins; Stormwater Ponds; Stormwater Wetlands Level 1; Stormwater Wetlands Level 2; and Gravel Wetlands

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Site Preparation: Have erosion and sediment controls been properly installed according to approved plans?				
Contributing Drainage Area: Has the contributing drainage area been fully stabilized?				
Does the area draining to the practice match the plans?				
BMP Geometry: Are the BMP dimensions correct as shown on the plans?				
Are the BMP side slopes constructed as called for on the plans?				
Is a geotextile or clay lining provided (where called for on the plans)?				
Is the BMP installed to the proper depth as shown on the plans?				
Are all internal features constructed as called for on the plans?				
Does the site have proper maintenance and inspection access?				
Embankment: Is suitable fill material used for construction of the embankment/berm?				
Is embankment properly compacted and at the proper elevation and slope?				
Pretreatment: Has the forebay or other pretreatment facility been installed according to the plans?				
Inlets and Conveyance: Have all inlets, flow paths, and underdrains (if called for) been properly installed and at the correct elevations?				

Stormwater Management Construction Inspection Report for: (con't)

Dry Detention Basins; Dry Extended Detention Basins; Multi-Purpose Detention Basins; Stormwater Ponds; Stormwater Wetlands Level 1; Stormwater Wetlands Level 2; and Gravel Wetlands

Inspection Items	Yes	No	N/A	Remarks
Outfall: Has the outfall been constructed with adequate erosion protection as specified on the plans?				
Is an emergency spillway provided?				
Overflow: Has the riser or outflow structure been properly installed and at the correct elevations?				
Pond Buffer/Vegetation (where applicable): Do the buffer dimensions match the plans?				
Does the vegetation meet the plan requirements, and is it in good health?				
Final Inspection: Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Enhanced Dry Swales; Enhanced Wet Swales; and Grass Channels

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Site Preparation: Have erosion and sediment controls been properly installed according to approved plans?				
Is stormwater runoff being diverted around the facility?				
Has the contributing drainage area been fully stabilized?				
BMP Geometry: Are the BMP dimensions and longitudinal slope correct as shown on the plans?				
Are the channel side slopes constructed as called for on the plans?				
Have the check dams been properly installed and to the correct elevations (where applicable)?				
Filter Fabric: If called for in the plans, has the filter fabric been installed on the sides of the BMP only according to the specifications?				
Underdrain: If called for in the plans, has the underdrain been installed at the proper l ocation and elevation?				
Are clean-outs installed as called for in the plans?				
Are perforated/non-perforated sections of underdrain installed correctly?				
Media Layer(s): Do the stone, sand, mulch, and/or other media meet specifications? (attach certification)				

Stormwater Management Construction Inspection Report for: (con't)

Enhanced Dry Swales; Enhanced Wet Swales; and Grass Channels

Inspection Items	Yes	No	N/A	Remarks
Have the media layers been installed to the design depths?				
Vegetation: Does the pervious area vegetation comply with the approved planting plan and specifications?				
Do the topsoil mixture, soil amendments, and/or soil compaction comply with the plans (if required)?				
Pretreatment: Are the pretreatment facilities installed according to the approved plans?				
Inlets and Overflow: Are inlet and overflow inverts at the correct elevation?				
Final Inspection: Can water properly flow through/into the BMP?				
Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Gravity Separators; Proprietary Systems; and Underground Detention

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Site Preparation: Have erosion and sediment controls been properly installed according to approved plans?				
Subgrade Preparation: Is subgrade suitable? (free of debris, standing water, properly graded)				
Prefabricated Structure: Does BMP conform to shop drawings?				
Do type and locations of openings meet the plan requirements?				
Cast-In-Place Structure: Does BMP conform to structural drawings?				
Does concrete meet strength and mix requirements? (attach certification)				
Access: Is access for each chamber provided as called for on the plans?				
Inlet: Is the inlet the correct size and elevation?				
Internal Conveyance: Are internal conveyance paths (underdrains, filter media, bypass) constructed as called for on the plans?				
Overflow/Bypass: Is the overflow or bypass constructed as called for in the plans?				
Backfill: Does the backfill soil meet the plans and specifications?				
Final Inspection: Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Green Roofs

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Deck Preparation: Is the deck free of all trash, debris, grease, oil, water, and moisture?				
Are all concrete surfaces properly cured, dry, and free of voids, cracks, or holes?				
Is a leak detection device installed as called for on the plans?				
Water Proofing: Is the water proofing layer installed as called for on the plans?				
Has a water test or leak detection test been conducted?				
Overflow Drains: Are the overflow drains installed as called for on the plans?				
Root Barrier: Is the root barrier installed as called for on the plans?				
Drainage Layer: Is the drainage layer installed as called for on the plans?				
Media: Does the planting media meet the material and depth requirements on the plans?				
Vegetation: Does the vegetation meet the plan requirements, and is it in good health?				
Irrigation: Does the irrigation system meet plan specifications?				
Final Inspection: Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Permeable Paver System; Pervious Concrete; and Porous Asphalt

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
Site Preparation: Have erosion and sediment controls been properly installed according to approved plans?				
Is stormwater runoff being diverted around the facility?				
Has the contributing drainage area been fully stabilized?				
Subgrade Preparation: Is subgrade suitable? (free of debris, standing water, properly graded)				
Has subgrade been compacted as specified in the plans?				
BMP Geometry: Are the BMP dimensions correct as shown on the plans?				
Filter Fabric: If called for in the plans, has the filter fabric been installed on the sides of the BMP only according to the specifications?				
Underdrain and Reservoir Layer: If called for in the plans, does the underdrain meet the plan requirements with correct hole pattern, elevation, and slope?				
Does the stone reservoir meet the plan requirements (clean, washed, free of fines) and is it installed to design depth?				
Surface Material: Does the surface material meet the plan requirements and has it been properly installed?				
Is the surface even and can runoff spread evenly across it?				
Has the surface material had adequate curing time (for Porous Asphalt and Pervious Concrete)?				

Stormwater Management Construction Inspection Report for: (con't)

Permeable Paver System; Pervious Concrete; and Porous Asphalt

Inspection Items	Yes	No	N/A	Remarks
Is the surface free of fines and areas of clogging?				
Over Flow: Have the overflow devices (where applicable) been installed at the correct elevation?				
Final Inspection: Can water infiltrate properly into the BMP?				
Does the reservoir storage layer drain within 48 hours?				
Is the BMP complete and fully functional?				

Stormwater Management Construction Inspection Report for:

Rainwater Harvesting

Project Name and Address: _____

_____

Project/File Number: _____

Date of Submittal: _____

Designer: _____

Telephone #: _____

Contractor: _____

Telephone #: _____

Inspector(s): _____

Date: _____ Time: _____

BMP Type: _____

Inspection Items	Yes	No	N/A	Remarks
General: Has the collection, treatment, and distribution system been designed and installed in accordance with the Georgia Rainwater Harvesting Guidelines?				
Subgrade Preparation: Has the subgrade been properly prepared and tank foundation installed as shown on plans?				
Contributing Drainage Area: Does the rooftop area draining to the tank match the plans?				
Conveyance and Pretreatment: Do the gutters match the plans with the correct sizing, elevation, and slope?				
Is the pretreatment or first flush diversion system properly sized and installed?				
Are mosquito screens properly installed on all tank openings?				
Indoor Use: If the collected water is to be used inside for toilet flushing or evaporative cooling, does the local building code allow that?				
Does the proposed treatment system meet the requirements of the Georgia Rainwater Harvesting Guidelines?				
Has the system been designed and installed in accordance with the Georgia State Amendments to the International Plumbing Code?				
Pump System: Have the pump (if applicable) and piping to end-uses (been properly installed?				

Stormwater Management Construction Inspection Report for: (con't)

Rainwater Harvesting

Inspection Items	Yes	No	N/A	Remarks
Overflow: Is the overflow device installed properly and at the correct elevation?				
Final Inspection: Is water conveyed into tank and to end-uses appropriately?				
Is the BMP complete and fully functional?				

Appendix D: Example Stormwater Facility Maintenance Agreement

Example Stormwater Facility Maintenance Agreement

STATE OF GEORGIA

[ENTER CITY OR COUNTY NAME]

AGREEMENT OF STORMWATER MANAGEMENT
STORMWATER FACILITY AND
GREEN INFRASTRUCTURE/LOW IMPACT DEVELOPMENT INTEGRATED MANAGEMENT PRACTICES (GI/LID IMPs)
INSPECTION AND MAINTENANCE

WHEREAS, the property owner, _____ recognizes that the storm drain structures, pipes,
(Development Entity or Owner Name)
water quality integrated management practices and all aspects of a stormwater management facility (hereinafter "stormwater management measures") must be maintained for the development called _____ of [CITY NAME], Georgia,
(Development Name)
[COUNTY NAME] County, Georgia, being more particularly described by the legal description in Exhibit "A" attached hereto and made a part hereof; and,

WHEREAS, the property owner, _____ , is the owner of the real property more particularly described
(Development Entity or Owner Name)
on the attached Exhibit "B" - Development Plan (hereinafter referred to as "the property"), and,

WHEREAS, _____ , whose title is _____ , is the person responsible for
(Authorized Representative Name)
carrying out all requirements of this Declaration and of the [CITY OR COUNTY NAME], Georgia Code and Area-wide MS4 stormwater management plan for the inspection and maintenance of the stormwater management measures on the property identified in Exhibit "B", and,

WHEREAS, the property owner, its administrators, executors, successors, heirs and assigns, agree that the health, safety and welfare of the citizens of the city require that stormwater management measures be constructed and maintained on the property to function as designed, and,

WHEREAS, the Stormwater Facility and GI/LID IMPs Inspection and Maintenance agreement(s) for the development called be recorded with _____ , of [CITY NAME], Georgia, [COUNTYNAME] County, Georgia, shall
(Development Name)
the [COUNTY NAME] County Clerk of Court and a copy of recorded agreement(s) provided to [CITY OF COUNTY DEPARTMENT NAME] prior to the release of a Certificate of Occupancy, and

Example Stormwater Facility Maintenance Agreement: (con't)

WHEREAS, the [CITY OR COUNTY NAME], Georgia Code and Area-wide MS4 permit require that the stormwater management measures, as shown on the approved development plans and specifications, be constructed and maintained by the property owner, its administrators, executors, successors, heirs and assigns.

NOW, THEREFORE, in consideration of the foregoing premises and following terms and conditions, the undersigned agrees as follows:

SECTION 1.
The stormwater management measures including GI/LID IMPs shall be constructed by the property owner in accordance with the plans and specifications for the development as submitted to and approved by the [ENTER CITY OF COUNTY NAME], Georgia (hereinafter "City OR County").

SECTION 2.
The property owner, its administrators, executors, successors, heirs and assigns shall maintain all aspects of the stormwater management measures including GI/LID IMPs in good working condition acceptable to the City and in accordance with the development specific Inspection and Maintenance Procedures (as defined below) to ensure the control measures functioning as designed. A schedule of long term maintenance activities, including how often routine inspection and maintenance will occur, shall be in accordance with the attached Exhibit "C" (collectively, the "Inspection and Maintenance Procedures"). Such Schedule shall also include plans for annual inspections by a qualified inspector, as determined by the [CITY OR COUNTY DEPARTMENT NAME], to ensure proper performance of the facility between scheduled maintenance and remedies for the default thereof.

SECTION 3.
The property owner shall establish a dedicated source of funding that will allow for a budget capable of covering the costs associated with maintenance, staff, equipment, and the repair and replacement of stormwater management measures including GI/LID IMPs components as necessary, and helps to ensure the continued functioning of IMPs as designed. The Property owner shall submit a copy of financial documentation (in form and substance as mutually agreed upon by the Property owner and the City OR County) confirming established dedicated source of funding to [CITY OF COUNTY DEPARTMENT NAME], if requested or prior to the release of a Certificate of Occupancy.

SECTION 4.
The property owner, its administrators, executors, successors, heirs and assigns shall provide records of all inspections, maintenance and repairs of the stormwater management measures to the [CITY OF COUNTY DEPARTMENT NAME] on an annual basis, if requested. Such records include items inspected and details of maintenance and repairs performed.

Example Stormwater Facility Maintenance Agreement: (con't)

SECTION 5.
The property owner, its administrators, executors, successors, heirs and assigns hereby grants permission to the City OR County, its authorized agents and employees, to enter upon the property for regular inspections, periodic investigations, observation, measurement, enforcement, and sampling and testing of the stormwater management measures whenever the City deems necessary. Inspections may include, but are not limited to: reviewing maintenance and repair records; sampling discharges, surface water, groundwater, and material or water in stormwater management measures; and evaluating the condition of the stormwater management measures and practices. The City OR County, its authorized agents and employees, shall duly notify the owner of the property or the representative on site prior to such entry, except in the case of an emergency.

SECTION 6.
In the event the property owner, its administrators, executors, successors, heirs and assigns fail to maintain the stormwater management measures according to the approved plans and the Maintenance and Inspection Schedule, the City OR County shall notify by certified mail the person specified herein as the person responsible for carrying out the maintenance plan. Such notice shall specify the measures necessary to comply with the site plans and the maintenance schedule and shall specify the amount of time (but in event less than thirty (30) days) within which such measures shall be completed. If the responsible person fails or refuses to meet the requirements of this Declaration, the City OR County, thirty (30) days (or the time set forth in the violation notice, whichever is greater) after the written notice is sent (except, that in the event the violation constitutes an immediate danger to public health or public safety, 24 hours notice shall be sufficient), may enter the property to correct a violation of the design standards or maintenance requirements by performing necessary work to place the facility or practice in proper working condition. The City OR County will assess the property owner or grantor for the cost of repair work. It is expressly understood that the City OR County is under no obligation to maintain or repair the stormwater management measures and in no event shall this Declaration be construed to impose any such obligation on the City OR County.

SECTION 7.
It is the intent of this Declaration to ensure the proper maintenance of the stormwater management measures including GI/LID IMPs by the property owner; provided, however, that this Declaration shall not be deemed to create or affect any additional liability on the property owner for damage alleged to result from or caused by storm water runoff in addition to any such liability otherwise existing under applicable law.

SECTION 8.
Sediment accumulation and other waste materials resulting from the operation of the stormwater management measures including IMPs shall be removed by the property owner. The property owner shall make arrangements at the property owner's expense for the removal and off-site disposal of all accumulated sediments and other waste materials.

Example Stormwater Facility Maintenance Agreement: (con't)

SECTION 9.
In the event the property owner sells or transfers the property, the transferring property owner shall provide to the [CITY OF COUNTY DEPARTMENT NAME], a Declaration of Transfer of Inspection and Maintenance Responsibilities of stormwater management measures including GI/LID IMPs signed by the transferring property owner and the transferee and witnessed by a public notary to document that all inspections and maintenance, and related financial responsibilities have been transferred and communicated to such transferee. Upon such transfer or conveyance of the property by the transferring property owner, all obligations of the transferring property owner hereunder shall automatically be transferred and assigned to, and assumed by transferee and such transferee shall and become the property owner under this Agreement.

SECTION 10.
The property owner, its administrators, executors, successors, heirs and assigns hereby indemnifies and holds harmless the City OR County and its authorized agents and employees for any and all damages, accidents, casualties, occurrences or claims which may arise or be asserted against the City from the construction, presence, existence or maintenance of the stormwater management measures by the property owner or the City OR County, except to the extent caused by the gross negligence or willful misconduct of the City OR County or its authorized agents and employees. In the event a claim is asserted against the City OR County, its authorized agents or employees, the City OR County shall promptly notify the property owner and the property owner shall defend at its own expense any suit based on such claim, except as set forth in the foregoing sentence.

SECTION 11.
This Agreement shall be recorded among the deed records of [COUNTY NAME] County and shall constitute a covenant running with the land shall be binding on the property owner. The City OR County will not release the Certificate of Occupancy for the property until such time that this agreement has been recorded with the [COUNTY NAME] County Clerk of Court.

SECTION 12.
This Agreement may be enforced by proceedings at law or in equity by or against the undersigned and their respective successors in interest.

SECTION 13.
Invalidation of anyone of the provisions of this Agreement shall in no way effect any other provision and all other provisions shall remain in full force and effect.

Example Stormwater Facility Maintenance Agreement: (con't)

SECTION 14.

This Agreement complies with the provisions of the City OR COUNTY of [City OR County Name] Code of Ordinances, Article [Article NUMBER AND TITLE] and [City OR County Name] MS4 Permit, Part 3, 3.3.10, and the property owner, its administrators, executors, successors, heirs and assigns acknowledge that it must obtain all required permits, submit all required plans and follow all provisions of Article [Article NUMBER AND TITLE]. Since under Article [Article NUMBER AND TITLE] the responsibility for the operation and maintenance of the stormwater management measures passes to any successor owner, this Declaration shall be binding on all subsequent owners of the property.

SECTION 15.

Additional provisions that relate directly to the individual needs and requirements of this specific site plan as identified in Exhibit "A" and Exhibit "B" are attached hereto and made a part hereof. Such additional provisions have been discussed with and presented to the Augusta Engineering Department Director.

IN WITNESS WHEREOF, the Declarant has executed this Declaration on the _____ day of _____ , 20____ .

Declarant:

Property Owner: _____

(Development Entity or Owner Name)

Signed and Sealed

_____ (Seal)

By: _____

_____

Witness

Title: _____

Corporate Seal

_____

Notary Public

EXHIBIT "A" Property legal description

EXHIBIT "B" Approved Development Plan

EXHIBIT "C" Stormwater Management Measures Inspection and Maintenance Schedule

GWINNETT COUNTY
STORMWATER MANAGEMENT MANUAL
2020 EDITION

VOLUME 2: TECHNICAL HANDBOOK

Gwinnett

BACK TO VOL 1

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1. Introduction

1.1 Objective of the Manual

The objective of the Gwinnett County Stormwater Management Manual is to provide guidance on the best post-construction stormwater management practices applicable to Gwinnett County to minimize the negative impacts of increasing stormwater runoff and its associated pollutants. The goal is to provide an effective tool for local governments and the development community to reduce both stormwater quality and quantity impacts and protect downstream areas and receiving waters.

This Manual does not cover construction site sediment and erosion control practices. Guidance on these practices can be found in the latest edition of the *Manual for Erosion and Sediment Control in Georgia*.

1.2 Organization of the Manual

The Gwinnett County Stormwater Management Manual is organized as a two volume set, with each volume published as a separate document. You are currently reading Volume 2 of the GCSMM Manual.

Volume 1 of the Manual, the *Local Government Guide to Stormwater Management*, is designed to provide guidance for local jurisdictions on the basic principles of effective urban stormwater management. Volume 1 covers the environmental, economic and social problems resulting from urban stormwater runoff and the need for local communities to address urban stormwater quantity and quality through recommended stormwater management standards and local stormwater programs. It also provides an overview of integrated stormwater management and technologies and tools for implementing stormwater management programs.

Volume 2 of the Manual, the *Technical Handbook*, provides guidance on the techniques and measures that can be implemented to meet a set of recommended stormwater management standards for new development and redevelopment. Volume 2 is designed to provide the site designer or engineer, as well as the local plan reviewer or inspector, with all of the information on best management practices (BMPs) required to effectively address and control both water quality and quantity on a development site. This includes guidance on site planning, better site design practices, hydrologic techniques, criteria for the selection and design of stormwater BMPs, and drainage system design, as well as construction and maintenance information.

The *Georgia Pollution Prevention Guidebook*, Volume 3 of the GSMM, is a compendium of pollution prevention practices for stormwater quality for use by local jurisdictions, businesses and industry, and local citizens.

1.3 Target Audience

The users of Volume 2 will be site planners, engineers, contractors, plan reviewers, and inspectors from local government and the development community.

Local jurisdictions may adopt and apply the recommended standards for new development and redevelopment in this Manual directly as part of their local development code. Further, local jurisdictions may use Volume 2 to review stormwater site plans and provide technical advice, and may adopt any part of the guidance and design criteria for best management practices and drainage design contained in this Manual as their local engineering design requirements. Check with the local review authority for more information.

Those parties involved with site development will utilize Volume 2 for technical guidance and information on the preparation of stormwater site plans, the use of better site design techniques, hydrologic techniques, selection and design of appropriate best management practices, and drainage (hydraulic) design.

1.4 How to Use This Volume

The following provides a guide to the various chapters of Volume 2 of the Manual.

- **Chapter 1 (Introduction).** This chapter discusses the overall purpose and organization of the Manual, the intended use and other background information.
- **Chapter 2 (Stormwater Management Planning, Design, & Implementation).** This chapter provides the framework for addressing stormwater runoff on new development and redevelopment sites. This chapter includes the following sections:

  - » Section 2.1 – *The Need for Stormwater Management.* This section provides an overview of the impacts of stormwater runoff.
  - » Section 2.2 – *Stormwater Management Standards & Numerical Sizing Criteria.* This section contains the stormwater management recommended standards for new development and redevelopment sites, explains the four sizing criteria for water quality, channel protection, overbank flood protection, and extreme flood protection, and describes the approaches for meeting the criteria through the use of better site design practices and best management practices (BMPs).
  - » Section 2.3 – *Stormwater Better Site Design & Techniques.* This section covers the toolkit of better site design practices and techniques that can be used to reduce the amount of stormwater runoff and pollutants generated from a site.
  - » Section 2.4 – *Stormwater Site Planning & Design.* This section outlines the typical contents and procedures for preparing a stormwater site plan.
- **Chapter 3 (Stormwater Hydrology).** This chapter presents engineering topics and methods used in stormwater drainage, conveyance and facility design.
  - » Section 3.1 – *Methods for Estimating Stormwater Runoff.* This section provides an overview of the different hydrologic methods and their application.
  - » Section 3.2 – *Methods for Estimating Stormwater Volume Reduction – Design Worksheet.* This section provides an overview of the spreadsheet developed to calculate runoff reduction and TSS removal.
  - » Section 3.3 – *Storage Design.* This section covers the criteria and general procedures for the design and evaluation of stormwater storage (detention and retention) facilities.
  - » Section 3.4 – *Outlet Structures.* This section outlines various stormwater facility outlet types and provides criteria and procedures for water quality outlet design.
- **Chapter 4 (Stormwater Best Management Practices).** This chapter contains the information and guidance for the selection and design of best management practices (BMPs) for managing stormwater quantity and quality. It is divided into the following sections:
  - » Section 4.1 – *Stormwater BMP Overview.* This section provides an overview of the best management practices that can be used to reduce and/or treat stormwater runoff and/or mitigate the effects of increased runoff peak rates, volumes, and velocities.
  - » Section 4.2 through 4.29 – *Individual BMP Sections.* These sections contain detailed information and design criteria for each best management practice and their applicability for sites with a demonstrated ability to meet stormwater management goals.
- **Chapter 5 (Stormwater Drainage System Design).** This chapter provides technical guidance on the various elements of stormwater drainage design. This chapter includes the following sections:
  - » Section 5.1 – *Stormwater Drainage Design Overview.*
  - » Section 5.2 – *Minor Drainage System Design.* This section provides guidelines and design criteria for gutter and inlet hydraulics, and provides an overview of storm drain pipe system design.
  - » Section 5.3 – *Culvert Design.* This section covers criteria and procedures for the design and evaluation of culverts.
  - » Section 5.4 – *Open Channel Design.* This section describes the criteria and calculations for the design of open stormwater drainage channels.
  - » Section 5.5 – *Energy Dissipation Design.* This section includes information and design criteria for a number of energy dissipators, including riprap aprons, riprap basins and baffled outlets.
- **Appendix A** – *Rainfall Tables for Georgia.* This appendix contains a weblink to the National Oceanic and Atmospheric Administration's website where users can access the most recent rainfall data available.
- **Appendix B** – *Best Management Practice Design Examples.* This appendix includes design examples for different best management practices: stormwater pond, bioretention area, surface sand filter, infiltration trench, vegetated filter strip, and enhanced (dry) swale.
- **Appendix C** – *Nomographs & Design Aids.* This appendix includes various nomographs and other design tools primarily referenced throughout Chapter 5.

- **Appendix D** – *Planting & Soil Guidance*. This appendix provides landscaping criteria and plant selection guidance for stormwater management facilities. A site specific landscaping plan for each BMP is recommended.
- **Appendix E** – *Best Management Practice Operations & Maintenance*. The appendix provides general information and checklists for the inspection and maintenance of post-construction stormwater best management practices. A site specific checklist regarding the inspection and maintenance needs for each BMP is recommended.

1.5 Regulatory Status of the Manual

The Georgia Stormwater Management Manual is designed to provide Georgia communities with comprehensive guidance on a Low Impact Development (LID)-based approach to natural resource protection, stormwater management and site design that they can use to better protect the state's valuable natural resources from the negative impacts of land development and nonpoint source pollution.

It is recommended that all Georgia communities use the information presented in this manual, or an equivalent post-construction stormwater management manual, to regulate new development and redevelopment activities. For those communities that are covered under the National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Program, adoption of this manual specifically Volume 2 (or an equivalent), is required.

Communities are encouraged to review and modify the contents of this manual, as necessary, to meet local watershed and stormwater management goals and objectives while still maintaining the essence of a Low Impact Development (LID)-based approach for stormwater management.

Gwinnett County has chosen to modify the Georgia Stormwater Management Manual by merging it with the previous County Design Manual, the SSFISS. The result is this new manual, the Gwinnett County Stormwater Management Manual (GCSMM).

1.6 How to Find the Manual on the Internet

All three volumes of the Georgia Stormwater Management Manual are available in Adobe Acrobat PDF document format for download at the following Internet address:
http://www.georgiastormwater.com

The Gwinnett County Stormwater Management Manual (GCSMM) is available in Adobe Acrobat PDF document format for download on the Gwinnett County Website.

1.7 Contact Information

If you have any technical questions or comments on the GSMM, please send an email to:
info@georgiastormwater.com

If you have any technical questions or comments concerning guidance in the GCSMM contact the Gwinnett County Department of Planning and Development, or the Gwinnett County Department of Water Resources.

2. Stormwater Management Planning, Design, & Implementation

2.1 The Need for Stormwater Management

2.1.1 Impacts of Development and Stormwater Runoff

Land development changes not only the physical, but also the chemical and biological conditions of Georgia's waterways and water resources. This chapter describes the changes that occur due to development and the resulting stormwater runoff impacts.

2.1.1.1 DEVELOPMENT CHANGES LAND AND RUNOFF

When land is developed, the hydrology, or the natural cycle of water is disrupted and altered. Clearing removes the vegetation that intercepts, slows and returns rainfall to the air through evaporation and transpiration. Grading flattens hilly terrain and fills in natural depressions that slow and provide temporary storage for rainfall. The topsoil and sponge-like layers of humus are scraped and removed and the remaining subsoil is compacted. Rainfall that once seeped into the ground now runs off the surface. The addition of buildings, roadways, parking lots and other surfaces that are impervious to rainfall further reduces infiltration and increases runoff.

Depending on the magnitude of changes to the land surface, the total runoff volume can increase dramatically. These changes not only increase the total volume of runoff, but also accelerate the rate at which runoff flows across the land. This effect is further exacerbated by drainage systems such as gutters, storm sewers and lined channels that are designed to quickly carry runoff to rivers and streams.



Figure 2.1.1-1 Clearing and Grading Alter the Hydrology of the Land

Development and impervious surfaces also reduce the amount of water that infiltrates into the soil and groundwater, thus reducing the amount of water that can recharge aquifers and feed streamflow during periods of dry weather.



Figure 2.1.1-2 Impervious Cover Increases Runoff Peak Flows and Volumes While Reducing Recharge

Finally, development and urbanization affect not only the quantity of stormwater runoff, but also its quality. Development increases both the concentration and types of pollutants carried by runoff. As it runs over rooftops and lawns, parking lots and industrial sites, stormwater picks up and transports a variety of contaminants and pollutants to downstream waterbodies. The loss of the original topsoil and vegetation removes a valuable filtering mechanism for stormwater runoff.

The cumulative impact of development and urban activities, and the resultant changes to both stormwater quantity and quality in the entire land area that drains to a stream, river, lake or estuary determines the conditions of the waterbody. This land area that drains to the waterbody is known as its watershed. Urban development within a watershed has a number of direct impacts on downstream waters and waterways. These impacts include:

- Changes to stream flow
- Changes to stream geometry
- Degradation of aquatic habitat
- Water quality impacts

The remainder of this section discusses these impacts and why effective stormwater management is needed to address and mitigate them.

2.1.2 Addressing Stormwater Impacts

The focus of this Manual is how to effectively deal with the impacts of urban stormwater runoff through effective and comprehensive *stormwater management*. Stormwater management involves the reduction, prevention, and mitigation of stormwater runoff quantity and quality impacts as described in this chapter through a variety of methods and mechanisms.

Volume 2 of this Manual deals with ways that developers in Georgia can effectively implement stormwater management to address the impacts of new development and redevelopment, and reduce, prevent, and mitigate problems associated with stormwater runoff. This is accomplished by:

- ❏ Developing land in a way that minimizes its impact on a watershed, and reduces both the amount of runoff and pollutants generated through infiltration, evapotranspiration, and reuse.
- ❏ Using the most current and effective erosion and sedimentation control practices during the *construction* phase of development
- ❏ Reducing and controlling stormwater runoff peaks, volumes, and velocities to prevent both downstream flooding and streambank channel erosion
- ❏ Treating *post-construction* stormwater runoff before it is discharged to a waterway
- ❏ Implementing pollution prevention practices to prevent stormwater from becoming contaminated in the first place
- ❏ Using various techniques to maintain groundwater recharge

The remainder of Chapter 2 outlines a technical approach for incorporating all of these stormwater management approaches into the development process. The next section discusses stormwater management standards and numerical sizing criteria for new development and redevelopment in Georgia that aim to meet the objectives above.

2.2 Stormwater Management Standards & Numerical Sizing Criteria

2.2.1 Overview

This section presents a comprehensive set of recommended performance standards for stormwater management for development activities in the state of Georgia. The overall aim is to provide an integrated approach to address both the water quality and quantity problems associated with stormwater runoff due to development.

The goal of a set of recommended stormwater management standards for areas of new development and significant redevelopment is to reduce the impact of post-construction stormwater runoff on the watershed. This can be achieved by:

1. Maximizing the use of site design and nonstructural methods such as canopy interception, infiltration, evapotranspiration and reuse to reduce the generation of runoff and pollutants;
2. Managing and treating stormwater runoff though the use of best management practices (BMPs);
3. Implementing pollution prevention practices to limit potential stormwater contaminants.

It should be noted that the standards presented here are recommended for all communities in Georgia. They may be adopted by local jurisdictions as stormwater management development **requirements** and/or may be modified to meet local or watershed-specific stormwater management goals and objectives. Please consult your local review authority for more information.

The recommended standards for development are designed to assist local governments in complying with regulatory and programmatic requirements for various state and Federal programs including the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit program and the National Flood Insurance Program under FEMA.

2.2.2 Recommended Standards for Development

2.2.2.1 APPLICABILITY

It is required that the stormwater management standards listed below be required for any new development or redevelopment site that meets one or more of the following criteria:

1. New development that includes the creation or addition of 5,000 square feet or greater of new impervious surface area, or that involves land disturbing activity of 1 acre of land or greater.
2. Redevelopment that includes the creation or addition of 5,000 square feet or greater of new impervious surface area, or that involves land disturbing activity of 1 acre or more.
3. Any commercial or industrial new development or redevelopment, regardless of size, with a Standard Industrial Classification (SIC) code that falls under the NPDES Industrial Stormwater Permit program, or is a hotspot land use as defined below.

Since runoff from smaller developments can cause water quality and quantity impacts as well, an individual community may choose to adopt more stringent area criteria, especially if it determines that a significant amount of development in the community falls below these thresholds. In addition, a community may choose to apply stormwater management standards on a case-by-case basis to smaller developments if it determines that the quantity, quality, and or rate of stormwater runoff coming from the site will cause significant impacts to the receiving waters due to the type or location of the development site or other circumstances.

Definitions

» **New development** is defined as land disturbing activities, structural development (construction, installation or expansion of a building or other structure), and/or creation of impervious surfaces on a previously undeveloped site.

» **Redevelopment** is defined as structural development (construction, installation, or expansion of a building or other structure), creation or addition of impervious surfaces, replacement of impervious surfaces not as part of routine maintenance, and land disturbing activities associated with structural or impervious development on a previously developed site. Redevelopment does not include such activities as exterior remodeling.

» **Previously developed site** is defined as a site that has been altered by paving, construction, and/or land use that would typically have required regulatory permitting to have been initiated (alterations may exist now or in the past).

Pre-development hydrology is defined as (a) for new development, the runoff curve number determined using natural conditions hydrologic analysis based on the natural, undisturbed condition of the site immediately before implementation of the proposed development; and (b) for redevelopment, the existing conditions hydrograph may take into account the existing development when defining the runoff curve number and calculating existing runoff, unless the existing development causes a negative impact on downstream property.

» A **hotspot** is defined as a land use or activity on a site that has the potential to produce higher than normally found levels of pollutants in stormwater runoff. As defined by the administrator, hotspot land use may include gasoline stations, vehicle service and maintenance areas, industrial facilities (both permitted under the Industrial Stormwater General Permit and others), material storage sites, garbage transfer facilities, and commercial parking lots with high-intensity use.

The goals and policies of individual communities should determine the specific definition of **pre-development**. It is recommended that pre-development be defined as "natural, undisturbed conditions." This can be simplified to a set type of vegetative condition, such as "woods in good condition," if appropriate. However, where redevelopment incentives are desired, or where flooding concerns do not currently exist, pre-development may be defined as the condition of the site immediately prior to the implementation of the proposed project.

Exemptions

In order to avoid excessive regulation on individual residential lots, maintenance and repair efforts, and environmental projects, the following development activities are required to be exempted from the stormwater management standards:

1. Individual single family residential lots (single family lots that are part of a subdivision or phased development project should not be exempt from the standards);

2. Additions or modifications to existing single-family structures;
3. Duplex residential units that do not meet the criteria listed above.
4. Land disturbing activity conducted by local, state, authority, or federal agencies, solely to respond to an emergency need to protect life, limb, or property or conduct emergency repairs;
5. Land disturbing activity that consists solely of cutting a trench for utility work and related pavement replacement; and
6. Land disturbing activity conducted by local, state, authority, or federal agencies, whose sole purpose is to implement stormwater management or environmental restoration.
7. Single family homes and duplex homes, not part of a larger common plan of development such as a subdivision, are no longer exempt from the applicability rule. If they meet the applicability criteria of impervious surface area or land disturbance acreage, they must meet the stormwater criteria.
8. Redevelopment of single family homes and duplex homes, not part of a larger common plan of redevelopment such as a subdivision, are no longer exempt from the applicability rule. If they meet the applicability criteria of impervious surface area or land disturbance acreage, they must meet the stormwater criteria.

Additional Requirements

New development or redevelopment in critical or sensitive areas, or as identified through a watershed study or plan, may be subject to additional performance and/or regulatory criteria. Furthermore, these sites may need to utilize or restrict certain structural practices in order to protect a special resource or address certain water quality or drainage problems identified for a drainage area.

Off-Site Compliance Alternatives

Where site conditions do not permit the achievement of the minimum runoff reduction goals for development or redevelopment onsite, alternatives exist for compliance as follows:

1. **Off-Site Mitigation** – Runoff reduction practices at a redevelopment or retrofit site are implemented at another location within the same watershed. The off-site project would likely be initiated by the site developer, and the MS4 plays a coordinating and/or project approval role.
2. **Fee in Lieu** – The developer pays the MS4 (or its assigned entity) an appropriate fee. Fees from multiple sites are aggregated by the MS4 to construct public stormwater projects. This requires an active role for the MS4.

These alternatives are discussed in further detail in Section 5.7 of Vol. 1.

2.2.2.2 REQUIRED STORMWATER MANAGEMENT STANDARDS

The following stormwater management performance standards shall be required for new development or redevelopment sites falling under the applicability criteria above. Standard #3-Runoff Reduction will be required after December 10, 2020.

❑ **Standard #1 – Natural Resource Inventory**

Prior to the start of any land disturbing activities (including any clearing or grading activities), acceptable site reconnaissance and surveying techniques shall be used to complete a thorough assessment of the natural resources, both terrestrial and aquatic, found on a development site.

The site's critical natural features and drainage patterns shall be identified early in the site planning process. The natural resources inventory shall be used to identify and map the natural resources on site, as they exist prior to the start of any land disturbing activities. The identification, and subsequent preservation and/or restoration of these natural resources, through the use of better site design practices, helps reduce the negative impacts of the land development process "by design".

Resources to be identified and mapped during the natural resources inventory, include, at a minimum (as applicable):

» Topography and Steep Slopes (i.e., Areas with Slopes Greater Than 15%)
» Natural Drainage Divides and Patterns
» Natural Drainage Features (e.g., swales, basins, depressional areas)
» Wetlands
» Water Bodies
» Floodplains
» Aquatic Buffers
» Shellfish Harvesting Areas
» Soils
» Erodible Soils

- » Groundwater Recharge Areas
- » Wellhead Protection Areas
- » Trees and Other Existing Vegetation
- » High Quality Habitat Areas
- » Protected River Corridors
- » Protected Mountains
- » Karst Areas

All relevant resources shall be shown on the Stormwater Management Site Plan (Standard #12).

❑ **Standard #2 –Better Site Design Practices for Stormwater Management**

All site designs shall implement a combination of approaches collectively known as *stormwater better site design practices* to the maximum extent practicable. Through the use of these practices and techniques, the impacts of urbanization on the natural hydrology of the site and water quality can be significantly reduced. The goal is to reduce the amount of stormwater runoff and pollutants that are generated, provide for natural on-site control and treatment of runoff, and optimize the location of stormwater management facilities. Better site design concepts can be viewed as both water quantity and water quality management tools and can reduce the size and cost of required BMPs.

Site designs shall preserve the natural drainage and treatment systems and reduce the generation of additional stormwater runoff and pollutants to the maximum extent practicable. More information on Better Site Design is provided in Section 2.3.

The use of certain better site design practices that provide water quality benefits allows for a reduction (known as a "credit") of the water quality volume. The applicable design practices and stormwater site design credits are covered in Section 2.3.2.

❑ **Standard #3 – Runoff Reduction**

Runoff reduction practices shall be sized and designed to retain the first 1.0 inch of rainfall on the site to the maximum extent practicable. Runoff reduction practices are stormwater BMPs used to disconnect impervious and disturbed pervious surfaces from the storm drain system, thereby reducing post-construction stormwater runoff rates, volumes, and pollutant loads. Since runoff reduction practices actually eliminate stormwater runoff (and the pollutants associated with it), rather than simply treating or detaining runoff, they can contribute to several of the other performance standards, while providing many additional benefits. If the entire 1.0 inch of rainfall can be retained onsite using runoff reduction methods, the community may choose to waive the water quality treatment volume in Standard #4. If the entire 1.0-inch runoff reduction standard cannot be achieved, the remaining runoff from the 1.2-inch rainfall event must be treated by BMPs to remove at least 80% of the calculated average annual post-development TSS loading from the site per Standard #4 Water Quality.

Runoff reduction percentages are assigned to applicable BMPs that reduce the amount of stormwater required for treatment, and subsequently reduce the other stormwater management volumes, incentivizing their use. Runoff reduction practices inherently reduce TSS and other pollutants to provide water quality treatment (i.e. 100% pollutant removal for stormwater retention, infiltration, evaporation, transpiration, or rainwater harvesting and reuse). This standard is quantified and expressed in terms of engineering design criteria through the specification of the runoff reduction volume (RR_V), which is equal to the runoff generated on a site from 1.0 inches of rainfall. Individual runoff reductions specific to each practice are described in detail in Chapter 4.

While runoff reduction practices provide important water quality benefits, as described in Volume 1, Chapter 2, certain conditions, such as karst topography, soils with very low infiltration rates, high groundwater, or shallow bedrock, may lead a community to choose to waive or reduce the runoff reduction requirement. Alternatively, these conditions can be addressed on a site-specific basis. If the RR_V of 1.0 inches of rainfall cannot be achieved, adequate documentation should be provided to the local development review authority to show that no additional runoff reduction practices can be used on the development site.

❑ **Standard #4 – Water Quality**

Stormwater management systems shall be designed to retain or treat the runoff from 85% of the storms that occur in an average year, and reduce average annual post-development total suspended solids loadings by 80%. Averaged from rainfall events across the state of Georgia, this equates to treating storm events of 1.2 inches or less, as well as the first 1.2 inches of runoff for all larger storm events.

Communities may choose to waive the water quality treatment volume from this standard if 100% of the 1.0-inch runoff reduction volume is achieved. If the entire 1.0-inch runoff reduction standard cannot be achieved, the remaining runoff from the 1.2-inch rainfall event must be treated by BMPs to remove at least 80% of the calculated average annual post-development TSS loading from the site.

This standard is quantified and expressed in terms of engineering design criteria through specification of the water quality volume (WQ_v), which is equal to the runoff generated on a site from 1.2 inches of rainfall. The WQ_v must be treated to the 80% TSS removal performance goal.

This standard assumes that BMPs will be designed, constructed and maintained according to the criteria in this Manual. Stormwater discharges from land uses or activities with higher or special potential pollutant loadings may require the use of specific structural practices and pollution prevention practices. A detailed overview of BMPs is provided in Chapter 4.

❑ **Standard #5 – Stream Channel Protection**

Stream channel protection shall be provided by using all of the following three approaches:

1. 24-hour extended detention storage of the 1-year, 24-hour return frequency storm event
2. Erosion prevention measures, such as energy dissipation and velocity control
3. Preservation of the applicable stream buffer.

Stream channel protection requirements are further described in Section 2.2.4.2.

The first method of providing stream bank protection is the extended detention of the 1-year, 24-hour storm for a period of 24 hours using BMPs. It is known that the increase in runoff due to development can dramatically increase stream channel erosion. This standard is intended to reduce the frequency, magnitude and duration of post-development bankfull flow conditions. The volume to be detained is also known as the channel protection volume (CP_v). The use of nonstructural site design practices and runoff reduction BMPs that reduce the total amount of runoff may also reduce CP_v by a proportional amount. Refer to **Table 4.1.3-1** (BMP Selection Guide) for applicable BMPs. Where runoff reduction practices are used, an adjusted curve number (CN) is computed that is lower than the original CN based on an actual stormwater volume removed from the total runoff, see Section 3.1.7.5 for additional information.

This requirement may be waived by a local jurisdiction for sites that discharge directly or through piped stormwater drainage systems into larger streams, rivers, wetlands, lakes, estuaries, or other situations where the reduction in the smaller flows will not have an impact on stream bank or channel integrity.

The second stream bank protection method is to implement velocity control, energy dissipation, stream bank stabilization, and erosion prevention practices and structures as necessary in the stormwater management system to prevent downstream erosion and stream bank damage. Energy dissipation and velocity control methods are discussed in Section 5.5.

The third method of providing for stream channel protection is through the establishment of riparian stream buffers on the development site. Stream buffers not only provide channel protection but also water quality benefits and protection of streamside properties from flooding. It is recommended that 100-foot buffers be established where feasible. Additional stream buffer guidelines are presented in Section 2.3.

❑ **Standard #6 – Overbank Flood Protection**

Overbank flood protection shall be provided by controlling the post-development peak discharge rate to the pre-development rate (natural or existing condition, as applicable) for the 2-year through the 25-year return frequency storm events. Overbank flood protection requirements are further described in Section 2.2.4.3.

The use of nonstructural site design practices and runoff reduction BMPs that reduce the total amount of runoff will also reduce Q_{p25} by a proportional amount. Refer to **Table 4.1.3-1** (BMP Selection Guide) for applicable BMPs. Where runoff reduction practices are used, an adjusted curve number (CN) is computed that is lower than the original CN based on an actual stormwater volume removed from the total runoff, see Section 3.1.7.5 for additional information.

This standard may be adjusted by a local jurisdiction for areas where all downstream conveyances and receiving waters have the natural capacity to handle the full build-out 25-year storm through a combination of channel capacity and overbank flood storage without increasing flood stages above pre-development flood levels.

❑ **Standard #7 – Extreme Flood Protection**

Extreme flood protection shall be provided by controlling and/or safely conveying the 100-year, 24-hour storm event (denoted Q_f). This is accomplished either by (1) controlling Q_f through BMPs to maintain the existing 100-year floodplain, or (2) by sizing the on-site conveyance system to safely pass Q_f and allowing it to discharge into a receiving water whose protected floodplain is sufficiently sized to account for extreme flow increases without causing damage. In this case, the extreme flood protection criterion may be waived by a local jurisdiction in lieu of provision of safe and effective conveyance to receiving waters that have the capacity to handle flow increases to maintain 100-year level.

The use of nonstructural site design practices and runoff reduction BMPs that reduce the total amount of runoff will also reduce Q_f by a proportional amount. Refer to **Table 4.1.3-1** (BMP Selection Guide) for applicable BMPs. Where runoff reduction practices are used, an adjusted curve number (CN) is computed that is lower than the original CN based on an actual stormwater volume removed from the total runoff, see Section 3.1.7.5 for additional information.

Existing and future floodplain areas shall be preserved to the extent possible. Extreme flood protection requirements are further described in Section 2.2.3.

❑ **Standard #8 – Downstream Analysis**

Due to peak flow timing and runoff volume effects, some structural practices fail to reduce discharge peaks to pre-development levels downstream from the development site. A downstream peak flow analysis shall be provided to the point in the watershed downstream of the site or the stormwater management system where the area of the site comprises 10% of the total drainage area. This is to help ensure that there are minimal downstream impacts from the developed site. The downstream analysis may result in the need to resize BMPs, or may allow the waiving of some unnecessary peak flow controls altogether. The use of a downstream analysis and the "ten-percent" rule are discussed in Section 3.1.9.

❑ **Standard #9 – Construction Erosion and Sedimentation Control**

Erosion and sedimentation control practices shall be utilized during the construction phase of development or during any land disturbing activities.

All new development and redevelopment sites must meet the regulatory requirements for land disturbance activities under the Georgia Erosion and Sedimentation Control Act and/or the NPDES General Permit for Construction Activities. This involves the preparation and implementation of an approved erosion and sedimentation control plan, including appropriate best management practices, during the construction phase of development.

Further guidance on practices for construction site erosion and sedimentation control can be found in the latest version of the *Manual for Erosion and Sediment Control in Georgia*.

Better site design practices and techniques that can reduce the total amount of area that needs to be cleared and graded should be implemented wherever possible. It is essential that erosion and sedimentation control be considered and implemented in stormwater concept plans and throughout the construction phase to prevent damage to natural stormwater drainage systems and previously constructed best management practices and conveyance facilities.

❑ **Standard #10 – Stormwater Management System Operation and Maintenance**

The stormwater management system, including all best management practices and conveyances, shall have an operation and maintenance plan to ensure that it continues to function as designed. See Appendix E for more information on stormwater operation and maintenance.

All new development and redevelopment sites are to prepare a comprehensive operation and maintenance plan for the on-site stormwater management system. This is to include all of the stormwater management system components, including drainage facilities, BMPs, and conveyance systems. To ensure that stormwater management systems function as they were designed and constructed, the operation and maintenance plan must provide:

1. A clear assignment of stormwater inspection and maintenance responsibilities
2. The routine and non-routine maintenance tasks to be undertaken
3. A schedule for inspection and maintenance
4. Any necessary legally binding maintenance agreements

❑ **Standard #11 – Pollution Prevention**

To the maximum extent practicable, the development or redevelopment project shall implement pollutant prevention practices and have a stormwater pollution prevention plan.

All new development and redevelopment sites are to consider pollution prevention in the design and operation of the site, and prepare a formal stormwater pollution prevention plan if circumstances warrant it. Specific land use types and hotspots may need to implement more rigorous pollution prevention practices. The preparation of pollution prevention plans and the full set of pollution prevention practices are covered in Volume 3 of this Manual.

❑ **Standard #12 – Stormwater Management Site Plan**

The development project shall prepare a stormwater management site plan for local government review that addresses Standard #1 through Standard #11. All new development and redevelopment sites will require the preparation of a stormwater management site plan for development activities. A stormwater site plan is a comprehensive report that contains the technical information and analysis to allow a local review authority to determine whether a proposed new development or redevelopment project meets local stormwater regulatory requirements and manages stormwater runoff so that stormwater runoff-related hazards are not created and existing runoff-related problems are not exacerbated, either upstream or downstream from or within the boundaries of the property being developed. See, Volume 1, Section 4.3 and other local stormwater regulatory requirements for specific guidance.

2.2.3 Numerical Sizing Criteria Overview

This section presents an integrated approach for meeting the volume-based stormwater runoff quality and quantity management standards for development (see Section 2.2.2) by addressing the key adverse impacts of stormwater runoff from a development site. The purpose is to provide a framework for designing a stormwater management system to:

- Improve water quality through runoff reduction and/or water quality treatment (Recommended Standard #3 and #4);
- Prevent downstream stream bank and channel erosion (Recommended Standard #5);
- Reduce downstream overbank flooding (Recommended Standard #6); and
- Safely pass or reduce the runoff from extreme storm events (Recommended Standard #7).

For these objectives, an integrated set of engineering criteria, known as the *Unified Stormwater Sizing Criteria*, have been developed which are used to size and design best management practices. **Table 2.2.3-1** briefly summarizes the criteria. Recommended standard #3 and #4 (water quality) can be achieved by using one of the two standards listed below. The local community will select and require either Runoff Reduction (Standard #3) and/or Water Quality Treatment (Standard #4). See Section 4.2.3 of Volume 1 for more information.

Table 2.2.3-1 Summary of the Gwinnett County Stormwater Sizing Criteria for Stormwater Control and Mitigation

Sizing Criteria		Description
Water Quality	Runoff Reduction, RR_v (Standard #3)	Retain or reduce the runoff for the first 1.0 inch of rainfall, or to the maximum extent practicable. Since runoff reduction practices eliminate stormwater runoff, and the pollutants associated with it, rather than treating or detaining, they can contribute to other stormwater management standards. If the entire 1.0 inch runoff reduction cannot be achieved, the remaining runoff from the 1.2 inch rainfall must be treated, as described in Standard #4.
	Treatment, WQ_v (Standard #4)	Retain or treat the runoff from 85% of the storms that occur in an average year. For Georgia, this equates to providing water quality treatment for the runoff resulting from a rainfall depth of 1.2 inches. The water quality treatment goal is to reduce average annual post-development total suspended solids loadings by 80%.
Channel Protection		Provide extended detention of the 1-year, 24 hour storm event released over a period of 24 hours to reduce bankfull flows and protect downstream channels from erosive velocities and unstable conditions.
Overbank Flood Protection		Provide peak discharge control of the 2-25-year, 24 hour storm events such that the post-development peak rate does not exceed the predevelopment rate to reduce overbank flooding.
Extreme Flood Protection		Evaluate the effects of the 100-year, 24 hour storm on the stormwater management system, adjacent property, and downstream facilities and property. Manage the impacts of the extreme storm event through detention controls and/or floodplain management.

Each of the unified stormwater sizing criteria are intended to be used in conjunction with the others to address the overall stormwater impacts from a development site. When used as a set, the unified criteria control the entire range of hydrologic events, from the smallest runoff producing rainfalls to the 100-year, 24 hour storm. **Figure 2.2.3-1** graphically illustrates the relative volume requirements of each of the unified stormwater sizing criteria as well as demonstrates that the criteria are "nested" within one another, i.e., the extreme flood protection volume requirement also contains the overbank flood protection volume, the channel protection volume and the water quality treatment volume. **Figure 2.2.3-2** shows how these volumes would be nested in a typical stormwater wet pond designed to handle all four criteria.

Also shown is the sediment storage volume. The pond must be dredged when the sediment storage volume is full to maintain its sediment removal effectiveness, and its channel, overbank flood and extreme flood protection capabilities.

The following pages describe the four sizing criteria in detail and present guidance on how to properly compute and apply the required storage volumes.

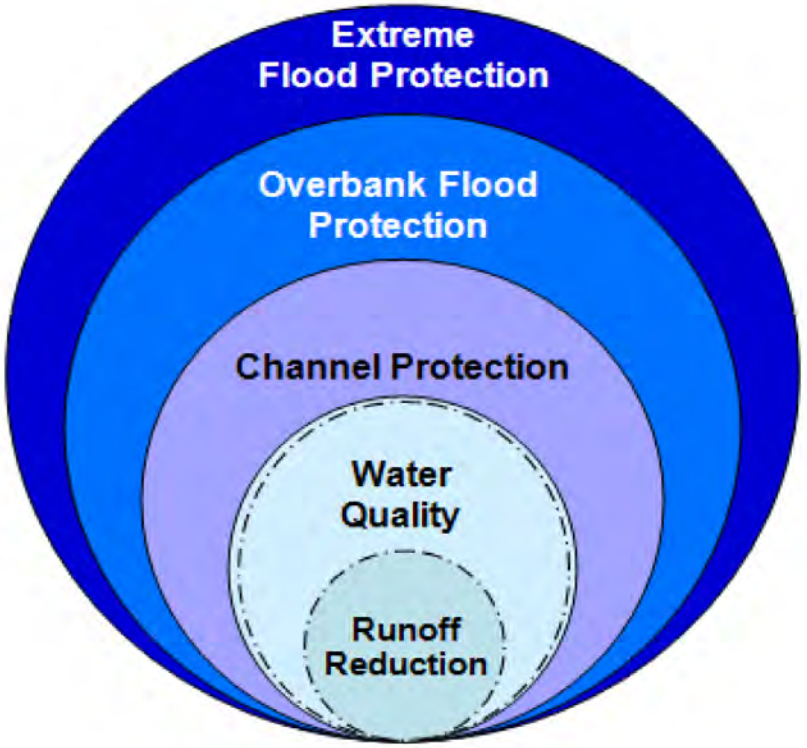


Figure 2.2.3-1 Representation of the Unified Stormwater Sizing Criteria

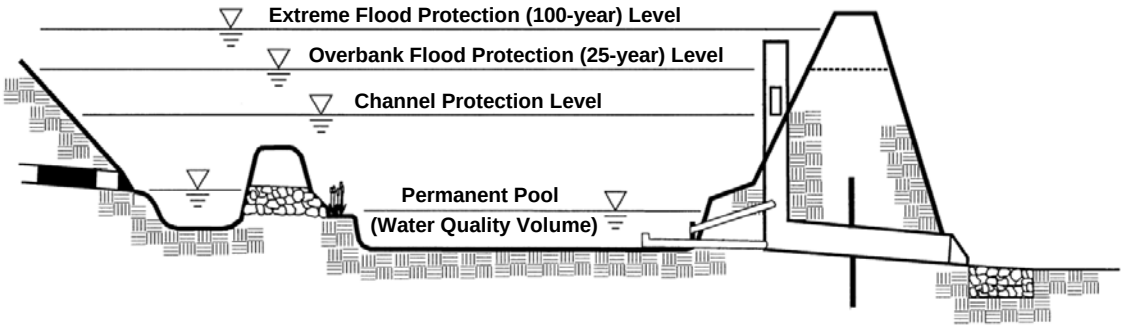


Figure 2.2.3-2 Unified Sizing Criteria Water Surface Elevations in a Stormwater (Wet) Pond

2.2.4 Description of Unified Stormwater Sizing Criteria

2.2.4.1 WATER QUALITY VOLUME (WQ_v)

As noted in Recommended Standard #3 and #4, the water quality goal can be accomplished either through runoff reduction or water quality treatment or some combination of the two. For more information on either water quality approach, see Section 2.2.2.2.

The Runoff Reduction approach to the Water Quality sizing criterion, denoted RR_v, specifies the reduction or elimination of the total pollution load inherent in stormwater runoff by intercepting and reducing or eliminating the first 1.0 inch of rainfall, or to the maximum extent practicable. The Runoff Reduction Volume is a runoff volume that is directly related to the amount of impervious cover at a site.

In numerical terms, it is equivalent to a rainfall depth of 1.0 inches (or other target rainfall amount specified by a local community) multiplied by the volumetric runoff coefficient (R_v) and the site area, and is calculated using the formula below:

$$RR_v = \frac{P \times R_v \times A}{12}$$

Where:

RR_v = runoff reduction volume (cubic ft)
P = target runoff reduction rainfall (often 1.0 inches)
R_v = 0.05 + 0.009(I) where I is *percent* impervious cover
A = site area in square feet

The Water Quality sizing criterion, denoted WQ_v, specifies the retention and/or treatment required to remove a significant percentage of the total pollution load inherent in stormwater runoff by intercepting and retaining or treating the 85th percentile storm event, which is equal to 1.2 inches (i.e., all the runoff from 85% of the storms that occur on average during the course of a year and a portion of the runoff from all storms greater than 1.2 inches). The Water Quality Volume is a runoff volume that is directly related to the amount of impervious cover at a site.

In numerical terms, it is equivalent to a rainfall depth of 1.2 inches multiplied by the volumetric runoff coefficient (R_v) and the site area, and is calculated using the formula below:

$$WQ_v = \frac{1.2R_vA}{12}$$

Where:

WQ_v = water quality volume (in cubic ft)
R_v = 0.05 + 0.009(I) where I is *percent* impervious cover
A = site area in square feet

Discussion

Hydrologic studies show that small-sized, frequently occurring storms account for the majority of rainfall events that generate stormwater runoff. Consequently, the runoff from these storms also accounts for a major portion of the annual pollutant loadings. Therefore, by eliminating, retaining, or treating these frequently occurring smaller rainfall events and a portion of the stormwater runoff from larger events, it is possible to effectively mitigate the water quality impacts from a developed area.

A water quality volume (WQ_v) is specified to size best management practices (BMPs) to reduce/eliminate or treat these small storms up to a maximum runoff depth and the "first flush" of all larger storm events. For Georgia, this maximum depth was determined to be the runoff generated from the 85th percentile storm event (i.e., the storm event that is greater than 85% of the storms that occur within an average year). The 85th percentile volume was considered the point of optimization between pollutant removal ability and cost-effectiveness. Capturing and treating a larger percentage of the annual stormwater runoff would provide only a small increase in additional pollutant removal, but would considerably increase the required size (and cost) of the best management practices.

Based on a rainfall analysis, a value of 1.2 inches for the 85th percentile storm was selected as an average for the entire state. **Thus, the statewide water quality treatment volume criterion is equal to the runoff from the first 1.2 inches of rainfall**. A stormwater management system designed for the WQ_v treatment will retain or treat the runoff from all storm events of 1.2 inches or less, as well as the first 1.2 inches of runoff for all larger storm events. For the runoff reduction approach, a best management practice eliminating or reducing the stormwater runoff from all storm events of 1.0 inches or less, as well as the first 1.0 inches of runoff for all larger storm events will also meet the Water Quality criterion. The correlation between the 1.2 inch treatment requirement for water quality volume and the 1.0 inch volume based reduction is the following:

Given that an 80% TSS removal rate for the 1.2 inch rainfall event is the standard for addressing water quality, 100% TSS removal through volume reduction of the 1.0 inch rainfall event will address the same requirement. In another method of describing total TSS removal, 80% of 1.2 inches (0.96) approximately equates to 100% of 1.0 inches.

The volumetric runoff coefficient (R_v) was derived from a regression analysis performed on rainfall runoff volume data from a number of cities nationwide and is a shortcut method considered adequate for runoff volume calculation for the type of small storms normally considered in stormwater quality calculations.

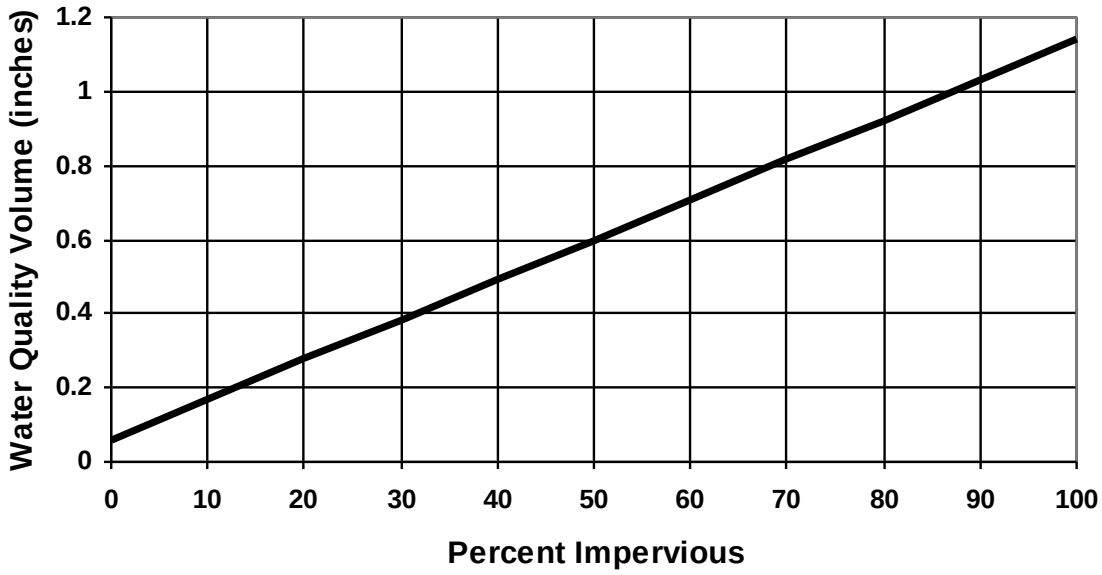


Figure 2.2.4-1 Water Quality Volume versus Percent Impervious Area

Figure 2.2.4-1 shows a plot of the Water Quality Volume versus impervious area percentage.

TSS Reduction Goal

This Manual follows the philosophy of removing pollutants to the "maximum extent practicable" through the use of a percentage removal performance goal. The approach taken in this Manual is to require treatment of the WQ_v from a site to reduce post-development total suspended solids (TSS) loadings by 80%, as measured on an average annual basis. TSS was chosen as the representative stormwater pollutant for measuring treatment effectiveness for several reasons:

1. The use of TSS as an "indicator" pollutant is well established.
2. Sediment and turbidity, as well as other pollutants of concern that adhere to suspended solids, are a major source of water quality impairment due to urban development in Georgia watersheds.
3. A large fraction of many other pollutants of concern are either removed along with TSS, or at rates proportional to the TSS removal.
4. The 80% TSS removal level is reasonably attainable using well-designed best management practices (for typical ranges of TSS concentration found in stormwater runoff).

TSS is a good indicator for many stormwater pollutants. However, the removal performance for pollutants that are soluble or that cannot be removed by settling will vary depending on the best management practice. For pollutants of specific concern, individual analyses of specific pollutant sources and the appropriate removal mechanisms should be performed.

Determining the Runoff Reduction (RR_V) and Water Quality Volumes (WQ_v)

» **Measuring Impervious Area**: The area of impervious cover can be taken directly off a set of plans or appropriate mapping. Where this is impractical, NRCS TR-55 land use/ impervious cover relationships can be used to estimate impervious cover. I is expressed as a percent value not a fraction (e.g., I = 30 for 30% impervious cover).

» **Multiple Drainage Areas**: When a development project contains or is divided into multiple drainage areas, RR_V and WQ_v should be calculated and addressed separately for each drainage area.

- Calculate the target RR_v for the entire site. To receive the runoff reduction credit for the project, the target RR_v should be met for all drainage areas within the site. Should a portion of the site not be managed by a BMP or a drainage area not providing the target RR_v, the other drainage areas will be required to have RR_v values greater than the target to ensure the entire site RR_v requirement is met.

OR

- Calculate the WQ_v for the entire site. To satisfy the WQ_v for the project, the WQ_v should be met for all drainage areas within the site. Should a portion of the site not be managed by a BMP or a drainage area not providing the WQ_v, the other drainage areas will be required to provide greater than the WQ_v to ensure the entire site WQ_v goal is met.

» **Off-site Drainage Areas**: Off-site drainage may be excluded from the calculation of the RR_V and WQ_v if the drainage is routed around the site.

» **Credits for Site Design Practices**: The use of certain better site design practices may allow the WQ_v to be reduced through the subtraction of a site design "credit." These site design credits are described in Section 2.3.

» **Determining the Peak Discharge for the Water Quality Storm**: When designing off-line structural control facilities, the peak discharge of the water quality storm (Q_{wq}) can be determined using the method provided in Section 3.1.

» **Extended Detention of the Water Quality Volume**: The water quality treatment requirement can be met by providing a 24-hour drawdown of a portion of WQ_v in a wet stormwater pond or wetland system (as described in Section 4.25). Referred to as water quality ED (extended detention), it is different than providing extended detention of the 1-year, 24 hour storm for the channel protection volume (CP_v). The ED portion of the WQ_v may be included when routing the CP_v.

» RR_V and WQ_v can be expressed in cubic feet by multiplying by 43,560.

» RR_V and WQ_v can also be expressed in watershed-inches by removing the area (A) and the "12" in the denominator.

2.2.4.2 CHANNEL PROTECTION (CP_V)

The Channel Protection sizing criterion specifies that *24 hours of extended detention be provided for runoff generated by the 1-year, 24-hour rainfall event* to protect downstream channels. The required volume needed for 1-year extended detention, denoted CP_v, is roughly equivalent to the required volume needed for peak discharge control of the 5- to 10-year storm.

- CP_v control is not required for post-development discharges less than 2.0 cfs at each individual discharge location
- The use of nonstructural site design practices and runoff reduction practices that reduce the total amount of runoff will also reduce the channel protection volume by a proportional amount.
- The channel protection criteria may be waived by a local jurisdiction for sites that discharge directly into larger streams, rivers, wetlands, lakes, or estuaries where the reduction in the smaller flows will not have an impact on stream bank or channel integrity.

Discussion

The increase in the frequency and duration of bankfull flow conditions in stream channels due to urban development is the primary cause of stream bank erosion and the widening and down-cutting of stream channels. Therefore, channel erosion downstream of a development site can be significantly reduced by storing and releasing stormwater runoff from the channel-forming runoff events (which corresponds approximately to the 1-year, 24 hour storm event) in a gradual manner to ensure that critical erosive velocities and flow volumes are not exceeded.

Determining the Channel Protection Volume (CP_v)

- » **CP_v Calculation Methods**: Several methods can be used to calculate the CP_v storage volume required for a site. Subsection 3.1.5 and Appendix B illustrate the recommended average outflow method for volume calculation.
- » **Hydrograph Generation**: The NRCS TR-55 hydrograph methods provided in Section 3.1 can be used to compute the runoff hydrograph for the 1-year, 24-hour storm.
- » **Rainfall Depths**: The rainfall depth of the 1-year, 24-hour storm will vary depending on location and can be determined from rainfall data found in the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 publication, or online using the *Precipitation Frequency Data Server* database for any location across Georgia (http://hdsc.nws.noaa.gov/hdsc/pfds/).
- » **Multiple Drainage Areas**: When a development project contains or is divided into multiple drainage areas, CP_v may be distributed proportionally to each drainage area.
- » **Off-site Drainage Areas**: Off-site drainage areas should be modeled as "present condition" for the 1-year storm event. If there are adequate upstream channel protection controls, then the off-site area can be modeled as "forested" or "natural" condition. A best management practice located "on-line" will need to safely bypass any off-site flows.
- » **Routing/Storage Requirements**: The required storage volume for the CP_v may be provided above the WQ_v storage in stormwater ponds and wetlands with appropriate hydraulic control structures for each storage requirement.
- » **Control Orifices**: Orifice diameters for CP_v control of less than 3 inches are not recommended without adequate clogging protection (see Section 3.3).

2.2.4.3 OVERBANK FLOOD PROTECTION (Q_{P25})

The Overbank Flood Protection criterion specifies that the *post-development 2-25-year, 24-hour storm peak discharge rates, denoted $Q_{p2\text{-}25}$, not exceed the pre-development (natural or existing condition, as applicable) discharge rates*. This is achieved through detention of runoff from the 2-25-year event.

- Larger storms (> 25-year) are partially attenuated through the control of Q_{p25}.
- The use of nonstructural site design practices and runoff reduction practices that reduce the total amount of runoff will also reduce Q_{p25} by a proportional amount.

Discussion

The purpose of overbank flood protection is to prevent an increase in the frequency and magnitude of damaging out-of-bank flooding (i.e., flow events that exceed the capacity of the channel and enter the floodplain). It is intended to protect downstream properties from flooding at middle-frequency storm events.

This criterion may be adjusted by a local jurisdiction for areas where all downstream conveyances are designed to handle runoff from the full buildout 25-year storm, or where it can be demonstrated that no downstream flooding will occur as a result of a proposed development (see Section 3.1.9). In this case, the overbank flood protection criterion may be waived by a local jurisdiction in lieu of provision of safe and effective conveyance to a major river system, lake, wetland, or estuary that have capacity to handle flow increases at the 25-year level.

Determining the Overbank Flood Protection Volume (Q_{p25})

- » **Peak-Discharge and Hydrograph Generation**: The NRCS TR-55 or USGS hydrograph methods provided in Section 3.1 can be used to compute the peak discharge rate and runoff for the 25-year, 24-hour storm.

- **Rainfall Depths**: The rainfall depth of the 2-25-year, 24-hour storm will vary depending on location. Within Gwinnett County this can be determined from rainfall data found in Chapter 3.1.3, Rainfall Estimation.
- **Off-site Drainage Areas:** Off-site drainage areas should be modeled as "present condition" for the 2-25-year storm event and do not need to be included in Overbank Flood Protection estimates, but can be ro ted through a best management practice.
- **Downstream Analysis**: Downstream areas should be checked to ensure there is no peak flow increase above pre-development conditions to the point where the site area is 10% of the total drainage to that point.

2.2.4.4 EXTREME FLOOD PROTECTION (Q_f)

The Extreme Flood Protection criterion specifies that all stormwater management facilities be designed to *safely handle the runoff from the 100-year, 24-hour return frequency storm event, denoted Q_f.* This is accomplished either by:

1. Controlling Q_f through on-site or regional best management practices to maintain the existing 100-year floodplain. This is done where residences or other structures have already been constructed within the 100-year floodplain fringe area; or
2. By sizing the on-site conveyance system to safely pass Q_f and allowing it to discharge into a receiving water whose protected full buildout floodplain is sufficiently sized to account for extreme flow increases without causing damage.

Local flood protection (levees, floodwalls, flood-proofing, etc.) and/or channel enlargements may be substituted as appropriate, as long as adequate conveyance and structural safety is ensured through the measure used, and stream environmental integrity is adequately maintained.

Discussion

The intent of the extreme flood protection is to prevent flood damage from infrequent but large storm events, maintain the boundaries of the mapped 100-year floodplain, and protect the physical integrity of the best management practices as well as downstream stormwater and flood control facilities.

It is recommended that Q_f be used in the routing of runoff through the drainage system and stormwater management facilities to determine the effects on the facilities, adjacent property, and downstream. Emergency spillways of best management practices should be designed appropriately to safely pass the resulting flows.

Determining the Extreme Flood Protection Criteria (Q_f)

- **Peak-Discharge and Hydrograph Generation**: The NRCS TR-55 or USGS hydrograph methods provided in Section 3.1 can be used to compute the peak discharge rate and runoff for the 100-year, 24-hour storm.
- **Rainfall Depths**: The rainfall depth of the 100-year, 24-hour storm to be used in calculations for Gwinnett County projects can be found in Volume II, Chapter 3.1.3 Rainfall Estimation.
- **Off-site Drainage Areas**: Off-site drainage areas should be modeled as "full buildout condition", with no detention, for the 100-year storm event to ensure safe passage of future flows.
- **On-site Drainage Areas**: The 100-year flow shall be based on on-site upstream areas being developed per the development plans.
- **Downstream Analysis**: If Q_f is being detained, downstream areas shall be checked to ensure there is no peak flow increase above pre-development conditions to the point where the site area is 10% of the total drainage to that point.

2.2.5 Meeting the Unified Stormwater Sizing Criteria Requirements

2.2.5.1 INTRODUCTION

There are two primary approaches for managing stormwater runoff and addressing the unified stormwater sizing criteria requirements on a development site:

1. The use of better site design practices to reduce the amount of stormwater runoff and pollutants generated and/or provide for natural runoff reduction, treatment, and control of runoff; and
2. The use of best management practices to provide runoff reduction, treatment, and control of stormwater runoff

This subsection introduces both of these approaches. Stormwater better site design practices are discussed in-depth in Section 2.3, while best management practices are covered in Chapter 4.

2.2.5.2 SITE DESIGN AS THE FIRST STEP IN ADDRESSING UNIFIED STORMWATER SIZING CRITERIA REQUIREMENTS

Using the site design process to reduce stormwater runoff and pollutants should always be the first consideration of the site designer and engineer in the planning of the stormwater management system for a development.

Through the use of a combination of approaches collectively known as stormwater better site design practices and techniques, it is possible to reduce the amount of runoff and pollutants that are generated, as well as provide for at least some nonstructural on-site treatment and control of runoff. Better site design concepts can be viewed as both water quantity and water quality management tools and can reduce the size and cost of required best management practices—sometimes eliminating the need for them entirely. The site design approach can result in a more natural and cost-effective stormwater management system that better mimics the natural hydrologic conditions of the site, has a lower maintenance burden and provides for more sustainability.

» Better site design includes:
  - Conserving natural features and resources
  - Using lower impact site design techniques
  - Reducing impervious cover
  - Utilizing natural features for stormwater management

For each of the above categories, there are a number of practices and techniques that aim to reduce the impact of urban development and stormwater runoff from the site. These better site design practices are described in detail in Section 2.3.

For several of the better site design practices, there is a direct economic benefit to their implementation for both stormwater quality and quantity through the application of site design "credits." In terms of the unified stormwater sizing criteria, **Table 2.2.5-1** shows how the use of nonstructural site design practices can provide a reduction in the amount of stormwater runoff that is required to be treated and/or controlled through the application of site design credits.

Table 2.2.5-1 Reductions or "Credits" to the Unified Stormwater Sizing Criteria through the Use of Better Site Design Practices

Sizing Criteria	Potential Benefits of the Use of Better Site Design Practices
Water Quality (RR_V & WQ_V)	• Better site design practices that reduce the total amount of runoff will also reduce RR_V & WQ_v by a proportional amount, through the overall volume and TSS removed. • Certain site design practices will allow for a further reduction to the RR_V and WQ_V. The site design credits are discussed in Section 2.3.
Channel Protection, Overbank Flood Protection, and Extreme Flood Protection (CP_v, Q_{p25}, Q_f)	• The use of better site design practices that reduce the total amount of runoff will also reduce CP_v, Q_{p25}, and Q_f by a proportional amount. • Floodplain preservation may allow waiving of overbank flood and/or extreme flood protection requirements.

2.2.5.3 RECOMMENDED BEST MANAGEMENT PRACTICES

Best management practices (sometimes referred to as structural practices or BMPs) are constructed stormwater management facilities designed to retain or treat stormwater runoff and/or mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to urbanization.

This Manual recommends a number of best management practices for meeting unified stormwater sizing criteria. The recommended practices are divided into three categories: **runoff reduction (RR_v), stormwater treatment (water quality volume, WQ_v)**, and **detention control**s. Some of the best management practices provide multiple benefits and may even fit into more than one of the previously mentioned categories.

Some stormwater practices are best suited to address runoff quality, while others are best suited to address runoff quantity. However, better site design and runoff reduction practices address both simultaneously. As discussed in Volume 1, Chapter 3, by reducing the impervious cover associated with a development, better site design techniques reduce the amount of runoff being generated by a development in the first place. Runoff reduction practices, on the other hand eliminate some of the runoff after it is generated. Instead of treating the runoff like a typical water quality practice, or detaining it like a typical water quality practice, they remove it – removing the pollutants along with it.

In Georgia, the state requirement for Water Quality is to remove 80% TSS from the 1.2" rainfall event. To comply with this requirement, there are several ways to incorporate better site design, runoff reduction practices, and best management practices in a design.

2.2.5.4 USING BEST MANAGEMENT PRACTICES TO MEET UNIFIED STORMWATER SIZING CRITERIA REQUIREMENTS

Best management practices should be considered after all reasonable attempts have been made to minimize stormwater runoff and maximize its control and treatment through the better site design methods. Once the need for structural practices has been established, one or more appropriate best management practices will need to be selected to handle the stormwater runoff storage and treatment requirements calculated using the unified stormwater sizing criteria. Guidance for choosing the appropriate best management practice(s) for a site is provided in Section 4.1.

2.2.5.5 TYPICAL STEPS IN ADDRESSING THE UNIFIED STORMWATER SIZING CRITERIA

Each development site is unique in how stormwater management objectives are met. The type of development, physical site conditions, location in the watershed, and other factors determine how the recommended stormwater management standards and unified stormwater sizing criteria are addressed.

Figure 2.2.5-2 provides a flowchart for the typical steps in stormwater management system design using the unified stormwater sizing criteria. This is a subset of the stormwater site planning process detailed in Section 2.4.

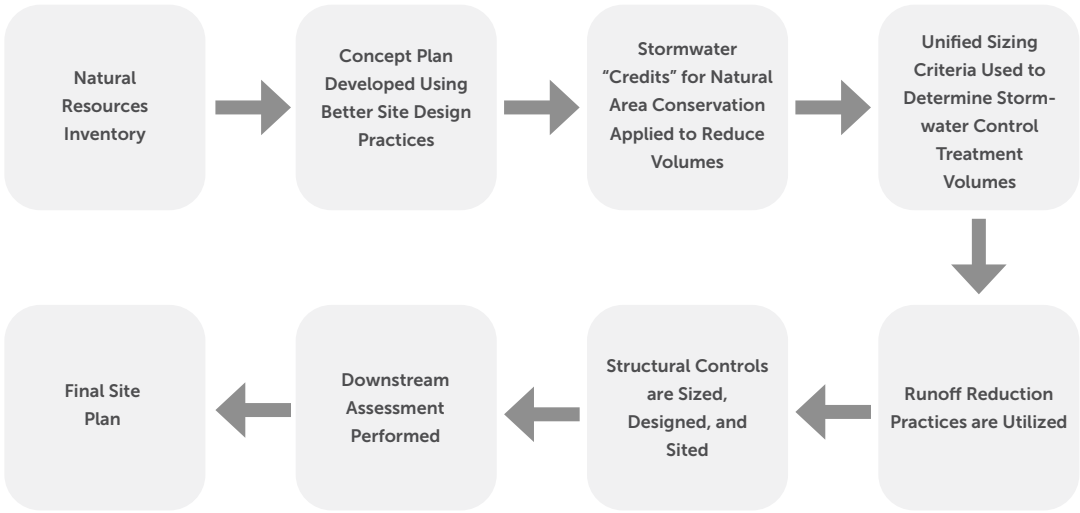


Figure 2.2.5-2 Typical Stormwater Management System Design Process

2.3 Stormwater Better Site Design & Techniques

2.3.1 Overview

2.3.1.1 INTRODUCTION

The first step in addressing stormwater management begins with the site planning and design process. Development projects can be designed to reduce their impact on watersheds when careful efforts are made to conserve natural areas, reduce impervious cover and better integrate stormwater treatment. By implementing a combination of these nonstructural approaches collectively known as *stormwater better site design practices*, it is possible to reduce the amount of runoff and pollutants that are generated from a site and provide for some nonstructural on-site treatment and control of runoff. The goals of better site design include:

- Managing stormwater (quantity and quality) as close to the point of origin as possible and minimizing collection and conveyance
- Preventing stormwater impacts rather than mitigating them
- Utilizing simple, nonstructural methods for stormwater management that are lower cost and lower maintenance than structural controls (best management practices)
- Creating a multifunctional landscape
- Using hydrology as a framework for site design

Better site design for stormwater management includes a number of site design techniques such as preserving natural features and resources, effectively laying out the site elements to reduce impact, reducing the amount of impervious surfaces, and utilizing natural features on the site for stormwater management. The aim is to reduce the environmental impact "footprint" of the site while retaining and enhancing the owner/developer's purpose and vision for the site. Many of the better site design concepts can reduce the cost of infrastructure while maintaining or even increasing the value of the property.

Reduction of adverse stormwater runoff impacts through the use of better site design should be the first consideration of the design engineer. Operationally, economically, and aesthetically, the use of better site design practices offers significant benefits over treating and controlling runoff downstream. Therefore, feasible opportunities for using these methods should be explored and exhausted before considering best management practices.

The reduction in runoff and pollutants using better site design can reduce the required runoff peak and volumes that need to be conveyed and controlled on a site and, therefore, the size and cost of necessary drainage infrastructure and best management practices. In some cases, the use of better site design practices may eliminate the need for structural controls entirely. Hence, better site design concepts can be viewed as both a water quantity and water quality management tool.

One of the site design practices described in this section provide a calculable reduction or site design "credit" which can be applied to the unified stormwater sizing criteria requirements. Section 2.3.2 discusses these practices and provide examples of their application.

The use of stormwater better site design can also have a number of other ancillary benefits including:

- Reduced construction costs
- Increased property values
- More open space for recreation
- More pedestrian friendly neighborhoods
- Protection of sensitive forests, wetlands and habitats
- More aesthetically pleasing and naturally attractive landscape
- Easier compliance with wetland and other resource protection regulations

2.3.1.2 LIST OF STORMWATER BETTER SITE DESIGN PRACTICES AND TECHNIQUES

The stormwater better site design practices and techniques covered in this Manual are grouped into four categories and are listed below:

❑ **Conservation of Natural Features and Resources**
- » Preserve Undisturbed Natural Areas
- » Preserve Riparian Buffers
- » Avoid Developing in Floodplains
- » Avoid Developing on Steep Slopes
- » Minimize Siting on Porous or Erodible Soils

❑ **Lower Impact Site Design Techniques**
- » Fit Design to the Terrain
- » Locate Development in Less Sensitive Areas
- » Reduce Limits of Clearing and Grading
- » Utilize Open Space Development
- » Consider Creative Development Design

❑ **Reduction of Impervious Cover**
- » Reduce Roadway Lengths and Widths
- » Reduce Building Footprints
- » Reduce the Parking Footprint
- » Reduce Setbacks and Frontages
- » Use Fewer or Alternative Cul-de-Sacs
- » Create Parking Lot Stormwater "Islands"

❑ **Utilization of Natural Features for Stormwater Management**
- » Use Buffers and Undisturbed Areas
- » Use Natural Drainageways Instead of Storm Sewers
- » Use Vegetated Swale Instead of Curb and Gutter
- » Use soil restoration practices to improve native soils
- » Drain Rooftop Runoff to Pervious Areas

More detail on each site design practice is provided in the Stormwater Better Site Design Practice Summary Sheets in Subsection 2.3.2. These summaries provide the key benefits of each practice, examples and details on how to apply them in site design.

2.3.1.3 USING STORMWATER BETTER SITE DESIGN PRACTICES

Site design should be done in unison with the design and layout of stormwater infrastructure in attaining stormwater management goals. **Figure 2.3.1-1** illustrates the stormwater better site design process that utilizes the four better site design categories.

The first step in stormwater better site design involves identifying significant natural features and resources on a site such as undisturbed forest areas, stream buffers and steep slopes that should be preserved to retain some of the original hydrologic function of the site.

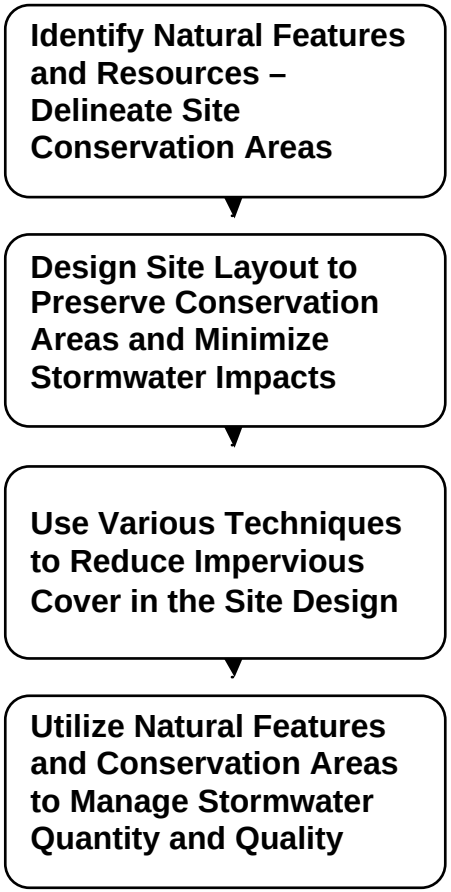


Figure 2.3.1-1 Stormwater Better Site Design Process

Next, the site layout is designed such that these conservation areas are preserved and the impact of the development is minimized. A number of techniques can then be used to reduce the overall imperviousness of the development site.

Finally, natural features and conservation areas can be utilized to serve stormwater quantity and quality management purposes.

2.3.2 Better Site Design Practices

2.3.2.1 CONSERVATION OF NATURAL FEATURES AND RESOURCES

Conservation of natural features is integral to better site design. The first step in the better site design process is to identify and preserve the natural features and resources that can be used in the protection of water resources by reducing stormwater runoff, providing runoff storage, reducing flooding, preventing soil erosion, promoting infiltration, and removing stormwater pollutants. Some of the natural features that should be taken into account include:

- Areas of undisturbed vegetation
- Floodplains and riparian areas
- Ridgetops and steep slopes
- Natural drainage pathways
- Intermittent and perennial streams
- Wetlands
- Aquifers and recharge areas
- Soils
- Shallow bedrock or high water table
- Other natural features or critical areas

Some of the ways used to conserve natural features and resources described over the next several pages include the following methods:

- Preserve Undisturbed Natural Areas
- Preserve Riparian Buffers
- Avoid Floodplains
- Avoid Steep Slopes
- Minimize Siting on Porous or Erodible Soils

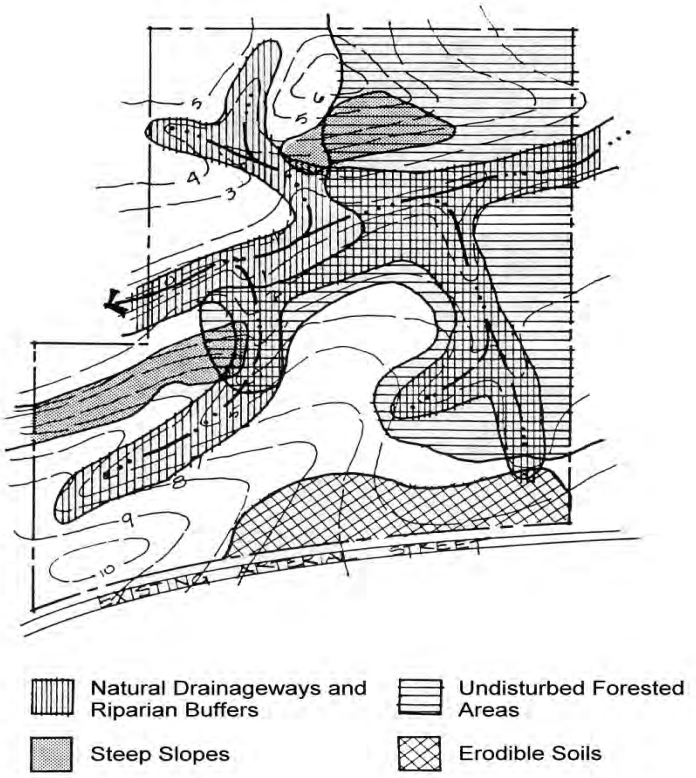


Figure 2.3.2-1 Example of Natural Feature Delineation
(Source: MPCA, 1989)

Delineation of natural features is typically done through a comprehensive site analysis and inventory before any site layout design is performed (see Section 2.4). From this site analysis, a concept plan for a site can be prepared that provides for the conservation and protection of natural features. **Figure 2.3.2-1** shows an example of the delineation of natural features on a base map of a development parcel.

Better Site Design Practice #1:

Preserve Undisturbed Natural Areas

» **Description**: Important natural features and areas such as undisturbed forested and vegetated areas, natural drainageways, stream corridors, wetlands and other important site features should be delineated and placed into conservation areas.

KEY BENEFITS

- Conserving undisturbed natural areas helps to preserve a portion of the site's natural pre-development hydrology
- Can be used as nonstructural stormwater filtering and infiltration zones
- Helps to preserve the site's natural character and aesthetic features
- May increase the value of the developed property
- A stormwater site design credit can be taken if allowed by the local review authority (see subsection 2.3.2)

USING THIS PRACTICE

- Delineate natural areas before performing site layout and design
- Ensure that conservation areas and native vegetation are protected in an undisturbed state throughout construction and occupancy

Discussion

Preserving natural conservation areas such as undisturbed forested and vegetated areas, natural drainageways, stream corridors and wetlands on a development site helps to preserve the original hydrology of the site and aids in reducing the generation of stormwater runoff and pollutants. Undisturbed vegetated areas also promote soil stabilization and provide for filtering, infiltration and evapotranspiration of runoff.

Natural conservation areas are typically identified through a site analysis using maps and aerial/satellite photography, or by conducting a site visit. These areas should be delineated before any site design, clearing or construction begins. When done before the concept plan phase, the planned conservation areas can be used to guide the layout of the site. **Figure 2.3.2-2** shows a site map with undisturbed natural areas delineated.

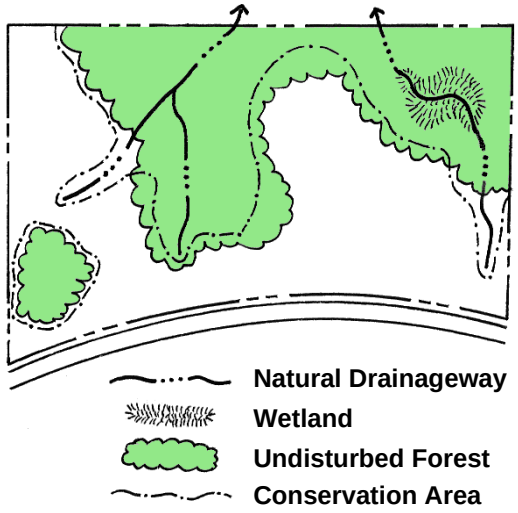


Figure 2.3.2-2 Delineation of Natural Conservation Areas

Conservation areas should be incorporated into site plans and clearly marked on all construction and grading plans to ensure that equipment is kept out of these areas and that native vegetation is kept in an undisturbed state. The boundaries of each conservation area should be mapped by carefully determining the limit which should not be crossed by construction activity.

Once established, natural conservation areas must be protected during construction and managed after occupancy by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements.

Better Site Design Practice #2:

Preserve Riparian Buffers

» **Description**: Naturally vegetated buffers should be delineated and preserved along perennial streams, rivers, lakes, and wetlands.

KEY BENEFITS

- Riparian buffers can be used as nonstructural stormwater filtering and infiltration zones
- Keeps structures out of the floodplain and provides a right-of-way for large flood events
- Helps to preserve riparian ecosystems and habitats

USING THIS PRACTICE

- Delineate and preserve naturally vegetated riparian buffers
- Ensure that buffers and native vegetation are protected throughout construction and occupancy

Discussion

A riparian buffer is a special type of natural conservation area along a stream, wetland or shoreline where development is restricted or prohibited. The primary function of buffers is to protect and physically separate a stream, lake or wetland from future disturbance or encroachment. If properly designed, a buffer can provide stormwater management functions, can act as a right-of-way during floods, and can sustain the integrity of stream ecosystems and habitats. An example of a riparian stream buffer is shown in **Figure 2.3.2-3**.



Figure 2.3.2-3 Riparian Stream Buffer

Forested riparian buffers should be maintained and reforestation should be encouraged where no wooded buffer exists. Proper restoration should include all layers of the forest plant community, including understory, shrubs and groundcover, not just trees. A riparian buffer can be of fixed or variable width, but should be continuous and not interrupted by impervious areas that would allow stormwater to concentrate and flow into the stream without first flowing through the buffer. Ideally, riparian buffers should be sized to include the 100-year floodplain as well as steep banks and freshwater wetlands. The buffer width needed to perform properly will depend on the size of the stream and the surrounding conditions, but a minimum 25-foot undisturbed vegetative buffer is needed for even the smallest perennial streams and a 50-foot or larger undisturbed buffer is ideal. Even with a 25-foot undisturbed buffer, additional zones can be added to extend the total buffer to at least 75 feet from the edge of the stream. The three distinct zones within the 75-foot width are shown in **Figure 2.3.2-4**. The function, vegetative target and allowable uses vary by zone as described in **Table 2.3.2-1**.

These recommendations are minimum standards to apply to most streams. Some streams and watershed may require additional measures to achieve protection. In some areas, specific state laws or local ordinances already require stricter buffers than are described here. The buffer widths discussed are not intended to modify or supersede deeper or more restrictive buffer requirements that are already in place.

As stated above, the streamside or inner zone should consist of a minimum of 25 feet of undisturbed mature forest. In addition to runoff protection, this zone provides bank stabilization as well as shading and protection for the stream. This zone should also include wetlands and any critical habitats, and its width should be adjusted accordingly. The middle zone provides a transition between upland development and the inner zone and should consist of managed woodland that allows for infiltration and filtration of runoff. An outer zone allows more clearing and acts as a further setback for impervious surfaces. It also functions to prevent encroachment and filter runoff. It is here that flow into the buffer should be transformed from concentrated flow into sheet flow to maximize ground contact with the runoff.

Development within the riparian buffer should be limited only to those structures and facilities that are absolutely necessary. Such limited development should be specifically identified in any codes or ordinances enabling the buffers. When construction activities do occur within the riparian corridor, specific mitigation measures should be required, such as deeper buffers or riparian buffer improvements.

Generally, the riparian buffer should remain in its natural state. However, some maintenance is periodically necessary, such as planting to minimize concentrated flow, the removal of exotic plant species when these species are detrimental to the vegetated buffer and the removal of diseased or damaged trees.

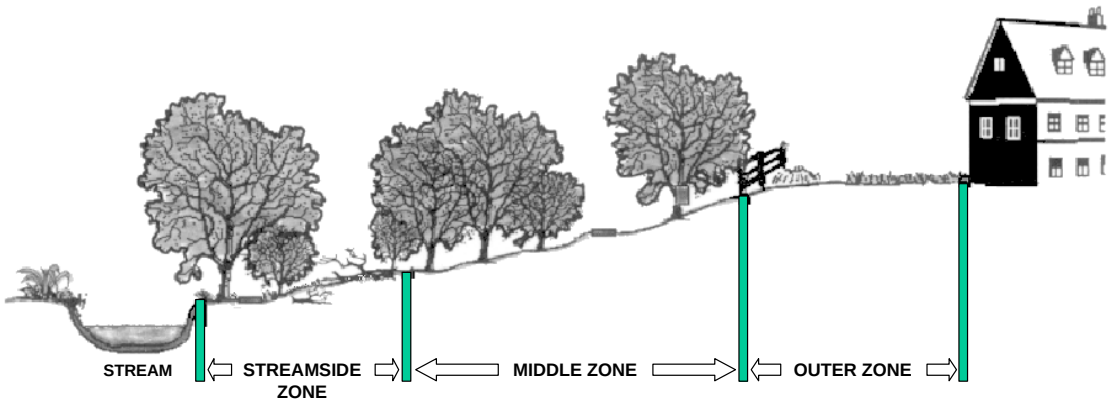


Figure 2.3.2-4 Three-Zone Stream Buffer System

Table 2.3.2-1 Riparian Buffer Management Zones

	Streamside Zone	Middle Zone	Outer Zone
Width	Minimum 25 feet plus wetlands and critical habitat	Variable depending on stream order, slope, and 100-year floodplain (min. 25 ft)	25-foot minimum setback from structures
Vegetative Target	Undisturbed mature forest. Reforest if necessary.	Managed forest, some clearing allowed.	Forest encouraged, but usually turf grass.
Allowable Uses	**Very Restricted** e.g., flood control, utility easements, footpaths	**Restricted** e.g., some recreational uses, some stormwater controls, bike paths	**Unrestricted** e.g., residential uses including lawn, garden, most stormwater controls

Better Site Design Practice #3:

Avoid Floodplains

» **Description**: Floodplain areas should be avoided for homes and other structures to minimize risk to human life and property damage, and to allow the natural stream corridor to accommodate flood flows.

KEY BENEFITS

- Preserving floodplains provides a natural right-of-way and temporary storage for large flood events
- Keeps people and structures out of harm's way
- Helps to preserve riparian ecosystems and habitats
- Can be combined with riparian buffer protection to create linear greenways

USING THIS PRACTICE

- Obtain maps of the 100-year floodplain from the local review authority
- Ensure that all development activities do not encroach on the designated floodplain areas

Discussion

Floodplains are the low-lying flat lands that border streams and rivers. When a stream reaches its capacity and overflows its channel after storm events, the floodplain provides for storage and conveyance of these excess flows. In their natural state they reduce flood velocities and peak flow rates by the passage of flows through dense vegetation. Floodplains also play an important role in reducing sedimentation and filtering runoff, and provide habitat for both aquatic and terrestrial life. Development in floodplain areas can reduce the ability of the floodplain to convey stormwater, potentially causing safety problems or significant damage to the site in question, as well as to both upstream and downstream properties. Most communities regulate the use of floodplain areas to minimize the risk to human life as well as to avoid flood damage to structures and property.

As such, floodplain areas should be avoided on a development site. Ideally, the entire 100-year full-buildout floodplain should be avoided for clearing or building activities, and should be preserved in a natural undisturbed state where possible. Floodplain protection is complementary to riparian buffer preservation. Both of these better site design practices preserve stream corridors in a natural state and allow for the protection of vegetation and habitat. Depending on the site topography, 100-year floodplain boundaries may lie inside or outside of a preserved riparian buffer corridor, as shown in **Figure 2.3.2-5**.

Maps of the 100-year floodplain can typically be obtained through the local review authority, through FEMA's website, or through the Georgia Flood M.A.P. website. Developers and builders should also ensure that their site design comply will any other relevant local floodplain and FEMA requirements.

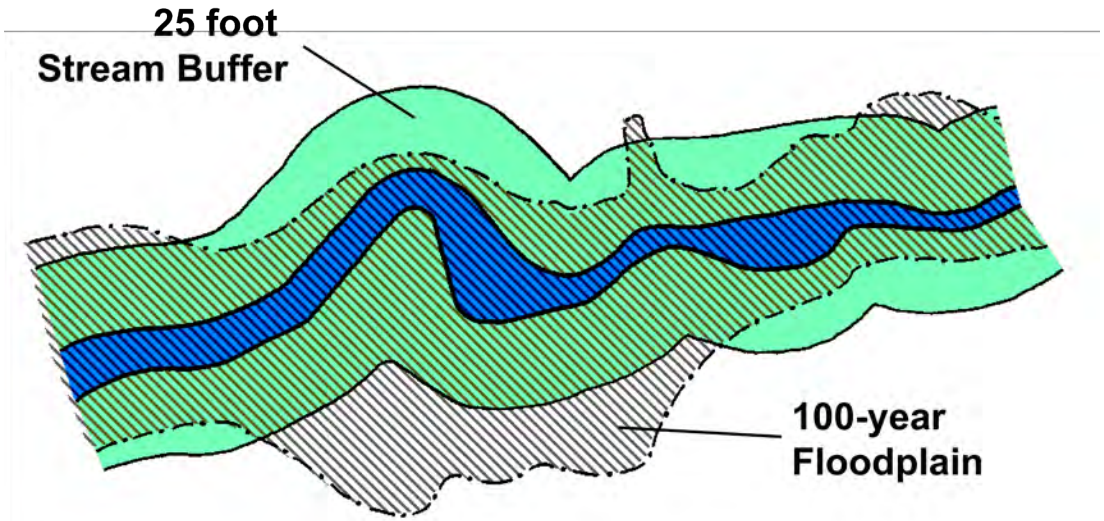


Figure 2.3.2-5 Floodplain Boundaries in Relation to a Riparian Buffer

Better Site Design Practice #4:

Avoid Steep Slopes

» **Description**: Steep slopes should be avoided due to the potential for soil erosion and increased sediment loading. Excessive grading and flattening of hills and ridges should be minimized.

KEY BENEFITS

- Preserving steep slopes helps to prevent soil erosion and degradation of stormwater runoff
- Steep slopes can be kept in an undisturbed natural condition to help stabilize hillsides and soils
- Building on flatter areas will reduce the need for cut-and-fill and grading

USING THIS PRACTICE

- Avoid development on steep slope areas, especially those with a grade of 15% or greater
- Minimize grading and flattening of hills and ridges

Discussion

Developing on steep slope areas has the potential to cause excessive soil erosion and stormwater runoff during and after construction. Past studies by the NRCS and others have shown that soil erosion is significantly increased on slopes of 15% or greater. In addition, the nature of steep slopes means that greater areas of soil and land area are disturbed to locate facilities on them compared to flatter slopes as demonstrated in **Figure 2.3.2-6**.

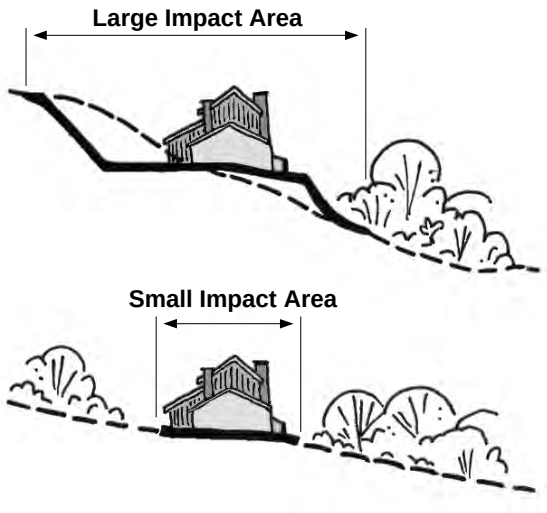


Figure 2.3.2-6 Flattening Steep Slopes for Building Sites Uses More Land Area Than Building on Flatter Slopes

(Source: MPCA, 1989)

Therefore, development on slopes with a grade of 15% or greater should be avoided if possible to limit soil loss, erosion, excessive stormwater runoff, and the degradation of surface water. Excessive grading should be avoided on all slopes, as should the flattening of hills and ridges. Steep slopes should be kept in an undisturbed natural condition to help stabilize hillsides and soils

On slopes greater than 25%, no development, regrading, or stripping of vegetation should be considered unless the disturbance is for roadway crossings or utility construction and it can be demonstrated that the roadway or utility improvements are absolutely necessary in the sloped area.

Better Site Design Practice #5:

Minimize Siting on Porous or Erodible Soils

» **Description**: Porous soils such as sand and gravels provide an opportunity for groundwater recharge of stormwater runoff and should be preserved as a potential stormwater management option. Unstable or easily erodible soils should be avoided due to their greater erosion potential.

KEY BENEFITS

- Areas with highly permeable soils can be used as nonstructural stormwater infiltration zones.
- Avoiding high erodible or unstable soils can prevent erosion and sedimentation problems and water quality degradation

USING THIS PRACTICE

- Use soil surveys to determine site soil types
- Leave areas of porous or highly erodible soils as undisturbed conservation areas

Discussion

Infiltration of stormwater into the soil reduces both the volume and peak discharge of runoff from a given rainfall event, and also provides for water quality treatment and groundwater recharge. Soils with maximum permeabilities (hydrologic soil group A and B soils such as sands and sandy loams) allow for the most infiltration of runoff into the subsoil. Thus, areas of a site with these soils should be conserved as much as possible and these areas should ideally be incorporated into undisturbed natural or open space areas. Conversely, buildings and other impervious surfaces should be located on those portions of the site with the least permeable soils.

Similarly, areas on a site with highly erodible or unstable soils should be avoided for land disturbing activities and buildings to prevent erosion and sedimentation problems as well as potential future structural problems. These areas should be left in an undisturbed and vegetated condition.

Soils on a development site should be mapped in order to preserve areas with porous soils, and to identify those areas with unstable or erodible soils as shown in **Figure 2.3.2-7**. Soil surveys can provide a considerable amount of information relating to all relevant aspects of soils. Appendix D of this Manual provides permeability, shrink-swell potential and hydrologic soils group information for all Georgia soil series. General soil types should be delineated on concept site plans to guide site layout and the placement of buildings and impervious surfaces.

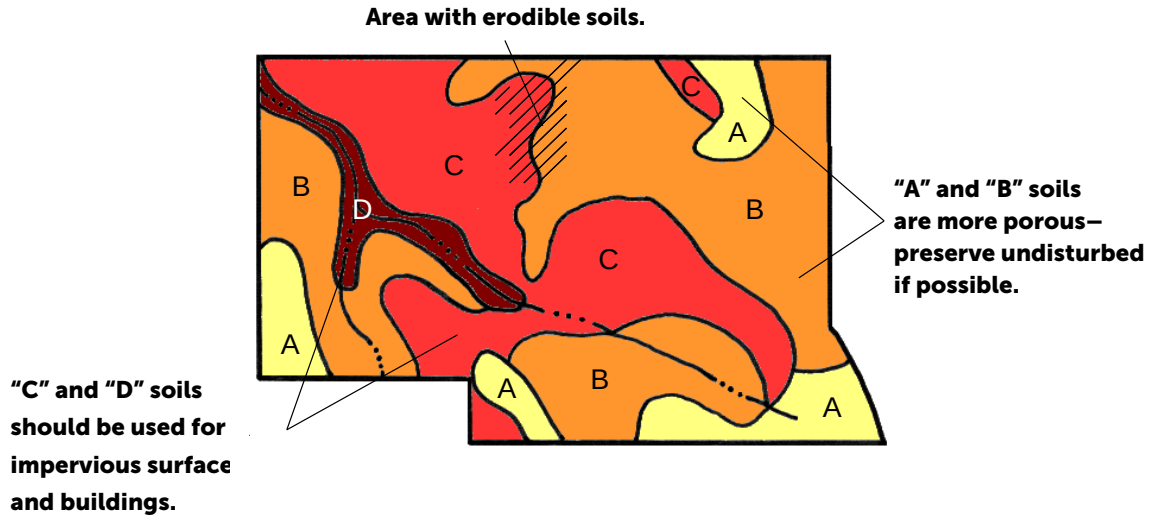


Figure 2.3.2-7 Soil Mapping Information Can Be Used to Guide Development

2.3.2.2 LOWER IMPACT SITE DESIGN TECHNIQUES

After a site analysis has been performed and conservation areas have been delineated, there are numerous opportunities in the site design and layout phase to reduce both water quantity and quality impacts of stormwater runoff. These primarily deal with the location and configuration of impervious surfaces or structures on the site and include the following practices and techniques covered over the next several pages:

- » Fit the Design to the Terrain
- » Locate Development in Less Sensitive Areas
- » Reduce Limits of Clearing and Grading
- » Utilize Open Space Development
- » Consider Creative Development Design

The goal of lower impact site design techniques is to lay out the elements of the development project in such a way that the site design (i.e. placement of buildings, parking, streets and driveways, lawns, undisturbed vegetation, buffers, etc.) is optimized for effective stormwater management. That is, the site design takes advantage of the site's natural features, including those placed in conservation areas, as well as any site constraints and opportunities (topography, soils, natural vegetation, floodplains, shallow bedrock, high water table, etc.) to prevent both on-site and downstream stormwater impacts.

Figure 2.3.2-8 shows a development that has utilized several lower impact site design techniques in its overall layout and design.

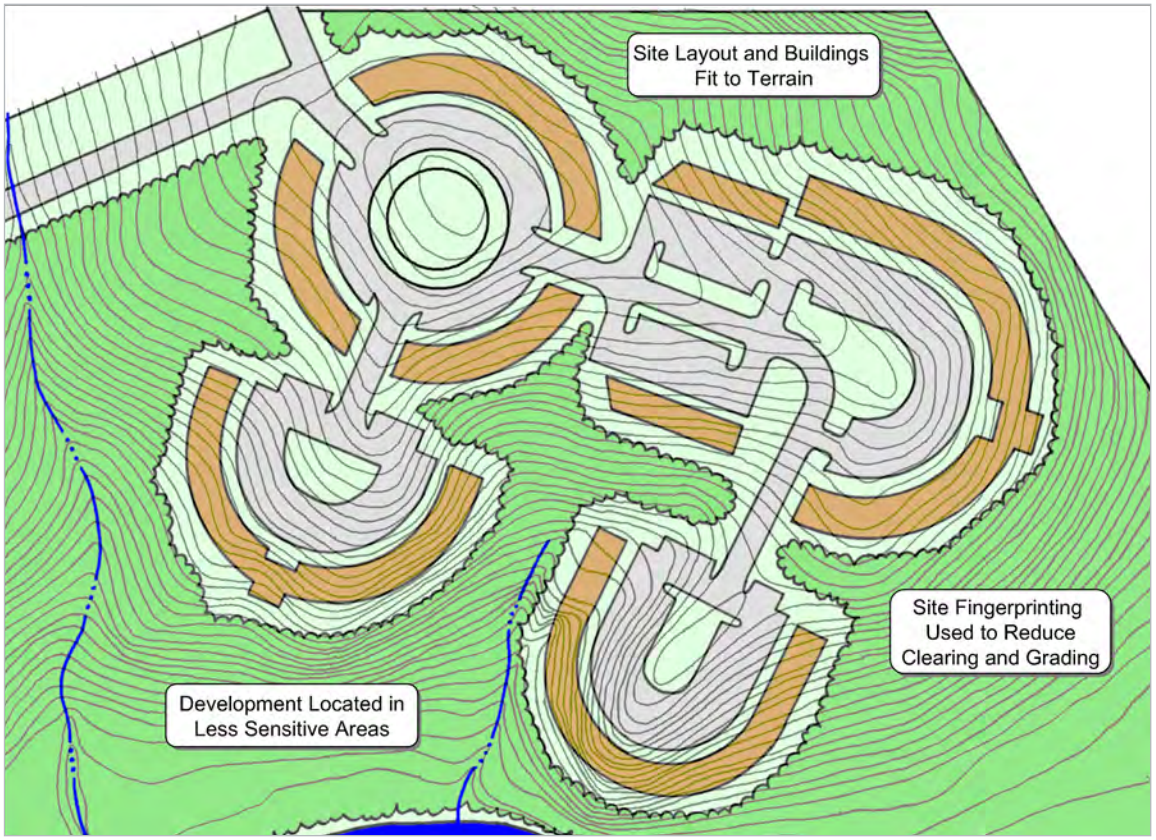


Figure 2.3.2-8 Development Design Utilizing Several Lower Impact Site Design Techniques

Better Site Design Practice #6:

Fit Design to the Terrain

» **Description**: The layout of roadways and buildings on a site should generally conform to the landforms on a site. Natural drainageways and stream buffer areas should be preserved by designing road layouts around them. Buildings should be sited to utilize the natural grading and drainage system and avoid the unnecessary disturbance of vegetation and soils.

KEY BENEFITS

- Helps to preserve the natural hydrology and drainageways of a site
- Reduces the need for grading and land disturbance
- Provides a framework for site design and layout

USING THIS PRACTICE

- Develop roadway patterns to fit the site terrain. Locate buildings and impervious surfaces away from steep slopes, drainageways and floodplains

Discussion

All site layouts should be designed to conform with or "fit" the natural landforms and topography of a site. This helps to preserve the natural hydrology and drainageways on the site, as well as reduces the need for grading and disturbance of vegetation and soils. **Figure 2.3.2-9** illustrates the placement of roads and homes in a residential development.

Roadway patterns on a site should be chosen to provide access schemes which match the terrain. In rolling or hilly terrain, streets should be designed to follow natural contours to reduce clearing and grading. Street hierarchies with local streets branching from collectors in short loops and cul-de-sacs along ridgelines help to prevent the crossing of streams and drainageways as shown in **Figure 2.3.2-10**.

In flatter areas, a traditional grid pattern of streets or "fluid" grids which bend and may be interrupted by natural drainageways may be more appropriate (see **Figure 2.3.2-11**). In either case, buildings and impervious surfaces should be kept off of steep slopes, away from natural drainageways, and out of floodplains and other lower lying areas. In addition, the major axis of buildings should be oriented parallel to existing contours.

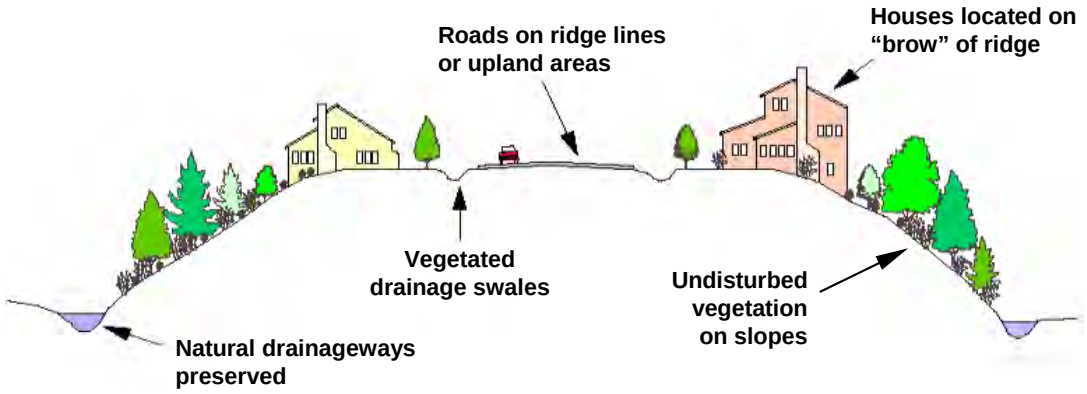


Figure 2.3.2-9 Preserving the Natural Topography of the Site
(Adapted from Sykes, 1989)



Figure 2.3.2-10 Subdivision Design for Hilly or Steep Terrain Utilizes Branching Streets From Collectors that Preserves Natural Drainageways and Stream Corridors



2.3.2-11 A Subdivision Design for Flat Terrain Uses a Fluid Grid Layout that is Interrupted by the Stream Corridor

Better Site Design Practice #7:

Locate Development in Less Sensitive Areas

» **Description**: To minimize the hydrologic impacts on the existing site land cover, the area of development should be located in areas of the site that are less sensitive to disturbance or have a lower value in terms of hydrologic function.

KEY BENEFITS

- Helps to preserve the natural hydrology and drainageways of a site
- Makes most efficient use of natural site features for preventing and mitigating stormwater impacts
- Provides a framework for site design and layout

USING THIS PRACTICE

- Lay out the site design to minimize the hydrologic impact of structures and impervious surfaces

Discussion

In much the same way that a development should be designed to conform to terrain of the site, a site layout should also be designed so that the areas of development are placed in the locations of the site that minimize the hydrologic impact of the project. This is accomplished by steering development to areas of the site that are less sensitive to land disturbance or have a lower value in terms of hydrologic function using the following methods:

- Locate buildings and impervious surfaces away from stream corridors, wetlands and natural drainageways. Use buffers to preserve and protect riparian areas and corridors.
- Areas of the site with porous soils should left in an undisturbed condition and/or used as stormwater runoff infiltration zones. Buildings and impervious surfaces should be located in areas with less permeable soils.
- Avoid land disturbing activities or construction on areas with steep slopes or unstable soils.
- Minimize the clearing of areas with dense tree canopy or thick vegetation, and ideally preserve them as natural conservation areas
- Ensure that natural drainageways and flow paths are preserved, where possible. Avoid the filling or grading of natural depressions and ponding areas.

Figure 2.3.2-12 shows a development site where the natural features have been mapped in order to delineate the hydrologically sensitive areas. Through careful site planning, sensitive areas can be set aside as natural open space areas (see Better Site Design Practice #9). In many cases, such areas can be used as buffer spaces between land uses on the site or between adjacent sites. contours.

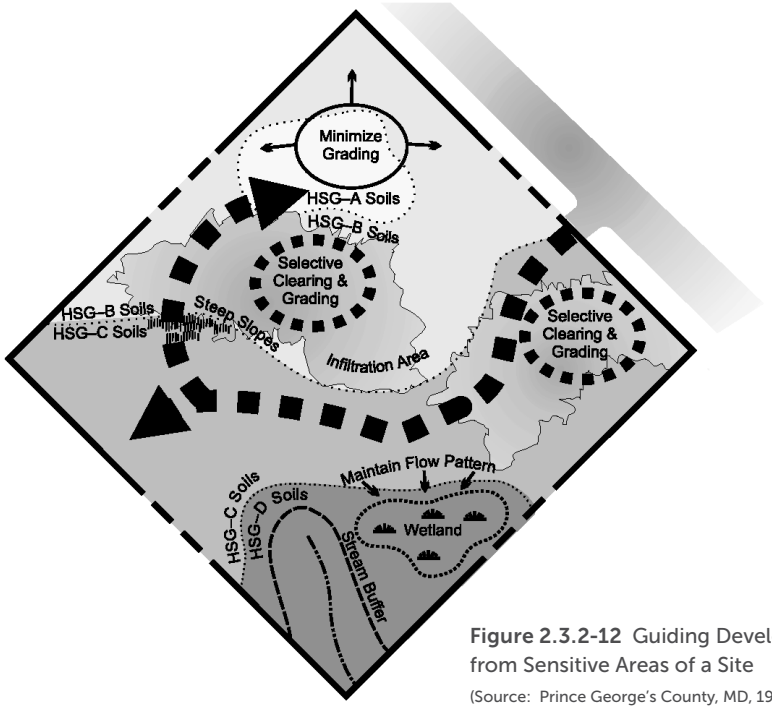


Figure 2.3.2-12 Guiding Development Away from Sensitive Areas of a Site
(Source: Prince George's County, MD, 1999)

Better Site Design Practice #8:

Reduce Limits of Clearing and Grading

» **Description**: Clearing and grading of the site should be limited to the minimum amount needed for the development and road access. Site footprinting should be used to disturb the smallest possible land area on a site.

KEY BENEFITS

- Preserves more undisturbed natural areas on a development site
- Techniques can be used to help protect natural conservation areas and other site features

USING THIS PRACTICE

- Establish limits of disturbance for all development activities
- Use site footprinting to minimize clearing and land disturbance

Discussion

Minimal disturbance methods should be used to limit the amount of clearing and grading that takes place on a development site, preserving more of the undisturbed vegetation and natural hydrology of a site. These methods include:

- Establishing a limit of disturbance (LOD) based on maximum disturbance zone radii/ lengths. These maximum distances should reflect reasonable construction techniques and equipment needs together with the physical situation of the development site such as slopes or soils. LOD distances may vary by type of development, size of lot or site, and by the specific development feature involved.
- Using site "footprinting" which maps all of the limits of disturbance to identify the smallest possible land area on a site which requires clearing or land disturbance. Examples of site footprinting is illustrated in **Figures 2.3.2-13** and **2.3.2-14**.
- Fitting the site design to the terrain.
- Using special procedures and equipment which reduce land disturbance.

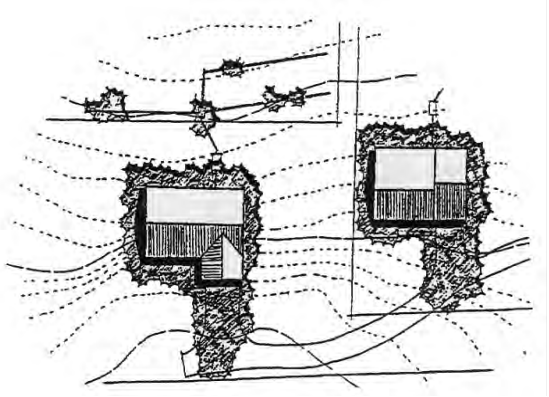


Figure 2.3.2-13
Establishing Limits of Clearing
(Source: DDNREC, 1997)



Figure 2.3.2-14 Example of Site Footprinting

Better Site Design Practice #9:

Utilize Open Space Development

» **Description**: Open space site designs incorporate smaller lot sizes to reduce overall impervious cover while providing more undisturbed open space and protection of water resources.

KEY BENEFITS

- Preserves conservation areas on a development site
- Can be used to preserve natural hydrology and drainageways
- Can be used to help protect natural conservation areas and other site features
- Reduces the need for grading and land disturbance
- Reduces infrastructure needs and overall development costs

USING THIS PRACTICE

- Use a site design which concentrates development and preserves open space and natural areas of the site

Discussion

Open space development, also known as *conservation development* or *clustering*, is a better site design technique that concentrates structures and impervious surfaces in a compact area in one portion of the development site in exchange for providing open space and natural areas elsewhere on the site. Typically smaller lots and/or nontraditional lot designs are used to cluster development and create more conservation areas on the site.

Open space developments have many benefits compared with conventional commercial developments or residential subdivisions: they can reduce impervious cover, stormwater pollution, construction costs, and the need for grading and landscaping, while providing for the conservation of natural areas. **Figures 2.3.2-15** and **2.3.2-16** show examples of open space developments.

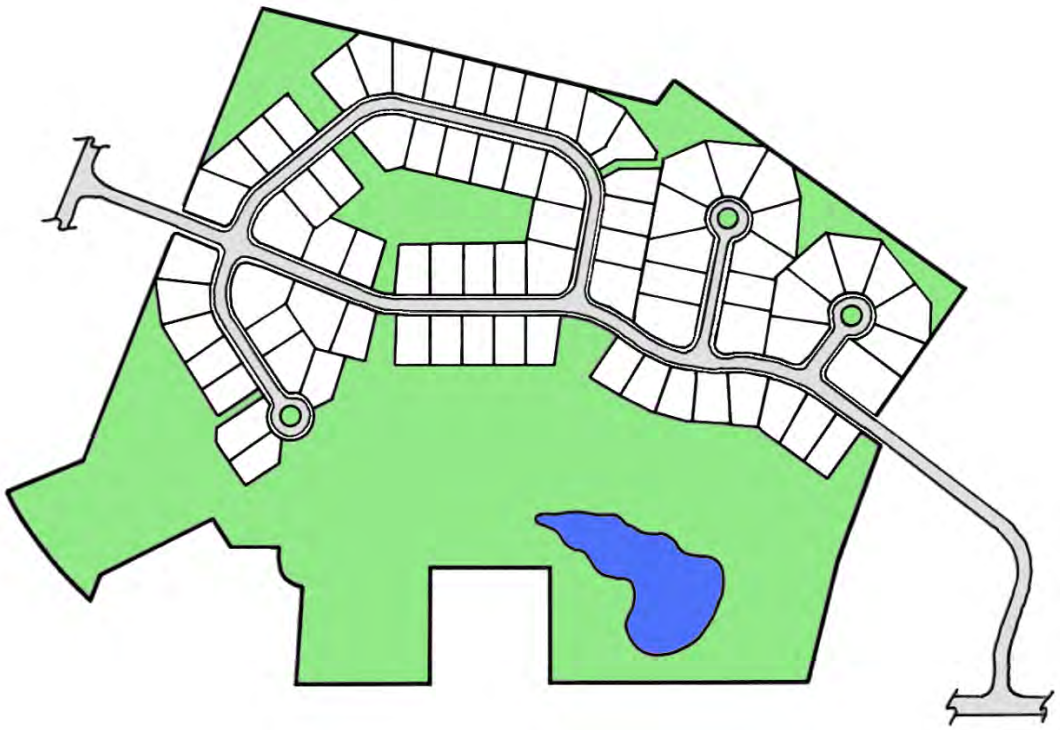


Figure 2.3.2-15 Open Space Subdivision Site Design Example

Along with reduced imperviousness, open space designs provide a host of other environmental benefits lacking in most conventional designs. These developments reduce potential pressure to encroach on conservation and buffer areas because enough open space is usually reserved to accommodate these protection areas. As less land is cleared during the construction process, alteration of the natural hydrology and the potential for soil erosion are also greatly diminished. Perhaps most importantly, open space design reserves 25 to 50 percent of the development site in conservation areas that would not otherwise be protected. Open space developments can also be significantly less expensive to build than conventional projects. Most of the cost savings are due to reduced infrastructure cost for roads and stormwater management controls and conveyances. While open space developments are frequently less expensive to build, developers find that these properties often command higher prices than those in more conventional developments.



Figure 2.3.2-16 Aerial View of an Open Space Subdivision

Several studies estimate that residential properties in open space developments garner premiums that are higher than conventional subdivisions and moreover, sell or lease at an increased rate.

Once established, common open space and natural conservation areas must be managed by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, the conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements.

Better Site Design Practice #10:

Consider Creative Development Design

» **Description**: Planned Unit Developments (PUDs) allow a developer or site designer the flexibility to design a residential, commercial, industrial, or mixed-use development in a fashion that best promotes effective stormwater management and the protection of environmentally sensitive areas.

KEY BENEFITS

- Allows flexibility to developers to implement creative site designs which include stormwater better site design practices
- May be useful for implementing an open space development

USING THIS PRACTICE

- Check with your local review authority to determine if the community supports PUDs
- Determine the type and nature of deviations allowed and other criteria for receiving PUD approval

Discussion

A Planned Unit Development (PUD) is a type of planning approval available in some communities which provides greater design flexibility by allowing deviations from the typical development standards required by the local zoning code with additional variances or zoning hearings.
The intent is to encourage better designed projects through the relaxation of some development requirements, in exchange for providing greater benefits to the community. PUDs can be used to implement many of the other stormwater better site design practices covered in this Manual and to create site designs that maximize natural nonstructural approaches to stormwater management.

Examples of the types of zoning deviations which are often allowed through a PUD process include:

- Allowing uses not listed as permitted, conditional or accessory by the zoning district in which the property is located
- Modifying lot size and width requirements
- Reducing building setbacks and frontages from property lines
- Altering parking requirements
- Increasing building height limits

A developer or site designer should consult their local review authority to determine whether the community supports PUD approvals. If so, the type and nature of deviations allowed from individual development requirements should be obtained from the review authority in addition to any other criteria that must be met to obtain a PUD approval.

2.3.3 Site Design Stormwater Credits

2.3.3.1 INTRODUCTION

Non-structural stormwater control practices are increasingly recognized as a critical feature in every site design. As such, a set of stormwater "credits" has been developed to provide developers and site designers an incentive to implement better site design practices that can reduce the volume of stormwater runoff and minimize the pollutant loads from a site. The credit system directly translates into cost savings to the developer by reducing the size of best management practices and conveyance facilities.

The basic premise of the credit system is to recognize the water quality benefits of certain site design practices by allowing for a reduction in the water quality treatment volume (WQ_v). If a developer incorporates one or more of the credited practices in the design of the site, the requirement for capture and treatment of the water quality volume will be reduced.

The Natural Area Conservation better site design practice provides a stormwater credit, given certain site-specific conditions are met. For example, natural area conservation credits **must** be protected by a conservation easement. Natural conservation areas are defined as undisturbed natural areas that are conserved on a site, thereby retaining their pre-development hydrologic and water quality characteristics.

It should be noted that better site design practices and techniques that reduce the overall impervious area on a site already implicitly reduce the total amount of stormwater runoff generated by a site (and thus reduce WQ_v) and are not further credited under this system.

For each potential credit, there is a minimum set of criteria and requirements which identify the conditions or circumstances under which the credit may be applied. The intent of the suggested numeric conditions (e.g., flow length, contributing area, etc.) is to avoid situations that could lead to a credit being granted without the corresponding reduction in pollution attributable to an effective site design modification.

Site designers are encouraged to utilize credits on a site. Greater reductions in stormwater storage volumes can be achieved when many credits are combined (e.g., disconnecting rooftops and protecting natural conservation areas). However, credits cannot be claimed twice for an identical area of the site (e.g. claiming credit for natural conservation areas and disconnecting rooftops over the same site area).

Due to local safety codes, soil conditions, and topography, some of these site design credits may be restricted. Designers are encouraged to consult with the appropriate approval authority to ensure if and when a credit is applicable and to determine restrictions on non-structural strategies.

2.3.3.2 STORMWATER CREDITS AND THE SITE PLANNING PROCESS

During the site planning process described in Section 2.4 there are several steps involved in site layout and design, each more clearly defining the location and function of the various components of the stormwater management system. The integration of site design credits can be integrated with this process as shown in **Table 2.3.3-2**.

Table 2.3.3-2 Integration of Site Design Credits with Site Development Process

Site Development Phase	Site Design Credit Activity
Feasibility Study	• Determine stormwater management requirements • Perform site reconnaissance to identify potential areas for and types of credits
Site Analysis	• Identify and delineate natural feature conservation areas (natural areas and stream buffers)
Concept Plan	• Preserve natural areas and stream buffers during site layout • Reduce impervious surface area through various techniques • Identify locations for use of vegetated channels and groundwater recharge • Look for areas to disconnect impervious surfaces • Document the use of site design credits
Preliminary and Final Plan	• Perform layout and design of credit areas – integrating them into treatment trains • Ensure unified stormwater sizing criteria are satisfied • Ensure appropriate documentation of site design credits according to local requirements
Construction	• Ensure protection of key areas • Ensure correct final construction of areas needed for credits
Final Inspection	• Develop maintenance requirements and documents • Ensure long term protection and maintenance • Ensure credit areas are identified on final plan and plat if applicable

2.3.3.3 SITE DESIGN CREDIT - NATURAL AREA CONSERVATION

A stormwater credit can be taken when undisturbed natural areas are conserved on a site, thereby retaining their pre-development hydrologic and water quality characteristics. Under this credit, a designer would be able to subtract conservation areas from total site area when computing water quality volume requirements. An added benefit will be that the post-development peak discharges will be smaller, and hence water quantity control volumes (CP_v, Q_{p25}, and Q_f) will be reduced due to lower post-development curve numbers or rational formula "C" values.

Rule: Subtract conservation areas from total site area when computing water quality volume requirements.

Criteria:

- Conservation area cannot be disturbed during project construction
- Conservation area must remain undisturbed (if disturbed in the future, the credit is no longer valid and additional water quality measures will be required)
- Shall be protected by limits of disturbance clearly shown on all construction drawings
- Shall be located within an acceptable conservation easement instrument that ensures perpetual protection of the proposed area. The easement must clearly specify how the natural area vegetation shall be managed and boundaries will be marked

[Note: managed turf (e.g., playgrounds, regularly maintained open areas) is not an acceptable form of vegetation management]

- Shall have a minimum contiguous area requirement of 10,000 square feet
- R_v is kept constant when calculating WQ_v

EXAMPLE

Residential Subdivision
Area = 38 acres
Natural Conservation Area = 7 acres
Impervious Area = 13.8 acres

$$\mathbf{R_v = 0.05 + 0.009\ (I) = 0.05 + 0.009\ (36.3\%) = 0.37}$$

Credit:
7.0 acres in natural conservation area
New drainage area = 38 – 7 = 31 acres

Before credit:
$\mathbf{WQ_v = (1.2)(0.37)(38)/12 = 1.40\ ac\text{-}ft}$
With credit:
$\mathbf{WQ_v = (1.2)(0.37)(31)/12 = 1.15\ ac\text{-}ft}$

(18% reduction in water quality volume)

2.4 Stormwater Site Planning & Design

2.4.1 Stormwater Management and Site Planning

2.4.1.1 INTRODUCTION

In order to most effectively address stormwater management objectives, consideration of stormwater runoff needs to be fully integrated into the site planning and design process. This involves a more comprehensive approach to site planning and a thorough understanding of the physical characteristics and resources of the site. The purpose of this section is to provide a framework for including effective and environmentally sensitive stormwater management into the site development process and to encourage a greater uniformity in stormwater management site plan preparation.

When designing the stormwater management system for a site, a number of questions need to be answered by the site planners and design engineers, including:

- How can the stormwater management system be designed to most effectively meet the stormwater management recommended standards (and any additional needs or objectives)?
- What are the opportunities for utilizing better site design practices to minimize the need for best management practices?
- What are the development site constraints that preclude the use of certain best management practices?
- What best management practices are most suitable and cost-effective for the site?

2.4.1.2 PRINCIPLES OF STORMWATER MANAGEMENT SITE PLANNING

The following principles should be kept in mind in preparing a stormwater management plan for a development site:

1. **The site design should utilize an integrated approach to deal with stormwater quantity, quality and streambank (channel) protection requirements.**

   The stormwater management infrastructure for a site should be designed to integrate drainage and water quantity control, water quality protection, and downstream channel protection. Site design should be done in unison with the design and layout of stormwater infrastructure to attain stormwater management goals. Together, the combination of better site design practices and effective infrastructure layout and design can mitigate the worst stormwater impacts of most urban developments while preserving stream integrity and aesthetic attractiveness.

2. **Stormwater management practices should strive to utilize the natural drainage system and require as little maintenance as possible.**

   Almost all sites contain natural features which can be used to help manage and mitigate runoff from development. Features on a development site might include natural drainage patterns, depressions, permeable soils, wetlands, floodplains, and undisturbed vegetated areas that can be used to reduce runoff, provide infiltration and stormwater filtering of pollutants and sediment, recycle nutrients, and maximize on-site storage of stormwater. Site design should seek to improve the effectiveness of natural systems rather than to ignore or replace them. Further, natural systems typically require low or no maintenance, and will continue to function many years into the future.

3. **Best management practices should be implemented only after all site design and nonstructural options have been exhausted.**

   Operationally, economically, and aesthetically, stormwater better site design and the use of natural techniques offer significant benefits over best management practices. Therefore, all opportunities for utilizing these methods should be explored before implementing best management practices such as wet ponds and sand filters.

4. **Structural stormwater solutions should attempt to be multi-purpose and be aesthetically integrated into a site's design.**

. A structural stormwater facility need not be an afterthought or ugly nuisance on a development site. A parking lot, soccer field or city plaza can serve as a temporary storage facility for stormwater. In addition, water features such as ponds and lakes, when correctly designed and integrated into a site, can increase the aesthetic value of a development.

5. **"One size does not fit all" in terms of stormwater management solutions.**

Although the basic problems of stormwater runoff and the need for its management remain the same, each site, project, and watershed presents different challenges and opportunities. For instance, an infill development in a highly urbanized town center or downtown area will require a much different set of stormwater management solutions than a low-density residential subdivision in a largely undeveloped watershed. Therefore, local stormwater management needs to take into account differences between development sites, different types of development and land use, various watershed conditions and priorities, the nature of downstream lands and waters, and community desires and preferences.

2.4.2 Preparation of Stormwater Management Site Plans

2.4.2.1 INTRODUCTION

A stormwater management site plan is a comprehensive report that contains the technical information and analysis to allow a local review authority to determine whether a proposed new development or redevelopment project meets the local stormwater regulatory requirements and/or the recommended stormwater management standards contained in this Manual. See Figure 2.2.5-2 for information on the stormwater design process.

This section describes the typical contents and general procedure for preparing a stormwater management site plan. The level of detail involved in the plan will depend on the project size and the individual site and development characteristics.

The preparation of a stormwater site plan ideally follows these steps: '

(Step 1) Pre-consultation Meeting and Joint Site Visit
(Step 2) Review of Local Requirements
(Step 3) Perform Site Analysis
(Step 4) Prepare Stormwater Concept Plan
(Step 5) Prepare Preliminary Stormwater Site Plan
(Step 6) Complete Final Stormwater Site Plan

2.4.2.2 PRE-CONSULTATION MEETING AND JOINT SITE VISIT

The most important action that can take place at the beginning of the development project is a pre-consultation meeting between the local review authority and the developer and their team to outline the stormwater management requirements and other regulations, and to assist the developer in assessing constraints, opportunities, and potential for stormwater design concepts utilizing low impact development and runoff reduction techniques.

This recommended step helps to establish a constructive partnership for the entire development process. A joint site visit, if possible, can yield a conceptual outline of the stormwater management plan and strategies. By walking the site, the two parties can identify and anticipate problems, define general expectations and establish general boundaries of natural feature protection and conservation areas. A major incentive for pre-consultation is that permitting and plan approval requirements will become clear at an early stage, increasing the likelihood that the approval process will proceed faster and more smoothly.

Prior to the joint site visit, it is helpful for the developer or the developer's design team to submit the following information for familiarity and review:

- Existing conditions plan (boundary information, topography, site features, etc.)
- Proposed site plan (proposed site features)
- Soil characteristics, infiltration rates, etc. (if available)
- Natural resources inventory
- Conceptual stormwater management plans

2.4.2.3 REVIEW OF LOCAL REQUIREMENTS & PERMITTING GUIDANCE

The site developer should be made familiar with the local stormwater management and development requirements and design criteria that apply to the site. These requirements may include:

- The recommended standards for stormwater management included in this Manual (see Section 2.2)
- Design storm frequencies
- Conveyance design criteria
- Floodplain criteria
- Buffer/setback criteria
- Wetland provisions
- Watershed-based criteria
- Erosion and sedimentation control requirements
- Maintenance requirements
- Need for physical site evaluations (infiltration tests, geotechnical evaluations, etc.)

Much of this guidance can be obtained at the pre-consultation meeting with the local review authority and should be detailed in various local ordinances (e.g., subdivision codes, stormwater and drainage codes, etc.)

Current land use plans, comprehensive plans, zoning ordinances, road and utility plans, watershed or overlay districts, and public facility plans should all be consulted to determine the need for compliance with other local and state regulatory requirements.

Opportunities for special types of development (e.g., clustering) or special land use opportunities (e.g., conservation easements or tax incentives) should be investigated. There may also be an ability to partner with a local community for the development of greenways, or other riparian corridor or open space developments.

The checklist on the following page (**Table 2.4.2-1**) provides a condensed summary of current restrictions as they relate to common site features that may be regulated under local, state or federal law. These restrictions fall into one of three general categories:

- Locating a best management practice within an area that is expressly prohibited by law.
- Locating a best management practice within an area that is strongly discouraged, and is only allowed on a case by case basis. Local, state and/or federal permits shall be obtained, and the applicant will need to supply additional documentation to justify locating the stormwater practice within the regulated area.
- Best management practices must be setback a fixed distance from the site feature.

This checklist is only intended as a general guide to location and permitting requirements as they relate to siting of best management practices. Consultation with the appropriate regulatory agency is the **best** strategy.

Table 2.4.2-1 Location and Permitting Checklist

Site Feature	Location and Permitting Guidance
Jurisdictional Wetland (Waters of the U.S) U.S. Army Corps of Engineers Section 404 Permit	• Jurisdictional wetlands should be delineated prior to siting structural practice. • Use of natural wetlands for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. • Stormwater should be treated prior to discharge into a natural wetland. • Structural practices may also be restricted in local buffer zones, although they may be utilized as a non-structural filter strip (i.e., accept sheet flow). • Should justify that no practical upland treatment alternatives exist. • Where practical, excess stormwater flows should be conveyed away from jurisdictional wetlands.
Stream Channel (Waters of the U.S) U.S. Army Corps of Engineers Section 404 Permit	• All Waters of the U.S. (streams, ponds, lakes, etc.) should be delineated prior to design. • Use of any Waters of the U.S. for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. • Stormwater should be treated prior to discharge into Waters of the U.S. • In-stream ponds for stormwater quality treatment are highly discouraged. • Must justify that no practical upland treatment alternatives exist. • Temporary runoff storage preferred over permanent pools. • Implement measures that reduce downstream warming.
Georgia Planning Act Groundwater Recharge Areas	• Prevention of groundwater contamination • Covers about 23% of State. Detailed mapping available at Regional Commissions of the Department of Community Affairs. • Permanent stormwater infiltration devices are prohibited in areas having high pollution susceptibility.
Georgia Planning Act Water Supply Watersheds	• Specific stream and reservoir buffer requirements. • May be imperviousness limitations • May be specific best management practice requirements.
100 Year Floodplain Local Stormwater Review Authority	• Grading and fill for structural practice construction is generally discouraged within the ultimate 100 year floodplain, as delineated by FEMA flood insurance rate maps, FEMA flood boundary and floodway maps, or more stringent local floodplain maps. • Floodplain fill cannot raise the floodplain water surface elevation by more than a tenth of a foot.
Stream Buffer Check with appropriate review authority whether stream buffers are required	• Consult local authority for stormwater policy. • Structural practices are discouraged in the streamside zone (within 25 feet or more of streambank, depending on the specific regulations). • There are specific additional requirements related to River Corridor Protection, the Metropolitan River Protection Act, the Metropolitan North Georgia Water Planning District, and the Georgia Scenic Rivers Act (which include wider and more stringent buffers).
Utilities Local Review Authority	• Call appropriate agency to locate existing utilities prior to design. • Note the location of proposed utilities to serve development. • Structural practices are discouraged within utility easements or rights of way for public or private utilities.
Roads Local DOT, DPW, or State DOT	• Consult local DOT or DPW for any setback requirement from local roads. • Consult DOT for setbacks from State maintained roads. • Approval must also be obtained for any stormwater discharges to a local or state-owned conveyance channel.
Structures Local Review Authority	• Consult local review authority for structural practice setbacks from structures.
Septic Drain fields Local Health Authority	• Consult local health authority. • Recommended setback is a minimum of 50 feet from drain field edge.
Water Wells Local Health Authority	• 100-foot setback for stormwater infiltration. • 50-foot setback for all other structural practices.

2.4.2.4 PERFORM SITE ANALYSIS AND INVENTORY

Using approved field and mapping techniques, the site engineer should collect and review information on the existing site conditions and map the following site features:

- Topography
- Drainage patterns and basins
- Intermittent and perennial streams
- Soils
- Ground cover and vegetation
- Existing development
- Existing stormwater facilities
- Adjacent areas

In addition, the site engineer should identify and map all previously unmapped natural features such as:

- Wetlands
- Critical habitat areas
- Boundaries of wooded areas
- Floodplain boundaries
- Steep slopes
- Required buffers
- Proposed stream crossing locations
- Other required protection areas (e.g., well setbacks)

Some of this information may be available from previously performed studies or from the previous feasibility study. For example, if a development site requires a permit under the Erosion and Sedimentation Act, most of the resource protection features will likely have been mapped as part of the land disturbance activity plan. Other recommended site information to map or obtain includes utilities information, seasonal groundwater levels, and geologic mapping.

Individual map or geographic information system (GIS) layers can be designed to facilitate an analysis of the site through what is known as map overlay, or a composite analysis. Each layer (or group of related information layers) is placed on the map in such a way as to facilitate comparison and contrast with other layers. A composite layer is often developed to show all the layers at the same time (see **Figure 2.4.2-1**). This composite layer can be a useful tool for defining the best buildable areas and delineating and preserving natural feature conservation areas.

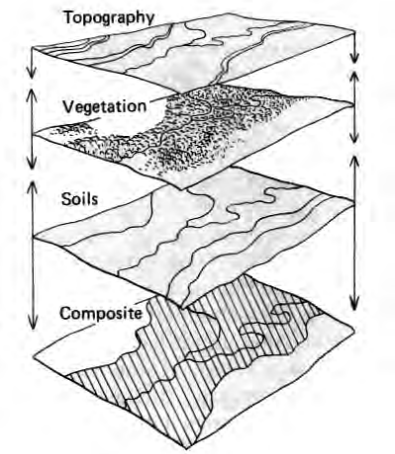


Figure 2.4.2-1 Composite Analysis
(Source: Marsh, 1983)

2.4.2.5 PREPARE STORMWATER CONCEPT PLAN

Based upon the review of existing conditions and site analysis, the design engineer should develop a concept site layout plan for the project.

During the concept plan stage the site designer will perform most of the layout of the site including the preliminary stormwater management system design and layout. The stormwater concept plan allows the design engineer to propose a potential site layout and gives the developer and local review authority a "first look" at the stormwater management system for the proposed development. The stormwater concept plan should be submitted to the local plan reviewer before detailed preliminary site plans are developed.

The following steps should be followed in developing the stormwater concept plan:

(Step 1) Use better site design approaches (see Section 2.3) as applicable to develop the site layout, including:

- Preserving the natural feature conservation areas defined in the site analysis
- Fitting the development to the terrain and minimizing land disturbance
- Reducing impervious surface area through various techniques
- Preserving and utilizing the natural drainage system wherever possible

(Step 2) Calculate preliminary estimates of the unified stormwater sizing criteria requirements for water quality, channel protection, overbank flooding protection and extreme flood protection based on the concept plan site layout (Section 2.2)

(Step 3) Determine the site design stormwater credits to be accounted for in the design of best management practices handling the water quality volume (Section 2.3)

(Step 4) Perform screening and preliminary selection of appropriate best management practices and identification of potential siting locations (Section 4.1).

It is extremely important at this stage that stormwater design is integrated into the overall site design concept in order to best reduce the impacts of the development as well as provide for the most cost-effective and environmentally sensitive approach. Using hydrology calculations, the goal of mimicking pre-development (natural or existing condition, as applicable) conditions can serve a useful purpose in planning the stormwater management system.

For local review purposes, the stormwater concept plan should include the following elements:

1. **Common address and legal description of site**

2. **Vicinity map**

3. **Existing conditions and proposed site layout mapping and plans (recommended scale of 1" = 50'), which illustrate at a minimum:**
   - Existing and proposed topography (minimum of 2-foot contours recommended)
   - Perennial and intermittent streams
   - Mapping of predominant soils from USDA soil surveys
   - Boundaries of existing predominant vegetation and proposed limits of clearing and grading
   - Location and boundaries of other natural feature protection and conservation areas such as wetlands, lakes, ponds, floodplains, stream buffers and other setbacks (e.g., drinking water well setbacks, septic setbacks, etc.)
   - Location of existing and proposed roads, buildings, parking areas and other impervious surfaces
   - Existing and proposed utilities (e.g., water, sewer, gas, electric) and easements
   - Preliminary estimates of unified stormwater sizing criteria requirements
   - Identification and calculation of stormwater site design credits
   - Preliminary selection and location, size, and limits of disturbance of proposed best management practices
   - Location of existing and proposed conveyance systems such as grass channels, swales, and storm drains
   - Flow paths
   - Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages
   - Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings

4. **Identification of preliminary waiver requests**

2.4.2.6 PREPARE PRELIMINARY STORMWATER SITE PLAN

The preliminary plan ensures that requirements and criteria are being complied with and that opportunities are being taken to minimize adverse impacts from the development.

The preliminary stormwater management site plan should consist of maps, narrative, and supporting design calculations (hydrologic and hydraulic) for the proposed stormwater management system, and should include the following sections:

1. **Natural Resources Inventory**
   - Natural Drainage Divides
   - Natural Drainage Features (e.g., swales, basins, depressional areas)
   - Wetlands
   - Water Bodies
   - Floodplains
   - Aquatic Buffers

- Shellfish Harvesting Areas
- Soils
- Erodible Soils
- Steep Slopes (i.e., Areas with Slopes Greater Than 15%)
- Groundwater Recharge Areas
- Wellhead Protection Areas
- Trees and Other Existing Vegetation
- High Quality Habitat Areas

2. **Existing Conditions Hydrologic Analysis**
   - A topographic map of existing site conditions (minimum 2-foot contour interval recommended) with the basin boundaries indicated
   - Acreage, soil types, and land cover of areas for each sub-basin affected by the project
   - All perennial and intermittent streams and other surface water features
   - All existing stormwater conveyances and structural control facilities
   - Direction of flow and exits from the site
   - Analysis of runoff provided by off-site areas upstream of the project site
   - Infiltration rates of existing soils
   - Methodologies, assumptions, site parameters, and supporting design calculations used in analyzing the existing conditions and site hydrology

3. **Natural Conditions Hydrologic Analysis (where applicable)**
   - In communities where pre-development is defined as natural conditions rather than existing conditions, or where natural conditions are a more appropriate hydrologic standard, such as discharges to impaired streams or floodprone areas, a natural conditions hydrologic analysis will be necessary. The natural conditions hydrologic analysis should include all of the elements described for Existing Conditions Hydrologic Analysis above.
   - In some cases, the existing topography may not be representative of natural conditions, and the hydrologic analysis should be modified for leveling or grading that has occurred.
   - A set type of vegetative condition such as "woods in good condition" may be used in the natural conditions hydrologic analysis. The Georgia Stormwater Quality Site Development Review Tool is used to calculate these conditions and can be found at the following website: www.gastormwater.com

4. **Post-Development Hydrologic Analysis**
   - A topographic map of developed site conditions (minimum 2-foot contour interval recommended) with the post-development basin boundaries indicated
   - Total area of post-development impervious surfaces and other land cover areas for each sub-basin affected by the project
   - Unified stormwater sizing criteria runoff calculations for water quality, channel protection, overbank flooding protection, and extreme flood protection for each sub-basin
   - Location and boundaries of proposed natural feature protection areas
   - Documentation and calculations for any applicable site design credits that are being utilized
   - Methodologies, assumptions, site parameters and supporting design calculations used in analyzing the existing conditions site hydrology

5. **Stormwater Management System**
   - Drawing or sketch of the stormwater management system including the location of non-structural site design features and the placement of existing and proposed structural stormwater controls. This drawing should show design water surface elevations, storage volumes available from zero to maximum head, location of inlets and outlets, location of bypass and discharge systems, and all orifice/restrictor sizes.
   - Narrative describing that appropriate and effective structural stormwater controls have been selected
   - Cross-section and profile drawings and design details for each of the structural stormwater controls in the system. This should include supporting calculations to show that the facility is designed according to the applicable design criteria.

- Hydrologic and hydraulic analysis of the stormwater management system for all applicable design storms (should include stage-storage or outlet rating curves, and inflow and outflow hydrographs)
- Documentation and supporting calculations to show that the stormwater management system adequately meets the unified stormwater sizing criteria
- Drawings, design calculations, and elevations for all existing and proposed stormwater conveyance elements including stormwater drains, pipes, culverts, catch basins, channels, swales, and areas of overland flow

6. **Downstream Analysis**
   - Supporting calculations for a downstream peak flow analysis using the ten-percent rule necessary to show safe passage of post-development design flows downstream
   - In some instances, the results from the downstream analysis may indicate a detention practice has an adverse impact on the watershed as a whole. In such cases, the local community may determine the detention practice is not warranted.

In calculating runoff volumes and discharge rates, consideration may need to be given to any planned future upstream land use changes. Depending on the site characteristics and given design criteria, upstream lands may need to be modeled as "existing condition" or "projected buildout/future condition" when sizing and designing on-site conveyances and stormwater practices.

2.4.2.7 COMPLETE FINAL STORMWATER SITE PLAN

The final stormwater management site plan adds further detail to the preliminary plan and reflects changes that are requested or required by the local review authority. The final stormwater site plan should include all of the revised elements of the preliminary plan as well as the following items:

1. **Erosion and Sedimentation Control Plan**
   - Must contain all the elements specified in the Georgia Erosion and Sediment Control Act and local ordinances and regulations
   - Sequence/phasing of construction and temporary stabilization measures
   - Temporary structures that will be converted into permanent best management practices

2. **Landscaping Plan**
   - Arrangement of planted areas, natural areas and other landscaped features on the site plan
   - Information necessary to construct the landscaping elements shown on the plan drawings
   - Descriptions and standards for the methods, materials and vegetation that are to be used in the construction

3. **Operations and Maintenance Plan**
   - Description of maintenance tasks, responsible parties for maintenance, funding, access and safety issues

4. **Evidence of Acquisition of Applicable Local and Non-local Permits**

5. **Waiver Requests**

The completed final stormwater site plan should be submitted to the local review authority for final approval prior to any construction activities on the development site.

2.4.2.8 OBTAIN NON-LOCAL PERMITS

The developer should obtain any applicable non-local environmental permit such as 404 wetland permits, 401 water quality certification, or construction NPDES permits prior to or in conjunction with final plan submittal. In some cases, a non-local permitting authority may impose conditions that require the original concept plan to be changed. Developers and engineers should be aware that permit acquisition can be a long, time-consuming process.

2.4.3 Stormwater Planning in the Development Process

2.4.3.1 GENERAL SITE DEVELOPMENT PROCESS

Figure 2.4.3-1 depicts a typical site development process from the perspective of the land developer. After an initial site visit the developer assesses the feasibility of the project. If the project is deemed workable, a survey is completed. The design team prepares a concept plan (often called a sketch plan) for consultation with the local review authority. A preliminary plan is then prepared and submitted for necessary reviews and approvals. Federal, state and local permits are applied for at various stages in the process.

After review by the local authority and possible public hearings, necessary revisions are made and a final construction plan is prepared. There may be several iterations between plan submittal and plan approval. Bonds are set and placed, contractors are hired, and construction of the project takes place. During and after construction numerous types of inspections take place. At the end of construction, there is a final inspection and a use and occupancy permit is issued for the structure itself.

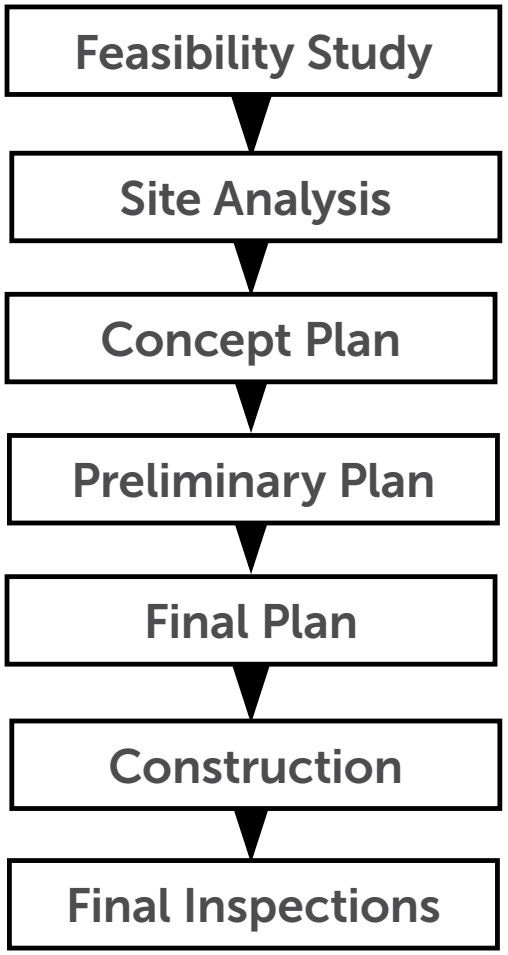


Figure 2.4.3-1
Typical Site Development Flowchart

2.4.3.2 STORMWATER SITE PLANNING AND DESIGN

Stormwater site planning and design is a subset of overall site development and must fit into the overall process if it is to be successful. **Table 2.4.3-1** on the next several pages shows how planning for the stormwater management system fits into the site development process from the perspective of the developer and site planner/engineer. For each step in the development process, the stormwater-related objectives are described, along with the key actions and major activities that are typically performed to meet those objectives.

Table 2.4.3-1 Stormwater Planning in the Site Development Process

Feasibility Study

Description:

A feasibility study is performed to determine the factors that may influence the decision to proceed with the site development, including the basic site characteristics, local and other governmental requirements, area information, surrounding developments, etc.

Stormwater-Related Objectives:

- Understand major site constraints and opportunities
- Understand local and other requirements

Key Actions:

- Initiate discussions with local review authority
- Pre-consultation between developer and plan reviewer
- Determine local stormwater management requirements

Major Activities:

- Base map development
- Review of project requirements
- Review of local development and stormwater management requirements
- Review of local stormwater master plans or comprehensive plans
- Joint site visit with local review authority
- Collection of secondary source information
- Determination of other factors or constraints impacting feasibility

Table 2.4.3-1 Stormwater Planning in the Site Development Process (continued)

Site Analysis

Description:

A site analysis is used to gain an understanding of the constraints and opportunities associated with the site through identification, mapping and assessment of natural features and resources. Potential conservation and resource protection areas are identified at this stage.

Stormwater-Related Objectives:

- Identify key site physical, environmental, and other significant resources
- Develop preliminary vision for stormwater management system

Key Actions:

- Site evaluation and delineation of natural feature protection areas

Major Activities:

- Mapping of natural resources: soils, vegetation, streams, topography, slope, wetlands, floodplains, aquifers
- Identification of other key cultural, historic, archaeological, or scenic features, orientation and exposure
- Identification of adjacent land uses
- Identification of natural feature protection and conservation areas
- Mapping of easements and utilities
- Integration of all layers – map overlay
- Other constraints and opportunities
- Identification of adjacent transportation and utility access

Table 2.4.3-1 Stormwater Planning in the Site Development Process (continued)

Concept Plan

Description:

A concept plan is used to provide both the developer and reviewer a preliminary look at the development and stormwater management concept. Based on the site analysis, a concept plan should take into account the constraints and resources available on the site. Several alternative "what if" concept plans can be created.

Stormwater-Related Objectives:

- Develop concept for stormwater management system
- Gain approval from developer and local review authority of concept plan

Key Actions:

- Develop site layout concept using better site design techniques where possible
- Perform initial runoff characterization based on site layout concept
- Determine necessary site design and/or best management practices needed to meet stormwater management requirements

Major Activities:

- Prepare sketches of functional land uses including conservation areas
- "What if" analysis of different design concepts
- Unified stormwater sizing criteria preliminary calculations
- Utilization of better site design concepts and crediting mechanisms in layout concept
- Preliminary selection and siting of best management practices
- Location of drainage/conveyance facilities

Table 2.4.3-1 Stormwater Planning in the Site Development Process (continued)

Preliminary and Final Plan

Description:

A preliminary site plan is created for local review, which includes roadways, building and parking locations, conservation areas, utilities, and stormwater management facilities. Following local approval, a final set of construction plans are developed.

Stormwater-Related Objectives:

- Prepare preliminary and final stormwater management site plan
- Secure local and non-local permits

Key Actions:

- Perform runoff characterization based on preliminary/final site plan
- Design best management practices and conveyance systems
- Perform downstream analysis

Major Activities:

- Preliminary/final site layout plan
- Unified stormwater sizing criteria calculations
- Calculation of site design credit
- Selection, siting and design of best management practices
- Development of erosion and sedimentation control plan and landscaping plan
- Applications for needed permits and waivers
- Design of drainage and conveyance facilities

Table 2.4.3-1 Stormwater Planning in the Site Development Process (continued)

Construction

Summary:

During the construction stage, the site must be inspected regularly to ensure that all elements are being built according to plan, and that all resource or conservation areas are suitably protected during construction.

Stormwater Objectives:

- Ensure that stormwater management facilities and site design practices are built as designed

Key Actions:

- Pre-construction meeting
- Inspection during construction

Major Activities:

- Execution of bonds
- Inspection during key phases or key installations
- Protection of best management practices
- Protection of conservation areas
- Erosion and sedimentation control
- Proper sequencing

Table 2.4.3-1 Stormwater Planning in the Site Development Process (continued)

Final Inspection

Summary:

After construction, the site must be inspected to ensure that all elements are completed according to plan. Long-term maintenance agreements should be executed.

Stormwater Objectives:

- Ensure that stormwater management facilities and site design practices are built and operating as designed
- Ensure long-term maintenance of best management practices and conveyances
- Ensure long-term protection of conservation and resource protection areas

Key Actions:

- Final inspection and submission of record drawings
- Maintenance inspections

Major Activities:

- Final stabilization
- As-built survey
- Final inspection and use permit
- Execution of maintenance agreements

References

Center for Watershed Protection. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection (CWP). Ellicott City, MD.

Center for Watershed Protection. 2000. *Maryland Stormwater Design Manual, Volumes I and II.* Center for Watershed Protection (CWP). Ellicott City, MD.

Delaware Department of Natural Resources and Environmental Control, 1997. *Conservation Design for Stormwater Management*. Prepared by the Brandywine Conservancy.

Department of Environmental Resources. 1999. Low-Impact Development Design Strategies, An Integrated Design Approach. Prince George's County, Maryland.

Marsh, W. 1983. *Landscape Planning: Environmental Applications*. John Wiley & Sons, New York.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas*. Saint Paul, Minnesota.

Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments. Washington D.C.

Schueler, Thomas R. 1995. *Site Planning for Urban Stream Protection*. Prepared by Center for Watershed Protection (CWP). Metropolitan Washington Council of Governments. Washington D.C.

Schueler, Thomas R. and Heather K. Holland. 2000. *The Practice of Watershed Protection*. Center for Watershed Protection (CWP), Ellicott City, MD.

Sykes, R. D. 1989. *Chapter 31 – Site Planning*. University of Minnesota. Minneapolis, Minnesota.

3. Stormwater Hydrology

3.1 Methods for Estimating Stormwater Runoff

3.1.1 Introduction to Hydrologic Methods

Hydrology deals with estimating peak flows, volumes, and time distributions of stormwater runoff. The analysis of these parameters is fundamental to the design of stormwater management facilities, such as storm drainage systems and best management practices. In the hydrologic analysis of a development site, there are a number of factors that affect the nature of stormwater runoff from the site. Some of the factors that need to be considered include:

- Rainfall amount and storm distribution
- Drainage area size, shape and orientation
- Ground cover and soil type
- Slopes of terrain and stream channel(s)
- Antecedent moisture condition
- Storage potential (floodplains, ponds, wetlands, reservoirs, channels, etc.)
- Watershed development potential
- Characteristics of the local drainage system

There are a number of empirical hydrologic methods that can be used to estimate runoff characteristics for a site or drainage subbasin; however, the following methods presented in this section have been selected to support hydrologic site analysis for the design methods and procedures included in the Manual:

- ❏ Rational Method
- ❏ NRCS TR-55 Unit Hydrograph Method
- ❏ U.S. Geological Survey (USGS) Regression Equations
- ❏ Water Quality Treatment Volume Calculation (which includes Runoff Reduction Calculations)
- ❏ Water Balance Calculations

These methods were selected based upon a verification of their accuracy in duplicating local hydrologic estimates for a range of design storms throughout the state and the availability of equations, nomographs, and computer programs to support the methods.

Table 3.1.1-1 lists the hydrologic methods and the circumstances for their use in various analysis and design applications. **Table 3.1.1-2** provides some limitations on the use of several methods.

Table 3.1.1-1 Applications of the Recommended Hydrologic Methods

Method	Manual Section	Rational Method	NRCS TR-55 Method	USGS Equations	Water Quality Volume
Water Quality Volume (WQ_v)	2.2				✓
Channel Protection Volume (CP_v)	2.2		✓		
Overbank Flood Protection (Q_{p25})	2.2		✓	✓	
Extreme Flood Protection (Q_f)	2.2		✓	✓	
Storage Facilities	3.3		✓	✓	
Outlet Structures	3.4		✓	✓	
Gutter Flow and Inlets	5.2	✓			
Storm Drain Pipes	5.2	✓	✓	✓	
Culverts	5.3	✓	✓	✓	
Small Ditches	5.4	✓	✓	✓	
Open Channels	5,4		✓	✓	
Energy Dissipation	5.5		✓	✓	

In general:

- The Rational Method is recommended for small highly impervious drainage areas such as parking lots and roadways draining into inlets and gutters.
- The USGS regression equations are recommended for drainage areas with characteristics within the ranges given for the equations. The USGS equations should be used with caution when there are significant storage areas within the drainage basin or where other drainage characteristics indicate that general regression equations might not be appropriate.

If other hydrologic methods are to be considered and used by a local review authority or design engineer, the method should first be calibrated to local conditions and tested for accuracy and reliability. If local streamgage data are available, these data can be used to develop peak discharges and hydrographs. The user is referred to standard hydrology textbooks for statistical procedures that can be used to estimate design flood events from stream gage data.

Note: It must be realized that any hydrologic analysis is only an approximation. The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex and too little data are available on the factors influencing the rainfall-runoff relationship to expect exact solutions.

Table 3.1.1-2 Constraints on Using Recommended Hydrologic Methods

Method	Size Limitations[1]	Comments
Rational	0-200 acres	Method can be used for estimating peak flows and the design of small site or subdivision storm sewer systems. Shall not be used for storage design.
NRCS TR-55[2]	0-2,000 acres*	Method can be used for estimating peak flows and hydrographs for all design applications.
USGS	25 acres to 25 mi^2	Method can be used for estimating peak flows for all design applications.
USGS	128 acres to 25 mi^2	Method can be used for estimating hydrographs for all design applications.
Water Quality	Limits set for each BMP	Method used for calculating the Water Quality Volume (WQ_v)

[1]Size limitation refers to the drainage basin for the stormwater management facility (e.g., culvert, inlet).
[2]There are many readily available programs (such as HEC-1) that utilize this methodology
*2,000-acre upper size limit applies to single basin simplified peak flow only.

3.1.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual, the symbols listed in **Table 3.1.2-1** will be used. These symbols were selected because of their wide use in technical publications. In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equations.

Table 3.1.2-1 Symbols and Definitions

Symbol	Definition	Units	Symbol	Definition	Units
A	Drainage area	acres	Q_f	Extreme Flood Protection Volume	ft^3
B_f	Baseflow	acres-feet	Q_i	Peak inflow discharge	cfs
C	Runoff coefficient	-	Q_o	Peak outflow discharge	cfs
C_f	Frequency factor	-	Q_p	Peak rate of discharge	cfs
CN	NRCS TR-55 runoff curve number	-	Q_{p25}	Overbank Flood Protection Volume	ft^3
CP_v	Channel Protection Volume	ft^3	Q_{wq}	Water Quality peak rate of discharge	cfs
d	Time interval	hours	q	Storm runoff during a time interval	in
E	Evaporation	ft	q_u	Unit peak discharge	cfs (or cfs/mi^2/inch)
E_t	Evapotranspiration	ft	R	Hydraulic radius	ft
F_p	Pond and swamp adjustment factor	-	R_o	Runoff	ft^3
G_h	Hydraulic gradient	-	R_v	Runoff Coefficient	
I or i	Runoff intensity	in/hr	RR_v	Runoff Reduction Volume	ft^3
I	Percent of impervious cover	%	S	Ground slope	ft/ft or %
I	Infiltration	ft	S	Potential maximum retention	in
I_a	Initial abstraction from total rainfall	in	S	Slope of hydraulic grade line	ft/ft
k_h	Infiltration rate	ft/day	T	Channel top width	ft
L	Flow length	ft	TL	Lag time	hours
n	Manning roughness coefficient	-	T_p	Time to peak	hr
NRCS	Natural Resources Conservation Service	-	t	Time	min
O_f	Overflow	ft^3	t_c	Time of concentration	min
P	Accumulated rainfall	in	TIA	Total impervious area	%
P_2	2-year, 24-hour rainfall	in	V	Velocity	ft/s
P_w	Wetted perimeter	ft	V	Pond volume	ft^3
PF	Peaking factor	-	V_r	Runoff volume	ft^3
Q	Rate of runoff	cfs (or inches)	V_s	Storage volume	ft^3
Q_d	Developed runoff for the design storm	in	WQ_v	Water Quality Volume	ft^3

3.1.3 Rainfall Estimation

The first step in any hydrologic analysis is an estimation of the rainfall that will fall on the site for a given time period. The amount of rainfall can be quantified with the following characteristics:

- *Duration (hours)* – Length of time over which rainfall (storm event) occurs
- *Depth (inches)* – Total amount of rainfall occurring during the storm duration
- *Intensity (inches per hour)* – Depth divided by the duration

The Frequency of a rainfall event is the recurrence interval of storms having the same duration and volume (depth). This can be expressed either in terms of exceedence probability or return period.

- *Exceedence Probability* – Probability that a storm event having the specified duration and volume will be exceeded in one given time period, typically 1 year
- *Return Period* – Average length of time between events that have the same duration and volume

Thus, if a storm event with a specified duration and volume has a 1% chance of occurring in any given year, then it has an exceedence probability of 0.01 and a return period of 100 years.

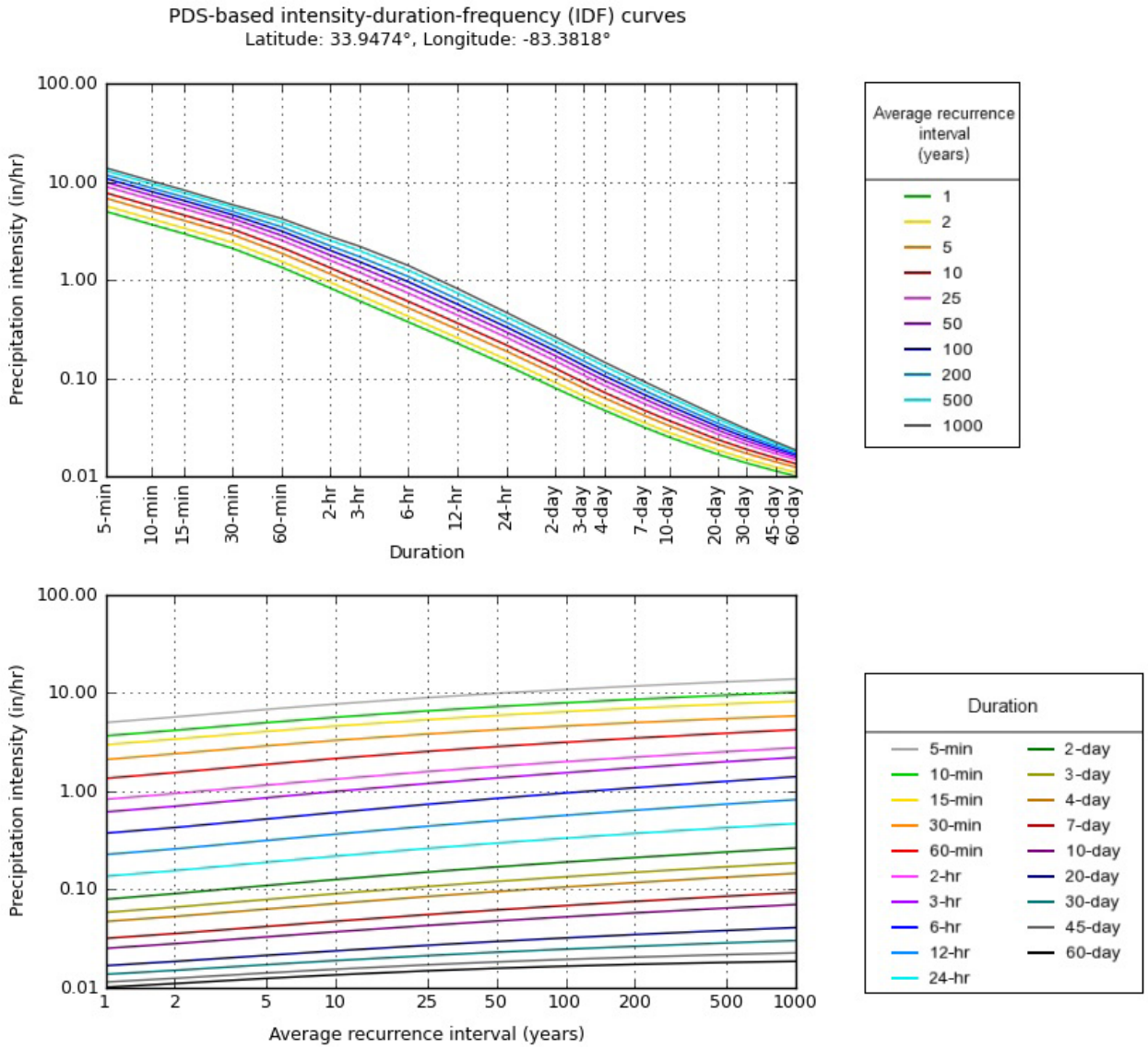


Figure 3.1.3-1 Example DDF Curve (Athens, Georgia)
(Source: NOAA Atlas 14, Volume 9, Version 2, 2013)

The tabular precipitation data for Gwinnett County provided below (**Table 3.1.3-1**) are applicable for storm durations from 5 minutes to 24 hours. The NOAA precipitation database also has a graphical display that shows the intensity duration frequency curve of any given precipitation data, but **Table 3.1.3-1** shall be used for all hydrologic analyses in Gwinnett County, for consistency.

Figure 3.1.3-2 (included as the 10-year 24-hour values from TP40) shows that the rainfall values vary south to north with generally constant values in a "V" pattern from east to west in central and south Georgia.



Figure 3.1.3-2 Rainfall Isohyetal Lines (10-year, 24-hour values)

Table 3.1.3-1 Rainfall Intensity (in/hr): Gwinnett County

Storm Duration		Return Period						
Hours	Minutes	1	2	5	10	25	50	100
0	5	4.91	5.64	6.86	7.90	9.32	10.5	11.6
0	10	3.59	4.13	5.03	5.78	6.83	7.65	8.48
0	15	2.92	3.36	4.09	4.70	5.55	6.22	6.90
0	30	2.05	2.37	2.88	3.32	3.93	4.40	4.89
1	0	1.31	1.51	1.83	2.11	2.51	2.83	3.16
2	0	0.800	0.915	1.11	1.28	1.53	1.73	1.94
3	0	0.596	0.678	0.820	0.945	1.13	1.28	1.44
6	0	0.367	0.414	0.495	0.568	0.676	0.765	0.860
12	0	0.227	0.254	0.302	0.344	0.406	0.456	0.509
24	0	0.137	0.155	0.185	0.211	0.248	0.277	0.307

Data taken from NOAA 14 for the centroid of Gwinnett County.

3.1.4 Rational Method

3.1.4.1 INTRODUCTION

An important formula for determining the peak runoff rate is the Rational Formula. It is characterized by:

- Consideration of the entire drainage area as a single unit
- Estimation of flow at the most downstream point only
- The assumption that rainfall is uniformly distributed over the drainage area and is constant over time

The Rational Formula follows the assumption that:

- The predicted peak discharge has the same probability of occurrence (return period) as the used rainfall intensity (I)
- The runoff coefficient (C) is constant during the storm event

When using the Rational Method some precautions should be considered:

- ❏ In determining the C value (runoff coefficient based on land use) for the drainage area, hydro-logic analysis should take into account any future changes in land use that might occur during the service life of the proposed facility.
- ❏ Since the Rational Method uses a composite C and a single t_c value for the entire drainage area, if the distribution of land uses within the drainage basin will affect the results of hydrologic analysis (e.g., if the impervious areas are segregated from the pervious areas), then basin should be divided into sub-drainage basins.
- ❏ The charts, graphs, and tables included in this section are given to assist the design engineer in applying the Rational Method. The design engineer should use sound engineering judgment in applying these design aids and should make appropriate adjustments when specific site characteristics dictate that these adjustments are appropriate.

3.1.4.2 APPLICATION

The Rational Method can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm drain pipe, culverts, and small ditches. It is most applicable to small, highly impervious areas. The recommended maximum drainage area that should be used with the Rational Method is 25 acres.

Neither the Rational Method, nor the Modified Rational Method, should be used for storage design, for calculating peak flows downstream of bridges, culverts or storm sewers that may act as restrictions and impact the peak rate of discharge, or any other application where a more detailed routing procedure is required.

3.1.4.3 EQUATIONS

The Rational Formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration, t_c (the time required for water to flow from the most remote point of the basin to the location being analyzed).

The Rational Formula is expressed as follows:

$$Q = CIA \qquad (3.1.1)$$

Where:

Q = maximum rate of runoff (cfs)

C = runoff coefficient representing a ratio of runoff to rainfall

I = average rainfall intensity for a duration equal to the t_c (in/hr)

A = drainage area contributing to the design location (acres)

The coefficients given in **Table 3.1.4-2** are applicable for storms of 5 year to 10 year frequencies. Less frequent, higher intensity storms may require modification of the coefficient because infiltration and other losses have a proportionally smaller effect on runoff (Wright-McLaughlin Engineers, 1969). The adjustment of the Rational Method for use with major storms can be made by multiplying the right side of the Rational Formula by a frequency factor C_f. The Rational Formula now becomes:

$$Q = C_f CIA \qquad (3.1.2)$$

The C_f values that can be used are listed in **Table 3.1.4-1**. The product of C_f times C shall not exceed 1.0.

Table 3.1.4-1 Frequency Factors for Rational Formula

Recurrence Interval (years)	C_f
10 or less	1.0
25	1.1
50	1.2
100	1.25

3.1.4.4 TIME OF CONCENTRATION

Use of the Rational Formula requires the time of concentration (t_c) for each design point within the drainage basin. The duration of rainfall is then set equal to the time of concentration and is used to estimate the design average rainfall intensity (I). The time of concentration consists of an overland flow time to the point where the runoff is concentrated or enters a defined drainage feature (e.g., open channel) plus the time of flow in a closed conduit or open channel to the design point.

Figure 3.1.4-1 can be used to estimate overland flow time. For each drainage area, the distance is determined from the inlet to the most remote point in the tributary area. From a topographic map, the average slope is determined for the same distance. The runoff coefficient (C) is determined by the procedure described in a subsequent section of this chapter.

To obtain the total time of concentration, the pipe or open channel flow time must be calculated and added to the inlet time. After first determining the average flow velocity in the pipe or channel, the travel time is obtained by dividing velocity into the pipe or channel length. Velocity can be estimated by using the nomograph shown in **Figure 3.1.4-2**. Note: time of concentration cannot be less than 5 minutes.

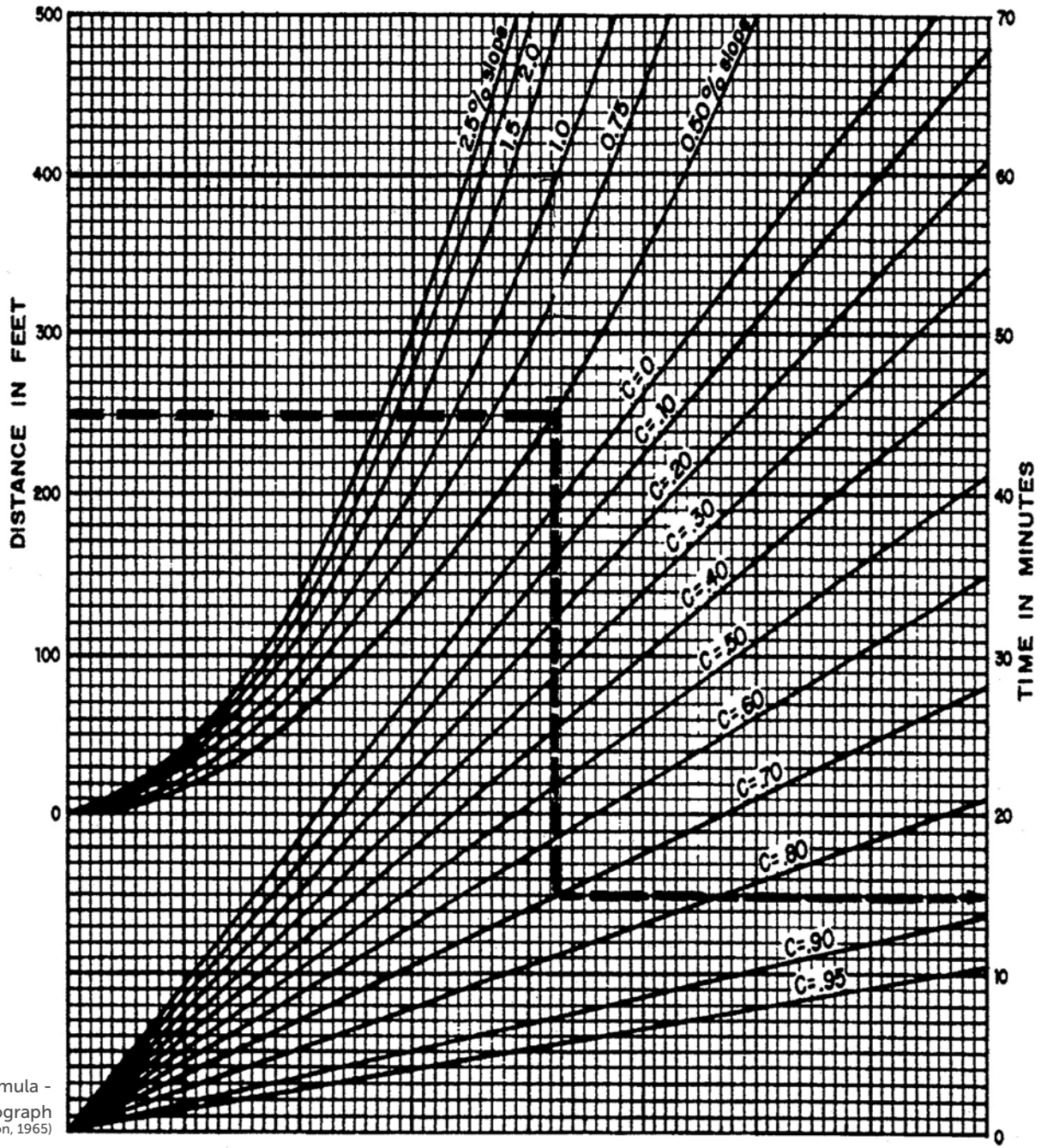
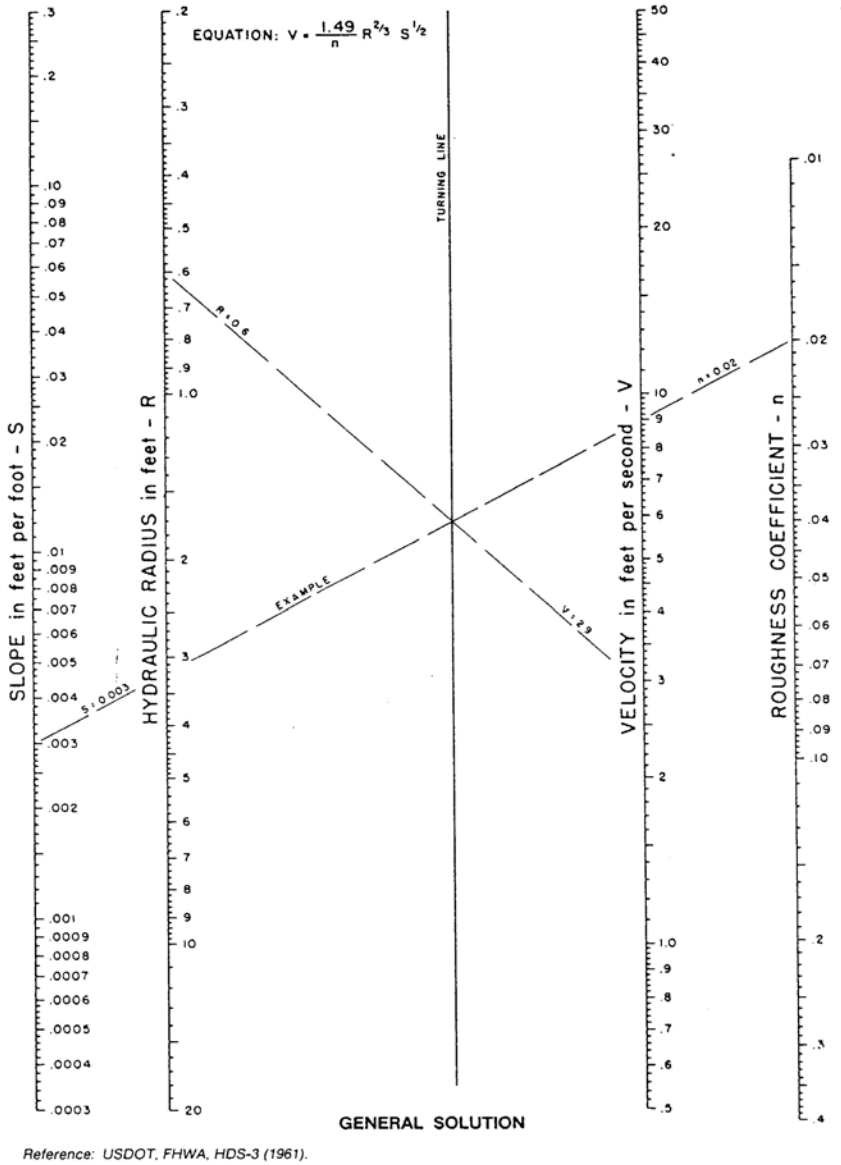


Figure 3.1.4-1 Rational Formula - Overland Time of Flow Nomograph
(Source: Airport Drainage, Federal Aviation Administration, 1965)



Reference: USDOT, FHWA, HDS-3 (1961).

Figure 3.1.4-2 Manning's Equation Nomograph
(Source: USDOT, FHWA, HDS-3 (1961))

To obtain the total time of concentration, the pipe or open channel flow time must be calculated and added to the inlet time. After first determining the average flow velocity in the pipe or channel, the travel time is obtained by dividing velocity into the pipe or channel length. Velocity can be estimated by using the nomograph shown in **Figure 3.1.4-2.** Note: time of concentration cannot be less than 5 minutes.

Another method that can be used to determine the overland flow portion of the time of concentration is the "Kinematic Wave Nomograph" (**Figure 3.1.4-3**). The kinematic wave method incorporates several variables including rainfall intensity and Manning's "n". In using the nomograph, the design engineer has two unknowns starting the computations: the time of concentration and the rainfall intensity. A value for the rainfall intensity "I" must be assumed. The travel time is determined iteratively.

If one has determined the length, slope and roughness coefficient, and selected a rainfall intensity table, the steps to use **Figure 3.1.4-3** are as follows:

(Step 1) Assume a rainfall intensity.
(Step 2) Use **Figure 3.1.4-3** (or the equation given in the figure) to obtain the first estimate of time of concentration.
(Step 3) Using the time of concentration obtained from Step 2, use the appropriate rainfall intensity from NOAA Atlas 14 and find the rainfall intensity corresponding to the computed time of concentration. If this rainfall intensity corresponds with the assumed intensity, the problem is solved. If not, proceed to Step 4.
(Step 4) Assume a new rainfall intensity that is between that assumed in Step 1 and that determined in Step 3.
(Step 5) Repeat Steps 1 through 3 until there is good agreement between the assumed rainfall intensity and that obtained from the rainfall intensity tables.

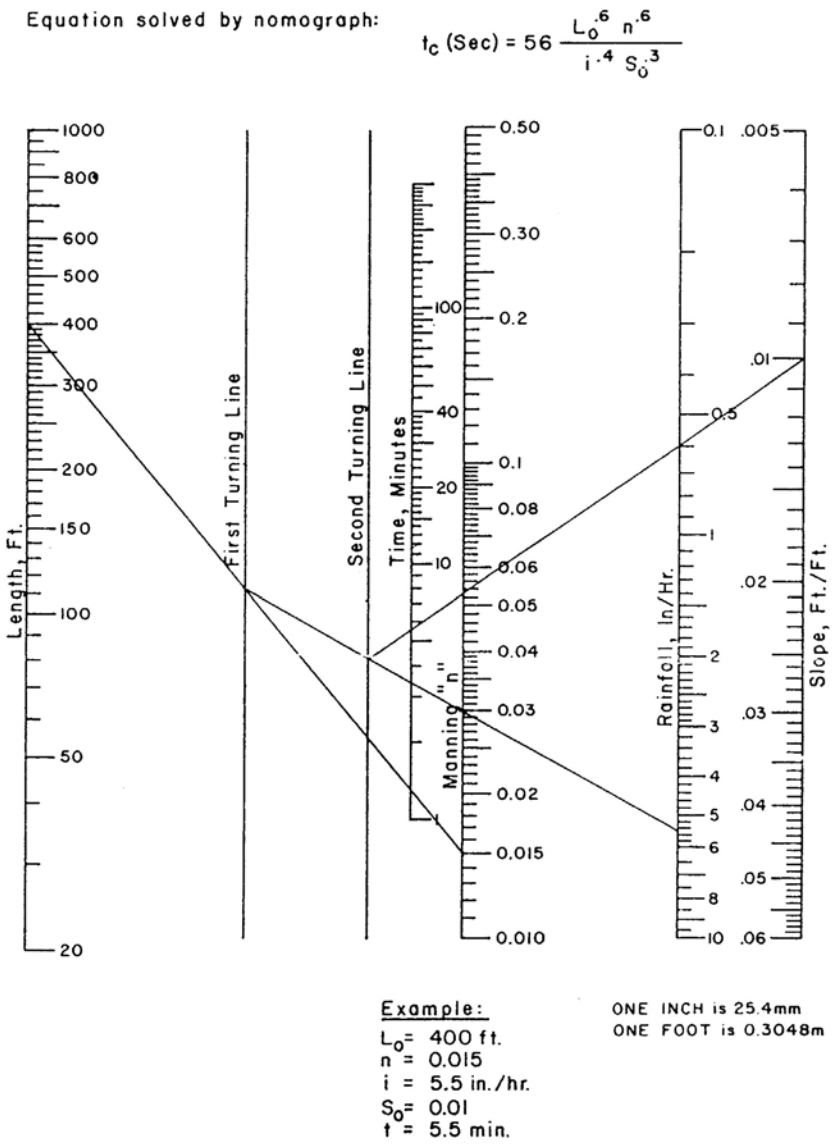


Figure 3.1.4-3 Kinematic Wave Nomograph
(Source: Manual For Erosion And Sediment Control In Georgia)

Generally, the time of concentration for overland flow is only a part of the overall design problem. Often one encounters swale flow, confined channel flow, and closed conduit flow-times that must be added as part of the overall time of concentration. When this situation is encountered, it is best to compute the confined flow-times as the first step in the overall determination of the time of concentration. This will give the designer a rough estimate of the time involved for the overland flow, which will give a better first start on the rainfall intensity assumption. For example, if the flow time in a channel is 15 minutes and the overland flow time from the ridge line to the channel is 10 minutes, then the total time of concentration is 25 minutes.

Other methods and charts may be used to calculate overland flow time if approved by the local review authority.

Two common errors should be avoided when calculating time of concentration. First, in some cases runoff from a portion of the drainage area which is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. Second, when designing a drainage system, the overland flow path is not necessarily the same before and after development and grading operations have been completed. Selecting overland flow paths in excess of 50 feet for impervious areas should be done only after careful consideration.

3.1.4.5 RAINFALL INTENSITY (I)

The rainfall intensity (I) is the average rainfall rate in in/hr for a duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from data given from NOAA Atlas 14.

3.1.4.6 RUNOFF COEFFICIENT (C)

The runoff coefficient (C) is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the design engineer.

While engineering judgment will always be required in the selection of runoff coefficients, typical coefficients represent the integrated effects of many drainage basin parameters. **Table 3.1.4-2** gives the recommended runoff coefficients for the Rational Method.

It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surfaces in the drainage areas. Composites can be made with the values from **Table 3.1.4-2** by using percentages of different land uses. In addition, more detailed composites can be made with coefficients for different surface types such as rooftops, asphalt, and concrete streets and sidewalks. The composite procedure can be applied to an entire drainage area or to typical "sample" blocks as a guide to the selection of reasonable values of the coefficient for an entire area.

It should be remembered that the Rational Method assumes that all land uses within a drainage area are uniformly distributed throughout the area. If it is important to locate a specific land use within the drainage area then another hydrologic method should be used where hydrographs can be generated and routed through the drainage system.

It may be that using only the impervious area from a highly impervious site (and the corresponding high C factor and shorter time of concentration) will yield a higher peak runoff value than by using the whole site. This should be checked particularly in areas where the overland portion is grassy (yielding a long t_c) to avoid underestimating peak runoff.

Table 3.1.4-2 Recommended Runoff Coefficient Values

Description of Area	Runoff Coefficients (C)	Description of Area	Runoff Coefficients (C)
Lawns		**Industrial**	
Sandy soil, flat, 2%	0.10	Light areas	0.70
Sandy soil, average, 2-7%	0.15	Heavy areas	0.80
Sandy soil, steep, >7%	0.20	**Parks, cemeteries**	**0.25**
Clay soil, flat, 2%	0.17	**Playgrounds**	0.35
Clay soil, average, 2-7%	0.22	**Railroad yard areas**	0.40
Clay soil, steep, >7%	0.35	**Streets**	
Unimproved areas (forest)	**0.15**	Asphalt and concrete	0.95
Business		Brick	0.85
Downtown areas	0.95	**Drives, walks, and roofs**	**0.95**
Neighborhood areas	0.70	**Gravel areas**	**0.50**
Residential		**Graded or no plant cover**	
Single-family areas	0.50	Sandy soil, flat, 0-5%	0.30
Multi-units, detached	0.60	Sandy soil, flat, 5-10%	0.40
Multi-units, attached	0.70	Clay soil, flat, 0-5%	0.50
Suburban	0.40	Clay soil, average, 5-10%	0.60
Apartment dwelling areas	0.70		

3.1.4.7 EXAMPLE PROBLEM

Following is an example problem that illustrates the application of the Rational Method to estimate peak discharges.

Estimates of the maximum rate of runoff are needed at the inlet to a proposed culvert for a 25-year return period.

Site Data

From a topographic map of the City of Roswell and a field survey, the area of the drainage basin upstream from the point in question is found to be 23 acres. In addition the following data were measured:

- Average overland slope = 2.0%
- Length of overland flow = 50 ft
- Length of main basin channel = 2,250 ft
- Slope of channel .018 ft/ft = 1.8%
- Roughness coefficient (n) of channel was estimated to be 0.090
- Roughness coefficient (n) of channel was estimated to be 0.090
- From existing land use maps, land use for the drainage basin was estimated to be:
  - » Residential (single family) - 80%
  - » Graded - sandy soil, 3% slope - 20%

From existing land use maps, the land use for the overland flow area at the head of the basin was estimated to be: Lawn - sandy soil, 2% slope

Overland Flow

A runoff coefficient (C) for the overland flow area is determined from **Table 3.1.4-2** to be 0.10.

Time of Concentration

From **Figure 3.1.4-1** with an overland flow length of 50 ft, slope of 2% and a C of 0.10, the overland flow time is 10 min. Channel flow velocity is determined from Figure 3.1.4-2 to be 3.1 ft/s (n = 0.090, R = 1.62 (from channel dimensions) and S = .018). Therefore,

$$\text{Flow Time} = \frac{2{,}250 \text{ feet}}{(3.1 \text{ ft/s})/(60 \text{ s/min})} = 12.1 \text{ minutes}$$

and t_c = 10 + 12.1 = 22.1 min (use 22 min)

Rainfall Intensity

From NOAA Atlas 14, and using a duration equal to 22 minutes,

I_{25} (25 yr return period) = 4.88 in/hr

Runoff Coefficient

A weighted runoff coefficient (C) for the total drainage area is determined below by utilizing the values from **Table 3.1.4-2**.

Land Use	Percent of Total Land Area	Runoff Coefficient	Weighted Runoff Coefficient*
Residential *(single family)*	0.80	0.50	0.40
Graded area	0.20	0.30	0.06
Total Weighted Runoff Coefficient - 0.46			

*Column 3 equals Column 1 multiplied by Column 2

Peak Runoff

The estimate of peak runoff for a 25-yr design storm for the given basin is:

$Q_{25} = C_f CIA = (1.10)(.46)(4.88)(23) = 57$ cfs

3.1.5 NRCS TR-55 Hydrologic Method

3.1.5.1 INTRODUCTION

The Soil Conservation Service (NRCS TR-55) hydrologic method requires basic data similar to the Rational Method: drainage area, a runoff factor, time of concentration, and rainfall. The NRCS

TR-55 approach, however, is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. Details of the methodology can be found in the *NRCS National Engineering Handbook,* Part 630, Hydrology.

A typical application of the NRCS TR-55 method includes the following basic steps:

(Step 1) Determination of curve numbers that represent different land uses within the drainage area.

(Step 2) Calculation of time of concentration to the study point.

(Step 3) Using the Type II or Type III rainfall distribution, total and excess rainfall amounts are determined. Note: See **Figure 3.1.5-1** for the geographic boundaries for the different NRCS TR-55 rainfall distributions.

(Step 4) Using the unit hydrograph approach, the hydrograph of direct runoff from the drainage basin can be developed.

3.1.5.2 APPLICATION

The NRCS TR-55 method can be used for both the estimation of stormwater runoff peak rates and the generation of hydrographs for the routing of stormwater flows. The simplified method of Subsection 3.1.5.7 can be used for drainage areas up to 2,000 acres. Thus, the NRCS TR-55 method can be used for most design applications, including storage facilities and outlet structures, storm drain systems, culverts, small drainage ditches and open channels, and energy dissipators.

3.1.5.3 EQUATIONS AND CONCEPTS

The hydrograph of outflow from a drainage basin is the sum of the elemental hydrographs from all the sub-areas of the basin, modified by the effects of transit time through the basin and storage in the stream channels. Since the physical characteristics of the basin including shape, size and slope are constant, the unit hydrograph approach assumes that there is considerable similarity in the shape of hydrographs from storms of similar rainfall characteristics. Thus, the unit hydrograph is a typical hydrograph for the basin with a runoff volume under the hydrograph equal to one (1.0) inch from a storm of specified duration. For a storm of the same duration but with a different amount of runoff, the hydrograph of direct runoff can be expected to have the same time base as the unit hydrograph and ordinates of flow proportional to the runoff volume. Therefore, a storm that produces 2 inches of runoff would have a hydrograph with a flow equal to twice the flow of the unit hydrograph. With 0.5 inches of runoff, the flow of the hydrograph would be one-half of the flow of the unit hydrograph.

The following discussion outlines the equations and basin concepts used in the NRCS TR-55 method.

Drainage Area - The drainage area of a watershed is determined from topographic maps and field surveys. For large drainage areas it might be necessary to divide the area into sub-drainage areas to account for major land use changes, obtain analysis results at different points within the drainage area, combine hydrographs from different sub-basins as applicable, and/or route flows to points of interest.

Rainfall - The NRCS TR-55 method applicable to the State of Georgia is based on a storm event that has a Type II or Type III time distribution. These distributions are used to distribute the 24-hour volume of rainfall for the different storm frequencies (**Figure 3.1.5-1**).

Rainfall-Runoff Equation - A relationship between accumulated rainfall and accumulated runoff was derived by NRCS TR-55 from experimental plots for numerous soils and vegetative cover conditions. The following NRCS TR-55 runoff equation is used to estimate direct runoff from 24 hour or 1 day storm rainfall. The equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (3.1.3)$$

Where:

Q = accumulated direct runoff (in)
P = accumulated rainfall (potential maximum runoff) (in)
$\mathbf{I_a}$ = initial abstraction including surface storage, interception, evaporation, and infiltration prior to runoff (in)
S = potential maximum soil retention (in)

An empirical relationship used in the NRCS TR-55 method for estimating I_a is:

$$I_a = 0.2S \qquad (3.1.4)$$

This is an average value that could be adjusted for flatter areas with more depressions if there are calibration data to substantiate the adjustment.

Substituting 0.2S for I_a in **equation 3.1.3**, the equation becomes:

$$Q = \frac{(P-0.2S)^2}{(P + 0.8S)} \qquad (3.1.5)$$

Where:

S = 1000/CN - 10
CN = NRCS TR-55 curve number.

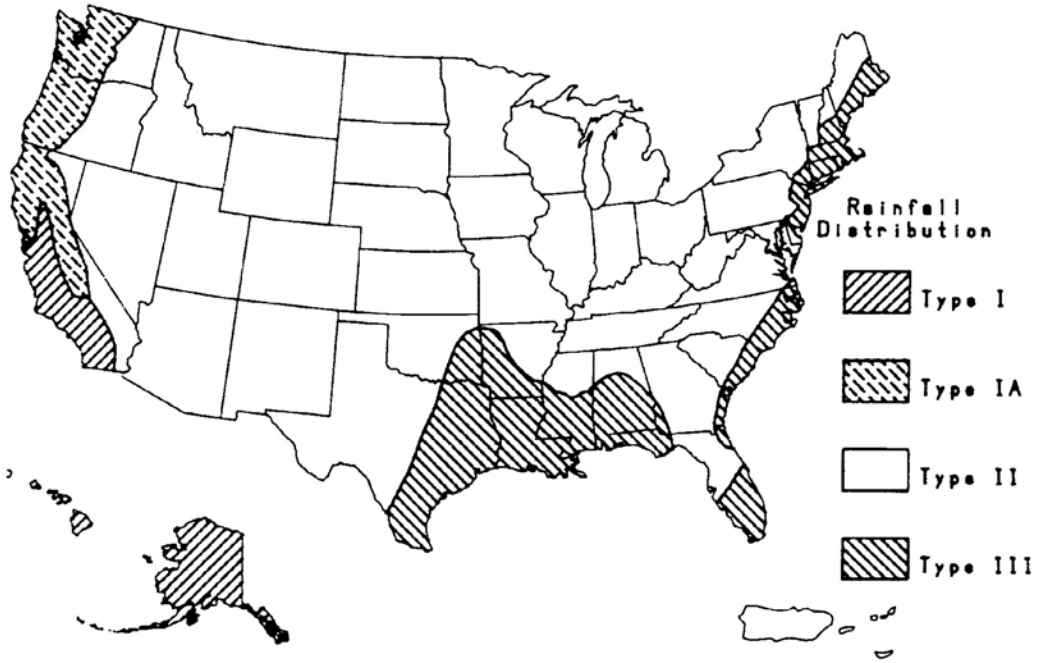


Figure 3.1.5-1 Approximate Geographic Boundaries
for NRCS TR-55 Rainfall Distributions

Figure 3.1.5-2 shows a graphical solution of this equation. For example, 4.1 inches of direct runoff would result if 5.8 inches of rainfall occurs on a watershed with a curve number of 85.

Equation 3.1.5 can be rearranged so that the curve number can be estimated if rainfall and runoff volume are known. The equation then becomes (Pitt, 1994):

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25QP)^{1/2}] \quad (3.1.6)$$

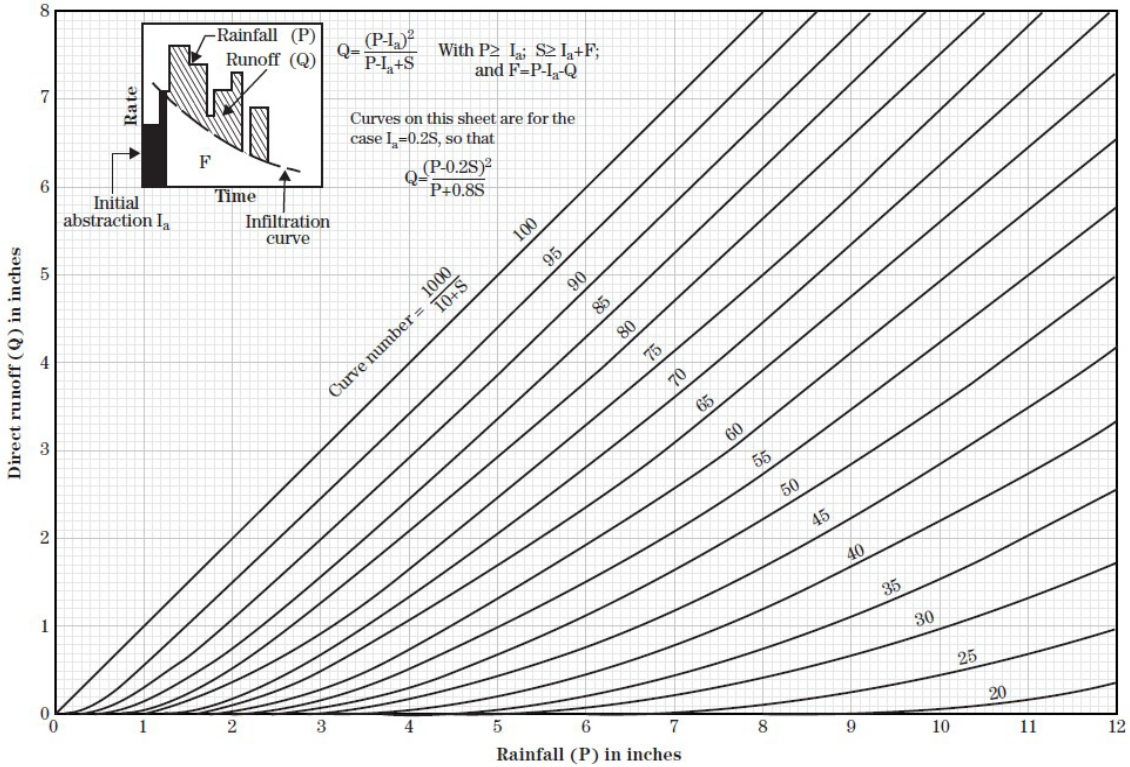


Figure 3.1.5-2 NRCS TR-55 Solution of the Runoff Equation
(Source: NRCS TR-55, NEH630, 2004)

3.1.5.4 RUNOFF FACTOR

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The NRCS TR-55 method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher the runoff potential. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration.

Based on infiltration rates, the NRCS TR-55 has divided soils into four hydrologic soil groups.

Group A: Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.

Group B: Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D: Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

A list of soils throughout the State of Georgia and their hydrologic classification can be found in the publication *Urban Hydrology for Small Watersheds, 2nd Edition, Technical Release* Number 55, 1986. Soil Survey maps can be obtained online at the United States Department of Agriculture (USDA) Natural Resource Conservation Commission's (NRCS) web soil survey online tool to classify the soil type. (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm)

Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected. Also, runoff curve numbers vary with the antecedent soil moisture conditions. Average antecedent soil moisture conditions (AMC II) are recommended for most hydrologic analysis, except in the design of state-regulated Category I dams where AMC III may be required. Areas with high water table conditions may want to consider using AMC III antecedent soil moisture conditions. This should be considered a calibration parameter for modeling against real calibration data. **Table 3.1.5-1** gives recommended curve number values for a range of different land uses.

When a drainage area has more than one land use, a composite curve number can be calculated and used in the analysis. It should be noted that when composite curve numbers are used, the analysis does not take into account the location of the specific land uses but sees the drainage area as a uniform land use represented by the composite curve number.

Composite curve numbers for a drainage area can be calculated by using the weighted method as presented below.

Composite Curve Number Calculation Example

Land Use	Percent of Total Land Area	Curve Number	Weighted Curve Number (%area x CN)
Residential 1/8 acre Soil group B	80%	85	68
Meadow Good conditions Soil group C	20%	71	14
Total Weighted Curve Number = 68 + 14 = 82			

The different land uses within the basin should reflect a uniform hydrologic group represented by a single curve number. Any number of land uses can be included, but if their spatial distribution is important to the hydrologic analysis, then sub-basins should be developed and separate hydrographs developed and routed to the study point.

3.1.5.5 URBAN MODIFICATIONS OF THE NRCS TR-55 METHOD

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for developed areas. For example, do the impervious areas connect directly to the drainage system, or do they outlet onto lawns or other pervious areas where infiltration can occur?

The curve number values given in **Table 3.1.5-1** are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over pervious areas and then into a drainage system. It is possible that curve number values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system, but allowing runoff to flow as sheet flow over significant pervious areas.

The following discussion will give some guidance for adjusting curve numbers for different types of impervious areas.

Connected Impervious Areas

The CNs provided in **Table 3.1.5-1** for various land cover types were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that:

(a) Pervious urban areas are equivalent to pasture in good hydrologic condition, and

(b) Impervious areas have a CN of 98 and are directly connected to the drainage system.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in **Table 3.1.5-1** are not applicable, use **Figure 3.1.5-3** to compute a composite CN. For example, **Table 3.1.5-1** gives a CN of 70 for a 1/2-acre lot in hydrologic soil group B, with an assumed impervious area of 25%. However, if the lot has 20% impervious area and a pervious area CN of 61, the composite CN obtained from **Figure 3.1.5-3** is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.

Unconnected Impervious Areas

Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use **Figure 3.1.5-4** if total impervious area is less than 30% or (2) use **Figure 3.1.5-3** if the total impervious area is equal to or greater than 30%, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

Table 3.1.5-1 Runoff Curve Numbers[1]

Cover description			Curve numbers for hydrological soil groups			
Cover type and hydrologic condition		*Average percent impervious area[2]*	A	B	C	D
Cultivated land:	without conservation treatment		72	81	88	91
	with conservation treatment		62	71	78	81
Pasture or range land:	poor condition		68	79	86	89
	good condition		39	61	74	80
Meadow:	good		30	58	71	78
Wood or forest land:	thin stand, poor cover		45	66	77	83
	good cover		25	55	70	77
Open space (laws, parks, golf courses, cemeteries, etc)[3]:	Poor condition (grass cover <50%)		68	79	86	89
	Fair condition (grass cover 50% to 75%)		49	69	79	84
	Good condition (grass cover >75%)		39	61	74	80
Impervious areas:	Paved parking lots, roofs, driveways, etc (excluding right-of-way)		98	98	98	98
Streets and roads:	Paved; curbs and storm drains (excluding right-of-way)		98	98	98	98
	Paved; open ditches (including right-of-way)		83	89	92	93
	Gravel (including right-of-way)		76	85	89	91
	Dirt (including right-of-way)		72	82	87	89
Urban Districts:	Commercial and business	85%	89	92	94	95
	Industrial	72%	81	88	91	93
Residential districts by average lot size:	1/8 acre or less (townhouses)	65%	77	85	90	92
	1/4 acre	38%	61	75	83	87
	1/3 acre	30%	57	72	81	86
	1/2 acre	25%	54	70	80	85
	1 acre	20%	51	68	79	84
	2 acres	12%	46	65	77	82
Developing urban areas and newly graded areas (pervious areas only, no vegetation)			77	86	91	94

[1]Average runoff condition, and I_a = 0.2S
[2]The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. If the impervious area is not connected, the NRCS TR-55 method has an adjustment to reduce the effect.
[3]CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

When impervious area is less than 30%, obtain the composite CN by entering the right half of **Figure 3.1.5-4** with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a 1/2-acre lot with 20% total impervious area (75% of which is unconnected) and pervious CN of 61, the composite CN from **Figure 3.1.5-4** is 66. If all of the impervious area is connected, the resulting CN (from **Figure 3.1.5-3**) would be 68.

3.1.5.6 TRAVEL TIME ESTIMATION

Travel time (T_t) is the time it takes water to travel from one location to another within a watershed, through the various components of the drainage system. Time of concentration (t_c) is computed by summing all the travel times for consecutive components of the drainage conveyance system from the hydraulically most distant point of the watershed to the point of interest within the watershed. Following is a discussion of related procedures and equations (USDA, 1986).

Travel Time

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection..

Travel time is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600V} \qquad (3.1.7)$$

Where:

T_t = travel time (hr)
L = flow length (ft)
V = average velocity (ft/s)
3600 = conversion factor from seconds to hours

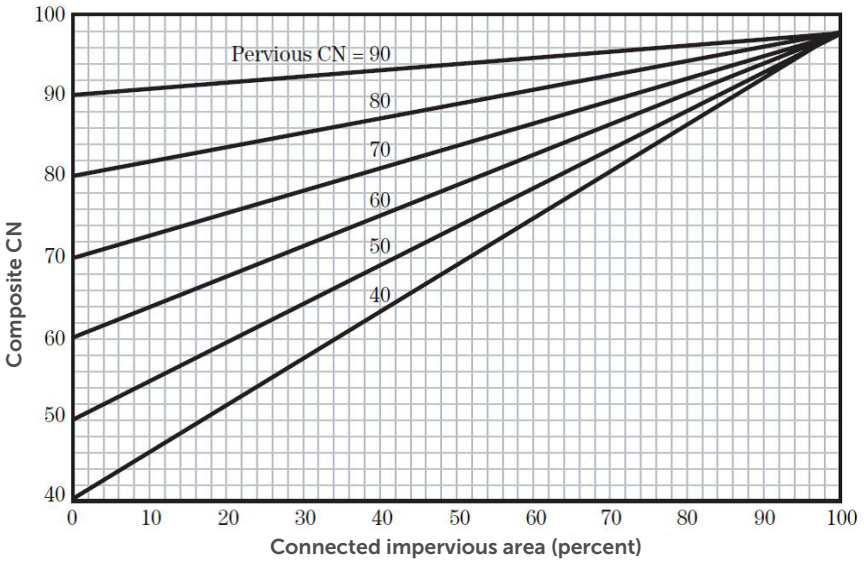


Figure 3.1.5-3 Composite CN with Connected Impervious Areas
(Source: NRCS TR-55, NEH630, 2004)

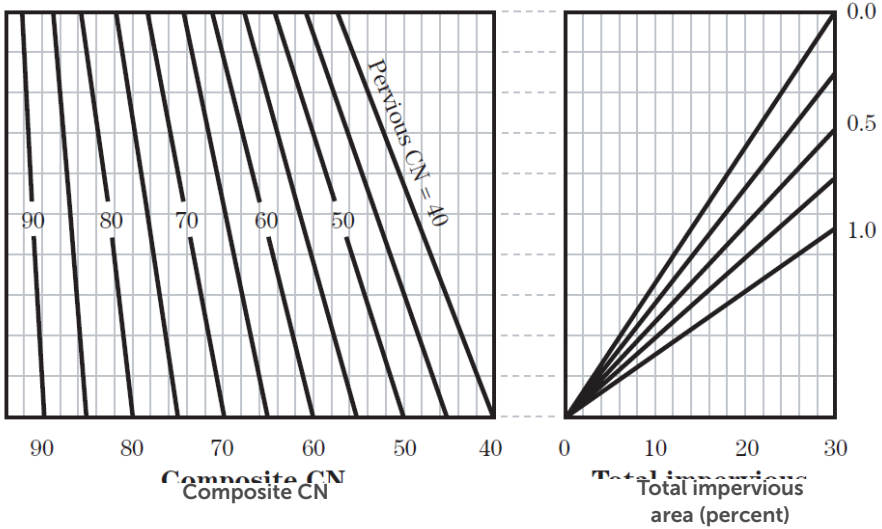


Figure 3.1.5-4 Composite CN with Unconnected Impervious Areas (Total Impervious Area Less Than 30%)
(Source: NRCS TR-55, NEH630, 2004)

Sheet Flow

Sheet flow can be calculated using the following formula:

$$T_t = \frac{0.42(nL)^{0.8}}{60(P_2)^{0.5}(S)^{0.4}} \quad (3.1.8)$$

Where:

T_t = travel time (hr)

n = Manning roughness coefficient (see **Table 3.1.5-2**)

L = flow length (ft)

P_2 = 2-year, 24-hour rainfall

S = land slope (ft/ft)

Table 3.1.5-2 Roughness Coefficients (Manning's n) for Sheet Flow[1]

Surface description		n
Smooth surfaces (concrete, asphalt, gravel, or bare soil):		0.011
Fallow (no residue):		0.05
Cultivated soils:	Residue cover <20%	0.06
	Residue cover >20%	0.17
Grass:	Short grass prairie	0.15
	Dense grasses[2]	0.24
	Bermuda grass	0.41
Range (natural):		0.13
Woods[3]:	Light underbrush	0.40
	Dense underbrush	0.80

[1]The n values are a composite of information by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Source: NRCS TR-55, TR-55, Second Edition, June 1986.

Shallow Concentrated Flow

After a maximum of 50 to 100 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from **Figure 3.1.5-5**, in which average velocity is a function of watercourse slope and type of channel.

Average velocities for estimating travel time for shallow concentrated flow can be computed from using **Figure 3.1.5-5,** or the following equations. These equations can also be used for slopes less than 0.005 ft/ft.

$$\text{Unpaved: } V = 16.13(S)^{0.5} \quad (3.1.9)$$

$$\text{Paved: } V = 20.33(S)^{0.5} \quad (3.1.10)$$

Where:

V = average velocity (ft/s)

S = slope of hydraulic grade line (watercourse slope, ft/ft)

After determining average velocity using **Figure 3.1.5-5** or **Equations 3.1.9** or **3.1.10**, use **Equation 3.1.7** to estimate travel time for the shallow concentrated flow segment.

Open Channels

Velocity in channels should be calculated from the Manning equation. Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, where channels have been identified by the local municipality, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity.

Average flow velocity for travel time calculations is usually determined for bank-full elevation assuming low vegetation winter conditions.

Manning's equation is:

$$V = \frac{1.49(R)^{2/3}(S)^{1/2}}{n} \qquad (3.1.11)$$

Where:

V = average velocity (ft/s)
R = hydraulic radius (ft) and is equal to A/P_w
A = cross sectional flow area (ft^2)
P_w = wetted perimeter (ft)
S = slope of the hydraulic grade line (ft/ft)
n = Manning's roughness coefficient for open channel flow

After average velocity is computed using **Equation 3.1.11**, T_t for the channel segment can be estimated using **Equation 3.1.7**.

Limitations

- ❏ Equations in this section should not be used for sheet flow longer than 50 feet for impervious land uses.
- ❏ In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate t_c.
- ❏ A culvert or bridge can act as detention structure if there is significant storage behind it. Detailed storage routing procedures should be used to determine the outflow through the culvert or bridge.

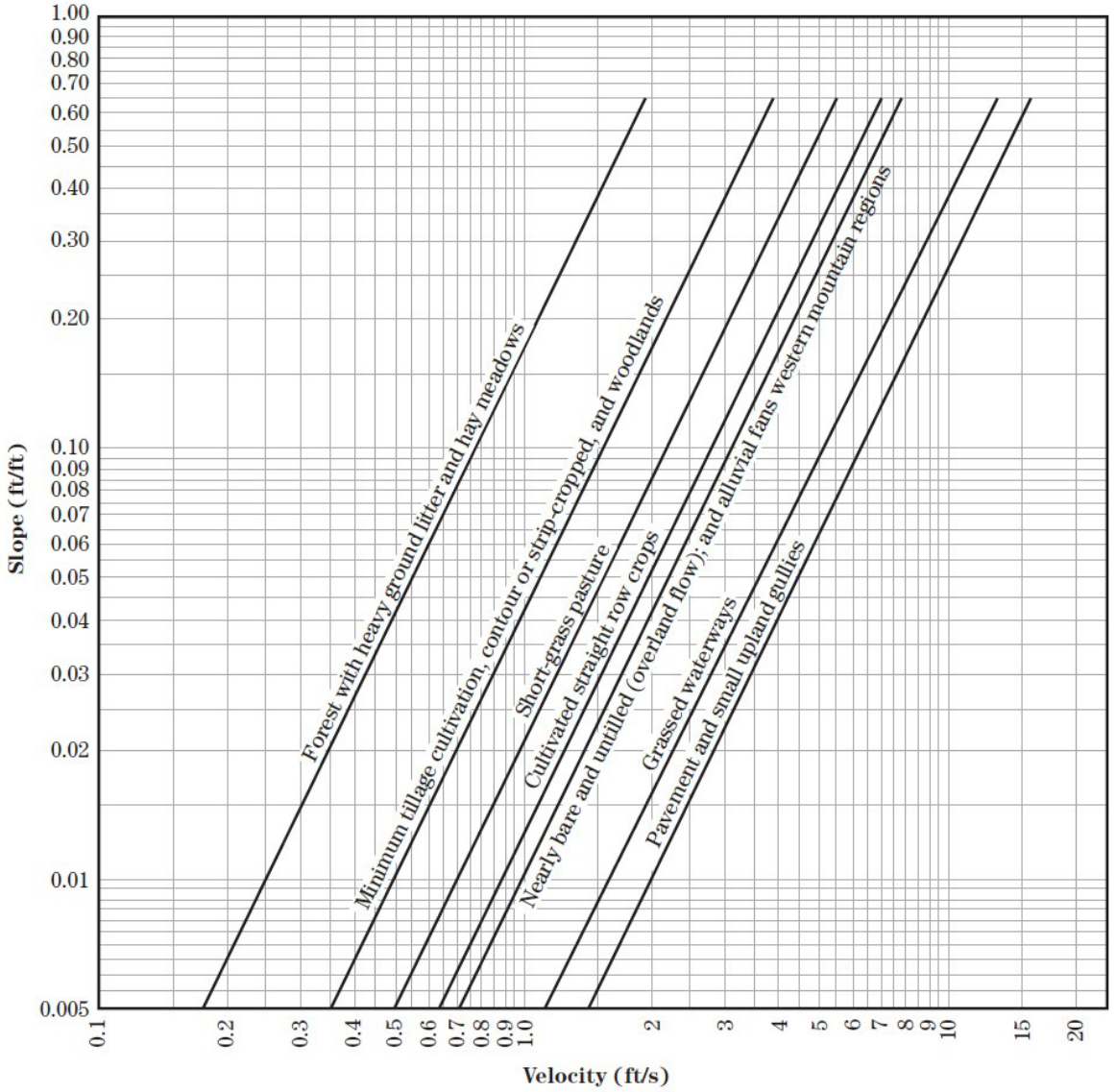


Figure 3.1.5-5 Average Velocities - Shallow Concentrated Flow
(Source: NRCS TR-55, NEH630, 2004)

3.1.5.7 SIMPLIFIED NRCS TR-55 PEAK RUNOFF RATE ESTIMATION

The following NRCS TR-55 procedures were taken from the NRCS TR-55 Technical Release 55 (USDA, 1986) which presents simplified procedures to calculate storm runoff volume and peak rate of discharges. These procedures are applicable to small drainage areas (typically less than 2,000 acres) with homogeneous land uses that can be described by a single CN value. The peak discharge equation is:

$$Q_p = q_u A Q F_p \qquad (3.1.12)$$

Where:

Q_p = peak discharge (cfs)
q_u = unit peak discharge (cfs/mi²/in)
A = drainage area (mi²)
Q = runoff (in)
F_p = pond and swamp adjustment factor

The input requirements for this method are as follows:

- t_c – hours
- Drainage area – mi²
- Type II or type III rainfall distribution
- 24-hour design rainfall
- CN value
- Pond and Swamp adjustment factor (If pond and swamp areas are spread throughout the watershed and are not considered in the t_c computation, an adjustment is needed.)

Computations for the peak discharge method proceed as follows:

(Step 1) The 24-hour rainfall depth is determined from the NOAA 14 data for the centroid of the County. See the table below.

24 Hour Depth (in.)	
Return Period	Rainfall Amount, in.
1	3.29
2	3.72
5	4.45
10	5.07
25	5.95
50	6.65
100	7.36

(Step 2) The runoff curve number, CN, is estimated from **Table 3.1.5-1** and direct runoff, Q_p, is calculated using **Equation 3.1.12**.

(Step 3) The CN value is used to determine the initial abstraction, I_a, from **Table 3.1.5-3**, and the ratio I_a/P is then computed (P = accumulated 24-hour rainfall).

(Step 4) (The watershed time of concentration is computed using the procedures in Subsection 3.1.4.4 and is used with the ratio Ia/P to obtain the unit peak discharge, q_{up}, from **Figure 3.1.5-6** for the Type II rainfall distribution and **Figure 3.1.5-7** for the Type III rainfall distribution. If the ratio I_a/P lies outside the range shown in the figures, either the limiting values or another peak discharge method should be used. Note: **Figures 3.1.5-6** and **3.1.5-7** are based on a peaking factor of 484. If a peaking factor of 300 is needed, these figures are not applicable and the simplified NRCS TR-55 method should not be used.

(Step 5) The pond and swamp adjustment factor, F_p, is estimated from below:

Pond and Swamp Areas (%)*	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

*Percent of entire drainage basin

(Step 6) The peak runoff rate is computed using **Equation 3.1.12**.

The accuracy of the peak discharge method is subject to specific limitations, including the following:

1. The watershed must be hydrologically homogeneous and describable by a single CN value.
2. The watershed may have only one main stream, or if more than one, the individual branches must have nearly equal time of concentrations.
3. Hydrologic routing cannot be considered.
4. The pond and swamp adjustment factor, F_p, applies only to areas located away from the main flow path.
5. Accuracy is reduced if the ratio I_a/P is outside the range given in **Figure 2-6**. If I_a/P is less than 0.1, use the line in **Figure 2-6** corresponding to I_a/P equals 0.10.
6. The weighted CN value must be greater than or equal to 40 and less than or equal to 98.
7. The same procedure should be used to estimate pre- and post-development time of concentration when computing pre- and post-development peak discharge.
8. The watershed time of concentration must be between 0.1 and 10 hours.

Table 3.1.5-3 I_a Values for Runoff Curve Numbers

Curve Number	I_a (in)	Curve Number	I_a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.636	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

Source: NRCS TR-55, TR-55, Second Edition, June 1986

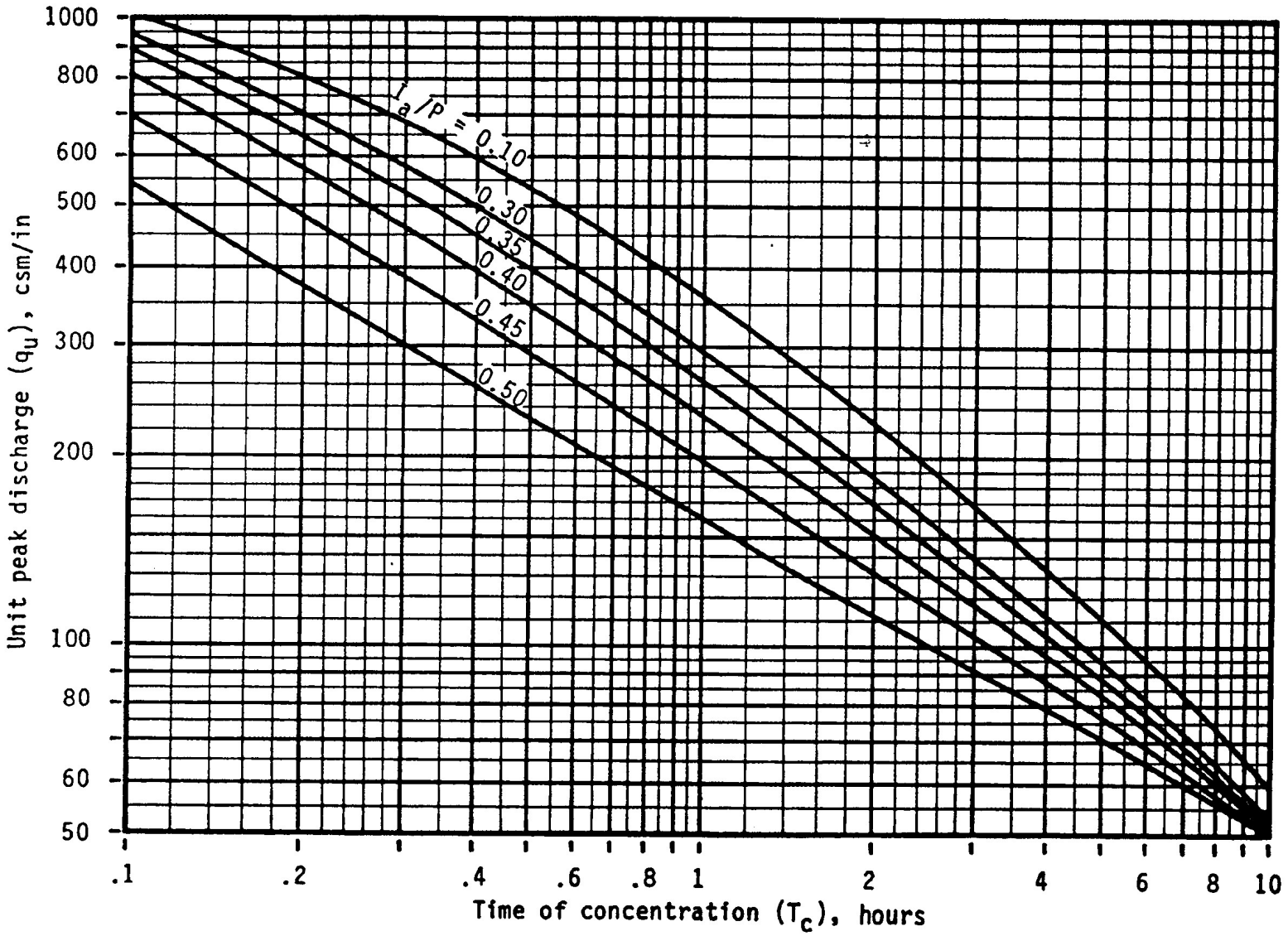


Figure 3.1.5-6 NRCS TR-55 Type II Unit Peak Discharge Graph
(Source: NRCS TR-55, TR-55, Second Edition, June 1986)

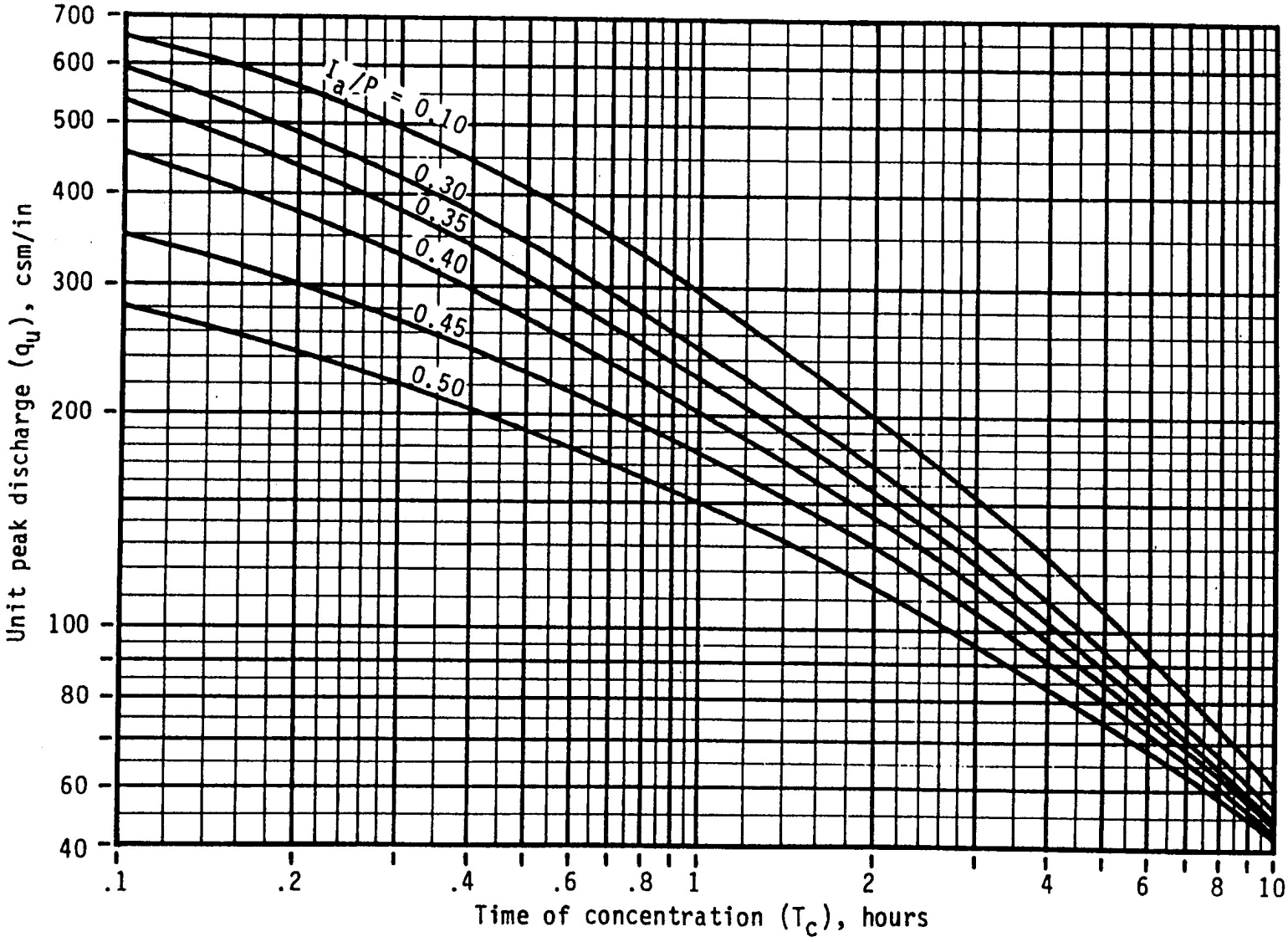


Figure 3.1.5-7 RCS TR-55 Type III Unit Peak Discharge Graph
(Source: NRCS TR-55, TR-55, Second Edition, June 1986)

3.1.5.8 EXAMPLE PROBLEM 1

Compute the 100-year peak discharge for a 50-acre wooded watershed located in Peachtree City, which will be developed as follows:

- Forest land - good cover (hydrologic soil group B) = 10 ac
- Forest land - good cover (hydrologic soil group C) = 10 ac
- 1/3 acre residential (hydrologic soil group B) = 20 ac
- Industrial development (hydrological soil group C) = 10 ac

Other data include the following: Total impervious area = 18 acres, % of pond / swamp area = 0

Computations

1. Calculate rainfall excess:

- The 100-year, 24-hour rainfall is 8.22 inches (From NOAA Atlas 14).
- The 1-year, 24-hour rainfall is 3.37 inches (From NOAA Atlas 14).
- Composite weighted runoff coefficient is:

Dev #	Area	% Total	CN	Composite CN
1	10 ac	20%	55	11.0
2	10 ac	20%	70	14.0
3	20 ac	40%	72	28.8
4	10 ac	20%	91	18.2
Total	50 ac	100%		72

*from Equation 3.1.5, Q (100-year) = 4.89 inches
Q_d (1-year developed) = 1.0 inches

2. Calculate time of concentration

The hydrologic flow path for this watershed = 1,890 ft

Segment	Type of Flow	Length (ft)	Slope (%)
1	Overland n=0.24	40	2.0
2	Shallow channel	750	1.7
3	Main channel*	1100	0.5

*For the main channel, n = .06 (estimated), width = 10 feet, depth = 2 feet, rectangular channel

Segment 1 - Travel time from **Equation 3.1.8** with P2 = 3.84 inches
(From NOAA Atlas 14)

$T_t = [0.42(0.24 \text{ X } 40)_{0.8}] / [(3.84)^{0.5} (.020)^{0.4}] =$ 6.26 minutes

Segment 2 - Travel time from **Figure 3.1.5-5** or **Equation 3.1.9**

V = 2.1 ft/sec (from **equation 3.1.9**)

T_t = 750 / 60(2.1) = 5.95 minutes

Segment 3 - Using e**quation 3.1.11**

V = (1.49/.06) (1.43)0.67 (.005)0.5 = 2.23 ft/sec

Tt = 1100 / 60 (2.23) = 8.22 minutes

t_c = 6.26 + 5.95 + 8.22 = 20.43 minutes (.34 hours)

3. Calculate I_a/P for Cn = 72 (**Table 3.1.5-1**), I_a = .778 (**Table 3.1.5-3**)
I_a/P = (.778 / 8.23) = .095 (Note: Use I_a/P = .10 to facilitate use of **Figure 3.1.5-6**. Straight line interpolation could also be used.)

4. Unit discharge q_u (100-year) from **Figure 3.1.5-6** = 650 csm/in, q_u (1-year) = 580 csm/in

5. Calculate peak discharge with F_p = 1 using equation 3.1.12
Q_{100} = 650 (50/640)(4.89)(1) = 248 cfs

3.1.5.9 HYDROGRAPH GENERATION

In addition to estimating the peak discharge, the NRCS TR-55 method can be used to estimate the entire hydrograph from a drainage area. The NRCS TR-55 has developed a Tabular Hydrograph procedure that can be used to generate the hydrograph for small drainage areas (less than 2,000 acres). The Tabular Hydrograph procedure uses unit discharge hydrographs that have been generated for a series of time of concentrations. In addition, NRCS TR-55 has developed hydrograph procedures to be used to generate composite flood hydrographs. For the development of a hydrograph from a homogeneous developed drainage area and drainage areas that are not homogeneous, where hydrographs need to be generated from sub-areas and then routed and combined at a point downstream, the design engineer is referred to the procedures outlined by the NRCS TR-55 in the 1986 version of TR-55 available from the *National Technical Information Service in Springfield, Virginia 22161*. The catalog number for TR-55, "Urban Hydrology for Small Watersheds," is PB87-101580.

The unit hydrograph equations used in the NRCS TR-55 method for generating hydrographs includes a constant to account for the general land slope in the drainage area. This constant, called a peaking factor, can be adjusted when using the method. A default value of 484 for the peaking factor represents rolling hills – a medium level of relief. NRCS TR-55 indicates that for mountainous terrain the peaking factor can go as high as 600, and as low as 300 for flat (coastal) areas. Referring to **Figure 3.1.6-1**, which shows the different hydrologic regions developed by the USGS for the state of Georgia, Region 3 represents the primary region of the state where modification of the peaking factor from 484 to 300 is most often warranted if the individual watershed possesses flat terrain.

As a result of hydrologic/hydraulic studies completed in the development of this Manual, the following are recommendations related to the use of different peaking factors:

- The NRCS TR-55 method can be used without modification (peaking factor left at 484) in Regions 1, 2 and 4 generally when performing modeling analysis.
- The NRCS TR-55 method can be modified in that a peaking factor of 484 to 300 can be used for modeling generally in Region 3 when watersheds are flat and have significant storage in the overbanks. These watersheds would be characterized by:
  - ❏ Mild Slopes (less than 2% slope)
  - ❏ Significant surface storage throughout the watershed in the form of standing water during storm events or inefficient drainage system

The NRCS TR-55 method can be similarly adjusted for any watershed that has flow and storage characteristics similar to a typical Region 3 stream

The development of a runoff hydrograph from a watershed is a laborious process not normally done by hand. For that reason only an overview of the process is given here to assist the designer in reviewing and understanding the input and output from a typical computer program. There are choices of computational interval, storm length (if the 24-hour storm is not going to be used), and other "administrative" parameters that are peculiar to each computer program.

The development of a runoff hydrograph for a watershed or one of many sub-basins within a more complex model involves the following steps:

(Step 1) Development or selection of a design storm hyetograph. Often the NRCS TR-55 24-hour storm described in Subsection 3.1.5.3 is used. This storm is recommended for use in Georgia.

(Step 2) Development of curve numbers and lag times for the watershed using the methods described in Subsections 3.1.5.4, 3.1.5.5, and 3.1.5.6.

(Step 3) Development of a unit hydrograph from either the standard (peaking factor of 484) or coastal area (peaking factor of 300) dimensionless unit hydrographs. See discussion below.

(Step 4) Step-wise computation of the initial and infiltration rainfall losses and, thus, the excess rainfall hyetograph using a derivative form of the NRCS TR-55 rainfall-runoff equation (**Equation 3.1.5**)

(Step 5) Application of each increment of excess rainfall to the unit hydrograph to develop a series of runoff hydrographs, one for each increment of rainfall (this is called "convolution."

(Step 6) Summation of the flows from each of the small incremental hydrographs (keeping proper track of time steps) to form a runoff hydrograph for that watershed or sub-basin.

To assist the designer in using the NRCS TR-55 unit hydrograph approach with a peaking factor of 300, **Figure 3.1.5-8** and **Table 3.1.5-4** have been developed. The unit hydrograph is used in the same way as the unit hydrograph with a peaking factor of 484.

The procedure to develop a unit hydrograph from the dimensionless unit hydrographs in the table below is to multiply each time ratio value by the time-to-peak (T_p) and each value of q/q_u by q_u calculated as:

$$q_u = (PF\ A) / (T_p) \qquad (3.1.13)$$

Where:

q_u = unit hydrograph peak rate of discharge (cfs)
PF = peaking factor (either 484 or 300)
A = area (mi^2)
d = rainfall time increment (hr)
T_p = time to peak = d/2 + 0.6 T_c (hr)

For ease of spreadsheet calculations, the dimensionless unit hydrographs for 484 and 300 can be approximated by the equation:

$$\frac{q}{q_u} = \left[\frac{t}{T_p} e^{\left(1-\frac{t}{T_p}\right)}\right]^X \qquad (3.1.14)$$

Where X is 3.79 for the PF=484 unit hydrograph and 1.50 for the PF=300 unit hydrograph.

Table 3.1.5-4 Dimensionless Unit Hydrographs

	484		300	
t/T_t	q/q_u	Q/Q_p	q/q_u	Q/Q_p
0.0	0.0	0.0	0.0	0.0
0.1	0.005	0.000	0.122	0.006
0.2	0.046	0.004	0.296	0.019
0.3	0.148	0.015	0.469	0.041
0.4	0.301	0.038	0.622	0.070
0.5	0.481	0.075	0.748	0.105
0.6	0.657	0.125	0.847	0.144
0.7	0.807	0.186	0.918	0.186
0.8	0.916	0.255	0.966	0.231
0.9	0.980	0.330	0.992	0.277
1.0	1.000	0.406	1.000	0.324
1.1	0.982	0.481	0.993	0.370
1.2	0.935	0.552	0.974	0.415
1.3	0.867	0.618	0.945	0.459
1.4	0.786	0.677	0.909	0.501
1.5	0.699	0.730	0.868	0.541
1.6	0.611	0.777	0.823	0.579
1.7	0.526	0.817	0.775	0.615
1.8	0.447	0.851	0.727	0.649
1.9	0.376	0.879	0.678	0.680
2.0	0.312	0.903	0.631	0.710
2.1	0.257	0.923	0.584	0.737
2.2	0.210	0.939	0.539	0.762
2.3	0.170	0.951	0.496	0.785
2.4	0.137	0.962	0.455	0.806
2.5	0.109	0.970	0.416	0.825
2.6	0.087	0.977	0.380	0.843
2.7	0.069	0.982	0.346	0.859
2.8	0.054	0.986	0.314	0.873
2.9	0.042	0.989	0.285	0.886
3.0	0.033	0.992	0.258	0.898
3.1	0.025	0.994	0.233	0.909
3.2	0.020	0.995	0.211	0.919
3.3	0.015	0.996	0.190	0.928
3.4	0.012	0.997	0.171	0.936
3.5	0.009	0.998	0.153	0.943
3.6	0.007	0.998	0.138	0.949
3.7	0.005	0.999	0.124	0.955
3.8	0.004	0.999	0.111	0.960
3.9	0.003	0.999	0.099	0.965
4.0	0.002	1.000	0.089	0.969
4.1			0.079	0.972
4.2			0.071	0.976
4.3			0.063	0.979
4.4			0.056	0.981
4.5			0.050	0.984
4.6			0.044	0.986
4.7			0.039	0.987
4.8			0.035	0.989
4.9			0.031	0.990
5.0			0.028	0.992
5.1			0.024	0.993
5.2			0.022	0.994
5.3			0.019	0.995
5.4			0.017	0.996
5.5			0.015	0.996
5.6			0.013	0.997
5.7			0.012	0.997
5.8			0.010	0.998
5.9			0.009	0.998
6.0			0.008	0.999
6.1			0.007	0.999
6.2			0.006	0.999
6.3			0.006	1.000

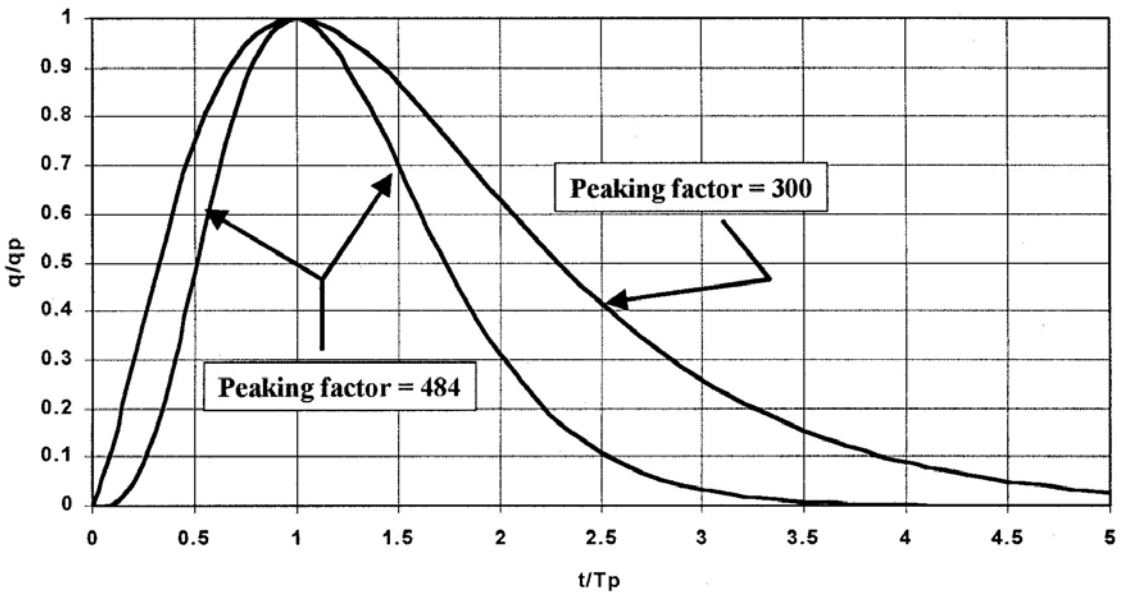


Figure 3.1.5-8 Dimensionless Unit Hydrographs for Peaking Factors of 484 and 300

Time		484		300	
t/T_p	time *(min)*	q/q_{pu}	q	q/q_{pu}	q
0	0	0	0.00	0	0.00
0.22	3.0	0.06	10.26	0.33	34.18
0.44	6.0	0.37	61.74	0.68	69.60
0.66	9.0	0.75	124.79	0.89	91.99
0.88	12.0	0.97	161.37	0.99	101.85
1	13.64	1	166	1	103
1.10	15.0	0.98	163.39	0.99	102.35
1.32	18.0	0.85	141.70	0.94	96.74
1.54	21.0	0.66	110.45	0.85	87.64
1.76	24.0	0.48	79.61	0.75	76.98
1.98	27.0	0.33	54.06	0.64	66.03
2.20	30.0	0.21	35.02	0.54	55.59
2.42	33.0	0.13	21.84	0.45	46.10
2.64	36.0	0.08	13.19	0.37	37.76
2.86	39.0	0.05	7.77	0.30	30.60
3.08	42.0	0.03	4.47	0.24	24.58
3.30	45.0	0.02	2.52	0.19	19.60
3.52	48.0	0.01	1.40	0.15	15.52
3.74	51.0	0.00	0.76	0.12	12.21
3.96	54.0	0.00	0.41	0.09	9.57
4.18	57.0	0.00	0.22	0.07	7.46
4.40	60.0	0.00	0.12	0.06	5.79
4.62	63.0	0.00	0.06	0.04	4.48
4.84	66.0	0.00	0.03	0.03	3.45
5.06	69.0	0.00	0.02	0.03	2.65
5.28	72.0	0.00	0.01	0.02	2.03
5.50	75.0	0.00	0.00	0.02	1.55
5.72	78.0			0.01	1.18
5.94	81.0			0.01	0.90
6.16	84.0			0.01	0.68
6.38	87.0			0.01	0.52
6.60	90.0			0.00	0.39
6.82	93.0			0.00	0.30
7.04	96.0			0.00	0.22
7.26	99.0			0.00	0.17
7.48	102.0			0.00	0.13
7.70	105.0			0.00	0.09
7.92	108.0			0.00	0.07
8.14	111.0			0.00	0.05
8.36	114.0			0.00	0.04
8.58	117.0			0.00	0.03
8.80	120.0			0.00	0.02
9.01	123.0			0.00	0.02
9.23	126.0			0.00	0.01
9.45	129.0			0.00	0.01
9.67	132.0			0.00	0.01
9.89	135.0			0.00	0.01
10.11	138.0			0.00	0.00

3.1.5.10 EXAMPLE PROBLEM 2

Compute the unit hydrograph for the 50-acre wooded watershed in Subsection 3.1.5.8.

Computations

1. Calculate T_p and time increment

The time of concentration (T_c) is calculated to be 20.24 minutes for this watershed. If we assume a computer calculation time increment (d) of 3 minutes then:

$T_p = d/2 + 0.6T_c = 3/2 + 0.6 * 20.24 = 13.64$ minutes (0.227 hrs)

2. Calculate q_{pu}

$q_{pu} = PF\ A/Tp = (484 * 50/640)/(0.227) = 166$ cfs

For a PF of 300 q_{pu} would be:

$q_{pu} = PF\ A/T_p = (300 * 50/640)/(0.227) = 103$ cfs

3. Calculate unit hydrograph for both 484 and 300.

Based on spreadsheet calculations using E**quations 3.1.13 and 3.1.14**, the table to the right has been derived.

3.1.6 U.S. Geological Survey Peak Flow and Hydrograph Method

3.1.6.1 INTRODUCTION

For the past 30 years the USGS has been collecting rain and streamflow data at various sites throughout the state of Georgia. The data from these efforts have been used to calibrate a USGS rainfall-runoff model. The U.S. Geological Survey Model was then used to develop peak dis-charge regression equations for the 2-, 5-, 10-, 25-, 50- and 100-year floods. In addition, the USGS used the statewide database to develop a dimensionless hydrograph that can be used to simulate flood hydrographs from rural and urban streams in Georgia. This USGS information is specific to geographical regions of Georgia. **Figure 3.1.6-1** shows the locations of these different regions.

3.1.6.2 APPLICATION

The USGS regression method is used for both the estimation of stormwater runoff peak rates and the generation of hydrographs for the routing of stormwater flows for larger drainage areas:

- 25 acres and larger for peak flow estimation
- 128 acres and larger for hydrograph generation

The USGS method can be used for most design applications, including the design of storage facilities and outlet structures, storm drain systems, culverts, small drainage ditches and open channels, and energy dissipators.

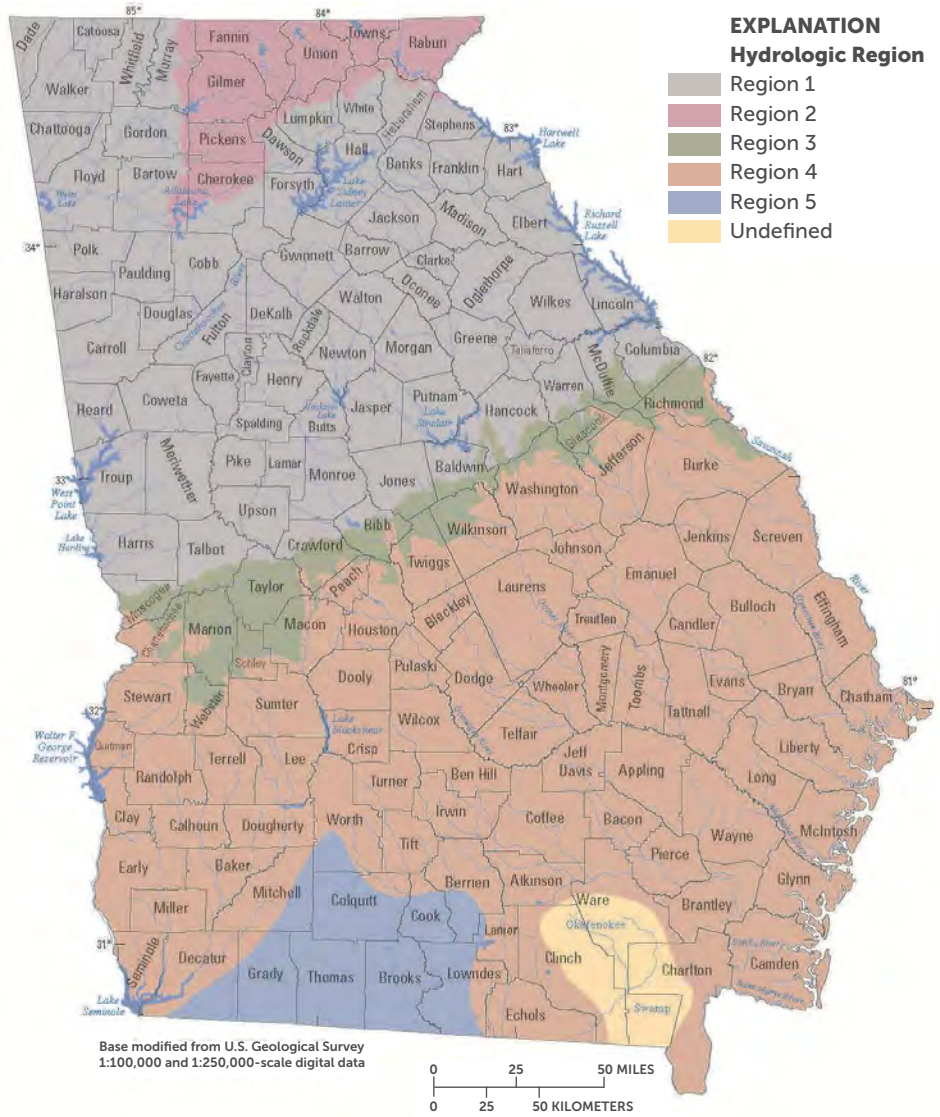


Figure 3.1.6-1 USGS Hydrologic Regions in Georgia
(Source: USGS, 2011)

3.1.6.3 PEAK DISCHARGE EQUATIONS

For a complete description of the USGS regression equations presented below, consult the latest USGS publications regarding both rural and urban flood frequencies. Based on the current USGS publications, a watershed is determined to be urban if 10% or more of the watershed basin is impervious. USGS regression equations have been removed from this Manual due to their periodic update. Check the USGS publications website for the most recent publications and regression equations. At the time of this Manual update, the following publications were available:

- **Urban Method:** Methods for Estimating the Magnitude and Frequency of Floods for Urban and Small, Rural Streams in Georgia, South Carolina, and North Carolina, 2011 (http://pubs.usgs.gov/sir/2014/5030/)
- **Rural Method**: Magnitude and Frequency of Rural Floods in the Southeastern United States, 2006: Volume 1, Georgia (http://pubs.usgs.gov/sir/2009/5043/)

In addition to the publications, USGS has also developed a spreadsheet tool to assist the designer in computing flood-frequency characteristics, for both the urban and rural methods. The spreadsheets are downloadable, using the links provided above, as Microsoft Excel documents

3.1.6.4 PEAK DISCHARGE LIMITATIONS FOR URBAN AND RURAL BASINS

Each USGS regression equation uses variables that represent the following:

- Drainage area (DRNAREA, DA, or A)
- Percent impervious cover; and
- Percent developed land

The most recent version of the USGS publications should also be used to verify the limitations of these variables within the peak discharge equations. These equations should not be used on any variables which have physical characteristics outside of their appropriate range.

3.1.6.5 HYDROGRAPHS

The USGS has developed a dimensionless hydrograph for Georgia streams having drainage areas of less than 500 mi^2. This dimensionless hydrograph can be used to simulate flood hydrographs for rural and urban streams throughout the State of Georgia. For a complete description of the USGS dimensionless hydrograph, consult the USGS publication *Simulation of Flood Hydrographs for Georgia Streams, Water-Resources Investigation Report 86-4004.* **Table 3.1.6-1** lists the time and discharge ratios for the dimensionless hydrograph.

Table 3.1.6-1 Dimensionless USGS Hydrograph

Time Ratio (t/T_L)	Discharge Ratio (Q/Q_p)	Time Ratio (t/T_L)	Discharge Ratio (Q/Q_p)
0.25	0.12	1.35	0.62
0.30	0.16	1.40	0.56
0.35	0.21	1.45	0.51
0.40	0.26	1.50	0.47
0.45	0.33	1.55	0.43
0.50	0.40	1.60	0.39
0.55	0.49	1.65	0.36
0.60	0.58	1.70	0.33
0.65	0.67	1.75	0.30
0.70	0.76	1.80	0.28
0.75	0.84	1.85	0.26
0.80	0.90	1.90	0.24
0.85	0.95	1.95	0.22
0.90	0.98	2.00	0.20
0.95	1.00	2.05	0.19
1.00	0.99	2.10	0.17
1.05	0.96	2.15	0.16
1.10	0.92	2.20	0.15
1.15	0.86	2.25	0.14
1.20	0.80	2.30	0.13
1.25	0.74	2.35	0.12
1.30	0.68	2.40	0.11

Source: USGS, 1986

The following lag time equations for calculating the dimensionless hydrograph can be found in the USGS publication: Lagtime Relations for Urban Streams in Georgia, Water-Resources Investigations Report 00-4049 4.

North of the Fall Line (rural):

$$T_L = 4.64A^{0.49}S^{-0.21} \quad (3.1.15)$$

South of the Fall Line (rural):

$$T_L = 13.6A^{0.43}S^{-0.31} \quad (3.1.16)$$

Regions 1, 2 and 3 (urban):

$$TL = 7.86A^{0.35}TIA^{-0.22}S^{-0.31} \quad (3.1.17)$$

Region 4 (urban):

$$TL = 6.10A^{0.35}TIA^{-0.22}S^{-0.31} \quad (3.1.18)$$

Where:

T_L = lag time (hours)
A = drainage area (mi^2)
S = main channel slope (ft/mi)
TIA = total impervious area (percent)

Using these lag time equations and the dimensionless hydrograph, a runoff hydrograph can be determined after the peak discharge is calculated.

3.1.6.6 HYDROGRAPH LIMITATIONS

List in the table shown at the right are the limitations of the variables within the lag time equations. The lag time equation should not be used for drainage areas that have physical characteristics outside the limits listed on this page.

3.1.6.7 EXAMPLE PROBLEM

For the 100-year flood, calculate the peak discharge for rural and developed conditions for the following drainage area located in Region 1 in the Atlanta metro area. For the developed conditions, develop the flood hydrograph for this drainage area.

- Drainage Area = 175 acres = 0.273 mi^2
- Main Channel Slope = 117 ft/mi
- Percent Impervious Area = 32%

Peak Discharge Calculations

100-year Rural Peak Discharge:

$Q_{100} = 776(DA)^{0.594}$ (*Taken from the most recent publication*)

$Q_{100} = 776(0.273)0^{.594} = 359$ cfs

100-year Developed (Urban) Peak Flow:

$Q_{100} = 753(DRNAREA)^{0.8038}10^{(0.0024*IMPNLCD06)}$ (*Taken from the most recent publication*)

$Q_{100} = 753(0.273)0.803810(0.0024*32) = 317$ cfs

Lag Time Calculations

$T_L = 7.86A^{0.35}TIA\text{-}0.22S\text{-}0.31 = 7.86\ (0.273)0.35\ (32)\text{-}0.22\ (117)\text{-}0.31 = 0.53$ hours

Hydrograph Calculations

Using the dimensionless USGS hydrograph given in **Table 3.1.6-1**, the following calculations are done to determine the coordinates of the flood hydrograph.

Time (t) = t/T_L x 0.53 t/T_L from **Table 3.1.6-1 on previous page**

Discharge (Q) = Q/Q_p x 561 Q/Q_p from T**able 3.1.6-1 on previous page**

Coordinates for the flood hydrograph are given in **Table 3.1.6-2** on the next page.

Physical Characteristics		Minimum	Maximum	Units
North of the Fall Line (rural)	A - Drainage Area	0.3	500	mi^2
	S - Main Channel Slope	5.0	200	feet per mile
South of the Fall Line (rural)	A - Drainage Area	0.2	500	mi^2
	S - Main Channel Slope	1.3	60	feet per mile
Regions 1, 2, & 3 (urban)	A - Drainage Area	0.04	19.1	mi^2
	S - Main Channel Slope	9.4	772	feet per mile
	TIA - Total Impervious Area	15.0	50.0	percent
Region 4 (urban)	A - Drainage Area	0.12	2.9	mi^2
	S - Main Channel Slope	19.4	110	feet per mile
	TIA - Total Impervious Area	6.1	42.4	percent

Table 3.1.6-2 Flood Hydrograph

Time Ratio (t/T_L)	Time (t) (Hours)	Discharge Ratio (Q/Q_p)	Discharge (cfs)	Time Ratio (t/T_L)	Time (t) (Hours)	Discharge Ratio (Q/Q_p)	Discharge (cfs)
0.25	0.13	0.12	67	1.35	0.72	0.62	348
0.30	0.16	0.16	90	1.40	0.74	0.56	314
0.35	0.19	0.21	118	1.45	0.77	0.51	286
0.40	0.21	0.26	146	1.50	0.80	0.47	264
0.45	0.24	0.33	185	1.55	0.82	0.43	241
0.50	0.27	0.40	224	1.60	0.85	0.39	219
0.55	0.29	0.49	275	1.65	0.87	0.36	202
0.60	0.32	0.58	325	1.70	0.90	0.33	185
0.65	0.34	0.67	376	1.75	0.93	0.30	168
0.70	0.37	0.76	426	1.80	0.95	0.28	157
0.75	0.40	0.84	471	1.85	0.98	0.26	146
0.80	0.42	0.90	505	1.90	1.01	0.24	135
0.85	0.45	0.95	533	1.95	1.03	0.22	123
0.90	0.48	0.98	550	2.00	1.06	0.20	112
0.95	0.50	1.00	561	2.05	1.09	0.19	107
1.00	0.53	0.99	555	2.10	1.11	0.17	95
1.05	0.56	0.96	539	2.15	1.14	0.16	90
1.10	0.58	0.92	516	2.20	1.17	0.15	84
1.15	0.61	0.86	482	2.25	1.19	0.14	79
1.20	0.64	0.80	449	2.30	1.22	0.13	73
1.25	0.66	0.74	415	2.35	1.25	0.12	67
1.30	0.69	0.68	381	2.40	1.27	0.11	62

Source: U.S.G.S., 1986

3.1.7 Water Quality Volume and Peak Flow

In addition to the discussion of the calculations provided below, full examples for five stormwater best management practices have been provided in Appendix B. Also, the same limitations associated with Peak Runoff Rate Estimations apply to the Water Quality Volume and Peak Flow calculations. See 3.1.5.7, Simplified NRCS TR-55 Peak Runoff Rate Estimation.

3.1.7.1 WATER QUALITY VOLUME CALCULATION

The Water Quality Volume (WQ_v) is the retention or treatment volume required to remove a significant percentage of the stormwater pollution load, defined in this Manual as an 80% removal of the average annual post-development total suspended solids (TSS) load. This is achieved by intercepting and retaining or treating a portion of the runoff from all storms and all the runoff from 85% of the storms that occur on average during the course of a year.

The water quality treatment volume is calculated by multiplying the 85th percentile annual rainfall event by the volumetric runoff coefficient (R_v) and the site area. R_v is defined as:

$$R_v = 0.05 + 0.009(I) \qquad (3.1.19)$$

Where: I = percent of impervious cover (%)

For the state of Georgia, the average 85th percentile annual rainfall event is 1.2 inches. Therefore, WQ_v is calculated using the following formula:

$$WQ_v = \frac{1.2\ R_v\ A}{12} \qquad (3.1.20)$$

Where:

WQ_v = water quality volume (acre-feet)
R_v = volumetric runoff coefficient
A = total drainage area (acres)

WQ_v can be expressed in inches simply as $1.2(R_v) = Q_{wv}$

3.1.7.2 WATER QUALITY VOLUME PEAK FLOW CALCULATION

The peak rate of discharge for the water quality design storm is needed for the sizing of off-line diversion structures, such as for sand filters and infiltration trenches. An arbitrary storm would need to be chosen using the Rational Method, and conventional NRCS TR-55 methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2 inches. This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the treatment practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels.

The following procedure can be used to estimate peak discharges for small storm events.
It relies on the Water Quality Volume and the simplified peak flow estimating method above. A brief description of the calculation procedure is presented below:

1. Using WQ_v, a corresponding Curve Number (CN) is computed utilizing the following equation:

$$CN = 1000/[10 + 5P + 10Qwv - 10(Q_{wv}^{2} + 1.25Q_{wv}P)^{1/2}]$$

Where:

P = rainfall, in inches (use 1.2 inches for the Water Quality Storm in Georgia)
Q_{wv} = Water Quality Volume, in inches ($1.2R_v$)

2. Once a CN is computed, the time of concentration (t_c) is computed (based on the methods described in this section).
3. Using the computed CN, tc and drainage area (A), in acres; the peak discharge (Q_{wq}) for the water quality storm event is computed using a slight modification of the Simplified NRCS TR-55 Peak Runoff Rate Estimation technique of Subsection 3.1.5.7. Use appropriate rainfall distribution type (either Type II or Type III in Georgia).
   - » Read initial abstraction (I_a), compute I_a/P
   - » Read the unit peak discharge (q_u) for appropriate t_c
   - » Using WQ_v, compute the peak discharge (Q_{wq})

$$Q_{wq} = q_u * A * Q_{wv}$$

Where:

Q_{wq} = the water quality peak discharge (cfs)
q_u = the unit peak discharge (cfs/mi^2/inch)
A = drainage area (mi^2)
Q_{wv} = Water Quality Volume, in inches ($1.2R_v$)

3.1.7.3 EXAMPLE PROBLEM

Using the data and information from the example problem in Subsection 3.1.5.8 calculate the water quality volume and the water quality peak flow.

Calculate water quality volume (WQ_v)

Compute volumetric runoff coefficient, R_v

$R_V = 0.05 + (0.009) = 0.05 + (0.009)(18/50 \times 100\%) = 0.37$

Compute water quality volume, WQ_v

$WQ_v = 1.2(RV)(A)/12 = 1.2(.37)(50)/12 = 1.85$ acre-feet

Calculate water quality peak flow

Compute runoff volume in inches, Q_{wv}:

$Q_{wv} = 1.2R_v = 1.2 * 0.37 = 0.44$ inches

Computer curve number:

$CN = 1000/[10 + 5P +10Q - 10(Q_{wv}^2 + 1.25Q_{wv} P)^{½}]$

$CN = 1000/[10 + 5*1.2 +10*0.252 - 10(0.252^2 + 1.25*0.252*1.2)^{½}] = 84$

$t_c = 0.34$ (computed previously)

$S = 1000/CN - 10 = 1000/84 - 10 = 1.90$ inches

$0.2S = I_a = 0.38$ inches

$I_a/P = 0.38/1.2 = 0.317$

Find q_u:

From **Figure 3.1.5-6** for $I_a/P = 0.317$

$q_u = 535$ cfs/mi^2/in

Compute water quality peak flow:

$Q_{wq} = q_u * A * Q_{wv} = 535 * 50/640 * 0.44 = 18.4$ cfs

3.1.7.4 RUNOFF REDUCTION VOLUME CALCULATION

The Runoff Reduction Volume (RR_v) is the retention volume calculated to infiltrate, evapotranspirate, or otherwise removed from a post-developed condition to more naturally mimic the natural hydrologic conditions. For additional information, see Section 2.2.2.2 (Standard #3).

The runoff reduction volume is calculated by multiplying the target runoff reduction rainfall event (typically 1.0 inches) by the volumetric runoff coefficient (Rv) and the site area. Rv is again defined as:

$$R_v = 0.05 + 0.009(I) \qquad (3.1.19)$$

Where:

I = percent of impervious cover (%)

For the state of Georgia, the recommended target runoff reduction rainfall is 1.0 inches. Therefore, RR_v is calculated using the following formula:

$$RR_v = \frac{P\ R_v\ A}{12}$$

Where:

RR_v = runoff reduction volume (cubic feet)

P = target runoff reduction rainfall

R_v = volumetric runoff coefficient

A = total drainage area (square feet)

3.1.7.5 ADJUSTED CURVE NUMBER PROCEDURE FOR PEAK FLOW REDUCTION

The following method utilizes the Natural Resource Conservation Service runoff equations originally provided in *Urban Hydrology for Small Watersheds* (USDA 1986) to compute a curve number adjustment that effectively reduces the peak flow of other storm events. A simplified approach has been provided that combines these runoff equations. The NRCS runoff equations are discussed in Subsection 3.1.5 and include **Equations 3.1.3**, **3.1.4**, and **3.1.**5. The following modified equation is discussed in the 2010 Center for Watershed Protection journal article titled, T*he Runoff Reduction Method*:

$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{(Modified Eq. 3.1.5)}$$

Where:

Q = runoff depth (in),

P = rainfall depth (in),

I_a = Initial abstraction (in),

S = potential maximum retention after runoff begins (in),

CN = Runoff Curve Number, and

R = Retention storage provided by runoff reduction practices (in).

To calculate "R", the provided RR_V of the practice(s) can be calculated by the following:

$$R = (VP)(RR\%) / Area$$

Where:

VP = Total Volume Provided by the BMP (See Chapter 4 for BMP sizing information)

RR% = runoff reduction credit provided by the BMP (See **Table 4.1.3-2** for RR%)

By solving the modified equation above for a new potential maximum retention value, S, the adjusted curve number can be back-calculated as a representation of the runoff reduction achieved in any particular storm event.

Runoff Reduction/Adjusted Curve Number Example

Using the given data and information provided below, calculate the runoff reduction volume and the adjusted curve number for channel protection assuming a best management practice is used that provides a runoff reduction removal percentage (RR%) of 50%.

Given Information:

- Site Area: 3.0 ac (130,680 ft^2)
- Impervious Area: 1.9 ac; or I=1.9/3.0 = 63.3%
- Pre-developed CN: 70
- Post-developed CN: 88
- P_{1YR}: 3.4 inches
- S: 1.36 (1000/CN – 10)
- Post-Q_{1YR}:2.18 inches (See **Equation 3.1.5**)

Calculate water runoff reduction volume (RR_v)

Compute volumetric runoff coefficient, R_v

RV = 0.05 + (0.009)(I)

= 0.05 + (0.009)(1.9/3 x 100%)

= 0.62

Compute runoff reduction volume, RR_v

RR_v = 1.0(RV)(A)/12

= 1.0(.62)(3)/12

= 0.155 acre-feet (6,752 cubic feet)

Calculate the minimum volume of the practice (VP_{MIN})

(VP_{MIN}) ≥ RR_V / (RR%)

= (6,752 ft^3) / (50%)

= 13,504 ft^3

Note: The Volume Provided (VP) of this practice must be a minimum of 13,504 ft^3.

Calculate the amount of Runoff Reduction (RR_V provided) by the practice. This information will be needed in the adjusted curve number calculation (converted to the variable "R"):

RR_V (provided) = (RR%) (VP)

= (50%) (13,504 ft^3)

= 6,752 ft^3

Adjusted Curve Number Procedure for Peak Flow Reduction of CP_V

Given Q = 2.18 in. and P = 3.4 in., Find "R" and "S" to back calculate an adjusted CN

$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$ (Modified Equation 3.1.5)

Retention storage (expressed in inches) for this basin is calculated by the following formula:

R = RR_V (provided) / Basin Area

= (6,752 ft^3) / A

= 6,752 ft^3 / 130,680 ft^2 (12 in / 1 ft)

= 0.62 inches

Solve for "S" to back calculate CN: S = 2.49

S = 1000/CN-10: therefore, Adjusted CN = 80.1

3.1.8 Water Balance Calculations

3.1.8.1 INTRODUCTION

Water balance calculations help determine if a drainage area is large enough, or has the right characteristics, to support a permanent pool of water during average or extreme conditions. When in doubt, a water balance calculation may be advisable for any best management practice that maintains a permanent volume of stormwater.

The details of a rigorous water balance are beyond the scope of this manual. However, a simplified procedure is described herein that will provide an estimate of pool viability and point to the need for more rigorous analysis. Water balance can also be used to help establish planting zones in a wetland design.

3.1.8.2 BASIC EQUATIONS

Water balance is defined as the change in volume of the permanent pool resulting from the total inflow minus the total outflow (actual or potential):

$$\Delta V = \Sigma I - \Sigma O \qquad (3.1.21)$$

Where:

Δ = "change in"
V = permanent pool volume (ac-ft)
Σ = "sum of"
I = Inflows (ac-ft)
O = Outflows (ac-ft)

The inflows consist of rainfall, runoff and baseflow into the pond. The outflows consist of infiltration, evaporation, evapotranspiration, and surface overflow out of the best management practice. **Equation 3.1.21** can be changed to reflect these factors.

$$\Delta V = P + Ro + Bf - I - E - Et - Of \qquad (3.1.22)$$

Where:

P = precipitation (ft)
Ro = runoff (ac-ft)
Bf = baseflow (ac-ft)
I = infiltration (ft)
E = evaporation (ft)
Et = evapotranspiration (ft)
Of = overflow (ac-ft)

Rainfall (P) – Rainfall values can be obtained from NOAA Atlas 14 at: http://hdsc.nws.noaa.gov/hdsc/pfds/

Monthly values are commonly used for calculations of values over a season. Rainfall is then the direct amount that falls on the permanent pool surface for the period in question. When multiplied by the permanent pool surface area (in acres) it becomes acre-feet of volume.

Runoff (Ro) – Runoff is equivalent to the rainfall for the period times the "efficiency" of the watershed, which is equal to the ratio of runoff to rainfall. In lieu of gage information, Q/P can be estimated one of several ways. The best method would be to perform long-term simulation modeling using rainfall records and a watershed model. Two other methods have been proposed.

Equation 3.1.19 gives a ratio of runoff to rainfall volume for a particular storm. If it can be assumed that the average storm that produces runoff has a similar ratio, then the R_v value can serve as the ratio of rainfall to runoff. Not all storms produce runoff in an urban setting. Typical initial losses (often called "initial abstractions") are normally taken between 0.1 and 0.2 inches. When compared to the rainfall records in Georgia, this is equivalent of about a 10% runoff volume loss. Thus a factor of 0.9 should be applied to the calculated R_v value to account for storms that produce no runoff. **Equation 3.1.23** reflects this approach. Total runoff volume is then simply the product of runoff depth (Q) times the drainage area to the pond.

$$Q = 0.9\,PR_v \qquad (3.1.23)$$

Where:

P = precipitation (in)
Q = runoff volume (in)
$\mathbf{R_v}$ = volumetric runoff coefficient [see **Equation 3.1.19**]

Ferguson (1996) has performed simulation modeling in an attempt to quantify an average ratio on a monthly basis. For the Atlanta area he has developed the following equation:

$$Q = 0.235P/S^{0.64} - 0.161 \qquad (3.1.24)$$

Where:

P = precipitation (in)
Q = runoff volume (in)
S = potential maximum retention (in) [see **Equation 3.1.5**]

Baseflow (Bf) – Most stormwater ponds and wetlands have little, if any, baseflow, as they are rarely placed across perennial streams. If so placed, baseflow must be estimated from observation or through theoretical estimates. Methods of estimation and baseflow separation can be found in most hydrology textbooks.

Infiltration (I) – Infiltration is a very complex subject and cannot be covered in detail here. The amount of infiltration depends on soils, water table depth, rock layers, surface disturbance, the presence or absence of a liner in the pond, and other factors. The infiltration rate is governed by the Darcy equation as:

$$I = Ak_hG_h \qquad (3.1.25)$$

Where:

I = infiltration (ac-ft/day)
A = cross sectional area through which the water infiltrates (ac)
$\mathbf{K_h}$ = saturated hydraulic conductivity or infiltration rate (ft/day)
$\mathbf{G_h}$ = hydraulic gradient = pressure head/distance

G_h can be set equal to 1.0 for pond bottoms and 0.5 for pond sides steeper than about 4:1. Infiltration rate can be established through testing, though not always accurately. As a first cut estimate **Table 3.1.8-1** can be used.

Table 3.1.8-1 Saturated Hydraulic Conductivity

Material	Hydraulic Conductivity	
	in/hr	ft/day
ASTM Crushed Stone No. 3	50,000	100,000
ASTM Crushed Stone No. 4	40,000	80,000
ASTM Crushed Stone No. 5	25,000	50,000
ASTM Crushed Stone No. 6	15,000	30,000
Sand	8.27	16.54
Loamy sand	2.41	4.82
Sandy loam	1.02	2.04
Loam	0.52	1.04
Silt loam	0.27	0.54
Sandy clay loam	0.17	0.34
Clay loam	0.09	0.18
Silty clay loam	0.06	0.12
Sandy clay	0.05	0.10
Silty clay	0.04	0.08
Clay	0.02	0.04

Source: Ferguson and Debo, "On-Site Stormwater Management," 1990

Evaporation (E) – Evaporation is from an open water surface. Evaporation rates are dependent on differences in vapor pressure, which, in turn, depend on temperature, wind, atmospheric pressure, water purity, and shape and depth of the pond. It is estimated or measured in a number of ways, which can be found in most hydrology textbooks. Pan evaporation methods are also used though there are only two pan evaporation sites active in Georgia (Lake Allatoona and Griffin). A pan coefficient of 0.7 is commonly used to convert the higher pan value to the lower lake values.

Table 3.1.8-2 Evaporation Monthly Distribution

J	F	M	A	M	J	J	A	S	O	N	D
3.2%	4.4%	7.4%	10.3%	12.3%	12.9%	13.4%	11.8%	9.3%	7.0%	4.7%	3.2%

Table 3.1.8-2 gives pan evaporation rate distributions for a typical 12-month period based on pan evaporation information from five stations in and around Georgia. Figure 3.1.8-1 depicts a map of annual free water surface (FWS) evaporation averages for Georgia based on a National Oceanic and Atmospheric Administration (NOAA) assessment done in 1982. FWS evaporation differs from lake evaporation for larger and deeper lakes, but can be used as an estimate for the type of structural stormwater ponds and wetlands being designed in Georgia. Total annual values can be estimated from this map and distributed according to **Figure 3.1.8-1**.

Evapotranspiration (Et) – Evapotranspiration consists of the combination of evaporation and transpiration by plants. The estimation of Et for crops in Georgia is well documented and has become standard practice. However, for wetlands the estimating methods are not documented, nor are there consistent studies to assist the designer in estimating the demand wetland plants would put on water volumes. Literature values for various places in the United States vary around the free water surface lake evaporation values. Estimating Et only becomes important when wetlands are being designed and emergent vegetation covers a significant portion of the pond surface. In these cases conservative estimates of lake evaporation should be compared to crop-based Et estimates and a decision made. Crop-based Et estimates can be obtained from typical hydrology textbooks or from the web sites mentioned above.

Overflow (Of) – Overflow is considered as excess runoff, and in water balance design is either not considered, since the concern is for average values of precipitation, or is considered lost for all volumes above the maximum pond storage. Obviously, for long-term simulations of rainfall-runoff, large storms would play an important part in pond design.

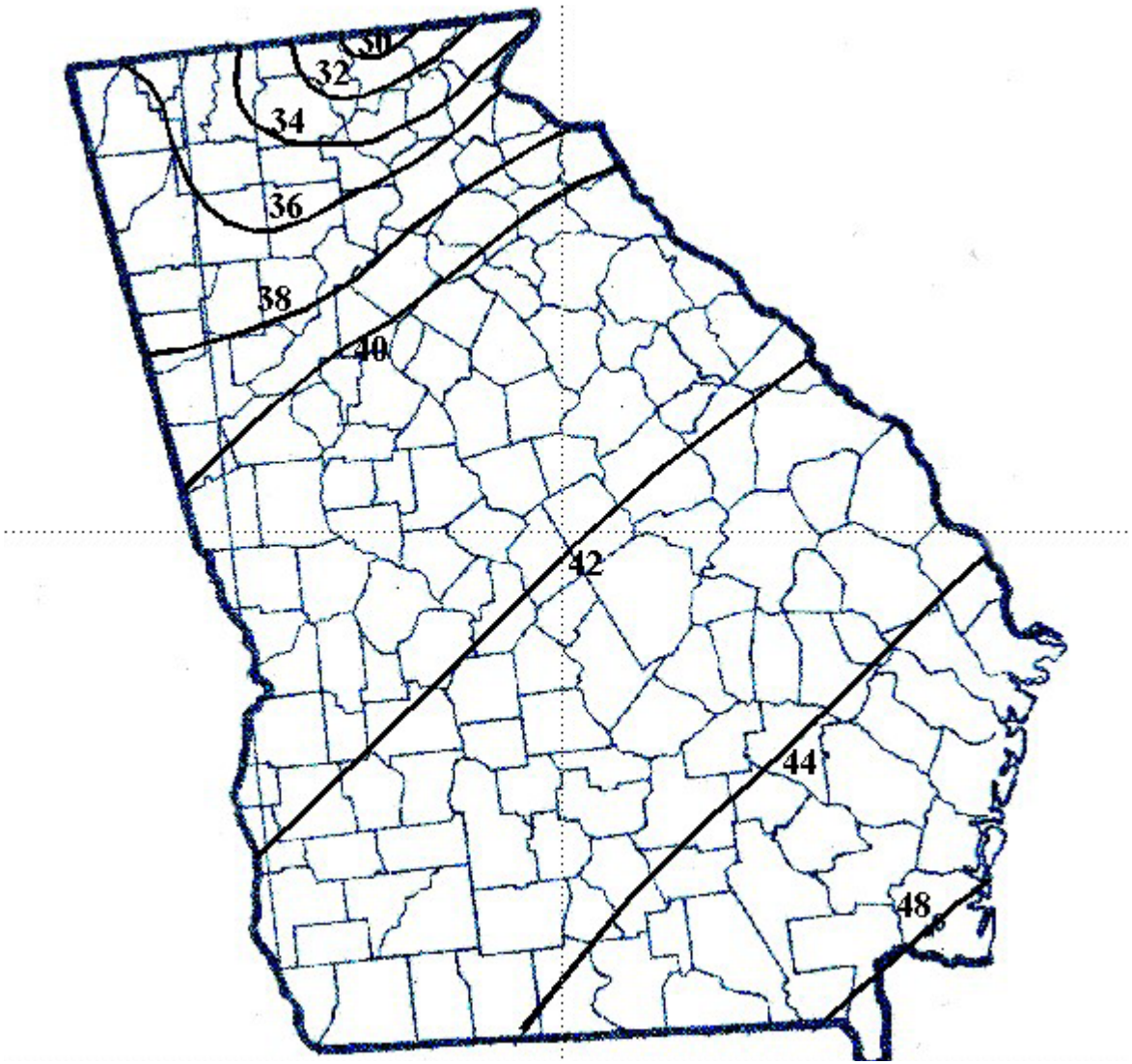


Figure 3.1.8-1 Average Annual Free Water Surface Evaporation (in inches)
(Source: NOAA, 1982)

3.1.8.3 EXAMPLE PROBLEM

Austin Acres, a 26-acre site in Augusta, is being developed along with an estimated 0.5-acre surface area pond. There is no baseflow. The desired pond volume to the overflow point is 2 acre-feet. Will the site be able to support the pond volume? From the basic site data we find that the site is 75% impervious with sandy clay loam soil.

- From **Equation 3.1.19**, R_v = 0.05 + 0.009 (75) = 0.73. With the correction factor of 0.9 the watershed efficiency is 0.65.
- The annual lake evaporation from **Figure 3.1.8-1** is about 42 inches.
- For a sandy clay loam the infiltration rate is I = 0.34 ft/day (**Table 3.1.8-1**).
- From a grading plan it is known that about 10% of the total pond area is sloped greater than 1:4.
- Monthly rainfall for Augusta was found from the Web site provided above.

Table 3.1.8-3 Summary Calculations for Each Month of the Year

1		J	F	M	A	M	J	J	A	S	O	N	D
2	Days/mo	31	28	31	30	31	30	31	31	30	31	30	31
3	Precipitation (in)	4.05	4.27	4.65	3.31	3.77	4.13	4.24	4.5	3.02	2.84	2.48	3.40
4	Evap Dist	3.2%	4.4%	7.4%	10.3%	12.3%	12.9%	13.4%	11.8%	9.3%	7.0%	4.7%	3.2%
5	R_o (ac-ft)	5.70	6.01	6.55	4.66	5.31	5.82	5.97	6.34	4.25	4.00	3.49	4.79
6	P (ac-ft)	0.17	0.18	0.19	0.14	0.16	0.17	0.18	0.19	0.18	0.12	0.10	0.14
7	E (ac-ft)	0.06	0.08	0.13	0.18	0.22	0.29	0.23	0.21	0.16	0.12	0.08	0.05
8	I (ac-ft)	5.01	4.52	5.01	4.85	5.01	4.85	5.01	5.01	4.85	5.01	4.85	5.01
9													
10	Balance (ac-ft)	0.81	1.59	1.61	-0.23	0.24	0.92	0.91	1.31	-0.63	-1.01	-1.33	-0.13
11	Running Balance (ac-ft)	0.81	2.00	2.00	1.77	2.00	2.00	2.00	2.00	1.87	0.36	0.00	0.00

Explanation of Table:

1. Months of year
2. Days per month
3. Monthly precipitation from web site is shown in **Figure 3.1.8-2**.
4. Distribution of evaporation by month from **Table 3.1.8-2**.
5. Watershed efficiency of 0.65 times the rainfall and converted to acre-feet.
6. Precipitation volume directly into pond equals precipitation depth times pond surface area divided by 12 to convert to acre-feet
7. Evaporation equals monthly percent of 42 inches from line 4 converted to acre-feet
8. Infiltration equals infiltration rate times 90% of the surface area plus infiltration rate times 0.5 (banks greater than 1:4) times 10% of the pond area converted to acre-feet
9. Lines 5 and 6 minus lines 7 and 8
10. Accumulated total from line 10 keeping in mind that all volume above 2 acre-feet overflows and is lost in the trial design

It can be seen that for this example the pond has potential to go dry in winter months. This can be remedied in a number of ways including compacting the pond bottom, placing a liner of clay or geosynthetics, and changing the pond geometry to decrease surface area.

```
Station: (90495) AUGUSTA_WSO_AIRPORT     From Year=1961 To Year=1990
Missing Data:   0.0%
                    Total Precipitation                          Snow    #Days Precip
    Mean   High--Yr    Low--Yr      1-Day Max     Mean  High--Yr =>.10 =>.50 =>1.
-------------------------------------------------------------------------------
Ja  4.05   8.91  87   0.75  81   2.78  25/1978    0.3   2.3  88     7      3     1
Fe  4.27   7.67  61   0.69  68   3.50   5/1985    1.0  14.0  73     7      3     1
Ma  4.65  11.92  80   0.88  68   5.31  10/1967    0.0   1.1  80     7      3     1
Ap  3.31   8.43  61   0.60  70   2.71  27/1961    0.0   0.0   0     5      2     1
Ma  3.77   9.61  79   1.57  87   4.44  31/1981    0.0   0.0   0     7      2     1
Jn  4.13   8.84  89   0.68  84   2.95  12/1964    0.0   0.0   0     6      3     1
Jl  4.24  11.43  67   1.02  87   3.67  21/1979    0.0   0.0   0     8      2     1
Au  4.50  11.34  86   0.65  80   5.95  29/1964    0.0   0.0   0     6      3     1
Se  3.02   9.51  75   0.31  84   4.55  20/1975    0.0   0.0   0     5      2     1
Oc  2.84  14.82  90   0.01  63   5.32  12/1990    0.0   0.0   0     4      2     1
No  2.48   7.76  85   0.57  73   3.43  22/1985    0.0   0.0   0     4      2     1
De  3.40   8.65  81   0.96  80   2.89  16/1970    0.0   0.4  71     6      3     1

An 44.66  66.04  64  32.96  78   5.95 29/08/64    1.4  14.4  73    71     30    13
Wi 11.71  20.26  87   5.62  86   3.50  5/02/85    1.3  14.4  73    20      8     3
Sp 11.73  19.93  84   4.00  85   5.31 10/03/67    0.0   1.1  80    18      8     3
Su 12.87  24.89  64   7.08  80   5.95 29/08/64    0.0   0.0   0    20      9     4
Fa  8.35  18.50  90   1.96  84   5.32 12/10/90    0.0   0.0   0    12      5     2
```

Figure 3.1.8-2 Augusta Precipitation Information

3.1.9 Downstream Hydrologic Assessment

The purpose of the overbank flood protection and extreme flood protection criteria is to protect downstream properties from flood increases due to upstream development. These criteria require the designer to control peak flow at the outlet of a site such that post-development peak discharge equals pre-development peak discharge. It has been shown that in certain cases this does not always provide effective water quantity control downstream from the site and may actually exacerbate flooding problems downstream. The reasons for this have to do with (1) the timing of the flow peaks, and (2) the total increase in volume of runoff. Further, due to a site's location within a watershed, there may be very little reason for requiring overbank flood control from a particular site. This section outlines a suggested procedure for determining the impacts of post-development stormwater peak flows and volumes on downstream flows that a community may require as part of a developer's stormwater management site plan. In summary, a downstream analysis may warrant a development to over-detain to protect downstream properties or may even warrant a reduction/elimination of detention because of the timing of peak discharges within the watershed.

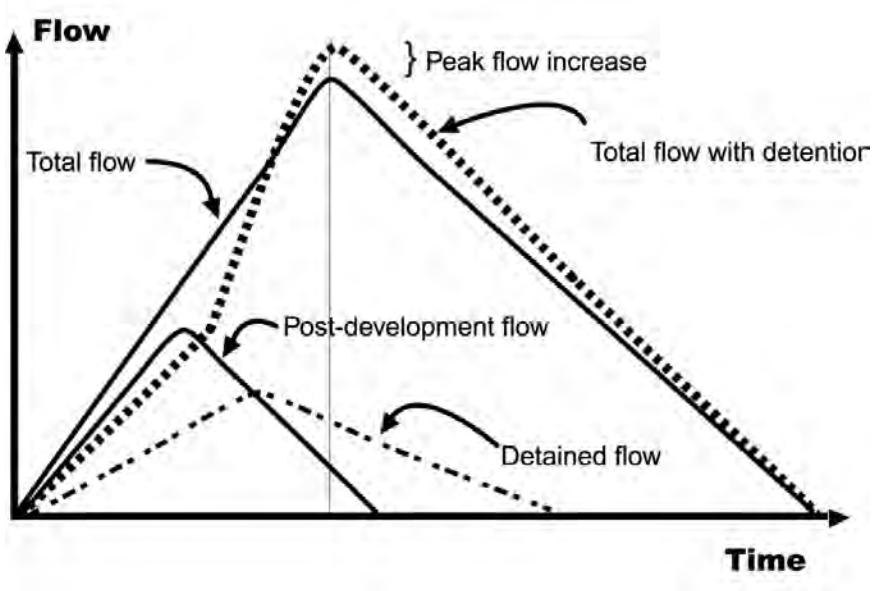


Figure 3.1.9-1 Detention Timing Example

3.1.9.1 REASONS FOR DOWNSTREAM PROBLEMS

Flow Timing

If water quantity control (detention) structures are indiscriminately placed in a watershed and changes to the flow timing are not considered, the structural control may actually increase the peak discharge downstream. The reason for this may be seen in **Figure 3.1.9-1**. The peak flow from the site is reduced appropriately, but the timing of the flow is such that the combined detained peak flow (the larger dashed triangle) is actually higher than if no detention were required. In this case, the shifting of flows to a later time brought about by the detention pond actually makes the downstream flooding worse than if the post-development flows were not detained.

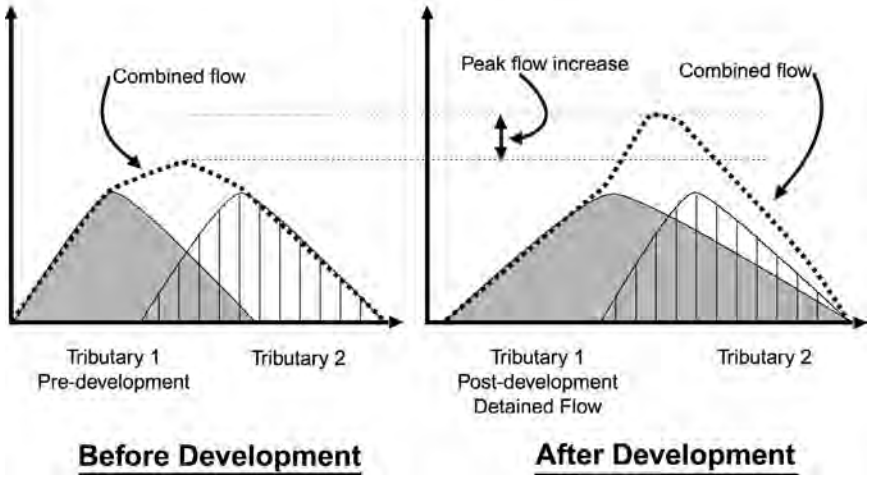


Figure 3.1.9-2 Effect of Increased Post-Development Runoff Volume with Detention on a Downstream Hydrograph

Increased Volume

An important impact of new development is an increase in the total runoff volume of flow. Thus, even if the peak flow is effectively attenuated, the longer duration of higher flows due to the increased volume may combine with downstream tributaries to increase the downstream peak flows.

Figure 3.1.9-2 illustrates this concept. The figure shows the pre- and post-development hydrographs from a development site (Tributary 1). The post-development runoff hydrograph meets the flood protection criteria (i.e., the post-development peak flow is equal to the pre-development peak flow at the outlet from the site). However, the post-development combined flow at the first downstream tributary (Tributary 2) is higher than pre-development combined flow. This is because the increased volume and timing of runoff from the developed site increases the combined flow and flooding downstream. In this case, the detention volume would have to have been increased to account for the downstream timing of the combined hydrographs to mitigate the impact of the increased runoff volume.

3.1.9.2 THE TEN-PERCENT RULE

In this Manual the "ten percent" criterion has been adopted as the most flexible and effective approach for ensuring that stormwater quantity detention ponds actually attempt to maintain pre-development peak flows throughout the system downstream.

The ten-percent rule recognizes the fact that a structural control providing detention has a "zone of influence" downstream where its effectiveness can be felt. Beyond this zone of influence the effect of structural control becomes relatively small and insignificant compared to the runoff from the total drainage area at that point. Based on studies and master planning results for a large number of sites, that zone of influence is considered to be the point where the drainage area controlled by the detention or storage facility comprises 10% of the total drainage area. For example, if the structural control drains 10 acres, the zone of influence ends at the point where the total drainage area is 100 acres or greater.

Typical steps in the application of the ten-percent rule are:

1. Determine the target peak flow for the site for predevelopment conditions.
2. Using a topographic map determine the lower limit of the zone of influence (10% point).
3. Using a hydrologic model determine the pre-development peak flows and timing of those peaks at each tributary junction beginning at the pond outlet and ending at the next tributary junction beyond the 10% point. Hydrographs shall be based on a 24-hour storm.
4. Change the land use on the site to post-development and rerun the model.
5. Design the structural control facility such that the overbank flood protection (2-25-year) post-development flows do not increase the peak flows at the outlet and the determined tributary junctions.
6. If it does increase the peak flow, the structural control facility must be redesigned or one of the following options considered:
   - Control of the overbank flood volume (Q_{p25}) may be waived by the local authority saving the developer the cost of sizing a detention basin for overbank flood control. In this case the ten-percent rule saved the construction of an unnecessary structural control facility that would have been detrimental to the watershed flooding problems. In some communities this situation may result in a fee being paid to the local government in lieu of detention. That fee would go toward alleviating downstream flooding or making channel or other conveyance improvements.
   - Work with the local government to reduce the flow elevation through channel or flow conveyance structure improvements downstream.
   - Obtain a flow easement from downstream property owners to the 10% point.

If the existing downstream conditions are overburdened by the pre-developed flows in the stream, then the developer and the County shall jointly participate to resolve the problem. The meaning of "overburdened" shall include but not be limited to situations where 25-year velocities exceed the non-erosive velocity of the stream, habitable structures are shown to be subject to flooding for any frequency up to and including the regulatory flood and storm water facilities that cannot carry the design storm in accordance with these regulations.

Even if the overbank flood protection requirement is eliminated, the water quality treatment (WQv), channel protection (CPv), and extreme flood protection (Qf) criteria will still be required.

3.1.9.3 EXAMPLE PROBLEM

Figure 3.1.9-3 illustrates the concept of the ten-percent rule for two sites in a watershed.

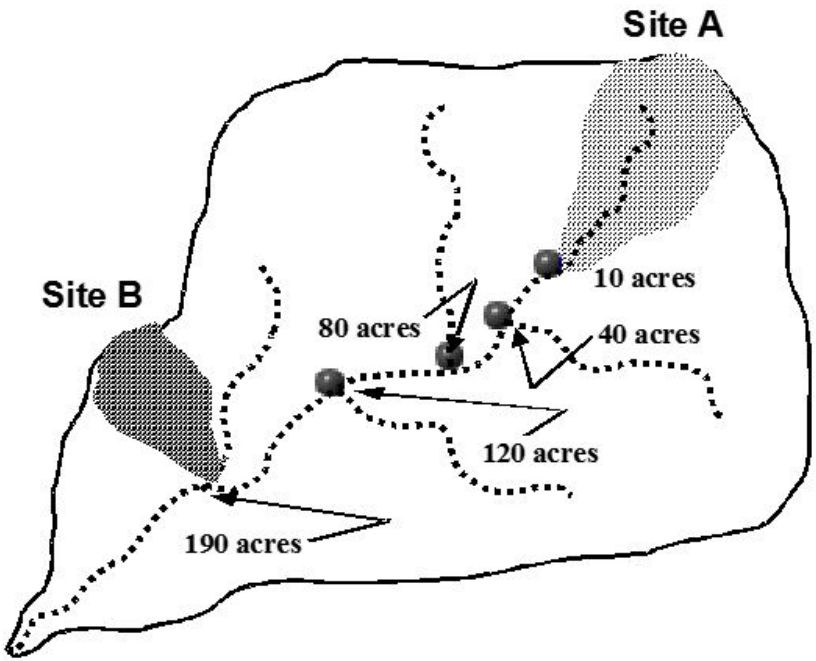


Figure 3.1.9-3 Example of the Ten-Percent Rule

Discussion

Site A is a development of 10 acres, all draining to a wet ED stormwater pond. The overbank flooding and extreme flood portions of the design are going to incorporate the ten-percent rule. Looking downstream at each tributary in turn, it is determined that the analysis should end at the tributary marked "80 acres." The 100-acre (10%) point is in between the 80-acre and 120-acre tributary junction points.

The assumption is that if there is no peak flow increase at the 80-acre point then there will be no increase through the next stream reach downstream through the 10% point (100 acres) to the 120-acre point. The designer constructs a simple HEC-1 model of the 80-acre areas using single existing condition sub-watersheds for each tributary. Key detention structures existing in other tributaries must be modeled. An approximate curve number is used since the actual peak flow is not key for initial analysis; only the increase or decrease is important. The accuracy in curve number determination is not as significant as an accurate estimate of the time of concentration. Since flooding is an issue downstream, the pond is designed (through several iterations) until the peak flow does not increase at junction points downstream to the 80-acre point.

Site B is located downstream at the point where the total drainage area is 190 acres. The site itself is only 6 acres. The first tributary junction downstream from the 10% point is the junction of the site outlet with the stream. The total 190 acres is modeled as one basin with care taken to estimate the time of concentration for input into the TR-20 model of the watershed. The model shows that a detention facility, in this case, will actually increase the peak flow in the stream.

3.2 Methods for Estimating Stormwater Volume Reduction

3.2.1 Introduction

The runoff reduction approach to addressing Water Quality requirements is discussed in detail in Volume 1 and Subsections 2.2.2 and 2.2.3 of Volume 2. Best management practices that incorporate stormwater runoff reduction are provided in Chapter 4. Within each BMP section of the manual, design steps have been provided for each unique application and practice, and detailed design examples are provided in Appendices B-2 (bioretention area), B-4 (infiltration trench), and B-5 (enhanced swale). Refer to **Table 4.1.3-1** (*BMP Selection Guide*) for applicable BMPs that can provide runoff reduction.

Where runoff reduction practices are used, an adjusted curve number (CN) is computed that is lower than the original CN based on an actual stormwater volume removed from the total runoff, see Subsection 3.1.7.5 for additional information. This adjusted CN calculation is performed for each storm event being analyzed after a portion of the stormwater runoff has been quantified and removed from the site. In other words, an adjusted CN can be computed separately for stream channel protection, overbank flood protection, and extreme flood protection storm events since the volume of runoff changes for any given rainfall event. The modified equation discussed in Subsection 3.1.7.5 was originally presented in the 2010 Center for Watershed Protection journal article titled, *The Runoff Reduction Method*.

The site development review tool has been created to aid in the design and documentation of stormwater management requirements. This tool can be accessed and downloaded at the following location: www.georgiastormwater.com, and at the Gwinnett County website.

Within the tool, an "Instructions" and "Tool Flowchart" tab have been created to provide specific input requirements and responsibilities of the end user. These same instructions and workflow process are particularly beneficial for local communities who will ultimately review the information as part of their stormwater management review process.

3.3 Storage Design

3.3.1 General Storage Concepts

3.3.1.1 INTRODUCTION

This section provides general guidance on stormwater runoff storage for meeting stormwater management control requirements (i.e., water quality treatment, downstream channel protection, overbank flood protection, and extreme flood protection).

Storage of stormwater runoff within a stormwater management system is essential to providing the extended detention of flows for water quality treatment and downstream channel protection, as well as for peak flow attenuation of larger flows for overbank and extreme flood protection. Runoff storage can be provided within an on-site system through the use of best management practices and/or nonstructural features and landscaped areas. **Figure 3.3.1-1** illustrates various storage facilities that can be considered for a development site.

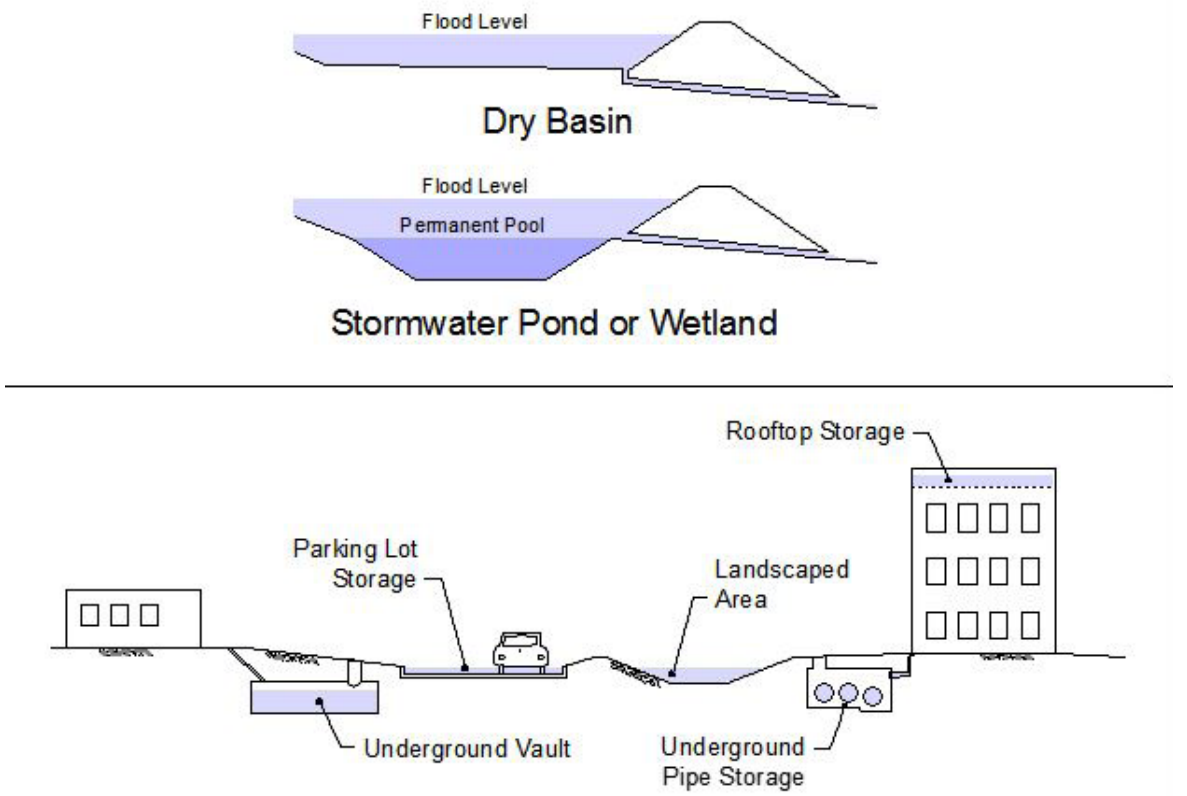


Figure 3.3.1-1 Examples of Typical Stormwater Storage Facilities

3.3.1.2 STORAGE CLASSIFICATION

Stormwater storage(s) can be classified as detention, extended detention or retention. Some facilities include one or more types of storage.

Stormwater *detention* is used to reduce the peak discharge and detain runoff for a specified short period of time. Detention volumes are designed to completely drain after the design storm has passed. Detention is used to meet overbank flood protection criteria, and extreme flood criteria where required.

Extended detention (ED) is used to drain a runoff volume over a specified period of time, typically 24 hours, and is used to meet channel protection criteria. Some best management practices (wet ED pond, micropool ED pond, and wetlands) also include extended detention storage of a portion of the water quality volume.

Retention facilities are designed to contain a permanent pool of water, such as stormwater ponds and wetlands, which is used for water quality treatment.

Storage facilities are often classified on the basis of their location and size. On-site storage is constructed on individual development sites. *Regional* storage facilities are constructed at the lower end of a subwatershed and are designed to manage stormwater runoff from multiple projects and/or properties. A discussion of regional stormwater controls is found in Section 4.1.

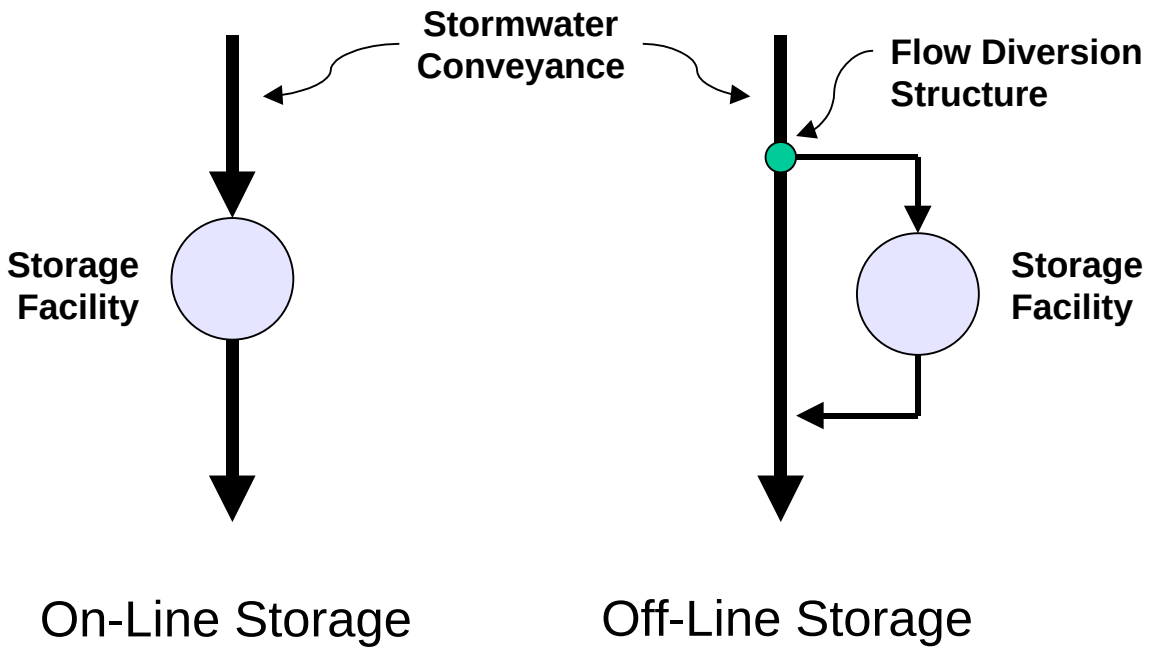


Figure 3.3.1-2 On-Line versus Off-Line Storage

Storage can also be categorized as on-line or off-line. On-line storage uses a structural control facility that intercepts flows directly within a conveyance system or stream. Off-line storage is a separate storage facility to which flow is diverted from the conveyance system. **Figure 3.3.1-2** illustrates on-line versus off-line storage.

3.3.1.3 STAGE-STORAGE RELATIONSHIP

A stage-storage curve defines the relationship between the depth of water and storage volume in a storage facility (see **Figure 3.3.1-3**). The volume of storage can be calculated by using simple geometric formulas expressed as a function of depth.

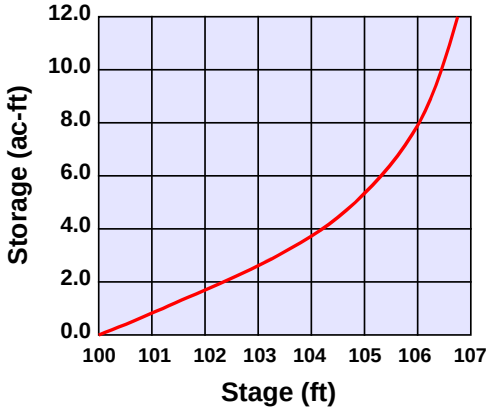


Figure 3.3.1-3 Stage-Storage Curve

The storage volume for natural basins may be developed using a topographic map and the double-end area, frustum of a pyramid, prismoidal or circular conic section formulas.

The double-end area formula (see **Figure 3.3.1-4**) is expressed as:

$$V_{1,2} = [(A_1 + A_2)/2]d \qquad (3.3.1)$$

Where:

$V_{1,2}$ = storage volume (ft^3) between elevations 1 and 2

A_1 = surface area at elevation 1 (ft^2)

A_2 = surface area at elevation 2 (ft^2)

d = change in elevation between points 1 and 2 (ft)

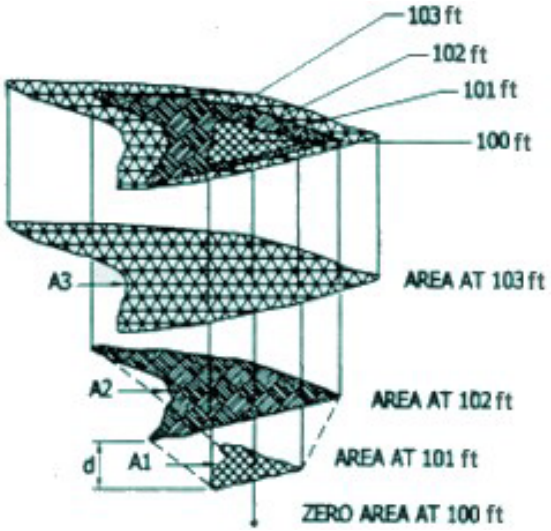


Figure 3.3.1-4 Double-End Area Method

The frustum of a pyramid formula is expressed as:

$$V = d/3\ [A_1 + (A_1 \times A_2)^{0.5} + A2]/3 \qquad (3.3.2)$$

Where:

V = volume of frustum of a pyramid (ft3)

d = change in elevation between points 1 and 2 (ft)

A_1 = surface area at elevation 1 (ft^2)

A_2 = surface area at elevation 2 (ft^2)

The prismoidal formula for trapezoidal basins is expressed as:

$$V = LWD + (L + W)\ ZD^2 + 4/3\ Z^2\ D^3 \qquad (3.3.3)$$

Where:

V = volume of trapezoidal basin (ft^3)

L = length of basin at base (ft)

W= width of basin at base (ft)

D = depth of basin (ft)

Z = side slope factor, ratio of horizontal to vertical

The circular conic section formula is:

$$V = 1.047\ D(R_1^2 + R_2^2 + R_1R_2) \qquad (3.3.4)$$

$$V = 1.047\ D(3\ R_1^2 + 3ZDR_1 + Z_2D^2) \qquad (3.3.5)$$

Where:

R_1 , R_2 = bottom and surface radii of the conic section (ft)

D = depth of basin (ft)

Z = side slope factor, ratio of horizontal to vertical

3.3.1.4 STAGE-DISCHARGE RELATIONSHIP

AA stage-discharge curve defines the relationship between the depth of water and the discharge or outflow from a storage facility (see **Figure 3.3.1-5**). A typical storage facility has two outlets or spillways: a principal outlet and a secondary (or emergency) outlet. The principal outlet is usually designed with a capacity sufficient to convey the design flows without allowing flow to enter the emergency spillway. A pipe culvert, weir, or other appropriate outlet can be used for the principal spillway or outlet.

The emergency spillway is sized to provide a bypass for floodwater during a flood that exceeds the design capacity of the principal outlet. This spillway should be designed taking into account the potential threat to downstream areas if the storage facility were to fail. The stage-discharge curve should take into account the discharge characteristics of both the principal spillway and the emergency spillway. For more details, see Section 3.4, *Outlet Structures*.

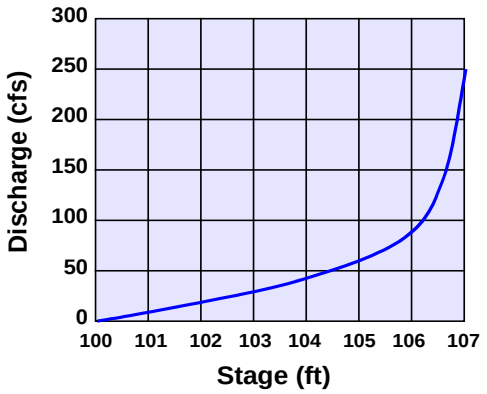


Figure 3.3.1-5 Stage-Discharge Curve

3.3.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual, the symbols listed in **Table 3.3.2-1** will be used. These symbols were selected because of their wide use in technical publications. In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equations.

Table 3.3.2-1 Symbols and Definitions

Symbol	Definition	Units
A	Cross sectional or surface area	ft^2
A_m	Drainage area	mi^2
C	Weir coefficient	-
d	Change in elevation	ft
D	Depth of basin or diameter of pipe	ft
t	Routing time period	sec
g	Acceleration due to gravity	ft/s^2
H	Head on structure	ft
H_c	Height of weir crest above channel bottom	ft
K	Coefficient	-
I	Inflow rate	cfs
L	Length	ft
Q, q	Peak inflow or outflow	cfs, in
R	Surface radii	ft
S, V_s	Storage volume	ft^3
t_b	Time base on hydrograph	hrs
T_I	Duration of basin inflow	hrs
t_p	Time to peak	hrs
V_s, S	Storage Volume	ft^3, in, acre-ft
V_r	Volume of runoff	ft^3, in, acre-ft
W	Width of basin	ft
Z	Side slope factor	-

3.3.3 General Storage Design Procedures

3.3.3.1 INTRODUCTION

This section discusses the general design procedures for designing storage to provide standard detention of stormwater runoff for overbank and extreme flood protection ($Q_{p2\text{-}25}$ and Q_f).

The design procedures for all structural control storage facilities are the same whether or not they include a permanent pool of water. In the latter case, the permanent pool elevation is taken as the "bottom" of storage and is treated as if it were a solid basin bottom for routing purposes.

It should be noted that the location of structural stormwater controls is very important as it relates to the effectiveness of these facilities to control downstream impacts. In addition, multiple storage facilities located in the same drainage basin will affect the timing of the runoff through the conveyance system, which could decrease or increase flood peaks in different downstream locations. Therefore, a downstream peak flow analysis should be performed as part of the storage facility design process (see Subsection 3.1.9).

In multi-purpose multi-stage facilities such as stormwater ponds, the design of storage must be integrated with the overall design for water quality treatment objectives. See Chapter 4 for further guidance and criteria for the design of structural stormwater controls.

An important consideration in these designs is the sediment volume that the system is capable of storing before performance and/or capacity are reduced. For larger watersheds, or regional detention facilities, the sediment volume is estimated from the sediment produced per year, times the years between dredging or similar maintenance. Provisions should be made in the layout to facilitate access for dredging equipment to the storage area and the maximum sediment depth should be defined. Maintenance plans should discuss dredging and set a time interval for evaluation such as once per year.

For smaller watersheds, and all other stormwater detention facilities, sedimentation can be addressed by a local community requirement for an as-built pond survey and/or certification process. During the construction phase of a development or redevelopment, sedimentation occurs and can reduce the storage capacity of the post-construction stormwater detention basin drastically. Once final stabilization of a site has occurred, the accumulated sediment should be removed and the detention basin surveyed to comply with the originally approved design volume. It is understood that sedimentation of a fully stabilized site over time is minimal for smaller watersheds, when compared to a larger watershed during active construction activities.

3.3.3.2 DATA NEEDS

The following data are needed for storage design and routing calculations:

- Inflow hydrograph for all selected design storms
- Stage-storage curve for proposed storage facility
- Stage-discharge curve for all outlet control structures
- Estimate of sediment deposited per year and the number of years desired before dredging.

3.3.3.3 DESIGN PROCEDURE

A general procedure for using the above data in the design of storage facilities is presented below.

(Step 1) Compute inflow hydrograph for runoff from the 2-25- (Q_{p2-25}), and 100-year (Q_f) design storms using the hydrologic methods outlined in Section 3.1. Both existing- and post-development hydrographs are required for 2-25-year design storms.

(Step 2) Perform preliminary calculations to evaluate detention storage requirements for the hydrographs from Step 1 (see Subsection 3.3.4).

(Step 3) Determine the physical dimensions necessary to hold the estimated volume from Step 2, including freeboard. Include the estimated volume of sediment storage (if appropriate). The maximum storage requirement calculated from Step 2 should be used. From the selected shape determine the maximum depth in the pond.

(Step 4) Select the type of outlet and size the outlet structure. The estimated peak stage will occur for the estimated volume from Step 2. The outlet structure should be sized to convey the allowable discharge at this stage.

(Step 5) Perform routing calculations using inflow hydrographs from Step 1 to check the preliminary design using a storage routing computer model. If the routed post-development peak discharges from the 2-25-year design storms exceed the existing-development peak discharges, then revise the available storage volume, outlet device, etc., and return to Step 3.

(Step 6) Perform routing calculations using the 100-year hydrograph to determine if any increases in downstream flows from this hydrograph will cause damages and/or drainage and flooding problems. If problems will be created (e.g., flooding of habitable dwellings, property damage, or public access and/or utility interruption) then the storage facility must be designed to control the increased flows from the 100-year storm. If not then consider emergency overflow from runoff due to the 100-year (or larger) design storm and established freeboard requirements.

(Step 7) Evaluate the downstream effects of detention outflows for the 25- and 100-year storms to ensure that the routed hydrograph does not cause downstream flooding problems. The exit hydrograph from the storage facility should be routed though the downstream channel system until a confluence point is reached where the drainage area being analyzed represents 10% of the total drainage area (see Subsection 3.1.9).

(Step 8) Evaluate the control structure outlet velocity and provide channel and bank stabilization if the velocity will cause erosion problems downstream.

Routing of hydrographs through storage facilities is critical to the proper design of these facilities. Although storage design procedures using inflow/outflow analysis without routing have been developed, their use in designing detention facilities has not produced acceptable results in many areas of the country, including Georgia.

Although hand calculation procedures are available for routing hydrographs through storage facilities, they are very time consuming, especially when several different designs and iterations are evaluated. Many standard hydrology and hydraulics textbooks give examples of hand-routing techniques. For this Manual, it assumed that designers will be using one of the many computer programs available for storage routing and thus other procedures and example applications will not be given here.

3.3.4 Preliminary Detention Calculations

3.3.4.1 INTRODUCTION

Procedures for preliminary detention calculations are included here to provide a simple method that can be used to estimate storage needs and also provide a quick check on the results of using different computer programs. Standard routing should be used for actual (final) storage facility calculations and design.

3.3.4.2 STORAGE VOLUME

For small drainage areas, a preliminary estimate of the storage volume required for peak flow attenuation may be obtained from a simplified design procedure that replaces the actual inflow and outflow hydrographs with the standard triangular shapes shown in **Figure 3.3.4-1**.

The required storage volume may be estimated from the area above the outflow hydrograph and inside the inflow hydrograph, expressed as:

$$V_S = 0.5T_I (Q_i - Q_O) \qquad (3.3.6)$$

Where:

V_S = storage volume estimate (ft^3)
Q_i = peak inflow rate (cfs)
Q_o = peak outflow rate (cfs)
T_i = duration of basin inflow (s)

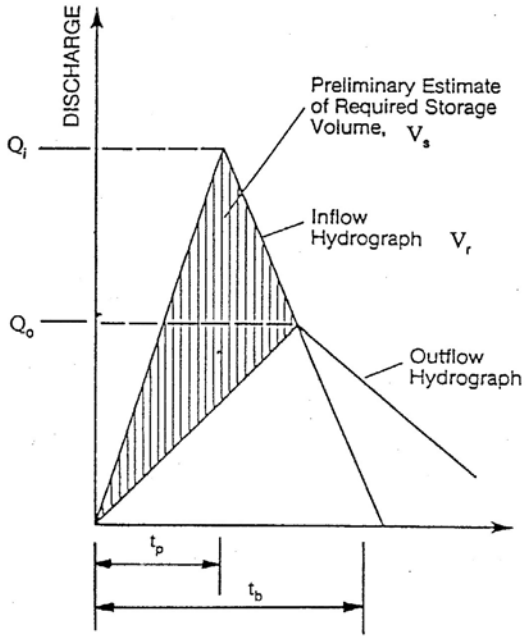


Figure 3.3.4-1 Triangular-Shaped Hydrographs (For Preliminary Estimate of Required Storage Volume)

3.3.4.3 ALTERNATIVE METHOD

An alternative preliminary estimate of the storage volume required for a specified peak flow reduction can be obtained by the following regression equation procedure (Wycoff and Singh, 1976).

(Step 1) Determine input data, including the allowable peak outflow rate, Q_O, the peak flow rate of the inflow hydrograph, Q_i, the time base of the inflow hydrograph, t_b, and the time to peak of the inflow hydrograph, t_p.

(Step 2) Calculate a preliminary estimate of the ratio V_S/V_r using the input data from Step 1 and the following equation:

$$\frac{V_S}{V_R} = \frac{1.291 \times \left(1 - \frac{Q_O}{Q_I}\right)^{0.753}}{\left(\frac{t_p}{t_b}\right)^{0.411}} \qquad (3.3.7)$$

Where:
V_S = volume of storage (in)
V_r = volume of runoff (in)
Q_O = outflow peak flow (cfs)
Q_i = inflow peak flow (cfs)
t_b = time base of the inflow hydrograph (hr) [Determined as the time from the beginning of rise to a point on the recession limb where the flow is 5% of the peak]
t_p = time to peak of the inflow hydrograph (hr)

(Step 3) Multiply the volume of runoff, V_r, times the ratio V_S/V_r, calculated in Step 2 to obtain the estimated storage volume V_S.

3.3.4.4 PEAK FLOW REDUCTION

A preliminary estimate of the potential peak flow reduction for a selected storage volume can be obtained by the following procedure.

(Step 1) Determine volume of runoff, V_r, peak flow rate of the inflow hydrograph, Q_i, time base of the inflow hydrograph, t_b, time to peak of the inflow hydrograph, t_p, and storage volume V_S.

(Step 2) Calculate a preliminary estimate of the potential peak flow reduction for the selected storage volume using the following equation (Wycoff and Singh, 1976):

$$Q_O/Q_i = 1 - 0.712(V_S/V_r)^{1.328}(t_b/t_p)^{0.546} \qquad (3.3.8)$$

Where:

Q_O = outflow peak flow (cfs)
Q_i = inflow peak flow (cfs)
V_S = volume of storage (in)
V_r = volume of runoff (in)
t_b = time base of the inflow hydrograph (hr) [Determined as the time from the beginning of rise to a point on the recession limb where the flow is 5 percent of the peak]
t_p = time to peak of the inflow hydrograph (hr)

(Step 3) Multiply the peak flow rate of the inflow hydrograph, Q_i, times the potential peak flow reduction calculated from Step 2 to obtain the estimated peak outflow rate, Q_O, for the selected storage volume.

3.3.5 Channel Protection Volume Estimation

3.3.5.1 INTRODUCTION

The Simplified NRCS TR-55 Peak Runoff Rate Estimation approach (see Subsection 3.1.5.7) can be used for estimation of the Channel Protection Volume (CP_v) for storage facility design.

This method should not be used for standard detention design calculations. See either Subsection 3.3.4 or the modified rational method in Subsection 3.3.6 for preliminary detention calculations without formal routing.

3.3.5.2 BASIC APPROACH

For CP_v estimation, using **Figures 3.1.5-6** and **3.1.5-7** in Section 3.1, the unit peak discharge (q_U) can be determined based on I_a/P and time of concentration (t_C). Knowing q_U and T (extended detention time, typically 24 hours), the q_O/q_I ratio (peak outflow discharge/peak inflow discharge) can be estimated from **Figure 3.3.5-1**.

Using the following equation from TR-55 for a Type II or Type III rainfall distribution, V_S/V_r can be calculated.

Note: **Figure 3.3.4-1** can also be used to estimate VS/Vr.

$$V_S/V_r = 0.682 - 1.43(q_O/q_I) + 1.64\,(q_O/q_I)^2 - 0.804(q_O/q_I)^3 \quad (3.3.9)$$

Where:

V_S = required storage volume (acre-feet)
V_r = runoff volume (acre-feet)
q_o = peak outflow discharge (cfs)
q_I = peak inflow discharge (cfs)

The required storage volume can then be calculated by:

$$V_S = \frac{(V_S/V_r)(Q_d)(A)}{12} \quad (3.3.10)$$

Where:

V_S and **V_r** are defined above
Q_d = the developed runoff for the design storm (inches)
A = total drainage area (acres)

While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 25-year storm.

3.3.5.3 EXAMPLE PROBLEM

Compute the 100-year peak discharge for a 50-acre wooded watershed located in Peachtree City, which will be developed as follows:

- Forest land - good cover (hydrologic soil group B) = 10 ac
- Forest land - good cover (hydrologic soil group C) = 10 ac
- 1/3 Acre residential (hydrologic soil group B) = 20 ac

Industrial development (hydrological soil group C) = 10 ac

Other data include the following:

- Total impervious area = 18 acres
- % of pond and swamp area = 0

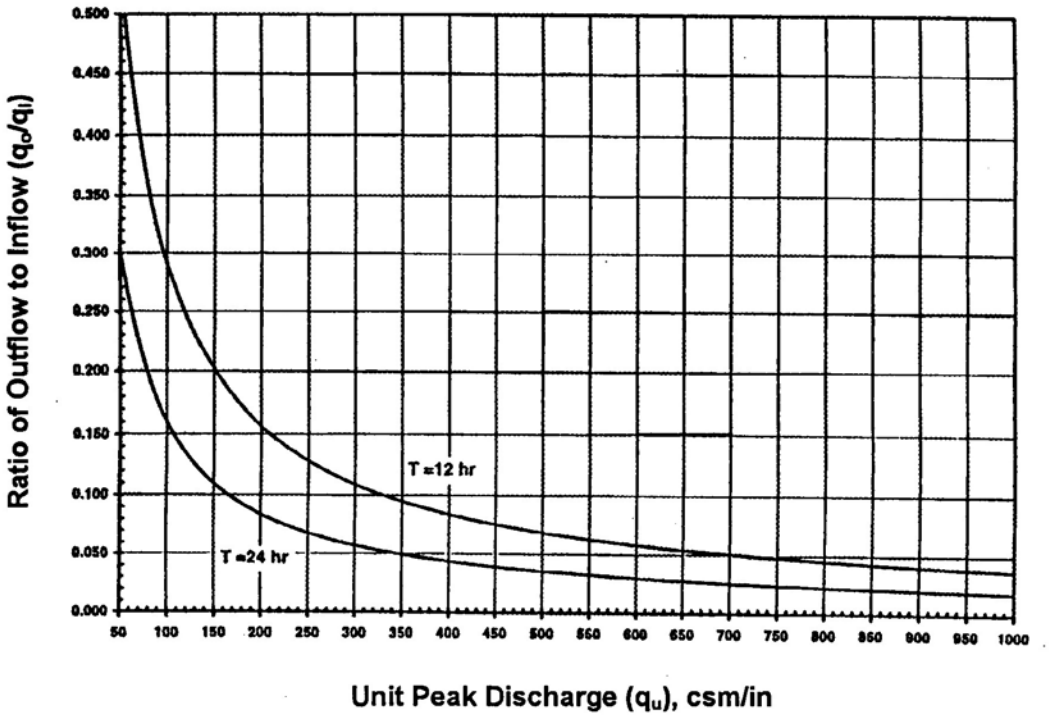


Figure 3.3.5-1 Detention Time vs. Discharge Ratios
(Source: MDE, 1998)

Computations

1. Calculate rainfall excess:

   » The 100-year, 24-hour rainfall is 8.22 inches (From NOAA Atlas 14).

   » The 1-year, 24 hour rainfall is 3.37 inches (From NOAA Atlas 14).

   » Composite weighted runoff coefficient is:

Dev #	Area	% Total	CN	Composite CN
1	10 ac	20%	55	11.0
2	10 ac	20%	70	14.0
3	20 ac	40%	72	28.8
4	10 ac	20%	91	18.2
Total	50 ac	100%		72

*from Equation 3.1.6, Q (100-year) = 4.89 inches
Q_d (1-year developed) = 1.0 inches

2. Calculate time of concentration

Segment	Type of Flow	Length (ft)	Slope (%)
1	Overland n=0.24	40	2.0%
2	Shallow channel	750	1.7%
3	Main channel	1100	0.5%

*For the main channel, n = .06 (estimated), width = 10 feet, depth = 2 feet, rectangular channel

The hydrologic flow path for this watershed = 1,890 ft

Segment 1 - Travel time from **equation 2.1.9** with P_2 = 3.84 in
(From NOAA Atlas 14)

$T_t = [0.42(0.24 \times 40)^{0.8}] / [(3.84)^{0.5} (.020)^{0.4}] = 6.26$ minutes

Segment 2 - Travel time from **Figure 3.1.5-5** or **equation 3.1.9**

V = 2.1 ft/sec (from **equation 3.1.9**)

T_t = 750 / 60 (2.1) = 5.95 minutes

Segment 3 - Using **equation 3.1.11**

V = (1.49/.06) $(1.43)^{0.67}$ $(.005)^{0.5}$ = 2.23 ft/sec

T_t = 1100 / 60 (2.23) = 8.22 minutes

t_c = 6.26 + 5.95 + 8.22 = 20.43 minutes (.34 hours)

3. Calculate I_a/P for C_n = 72 (**Table 3.1.5-1**), I_a = .778 (**Table 3.1.5-3**)

I_a/P = (.778 / 8.23 = .095

Note: Use I_a/P = .10 to facilitate use of **Figure 3.1.5-6.** Straight line interpolation could also be used.

4. Unit discharge q_u (100-year) from **Figure 3.1.5-6** = 650 csm/in, q_u (1-year) = 580 csm/in

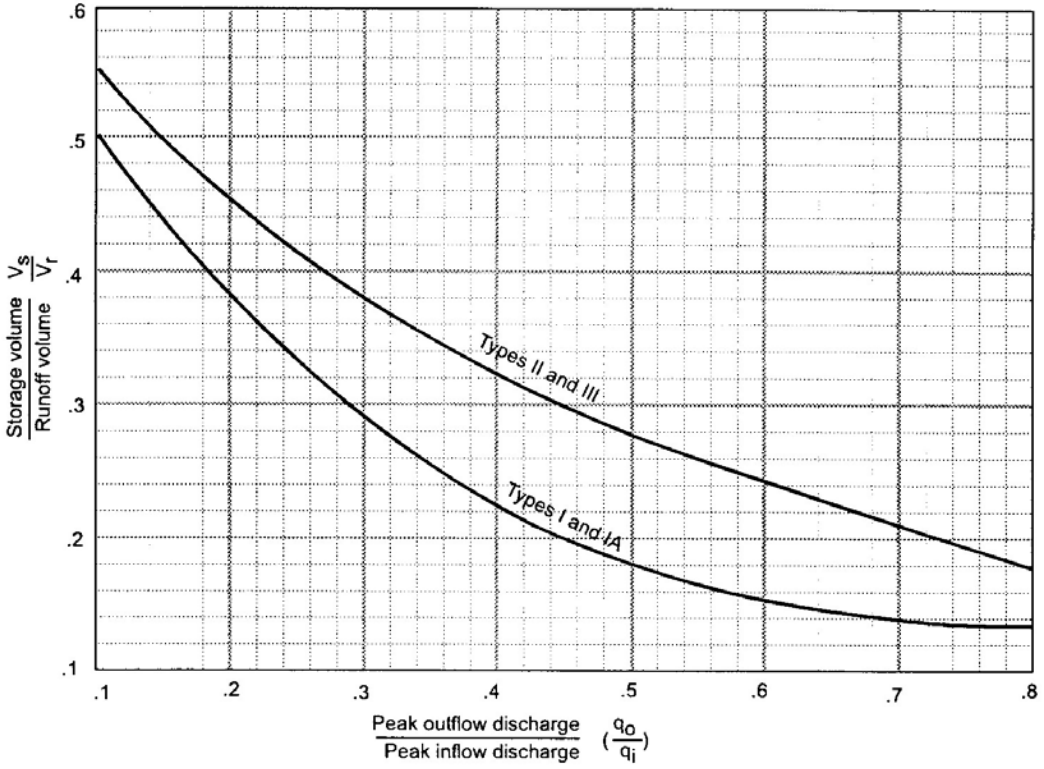


Figure 3.3.5-2 Approximate Detention Basin Routing for Rainfall Types I, IA, II, and III
(Source: TR-55, 1986)

5. Calculate peak discharge with F_p = 1 using **equation 3.1.12**

Q_{100} = 650 (50/640)(4.89)(1) = 248 cfs

6. Calculate water quality volume (WQ_v)

Compute runoff coefficient, R_v

R_V = 0.50 + (IA)(0.009)
= 0.50 + (18)(0.009)
= 0.21

Compute water quality volume, WQ_v

WQ_v = 1.2(R_V)(A)/12
= 1.2(.21)(50)/12
= 1.05 acre-feet

7. (Calculate channel protection volume (CP_v = V_S)

Knowing q_u (1-year) = 580 csm/in from Step 3 and T (extended detention time of 24 hours), find q_O/q_I from **Figure 3.3.5-1**.

q_O/q_I = 0.03

For a Type II rainfall distribution:

V_S/V_r = 0.682 – 1.43 (q_O/q_I) + 1.64 $(q_O/q_I)^2$ – 0.804 $(q_O/q_I)^3$
= 0.682 – 1.43 (0.03) + 1.64 (0.03) – 0.804 (0.03)
= 0.64

Therefore, stream channel protection volume with Q_d (1-year developed) = 1.0 inches, from Step 1, is CP_v = V_S = $(V_S/V_r)(Q_d)(A)/12$ = (0.64)(1.0)(50)/12 = 2.67 acre-feet

3.3.6 The Modified Rational Method

3.3.6.1 INTRODUCTION

For drainage areas of *less than 5 acres*, a modification of the Rational Method can be used for the estimation of storage volumes for detention calculations.

The Modified Rational Method uses the peak flow calculating capability of the Rational Method paired with assumptions about the inflow and outflow hydrographs to compute an approximation of storage volumes for simple detention calculations. There are many variations on the approach. **Figure 3.3.6-1** illustrates one application. The rising and falling limbs of the inflow hydrograph have a duration equal to the time of concentration (t_c). An allowable target outflow is set (Q_a) based on pre-development conditions. The storm duration is t_d, and is varied until the storage volume (shaded gray area) is maximized. It is normally an iterative process done by hand or on a spreadsheet. Downstream analysis is not possible with this method as only approximate graphical routing takes place.

3.3.6.2 DESIGN EQUATIONS

The design of detention using the Modified Rational Method is presented as a noniterative approach suitable for spreadsheet calculation (Debo & Reese, 1995).
The allowable release rate can be determined from:

$$Q_a = C_a\, i\, A \qquad (3.3.11)$$

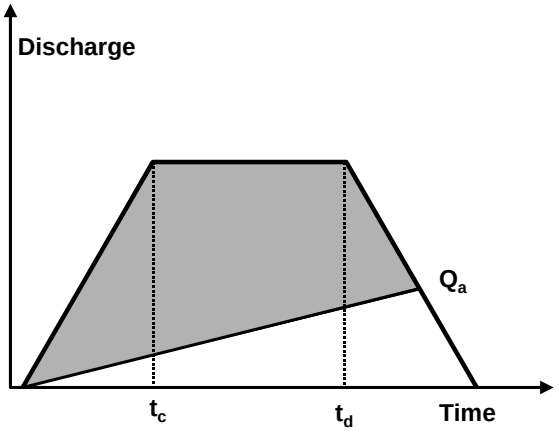


Figure 3.3.6-1 Modified Rational Definitions

Where:

Q_a = allowable release rate (cfs)
C_a = pre-development Rational Method runoff coefficient
i = rainfall intensity for the corresponding time of concentration (in/hr)
A = area (acres)

The critical duration of storm, the time value to determine rainfall intensity, at which the storage volume is maximized is:

$$T_d = \sqrt{\frac{2CAab}{Q_a}} - b \qquad (3.3.12)$$

Where:

T_d = critical storm duration (min)
Q_a = allowable release rate (cfs)

C = developed condition Rational Method runoff coefficient
A = area (acres)

a, b = rainfall factors dependent on location and return period taken from **Table 3.3.6-1.**

The required storage volume, in cubic feet can be obtained from **Equation 3.3.13**.

$$V_{preliminary} = 60\,[CAa - (2CabAQ_a)^{1/2} + (Q_a/2)\,(b\text{-}t_c)] \qquad (3.3.13a)$$

$$V_{max} = V_{preliminary} * P_{180}/P_{td} \qquad (3.3.13b)$$

Where:

$V_{preliminary}$ = preliminary required storage (ft^3)
V_{max} = required storage (ft^3)
t_c = time of concentration for the developed condition (min)
P_{180} = 3-hour (180-minute) storm depth (in)
P_{td} = storm depth for the critical duration (in)
All other variables are as defined above

The equations above include the use of an adjustment factor to the calculated storage volume to account for undersizing. The factor (P_{180}/P_{td}) is the ratio of the 3-hour storm depth for the return frequency divided by the rainfall depth for the critical duration calculated in **Equation 3.3.12**. The Modified Rational Method also often undersizes storage facilities in flat and more sandy areas where the target discharge may be set too large, resulting in an oversized orifice. In these locations a C factor of 0.05 to 0.1 should be used.

3.3.6.3 EXAMPLE PROBLEM

A 5-acre site is to be developed in Atlanta. Based on site and local information, it is determined that channel protection is not required and that limiting the 25-year and 100-year storm is also not required. The local government has determined that the development must detain the 2-year and 10-year storms. Rainfall values are taken from NOAA Atlas 14. The following key information is obtained:

A = 5 acres
Slope is about 5%
Pre-development t_c = 21 minutes and C factor = 0.22
Post-development t_c = 10 minutes and C factor = 0.80

Steps	2 - year	10 - year
t_c (min)	21	21
i (in/hr)	3.34	4.51
Q_a (**Equation 3.3.11**) (cfs)	3.67	4.96
a (from **Table 3.3.6-1**)	123.19	184.23
b (from **Table 3.3.6-1**)	15.91	19.96
V_{max} (**Equation 3.3.13**) (ft^3)	16,017	23,199
P_{180} (from NOAA Atlas 14) (in)	2.43	3.42
T_d (**Equation 3.3.12**) (min)	49	57
P_{td} (from NOAA Atlas 14) (in)	1.62	2.70
V_{max} (**Equation 3.3.13**) (ft^3)	24,025	29,385

Table 3.3.6-1 Rainfall Factors "a" and "b" for the Modified Rational Method (1-year through 100-year return periods)

City		Return Interval						
		1	2	5	10	25	50	100
Albany	a	126.72	159.17	198.14	230.00	271.84	305.29	341.98
	b	16.02	19.72	22.52	24.49	26.00	26.97	28.23
Atlanta	a	97.05	123.19	157.99	184.23	219.21	249.86	278.71
	b	12.88	15.91	18.44	19.96	21.13	22.28	23.01
Athens	a	106.01	126.29	162.23	187.80	224.41	253.05	281.69
	b	15.41	16.95	19.57	20.87	22.19	22.99	23.68
Augusta	a	119.32	142.78	171.04	192.10	221.48	247.98	271.24
	b	17.05	19.12	20.34	20.96	21.40	22.10	22.32
Bainbridge	a	128.79	171.90	215.02	245.38	291.64	329.59	367.38
	b	16.39	21.13	24.33	25.87	27.73	29.12	30.26
Brunswick	a	177.81	191.06	233.75	266.24	314.79	352.59	367.38
	b	26.30	24.13	27.51	29.49	31.77	33.16	34.22
Columbus	a	113.09	142.00	177.92	205.63	246.52	273.92	306.45
	b	15.67	17.87	20.34	21.88	23.63	24.11	25.13
Macon	a	111.40	139.06	176.78	203.43	242.56	272.93	306.45
	b	15.48	17.68	20.55	21.94	23.47	24.38	25.59
Metro Chattanooga	a	93.15	116.20	148.58	171.22	201.95	227.07	254.06
	b	14.25	15.97	18.00	18.91	19.60	20.12	20.84
Peachtree City	a	101.63	125.43	160.73	185.58	219.86	250.95	277.86
	b	13.72	15.94	18.64	19.91	21.02	22.25	22.81
Rome	a	88.91	120.41	159.75	188.99	229.97	264.15	292.64
	b	12.10	16.05	19.06	20.82	22.51	23.81	24.21
Roswell	a	93.33	126.28	159.12	182.23	219.74	246.68	273.06
	b	12.28	16.92	19.00	19.96	21.54	22.17	22.67
Savannah	a	135.97	178.06	230.29	266.68	325.90	373.89	418.97
	b	19.41	23.22	28.28	30.80	34.41	36.82	38.60
Toccoa	a	114.77	124.54	164.15	192.50	234.48	266.57	299.01
	b	19.58	17.40	20.33	21.85	23.67	24.65	25.51
Valdosta	a	132.93	165.35	203.32	229.47	269.41	301.00	333.57
	b	16.72	19.94	22.63	23.79	25.20	26.10	26.98
Vidalia	a	120.40	161.23	201.42	230.71	272.84	310.23	343.58
	b	15.00	20.17	23.69	25.24	26.80	28.32	29.15

3.4 Outlet Structures

3.4.1 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual, the symbols listed in **Table 3.4.1-1** will be used. These symbols were selected because of their wide use in technical publications.

In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equations.

Table 3.4.1-1 Symbols and Definitions

Symbol	Definition	Units
A, a	Cross sectional or surface area	ft^2
A_m	Drainage area	mi^2
D	Breadth of weir	ft
C	Weir coefficient	-
d	Change in elevation	ft
D	Depth of basin or diameter of pipe	ft
g	Acceleration due to gravity	ft/s^2
H	Head on structure	ft
H_c	Height of weir crest above channel bottom	ft
K, k	Coefficient	-
L	Length	ft
n	Manning's n	-
Q, q	Peak inflow or outflow	cfs, in
V_u	Approach velocity	ft/s
WQ_v	Water quality volume	ac-ft
w	Maximum cross sectional bar width facing the flow	in
x	Minimum clear spacing between bars	in
Θ	Angle of v-notch	degrees
$Θ_g$	Angle of the grate with respect to the horizontal	degrees

3.4.2 Primary Outlets

3.4.2.1 INTRODUCTION

Primary outlets provide the critical function of the regulation of flow for structural stormwater controls. There are several different types of outlets that may consist of a single stage outlet structure, or several outlet structures combined to provide multi-stage outlet control.

For a single stage system, the stormwater facility can be designed as a simple pipe or culvert. For multistage control structures, the inlet is designed considering a range of design flows.

A stage-discharge curve is developed for the full range of flows that the structure would experience. The outlets are housed in a riser structure connected to a single outlet conduit. An alternative approach would be to provide several pipe or culvert outlets at different levels in the basin that are either discharged separately or are combined to discharge at a single location.

This section provides an overview of outlet structure hydraulics and design for stormwater storage facilities. The design engineer is referred to an appropriate hydraulics text for additional information on outlet structures not contained in this section.

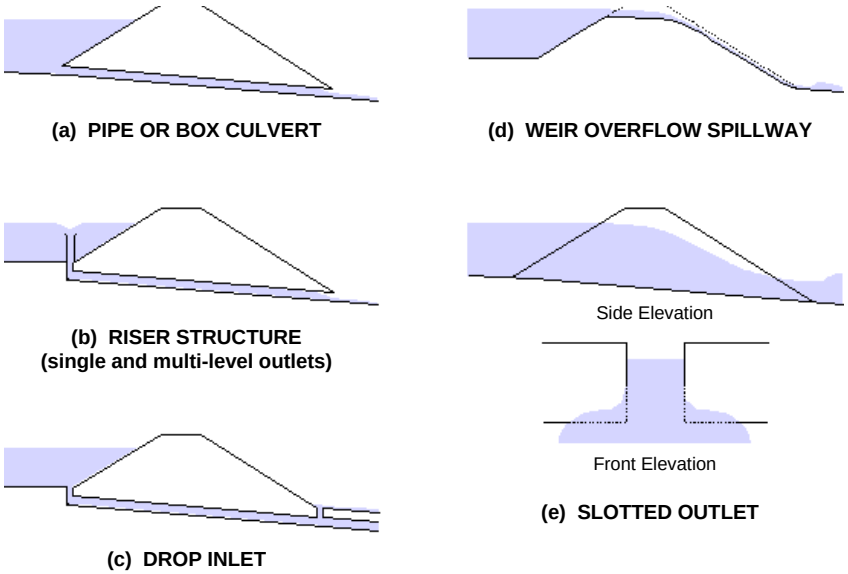


Figure 3.4.2-1 Typical Primary Outlets

3.4.2.2 OUTLET STRUCTURE TYPES

There are a wide variety of outlet structure types, the most common of which are covered in this section. Descriptions and equations are provided for the following outlet types for use in stormwater facility design:

- Orifices
- Perforated risers
- Pipes / Culverts
- Sharp-crested weirs
- Broad-crested weirs
- V-notch weirs
- Proportional weirs
- Combination outlets

Each of these outlet types has a different design purpose and application:

- Water quality and channel protection flows are normally handled with smaller, more protected outlet structures such as reverse slope pipes, hooded orifices, orifices located within screened pipes or risers, perforated plates or risers, and V-notch weirs.
- Larger flows, such as overbank protection and extreme flood flows, are typically handled through a riser with different sized openings, through an overflow at the top of a riser (drop inlet structure), or a flow over a broad crested weir or spillway through the embankment. Overflow weirs can also be of different heights and configurations to handle control of multiple design flows.

3.4.2.3 ORIFICES

An orifice is a circular or rectangular opening of a prescribed shape and size. The flow rate depends on the height of the water above the opening and the size and edge treatment of the orifice.

For a single orifice, as illustrated in **Figure 3.4.2-2(a)**, the orifice discharge can be determined using the standard orifice equation below.

$$Q = CA\,(2gH)^{0.5} \qquad (3.4.1)$$

Where:

Q = the orifice flow discharge (cfs)
C = discharge coefficient
A = cross-sectional area of orifice or pipe (ft^2)
g = acceleration due to gravity (32.2 ft/s^2)
D = diameter of orifice or pipe (ft)
H = effective head on the orifice, from orifice center to the water surface

If the orifice discharges as a free outfall, then the effective head is measured from the center of the orifice to the upstream (headwater) surface elevation. If the orifice discharge is submerged, then the effective head is the difference in elevation of the headwater and tailwater surfaces as shown in **Figure 3.4.2-2(b).**

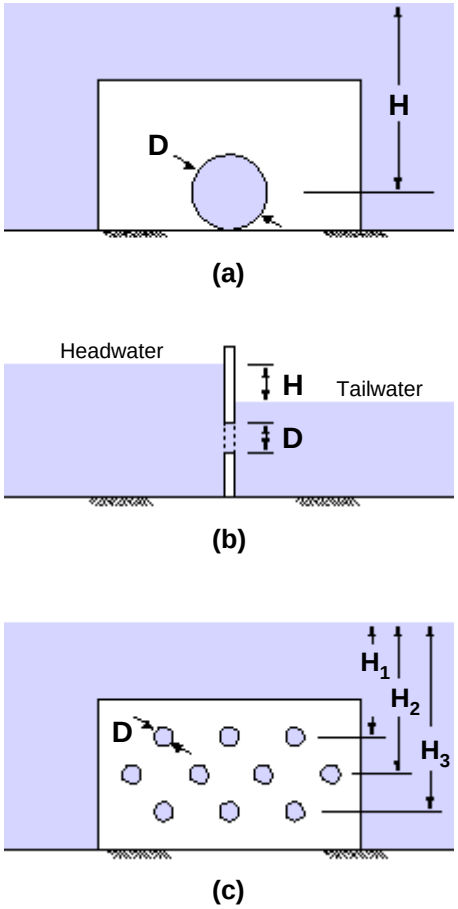


Figure 3.4.2-2 Orifice Definition

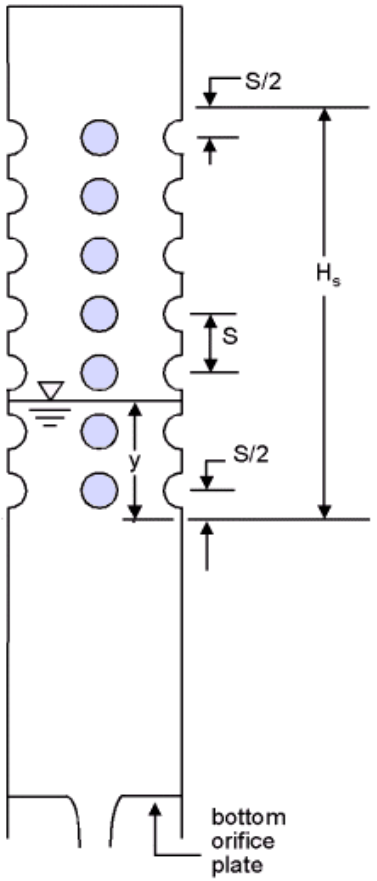


Figure 3.4.2-3 Perforated Riser

When the material is thinner than the orifice diameter, with sharp edges, a coefficient of 0.6 should be used. For square-edged entrance conditions the generic orifice equation can be simplified:

$$Q = 0.6A\,(2gH)^{0.5} = 3.78D^2H^{0.5} \quad (3.4.2)$$

When the material is thicker than the orifice diameter a coefficient of 0.80 should be used. If the edges are rounded, a coefficient of 0.92 can be used.

Flow through multiple orifices, such as the perforated plate shown in **Figure 3.4.2-2(c)**, can be computed by summing the flow through individual orifices. For multiple orifices of the same size and under the influence of the same effective head, the total flow can be determined by multiplying the discharge for a single orifice by the number of openings.

Perforated orifice plates for the control of discharge can be of any size and configuration. However, the Denver Urban Drainage and Flood Control District has developed standardized dimensions that have worked well. **Table 3.4.2-1** gives appropriate dimensions. The vertical spacing between hole centerlines is always 4 inches.

For rectangular slots the height is normally 2 inches with variable width. Only one column of rectangular slots is allowed.

Table 3.4.2-1 Circular Perforation Sizing

Hole Diameter (in)	Minimum Column Hole Centerline Spacing (in)	Flow Area per Row (in²)		
		1 column	2 columns	3 columns
1/4	1	0.05	0.1	0.15
5/16	2	0.08	0.15	0.23
3/8	2	0.11	0.22	0.33
7/16	2	0.15	0.3	0.45
1/2	2	0.2	0.4	0.6
9/16	3	0.25	0.5	0.75
5/8	3	0.31	0.62	0.93
11/16	3	0.37	0.74	1.11
3/4	3	0.44	0.88	1.32
13/16	3	0.52	1.04	1.56
7/8	3	0.6	1.2	1.8
15/16	3	0.69	1.38	2.07
1	4	0.79	1.58	2.37
1 1/16	4	0.89	1.78	2.67
1 1/8	4	0.99	1.98	2.97
1 3/16	4	1.11	2.22	3.33
1 1/4	4	1.23	2.46	3.69
1 5/16	4	1.35	2.7	4.05
1 3/8	4	1.48	2.96	4.44
1 7/16	4	1.62	3.24	4.86
1 1/2	4	1.77	3.54	5.31
1 9/16	4	1.92	3.84	5.76
1 5/8	4	2.07	4.14	6.21
1 11/16	4	2.24	4.48	6.72
1 3/4	4	2.41	4.82	7.23
1 13/16	4	2.58	5.16	7.74
1 7/8	4	2.76	5.52	8.28
1 15/16	4	2.95	5.9	8.85
2	4	3.14	6.28	9.42
Number of columns refers to parallel columns of holes				
Minimum steel plate thickness		1/4"	5/16"	3/8"

Source: Urban Drainage and Flood Control District, Denver, CO

Figure 3.4.2-4 provides a schematic of an orifice plate outlet structure for a wet ED pond showing the design pool elevations and the flow control mechanisms.

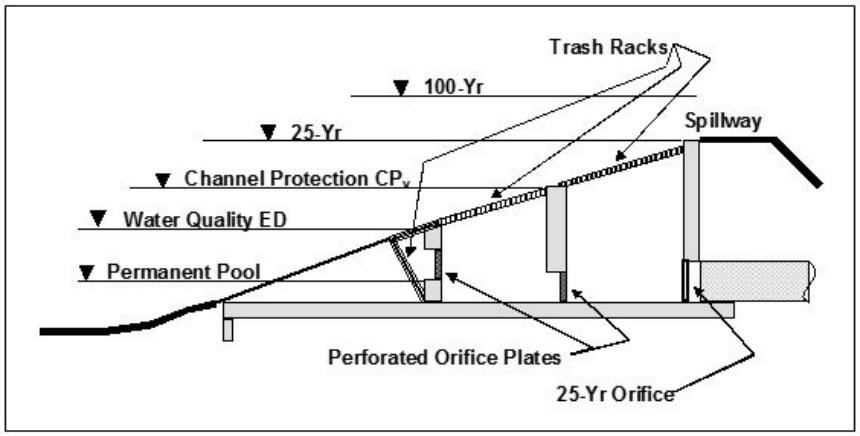


Figure 3.4.2-4 Schematic of Orifice Plate Outlet Structure

3.4.2.4 PERFORATED RISERS

A special kind of orifice flow is a perforated riser as illustrated in **Figure 3.4.2-3**. In the perforated riser, an orifice plate at the bottom of the riser, or in the outlet pipe just downstream from the elbow at the bottom of the riser, controls the flow. It is important that the perforations in the riser convey more flow than the orifice plate so as not to become the control.

Referring to Figure 3.4.2-3, a shortcut formula has been developed to estimate the total flow capacity of the perforated section (McEnroe, 1988):

$$Q = C_p \frac{2A_p}{3H_s}\sqrt{2g}H^{3/2} \qquad (3.4.3)$$

Where:

Q = discharge (cfs)
C_p = discharge coefficient for perforations (normally 0.61)
A_p = cross-sectional area of all the holes (ft^2)
H_s = distance from S/2 below the lowest row of holes to S/2 above the top row (ft)

3.4.2.5 PIPES AND CULVERTS

Discharge pipes are often used as outlet structures for stormwater control facilities. The design of these pipes can be for either single or multi-stage discharges. A reverse-slope underwater pipe is often used for water quality or channel protection outlets.

Pipes smaller than 12 inches in diameter may be analyzed as a submerged orifice as long as H/D is greater than 1.5. *Note: For low flow conditions when the flow reaches and begins to overflow the pipe, weir flow controls (see Subsection 3.4.2.6). As the stage increases the flow will transition to orifice flow.*

Pipes greater than 12 inches in diameter should be analyzed as a discharge pipe with headwater and tailwater effects taken into account. The outlet hydraulics for pipe flow can be determined from the outlet control culvert nomographs and procedures given in Section 5.3, *Culvert Design*, or by using **Equation 3.4.4** (NRCS, 1984).

The following equation is a general pipe flow equation that is derived through the use of the Bernoulli and continuity principles.

$$Q = a[(2gH) / (1 + k_m + k_pL)]0.5 \qquad (3.4.4)$$

Where:

Q = discharge (cfs)
a = pipe cross sectional area (ft^2)
g = acceleration of gravity (ft/s^2)
H = elevation head differential (ft)
k_m = coefficient of minor losses (use 1.0)
k_p = pipe friction coefficient = $5087n^2/D^{4/3}$
L = pipe length (ft)

3.4.2.6 SHARP-CRESTED WEIRS

If the overflow portion of a weir has a sharp, thin leading edge such that the water springs clear as it overflows, the overflow is termed a sharp-crested weir. If the sides of the weir also cause the through flow to contract, it is termed an end-contracted sharp-crested weir. Sharp-crested weirs have stable stage-discharge relations and are often used as a measurement device. A sharp-crested weir with no end contractions is illustrated in **Figure 3.4.2-5(a)**. The discharge equation for this configuration is (Chow, 1959):

$$Q = [(3.27 + 0.4(H/H_c)] \, LH^{1.5} \qquad (3.4.5)$$

Where:

Q = discharge (cfs)
H = head above weir crest excluding velocity head (ft)
$\mathbf{H_c}$ = height of weir crest above channel bottom (ft)
L = horizontal weir length (ft)

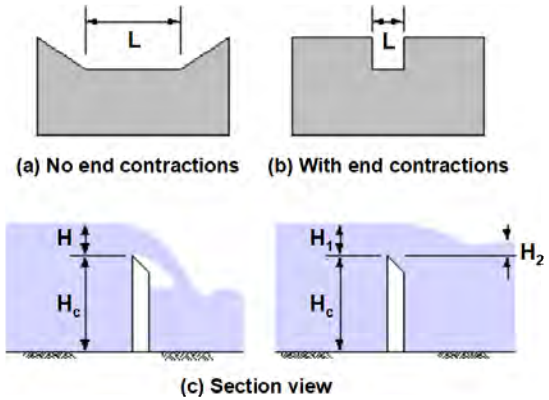


Figure 3.4.2-5 Sharp-Crested Weir

A sharp-crested weir with two end contractions is illustrated in **Figure 3.4.2-5(b)**. The discharge equation for this configuration is (Chow, 1959):

$$Q = [(3.27 + 0.04(H/H_c)] \, (L - 0.2H) \, H^{1.5} \qquad (3.4.6)$$

Where:

Q = discharge (cfs)
H = head above weir crest excluding velocity head (ft)
$\mathbf{H_c}$ = height of weir crest above channel bottom (ft)
L = horizontal weir length (ft)

A sharp-crested weir will be affected by submergence when the tailwater rises above the weir crest elevation. The result will be that the discharge over the weir will be reduced. The discharge equation for a sharp-crested submerged weir is (Brater and King, 1976):

$$Q_S = Q_f \, (1 - (H_2/H_1)^{1.5})^{0.385} \qquad (3.4.7)$$

Where:

$\mathbf{Q_S}$ = submergence flow (cfs)
$\mathbf{Q_f}$ = free flow (cfs)
$\mathbf{H_1}$ = upstream head above crest (ft)
$\mathbf{H_2}$ = downstream head above crest (ft)

3.4.2.7 BROAD-CRESTED WEIRS

A weir in the form of a relatively long raised channel control crest section is a broad-crested weir. The flow control section can have different shapes, such as triangular or circular. True broad-crested weir flow occurs when upstream head above the crest is between the limits of about 1/20 and 1/2 the crest length in the direction of flow. For example, a thick wall or a flat stop log can act like a sharp-crested weir when the approach head is large enough that the flow springs from the upstream corner. If upstream head is small enough relative to the top profile length, the stop log can act like a broad-crested weir (USBR, 1997).

The equation for the broad-crested weir is (Brater and King, 1976):

$$Q = CLH^{1.5} \qquad (3.4.8)$$

Where:

Q = discharge (cfs)
C = broad-crested weir coefficient
L = broad-crested weir length perpendicular to flow (ft)
H = head above weir crest (ft)

If the upstream edge of a broad-crested weir is so rounded as to prevent contraction and if the slope of the crest is as great as the loss of head due to friction, flow will pass through critical depth at the weir crest; this gives the maximum C value of 3.087. For sharp corners on the broad-crested weir, a minimum C value of 2.6 should be used. Information on C values as a function of weir crest breadth and head is given in **Table 3.4.2-2**.

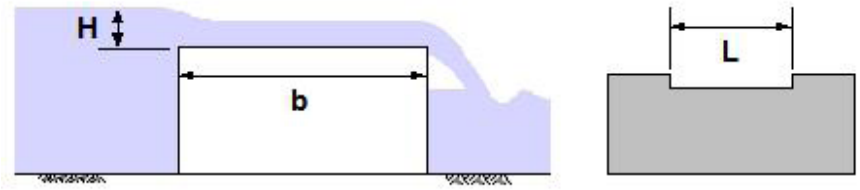


Figure 3.4.2-6 Broad-Crested Weir

Table 3.4.2-2 Broad-Crested Weir Coefficient (C) Values

Measured Head (H)*	Weir Crest Breadth (b) in feet										
In feet	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.27	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

* Measured at least 2.5H upstream of the weir.

Source: Brater and King (1976)

3.4.2.8 V-NOTCH WEIRS

The discharge through a V-notch weir (**Figure 3.4.2-7**) can be calculated from the following equation (Brater and King, 1976).

$$Q = 2.5 \tan (\theta/2) H^{2.5} \qquad (3.4.9)$$

Where:

Q = discharge (cfs)
θ = angle of V-notch (degrees)
H = head on apex of notch (ft)

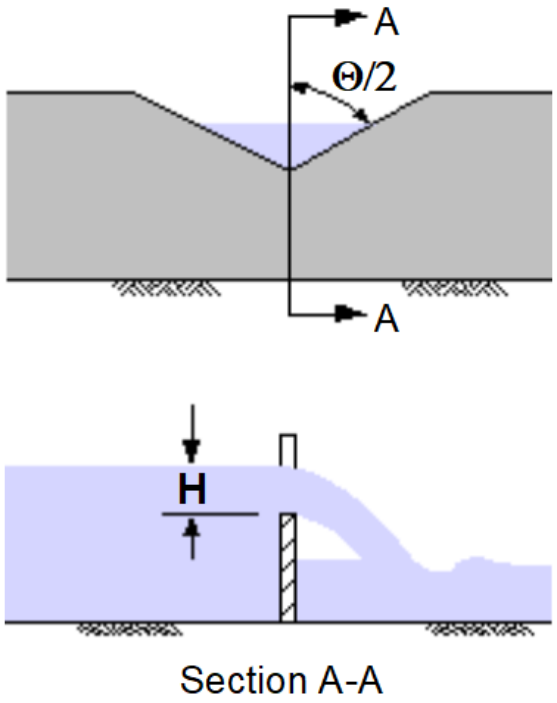


Figure 3.4.2-7 V-Notch Weir

3.4.2.9 PROPORTIONAL WEIRS

Although more complex to design and construct, a proportional weir may significantly reduce the required storage volume for a given site. The proportional weir is distinguished from other control devices by having a linear head-discharge relationship achieved by allowing the discharge area to vary nonlinearly with head. A typical proportional weir is shown in **Figure 3.4.2-8**. Design equations for proportional weirs are (Sandvik, 1985):

$$Q = 4.97 a^{0.5} b (H - a/3) \qquad (3.4.10)$$

$$x/b = 1 - (1/3.17) (\arctan (y/a)^{0.5}) \qquad (3.4.11)$$

Where:

Q = discharge (cfs)
Dimensions a, b, H, x, and y are shown in **Figure 3.4.2-8**

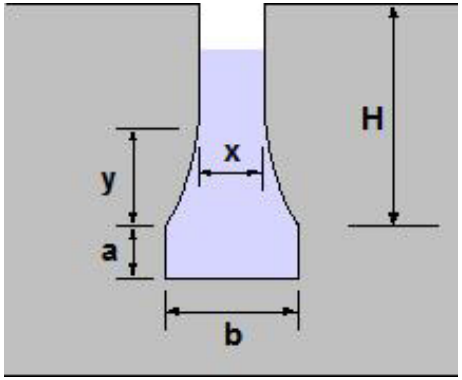


Figure 3.4.2-8 Proportional Weir Dimensions

3.4.2.10 COMBINATION OUTLETS

Combinations of orifices, weirs and pipes can be used to provide multi-stage outlet control for different control volumes within a storage facility (i.e., water quality volume, channel protection volume, overbank flood protection volume, and/or extreme flood protection volume).

They are generally of two types of combination outlets: shared outlet control structures and separate outlet controls. Shared outlet control is typically a number of individual outlet openings (orifices), weirs or drops at different elevations on a riser pipe or box which all flow to a common larger conduit or pipe. **Figure 3.4.2-9** shows an example of a riser designed for a wet ED pond. The orifice plate outlet structure in **Figure 3.4.2-4** is another example of a combination outlet.

Separate outlet controls are less common and may consist of several pipe or culvert outlets at different levels in the storage facility that are either discharged separately or are combined to discharge at a single location.

The use of a combination outlet requires the construction of a composite stage-discharge curve (as shown in **Figure 3.4.2-10**) suitable for control of multiple storm flows. The design of multi-stage combination outlets is discussed later in this section.

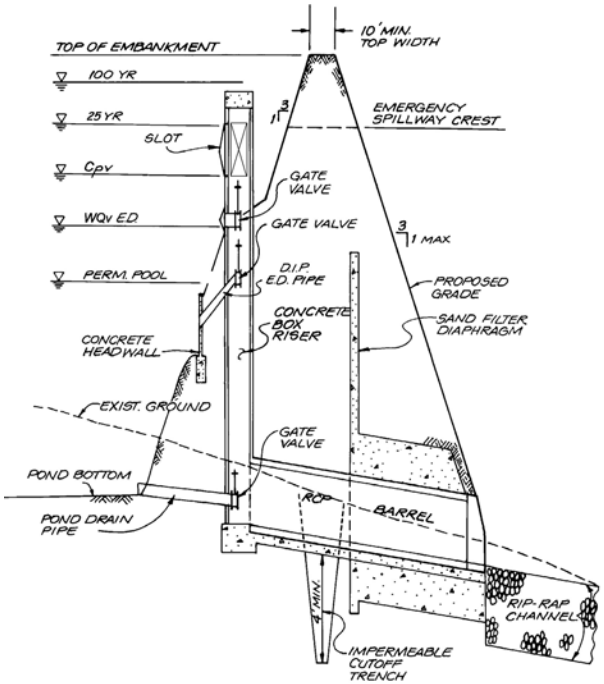


Figure 3.4.2-9 Schematic of Combination Outlet Structure

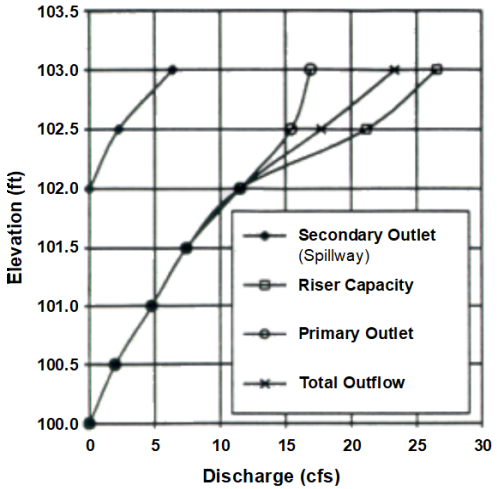


Figure 3.4.2-10 Composite Stage-Discharge Curve

3.4.3 Extended Detention (Water Quality and Channel Protection) Outlet Design

3.4.3.1 INTRODUCTION

Extended detention orifice sizing is required in design applications that provide extended detention for downstream channel protection or the ED portion of the water quality volume. In both cases an extended detention orifice or reverse slope pipe can be used for the outlet. For a structural control facility providing both WQ_v extended detention and CP_v control (wet ED pond, micropool ED pond, and shallow ED wetland), there will be a need to design two outlet orifices – one for the water quality control outlet and one for the channel protection

(The following procedures are based on the water quality outlet design procedures included in the Virginia Stormwater Management Handbook, 1999)

The outlet hydraulics for peak control design (overbank flood protection and extreme flood protection) is usually straightforward in that an outlet is selected that will limit the peak flow to some predetermined maximum. Since volume and the time required for water to exit the storage facility are not usually considered, the outlet design can easily be calculated and routing procedures used to determine if quantity design criteria are met.

In an extended detention facility for water quality treatment or downstream channel protection, however, the storage volume is detained and released over a specified amount of time (e.g., 24-hours). The release period is a brim drawdown time, beginning at the time of peak storage of the water quality volume until the entire calculated volume drains out of the basin. This assumes that the brim volume is present in the basin prior to any discharge. In reality, however, water is flowing out of the basin prior to the full or brim volume being reached. Therefore, the extended detention outlet can be sized using either of the following methods:

1. Use the maximum hydraulic head associated with the storage volume and maximum flow, and calculate the orifice size needed to achieve the required drawdown time, and route the volume through the basin to verify the actual storage volume used and the drawdown time.
2. Approximate the orifice size using the average hydraulic head associated with the storage volume and the required drawdown time.

These two procedures are outlined in the examples below and can be used to size an extended detention orifice for water quality and/or channel protection.

3.4.3.2 METHOD 1: MAXIMUM HYDRAULIC HEAD WITH ROUTING

A wet ED pond sized for the required water quality volume will be used here to illustrate the sizing procedure for an extended-detention orifice.

Given the following information, calculate the required orifice size for water quality design.

Given: Water Quality Volume (WQ_v) = 0.76 ac ft = 33,106 ft^3
Maximum Hydraulic Head (H_{max}) = 5.0 ft (from stage vs. storage data)

(Step 1) Determine the maximum discharge resulting from the 24-hour drawdown requirement. It is calculated by dividing the Water Quality Volume (or Channel Protection Volume) by the required time to find the average discharge, and then multiplying by two to obtain the maximum discharge.

Q_{avg} = 33,106 ft^3 / (24 hr)(3,600 s/hr) = 0.38 cfs
$Q_{max} = 2 * Q_{avg} = 2 * 0.38 = 0.76$ cfs

(Step 2) Determine the required orifice diameter by using the orifice **Equation (3.4.8)** and Q_{max} and H_{max}:

$Q = CA(2gH)^{0.5}$, or $A = Q / C(2gH)^{0.5}$
$A = 0.76 / 0.6[(2)(32.2)(5.0)]^{0.5} = 0.071$ ft^3

Determine pipe diameter from
$A = 3.14d^2/4$, then $d = (4A/3.14)^{0.5}$
$D = [4(0.071)/3.14]^{0.5} = 0.30$ ft = 3.61 in

Use a 3.6-inch diameter water quality orifice.

Routing the water quality volume of 0.76 ac ft through the 3.6-inch water quality orifice will allow the designer to verify the drawdown time, as well as the maximum hydraulic head elevation. The routing effect will result in the actual drawdown time being less than the calculated 24 hours. Judgment should be used to determine whether the orifice size should be reduced to achieve the required 24 hours or if the actual time achieved will provide adequate pollutant removal.

3.4.3.3 METHOD 2: AVERAGE HYDRAULIC HEAD AND AVERAGE DISCHARGE

Using the data from the previous example (3.4.3.2) use Method 2 to calculate the size of the outlet orifice.

Given: Water Quality Volume (WQ_v) = 0.76 ac ft = 33,106 ft^3
Average Hydraulic Head (h_{avg}) = 2.5 ft (from stage vs storage data)

(Step 1) Determine the average release rate to release the water quality volume over a 24-hour time period.

Q = 33,106 ft^3 / (24 hr)(3,600 s/hr) = 0.38 cfs

(Step 2) Determine the required orifice diameter by using the orifice **Equation (3.4.8)** and the average head on the orifice:

$Q = CA(2gH)^{0.5}$, or $A = Q / C(2gH)^{0.5}$
$A = 0.38 / 0.6[(2)(32.2)(2.5)]^{0.5} = 0.05$ ft^3

Determine pipe diameter from
$A = 3.14r^2 = 3.14d^2/4$, then $d = (4A/3.14)^{0.5}$
$D = [4(0.05)/3.14]^{0.5} = 0.252$ ft = 3.03 in

Use a 3-inch diameter water quality orifice.

Use of Method 1, utilizing the maximum hydraulic head and discharge and routing, results in a 3.6-inch diameter orifice (though actual routing may result in a changed orifice size) and Method 2, utilizing average hydraulic head and average discharge, results in a 3.0-inch diameter orifice.

3.4.4 Multi-Stage Outlet Design

3.4.4.1 INTRODUCTION

A combination outlet such as a multiple orifice plate system or multi-stage riser is often used to provide adequate hydraulic outlet controls for the different design requirements (e.g., water quality, channel protection, overbank flood protection, and/or extreme flood protection) for stormwater ponds, stormwater wetlands and detention-only facilities. Separate openings or devices at different elevations are used to control the rate of discharge from a facility during multiple design storms. As discussed in the previous section, **Figures 3.4.2-4** and **3.4.2-9** are examples of multi-stage combination outlet systems.

A design engineer may be creative to provide the most economical and hydraulically efficient outlet design possible in designing a multi-stage outlet. Many iterative routings are usually required to arrive at a minimum structure size and storage volume that provides proper control. The stage-discharge table or rating curve is a composite of the different outlets that are used for different elevations within the multi-stage riser (see **Figure 3.4.2-10**).

3.4.4.2 MULTI-STAGE OUTLET DESIGN PROCEDURE

Below are the steps for designing a multi-stage outlet. Note that if a structural control facility will not control one or more of the required storage volumes (WQ_v, CP_v, $Q_{p25,}$ and Q_f), then that step in the procedure is skipped

(Step 1) **Determine Stormwater Control Volumes.**
Using the procedures from Sections 3.1 and 3.3, estimate the required storage volumes for water quality treatment (WQ_v), channel protection (CP_v), and overbank flood control (Q_{p25}) and extreme flood control (Q_f).

(Step 2) **Develop Stage-Storage Curve.**
Using the site geometry and topography, develop the stage-storage curve for the facility in order to provide sufficient storage for the control volumes involved in the design.

(Step 3) **Design Water Quality Outlet.**
Design the water quality extended detention (WQv-ED) orifice using either Method 1 or Method 2 outlined in Subsection 3.4.3. If a permanent pool is incorporated into the design of the facility, a portion of the storage volume for water quality will be above the elevation of the permanent pool. The outlet can be protected using either a reverse slope pipe, a hooded protection device, or another acceptable method (see Subsection 3.4.5).

(Step 4) **Design Channel Protection Outlet.**
Design the stream channel protection extended detention outlet (CP_v-ED) using either method from Subsection 3.4.3. For this design, the storage needed for channel protection will be "stacked" on top of the water quality volume storage elevation determined in Step 3. The total stage-discharge rating curve at this point will include water quality control orifice and the outlet used for stream channel protection. The outlet should be protected in a manner similar to that for the water quality orifice.

(Step 5) **Design Overbank Flood Protection Outlet.**
The overbank protection volume is added above the water quality and channel protection storage. Establish the Q_{p25} maximum water surface elevation using the stage-storage curve and subtract the CP_v elevation to find the 25-year maximum head. Select an outlet type and calculate the initial size and geometry based upon maintaining the predevelopment 2-25-year peak discharge rate. Note that multiple weirs/orifices may be needed to control the different storms Develop a stage-discharge curve for the combined set of outlets (WQ_v, CP_v and Q_{p25}).

This procedure is repeated for control (peak flow attenuation) of the 100-year storm (Q_f), if required.

(Step 6) **Check Performance of the Outlet Structure.**
Perform a hydraulic analysis of the multi-stage outlet structure using reservoir routing to ensure that all outlets will function as designed. Several iterations may be required to calibrate and optimize the hydraulics and outlets that are used. Also, the structure should operate without excessive surging, noise, vibration, or vortex action at any stage. This usually requires that the structure have a larger cross-sectional area than the outlet conduit.

The hydraulic analysis of the design must take into account the hydraulic changes that will occur as depth of storage changes for the different design storms. As shown in **Figure 3.4.4-1**, as the water passes over the rim of a riser, the riser acts as a weir. However, when the water surface reaches a certain height over the rim of a riser, the riser will begin to act as a submerged orifice. The designer must compute the elevation at which this transition from riser weir flow control to riser orifice flow control takes place for an outlet where this change in hydraulic conditions will change. Also note in **Figure 3.4.4-1** that as the elevation of the water increases further, the control can change from barrel inlet flow control to barrel pipe flow control. **Figure 3.4.4-2** shows another condition where weir flow can change to orifice flow, which must be taken into account in the hydraulics of the rating curve as different design conditions results in changing water surface elevations.

(Step 7) **Size the Emergency Spillway.**
It is recommended that all stormwater impoundment structures have a vegetated emergency spillway (see Subsection 3.4.6). An emergency spillway provides a degree of safety to prevent overtopping of an embankment if the primary outlet or principal spillway should become clogged, or otherwise inoperative. The 100-year storm should be routed through the outlet devices and emergency spillway to ensure the hydraulics of the system will operate as designed.

(Step 8) **Design Outlet Protection.**
Design necessary outlet protection and energy dissipation facilities to avoid erosion problems downstream from outlet devices and emergency spillway(s). See Section 5.5, *Energy Dissipation Design*, for more information.

(Step 9) **Perform Buoyancy Calculations.**
Perform buoyancy calculations for the outlet structure and footing. Flotation will occur when the weight of the structure is less than or equal to the buoyant force exerted by the water.

(Step 10) **Provide Seepage Control.**
Seepage control should be provided for the outflow pipe or culvert through an embankment. The two most common devices for controlling seepage are (1) filter and drainage diaphragms and (2) anti-seep collars.

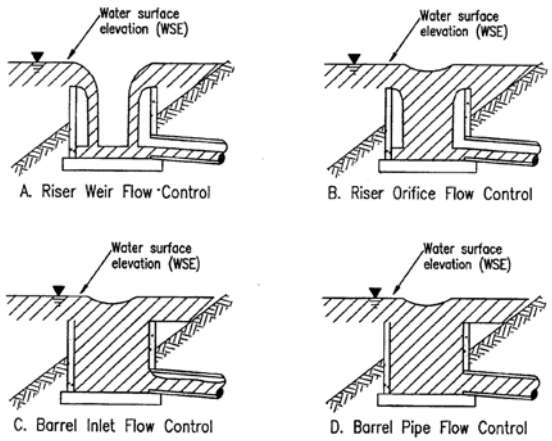


Figure 3.4.4-1 Riser Flow Diagrams
(Source: VDCR, 1999)

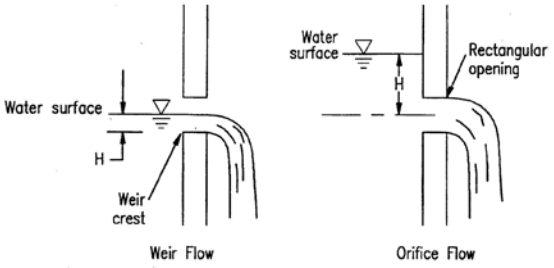


Figure 3.4.4-2 Weir and Orifice Flow
(Source: VDCR, 1999)

- The use of a hooded outlet for a stormwater pond or wetland with a permanent pool (see **Figures 3.4.5-2** and **3.4.5-3**).
- Internal orifice protection through the use of an over-perforated vertical stand pipe with ½-inch orifices or slots that are protected by wirecloth and a stone filtering jacket (see **Figure 3.4.5-4**).
- Internal orifice protection through the use of an adjustable gate valves can to achieve an equivalent orifice diameter.

3.4.5 Extended Detention Outlet Protection

Small, low flow orifices such as those used for extended detention applications can easily clog, preventing the structural control from meeting its design purpose(s) and potentially causing adverse impacts. Therefore, extended detention orifices need to be adequately protected from clogging. There are a number of different anti-clogging designs, including:

- The use of a reverse slope pipe attached to a riser for a stormwater pond or wetland with a permanent pool (see **Figure 3.4.5-1**). The inlet is submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond.

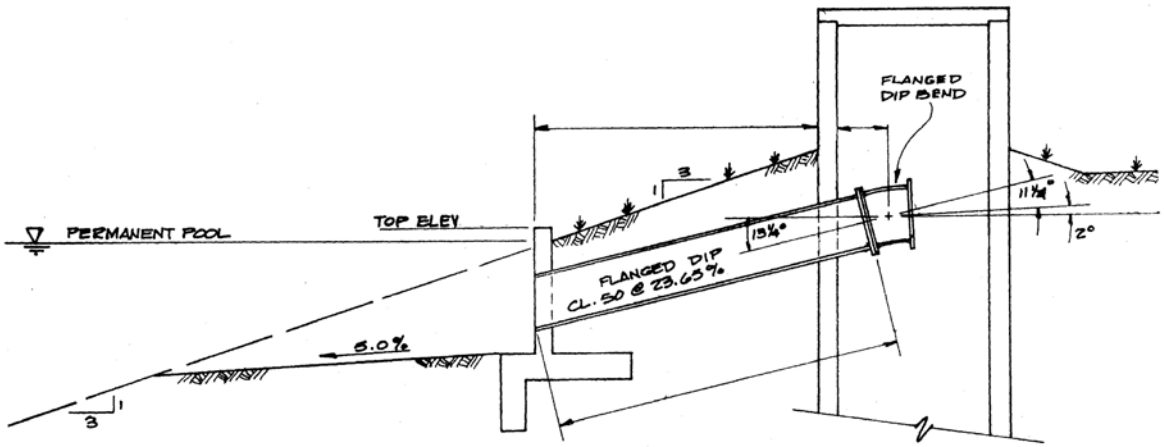


Figure 3.4.5-1 Reverse Slope Pipe Outlet

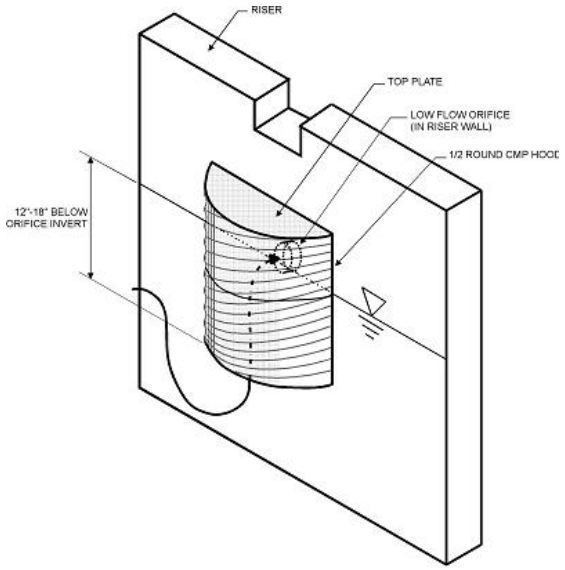


Figure 3.4.5-3 Half-Round CMP Orifice Hood

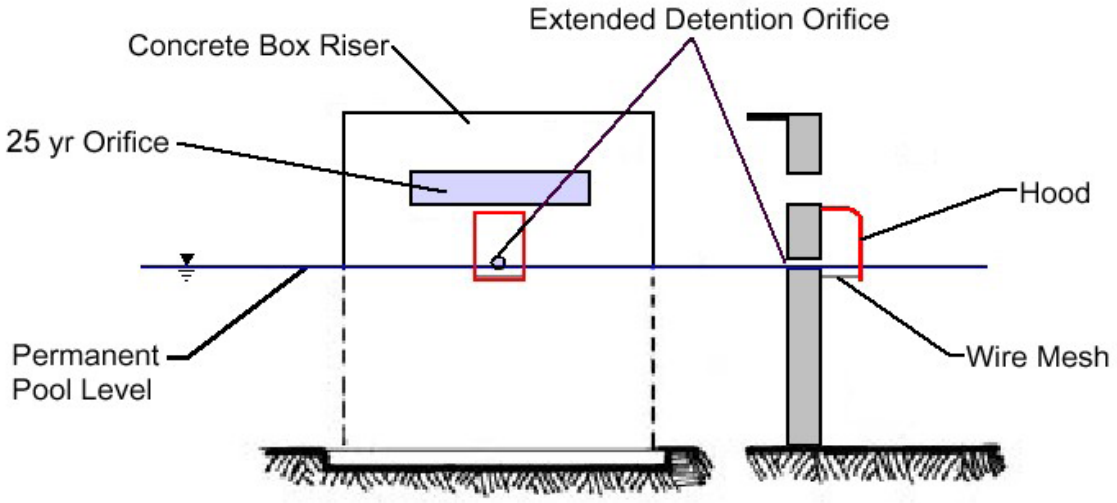


Figure 3.4.5-2 Hooded Outlet

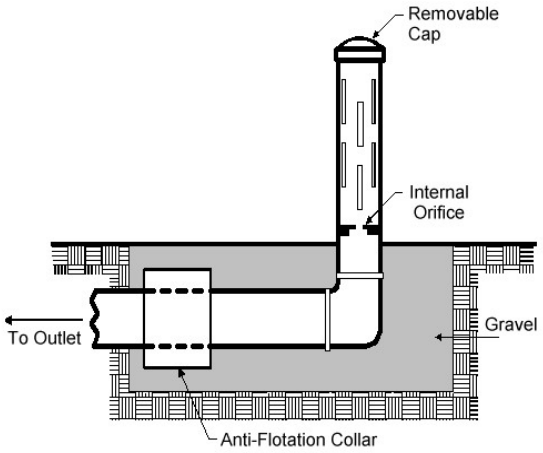


Figure 3.4.5-4 Internal Control for Orifice Protection

3.4.6 Trash Racks and Safety Grates

3.4.6.1 INTRODUCTION

The susceptibility of larger inlets to clogging by debris and trash needs to be considered when estimating their hydraulic capacities. In most instances trash racks will be needed. Trash racks and safety grates are a critical element of outlet structure design and serve several important functions:

- Keeping debris away from the entrance to the outlet works where they will not clog the critical portions of the structure
- Capturing debris in such a way that relatively easy removal is possible
- Ensuring that people and large animals are kept out of confined conveyance and outlet areas
- Providing a safety system that prevents anyone from being drawn into the outlet and allows them to climb to safety

When designed properly, trash racks serve these purposes without interfering significantly with the hydraulic capacity of the outlet (or inlet in the case of conveyance structures) (ASCE, 1985; Allred-Coonrod, 1991). The location and size of the trash rack depends on a number of factors, including head losses through the rack, structural convenience, safety and size of outlet. Well-designed trash racks can also have an aesthetically pleasing appearance.

An example of trash racks used on a riser outlet structure is shown in **Figure 3.4.6-1**. Trash rack design should be based on the effective opening of the trash rack compared to the orifice, or outlet size. The outlet size should be the controlling or smaller open area, when compared to the effective open area of the trash rack.

The inclined vertical bar rack is most effective for lower stage outlets. Debris will ride up the trash rack as water levels rise. This design also allows for removal of accumulated debris with a rake while standing on top of the structure.

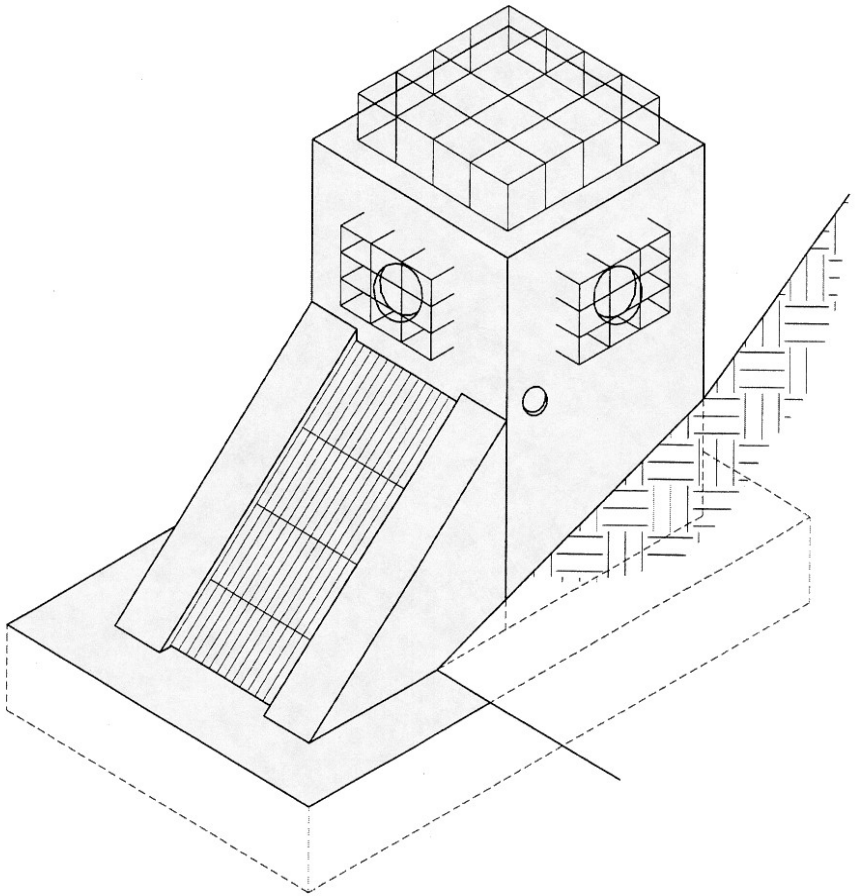


Figure 3.4.6-1 Example of Various Trash Racks Used on a Riser Outlet Structure
(Source: VDCR, 1999)

3.4.6.2 TRASH RACK DESIGN

Trash racks must be large enough such that partial plugging will not adversely restrict flows reaching the control outlet. There are no universal guidelines for the design of trash racks to protect detention basin outlets, although a commonly used "rule-of-thumb" is to have the trash rack area at least ten times larger than the control outlet orifice.

The surface area of all trash racks should be maximized and the trash racks should be located a suitable distance from the protected outlet to avoid interference with the hydraulic capacity of the outlet. The spacing of trash rack bars must be proportioned to the size of the smallest outlet protected. However, where a small orifice is provided, a separate trash rack for that outlet should be used, so that a simpler, sturdier trash rack with more widely spaced members can be used for the other outlets. Spacing of the rack bars should be wide enough to avoid interference, but close enough to provide the level of clogging protection required.

To facilitate removal of accumulated debris and sediment from around the outlet structure, the racks should have hinged connections. If the rack is bolted or set in concrete it will preclude removal of accumulated material and will eventually adversely affect the outlet hydraulics.

Since sediment will tend to accumulate around the lowest stage outlet, the inside of the outlet structure for a dry basin should be depressed below the ground level to minimize clogging due to sedimentation. Depressing the outlet bottom to a depth below the ground surface at least equal to the diameter of the outlet is recommended.

Trash racks at entrances to pipes and conduits should be sloped at about 3H:1V to 5H:1V to allow trash to slide up the rack with flow pressure and rising water level—the slower the approach flow, the flatter the angle. Rack opening rules-of-thumb are found in literature. Figure 3.4.6-2 gives opening estimates based on outlet diameter (UDFCD, 1992). Judgment should be used in that an area with higher debris (e.g., a wooded area) may require more opening space.

The bar opening space for small pipes should be less than the pipe diameter. For larger diameter pipes, openings should be 6 inches or less. Collapsible racks have been used in some places if clogging becomes excessive or a person becomes pinned to the rack.

Alternately, debris for culvert openings can be caught upstream from the opening by using pipes placed in the ground or a chain safety net (USBR, 1978; UDFCD, 1992). Racks can be hinged on top to allow for easy opening and cleaning.

The control for the outlet should not shift to the grate, nor should the grate cause the headwater to rise above planned levels. Therefore head losses through the grate should be calculated. A number of empirical loss equations exist though many have difficult to estimate variables. Two will be given to allow for comparison.

Metcalf & Eddy (1972) give the following equation (based on German experiments) for losses. Grate openings should be calculated assuming a certain percentage blockage as a worst case to determine losses and upstream head. Often 40 to 50% is chosen as a working assumption.

$$H_g = K_{g1} (w/x)^{4/3} (V_u^2/2g) \sin \theta_g \quad (3.4.12)$$

Where:

H_g = head loss through grate (ft)

K_{g1} = bar shape factor:

- 2.42 - sharp edged rectangular
- 1.83 - rectangular bars with semicircular upstream
- 1.79 - circular bars
- 1.67 - rectangular bars with semi-circular up- and downstream faces

w = maximum cross-sectional bar width facing the flow (in)

x = minimum clear spacing between bars (in)

V_u = approach velocity (ft/s)

θ_g = angle of the grate with respect to the horizontal (degrees)

The Corps of Engineers (HDC, 1988) has developed curves for trash racks based on similar and additional tests. These curves are for vertical racks but presumably they can be adjusted, in a manner similar to the previous equation, through multiplication by the sine of the angle of the grate with respect to the horizontal.

$$H_g = \frac{K_{g2} V_u^2}{2g} \qquad (3.4.13)$$

Where K_{g2} is defined from a series of fit curves as:

- Sharp edged rectangular (length/thickness = 10)
  $K_{g2} = 0.00158 - 0.03217\ A_r + 7.1786\ A_r^2$
- Sharp edged rectangular (length/thickness = 5)
  $K_{g2} = -0.00731 + 0.69453\ A_r + 7.0856\ A_r^2$
- Round edged rectangular (length/thickness = 10.9)
  $K_{g2} = -0.00101 + 0.02520\ A_r + 6.0000\ A_r^2$
- Circular cross section
  $K_{g2} = 0.00866 + 0.13589\ A_r + 6.0357\ A_r^2$
- A_r is the ratio of the area of the bars to the area of the grate section.

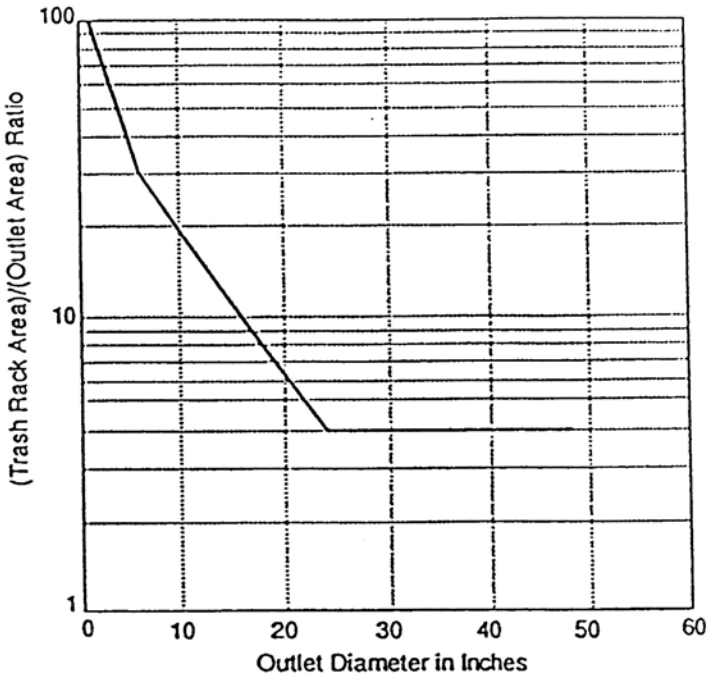


Figure 3.4.6-2 Minimum Rack Size vs. Outlet Diameter
(Source: UDCFD, 1992)

3.4.7 Secondary Outlets

3.4.7.1 INTRODUCTION

The purpose of a secondary outlet (emergency spillway) is to provide a controlled overflow for flows in excess of the maximum design storm for a storage facility. **Figure 3.4.7-1** shows an example of an emergency spillway.

In many cases, on-site stormwater storage facilities do not warrant elaborate studies to determine spillway capacity. While the risk of damage due to failure is a real one, it normally does not approach the catastrophic risk involved in the overtopping or breaching of a major reservoir. By contrast, regional facilities with homes immediately downstream could pose a significant hazard if failure were to occur, in which case emergency spillway considerations are a major design factor.

3.4.7.2 EMERGENCY SPILLWAY DESIGN

Emergency spillway designs are open channels, usually trapezoidal in cross section, and consist of an inlet channel, a control section, and an exit channel (see **Figure 3.4.7-1**). The emergency spillway is proportioned to pass flows in excess of the design flood (typically the 100-year flood or greater) without allowing excessive velocities and without overtopping of the embankment. Flow in the emergency spillway is open channel flow (see Section 5.4, *Open Channel Design*, for more information). Normally, it is assumed that critical depth occurs at the control section.

Every embankment shall be provided with an open channel emergency spillway, unless all of the following apply:

- The principal spillway is a closed conduit having a cross-sectional area that can pass 125 percent of the 100-year storm routed peak discharge.
- The principal spillway is a closed conduit having a cross-sectional area of at least one square foot per each three acres of drainage area.
- The principal spillway capacity is at least equal to the capacity required for an open channel emergency spillway.
- The low point of the dam crest is not in a fill section except for roadway embankments.
- A trash rack or other debris protection is provided on the outlet control.

For normally-dry detention basins, ponds, and lakes, having a dam height of less than 9 feet and which are incapable of impounding more than 20 acre-feet of water, and for which the probable sequences of dam failure are not severe, emergency spillway capacity should be at least equal to the routed 100-year peak flow out of the detention facility assuming the principal spillway is blocked.

For normally-dry detention basins, ponds, and lakes, having a dam height of 9 feet or more and which are capable of impounding 20 acre feet or more of water, emergency spillway capacity should be at least equal to the greater of either the routed 100-year peak flowrate out of the facility assuming the principal spillway is blocked, or the routed one-fourth PMP hydrograph out of the facility. In cases when State or Federal regulations may require greater spillway capacity, those more stringent regulations shall govern.

NRCS (NRCS TR-55) manuals provide guidance for the selection of emergency spillway characteristics for different soil conditions and different types of vegetation. The selection of degree of retardance for a given spillway depends on the vegetation. Knowing the retardance factor and the estimated discharge rate, the emergency spillway bottom width can be determined. For erosion protection during the first year, assume minimum retardance. Both the inlet and exit channels should have a straight alignment and grade. Spillway side slopes should be no steeper the 3:1 horizontal to vertical.

The most common type of emergency spillway used is a broad-crested overflow weir cut through original ground next to the embankment. The transverse cross section of the weir cut is typically trapezoidal in shape for ease of construction. Such an excavated emergency spillway is illustrated to the right.

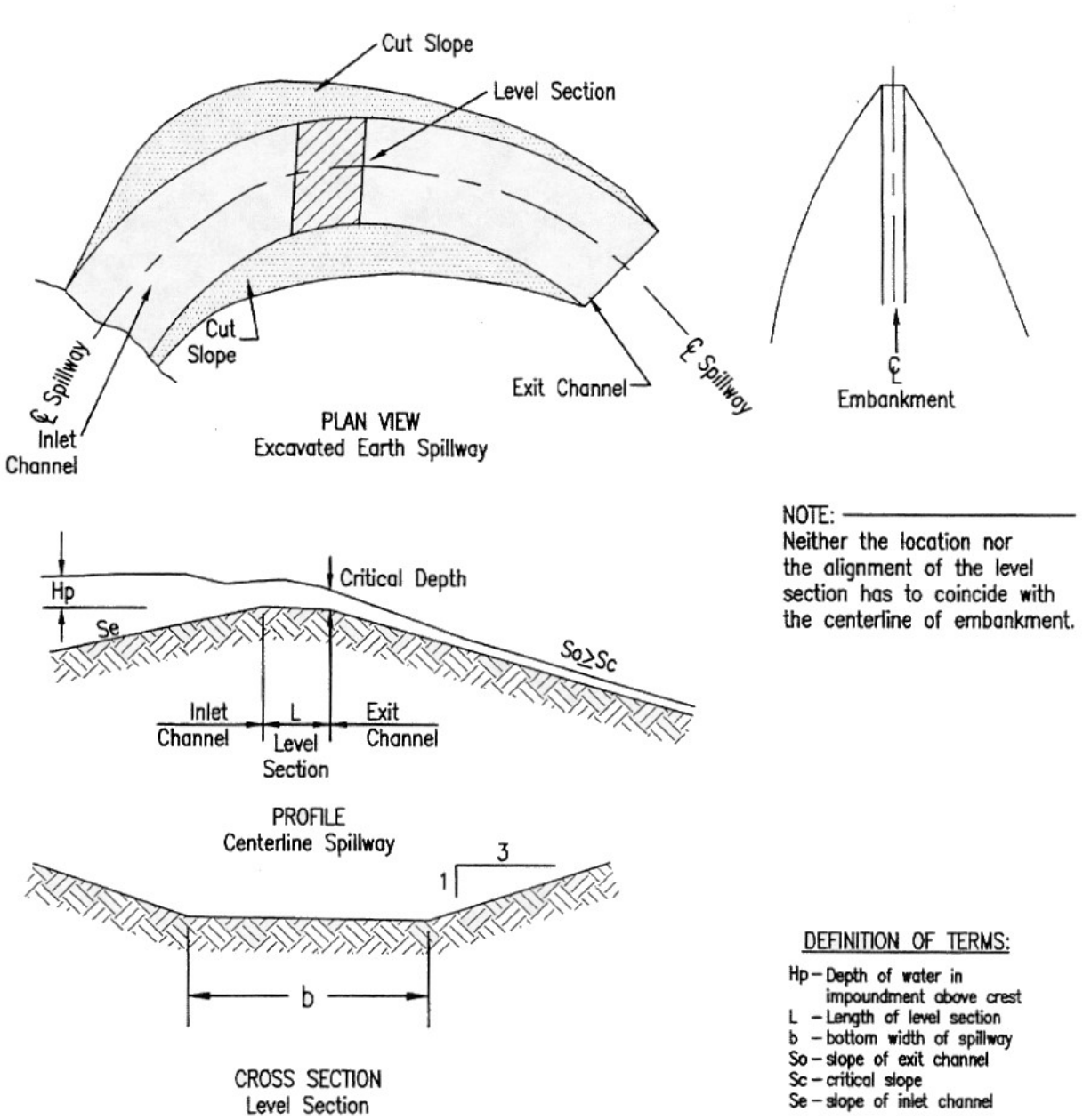


Figure 3.4.7-1 Emergency Spillway
(Source: VDCR, 1999)

References

Battiata, Joseph, Kelly Collins, David Hirschman, and Greg Hoffman. *The Runoff Reduction Method.* Center for Watershed Protection, Mechanicsville, VA.

Brater, Ernist F., Horace W. King. 1976. *Handbook of Hydraulics*. 6th ed. NY: McGraw Hill Book Co.

Chow, C. N. 1959. *Open Channel Hydraulics.* New York: McGraw Hill Book Company.

Debo, Thomas N. and Andrew J. Reese. 1995. *Municipal Stormwater Management*. Lewis Publishers: CRC Press, Inc., Boca Raton, Florida.

Ferguson, Bruce K. and Thomas Neil Debo. 1990. *On-site Stormwater Management.*

Hershfield, David M. 1961. *Rainfall Frequency Atlas of the United States, Technical Paper No. 40.* Engineering Division, Soil Conservation Service U.S. Department of Agriculture. Washington D.C.

Maryland Department of the Environment. 2000. *Maryland Stormwater Design Manual, Volumes I and II.* Center for Watershed Protection (CWP), Ellicott City, MD.

McEnroe, B.M., J.M. Steichen and R.M. Schweiger. 1988. *Hydraulics of Perforated Riser Inlets for Underground Outlet Terraces*. Trans ASAE, Vol. 31, No. 4, 1988.

NOAA. 1997. *Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States, NOAA Technical Memo NWS HYDRO-35.* National Oceanic and Atmospheric Administration (NOAA).

NOAA. 2013. *Atlas 14, Version 9.* National Oceanic and Atmospheric Administration (NOAA).

Pitt, Robert. 1994. *Small Storm Hydrology*. Unpublished report. Department of Civil Engineering, University of Alabama. Birmingham, Alabama.

Sandvik, A. 1985. *Proportional Weirs for Stormwater Pond Outlets*. Civil Engineering, March 1985, ASCE pp. 54-56.

Urban Drainage and Flood Control District. 1999. *Criteria Manual*. Denver, CO.

U.S. Department of Agriculture, Natural Resource Conservation Service, Engineering Division. 2004. *NRCS National Engineering Handbook 630.* Natural Resource Conservation Service (NRCS).

U.S. Department of Agriculture, Natural Resource Conservation Service, Engineering Division. 1986. *Urban Hydrology for Small Watersheds.* Technical Release 55. Natural Resource Conservation Service (NRCS).

U.S. Department of the Interior. 1997. *Water Measurement Manual.* 3rd ed. Bureau of Reclamation. Washington D.C.

U.S. Department of Transportation, Federal Highway Administration. 1984. *Hydrology*. Hydraulic Engineering Circular No. 19.

USGS. 2011. *Flood-frequency Relations for Urban Streams in Georgia*. Water Resources Investigation Report. U.S. Geological Survey.

USGS. 2003. *Techniques for Estimating Magnitude and Frequency of Floods in Rural Basins of Georgia*. Water Resources Investigation Report. U.S. Geological Survey.

Virginia Department of Conservation and Recreation. 1999. *Virginia Stormwater Management Handbook.*

Wycoff, Ronald L. and Udai P. Singh. 1976. *Preliminary Hydrologic Design of Small Flood Detention Reservoirs*. Water Resources Bulletin. Vol. 12, No. 2, pp 337-47.

4. Stormwater Best Management Practices

4.1 Stormwater Best Management Practices Overview

4.1.1 Best Management Practices

4.1.1.1 INTRODUCTION

Stormwater Best Management Practices (BMPs) are engineered facilities designed to reduce and/or treat stormwater runoff, which mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to urbanization. BMPs mitigate increased pollutant loads by trapping a portion of suspended solids and the associated pollutants that are adsorbed thereon and reduce or remove the pollutants through a variety of physical, biological, and chemical functions. This section provides an overview of BMPs that can be used to address the minimum stormwater management standards outlined in Section 2.2.

In terms of the Unified Stormwater Sizing Criteria, a BMP, or treatment train that includes two or more BMPs, shall be designed to meet the following requirements:

- Treat the Water Quality Volume, WQ_v (the runoff generated by first 1.2 inches of rainfall);
- Control the Channel Protection Volume, CP_v (24 hours of extended detention for the one-year, 24-hour rainfall event), where necessary or required;
- Control for Overbank Flood Protection, Q_{p25} (detention of the post-development 25-year, 24-hour storm peak discharge rate to the pre-development rate), where required; and
- Provide for Extreme Flood Protection by either: (1) control of the peak discharge increase from the 100-year, 24-hour storm event, Q_f, through detention; or (2) safely pass Q_f through the structural control and allow it to discharge into a receiving water whose protected floodplain is sufficiently sized to account for extreme flow increases without causing damage.

Localities choosing to adopt the GSMM as a guidance document may have more stringent local requirements for Flood Protection, such as detention of the post-development 50-year, 24-hour storm peak discharge rate to the pre-development rate. These localities may wish to develop their own Technical Reference Sections (or Manual).

4.1.1.2 TYPES OF BEST MANAGEMENT PRACTICES

Table 4.1.1-1 lists many types of BMPs. These BMPs are recommended for use in a wide variety of applications. A detailed discussion of each of the BMPs, as well as design criteria and procedures for each, can be found in Sections 4.2 through 4.29.

Table 4.1.1-1 Best Management Practices

BMP	Description
Bioretention Areas	Bioretention areas are shallow stormwater basins or landscaped areas that utilize engineered soils and vegetation to capture and treat stormwater runoff. Bioretention areas may be designed with an underdrain that returns runoff to the conveyance system or designed without an underdrain to exfiltrate runoff into the soil.
Bioslopes	Bioslopes are linear, non-structural BMPs with a permeable media that allows stormwater runoff to infiltrate and filter through the practice before exiting through an underdrain. Generally, a pre-treatment device, such as filter strip, grass shoulder, or pea gravel diaphragm, is placed upstream of the bioslope to capture sediment and debris.
Downspout Disconnects	A downspout disconnect spreads rooftop runoff from individual downspouts across lawns, vegetated areas, and other pervious areas, where the runoff is slowed, filtered, and can infiltrate into the native soils.
Dry Detention / Dry Extended Detention Basins	Dry detention basins and dry extended detention (ED) basins are surface facilities intended to provide temporary storage of stormwater runoff to reduce downstream water quantity impacts.
Dry Wells	Dry wells are shallow excavations, typically filled with stone, that are designed to intercept and temporarily store post-construction stormwater runoff under the ground surface until it infiltrates into the underlying and surrounding soils. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.
Enhanced Dry or Wet Swales	Enhanced swales are vegetated open channels that are designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other structures.
Grass Channels	Grass channels are vegetated open channels that provide "biofiltering" of stormwater runoff as it flows across the grass surface. Grass channels may reduce time of concentration, thereby potentially reducing peak discharges, especially for smaller storms.
Gravity Oil / Grit Separators	Gravity oil / grit separators are hydrodynamic controls that use the movement of stormwater runoff through a specially-designed structure to remove target pollutants. They are typically used on smaller, impervious, commercial sites and urban hotspots.
Green Roofs	Green roofs represent an alternative to traditional impervious roof surfaces and typically consist of underlying water proofing, drainage systems, and an engineered planting media. Stormwater runoff is captured and temporarily stored in the engineered planting media, where it is subjected to evaporation and transpiration before being conveyed back into the storm drain system. There are two different types of green roof systems. Intensive green roofs have a thick layer of soil, can support a diverse plant community, and may include trees. Extensive green roofs have a much thinner layer of soil that is comprised primarily of drought tolerant vegetation.
Infiltration Practices	An infiltration practice is a shallow excavation, typically filled with stone or an engineered soil mix, which is designed to temporarily hold stormwater runoff until it infiltrates into the surrounding soils. Infiltration practices are able to reduce stormwater quantity, recharge the groundwater, and reduce pollutant loads.
Multi-Purpose Detention Basins	Multi-purpose detention basins are on-site areas used for one or more specific activities, such as parking lots and rooftops, as well as for the temporary storage of runoff.
Organic Filters	Organic filters are surface media filters that use organic materials, such as leaf compost or a peat/sand mixture, as the filter media. Runoff is filtered through the media prior to discharging through an underdrain system. The organic media may be able to provide enhanced removal of some contaminants, such as heavy metals.

Table 4.1.1-1 Best Management Practices (continued)

BMP	Description
Permeable Paver Systems	A permeable paver system is a pavement surface composed of structural units with void areas that are filled with pervious materials such as gravel, sand, or grass turf. The system is installed over a gravel base course that provides structural support and stores stormwater runoff that infiltrates through the system into underlying permeable soils.
Pervious Concrete	Pervious concrete is the term for a mixture of coarse aggregate, portland cement, and water that allows for rapid infiltration of water. The concrete overlays a stone aggregate reservoir that provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an underdrain system.
Porous Asphalt	Porous asphalt is asphalt with large void spaces to allow water to drain through it. Porous asphalt allows water to infiltrate into the subsoil through the paved surface and a base, aggregate layer that acts as both a structural layer and container to temporarily hold water. Porous asphalt is generally used on sidewalks, bicycle paths, or roads with low traffic volumes.
Proprietary Systems	Proprietary controls are manufactured structural control systems available from commercial vendors that are designed to treat stormwater runoff and/or provide water quantity control. Proprietary systems often can be used on small sites and in space-limited areas.
Rainwater Harvesting	Rainwater harvesting is a common stormwater management practice used to catch rainfall and store it for later use. Typically, gutters and downspout systems are used to collect the water from roof tops and direct it to a storage tank. Rainwater harvesting systems can be either above or below the ground. Once captured in the storage tank, the water may be used for non-potable indoor (requires treatment) and outdoor uses.
Regenerative Stormwater Conveyance	A regenerative stormwater conveyance (RSC) is a practice that provides treatment, infiltration, and conveyance to stormwater runoff through a combination of pools, riffles (with either cobble rocks or boulders), native vegetation, an underlying sand layer, and wood chips. RSCs can also be used to repair areas with large amounts of erosion.
Sand Filter: » Surface Sand Filter » Perimeter Sand Filter » Underground Sand Filter	Sand filters are multi-chamber structures designed to treat stormwater runoff through filtration, using a sand bed as its primary filter media. Filtered runoff may be returned to the conveyance system through an underdrain system, or allowed to partially exfiltrate into the soil. A surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a filter bed chamber. A perimeter sand filter is an enclosed system typically just below the ground in a vault along the edge of an impervious area such as a parking lot. Underground sand filters are sand filter systems located in an underground vault.
Site Reforestation / Revegetation	Site reforestation/revegetation is a process of planting trees, shrubs and other native vegetation in disturbed pervious areas to restore the area to pre-development or better conditions. The process can be used to establish mature native plant communities, such as forests, in pervious areas that have been disturbed by clearing, grading and other land disturbing activities. These plant communities intercept rainfall and slow and filter the stormwater runoff to improve infiltration in the ground. Areas that have been reforested or revegetated should be maintained in an undisturbed, natural state over time. These areas must be designated as conservation areas and protected in perpetuity through a legally enforceable conservation instrument (e.g., conservation easement, deed restriction).
Soil Restoration	Soil restoration is the process of tilling and adding compost and other amendments to soils to restore them to their pre-development conditions. This improves the soil's ability to reduce post-construction stormwater runoff rates, volumes and pollutant loads. This process is ideal for areas that have been disturbed by clearing, grading and other land disturbing activities. This process is generally used in conjunction with other practices including, but not limited to, vegetated filter strips, grass channels, and simple downspout disconnections.

Table 4.1.1-1 Best Management Practices (continued)

BMP	Description
Stormwater Planters / Tree Boxes	Stormwater planters are similar to bioretention areas in their design purpose to detain, filter, and infiltrate stormwater. In addition, stormwater planters utilize native or non-invasive flowers, shrubs and trees to provide aesthetic qualities to the site. Planters and tree boxes receive stormwater from a variety of sources such as, rooftops, downspouts and runoff from streets.
Stormwater Ponds: » Wet Pond » Wet Extended Detention Pond » Micropool Extended Detention Pond » Multiple Pond Systems	Stormwater ponds are constructed stormwater retention basins that have a permanent pool (or micropool) of water. Some runoff reduction is achieved within a stormwater pond or detention system through evaporation and transpiration. Stormwater ponds provide water quality treatment through sediment precipitation in the permanent pool.
Stormwater Wetlands: » Shallow Wetland » Extended Detention Shallow Wetland » Pond/Wetland Systems » Pocket Wetland	Stormwater wetlands are constructed wetland systems used for stormwater management. Stormwater wetlands consist of a combination of shallow marsh areas, open water, and semi-wet areas above the permanent water surface. As stormwater runoff flows through a wetland, it is treated, primarily through gravitational settling and biological uptake.
Submerged Gravel Wetlands	Submerged gravel wetland systems use wetland plants in submerged gravel or crushed rock media to remove stormwater pollutants. An anaerobic zone is created within the gravel wetland that provides additional treatment for contaminants.
Underground Detention	Underground detention tanks and vaults provide temporary storage of stormwater runoff for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area.
Vegetated Filter Strip	Vegetated filter strips are uniformly graded and densely vegetated sections of land that provide "biofiltering" of stormwater runoff as it flows across the surface.

4.1.1.3 USING OTHER OR NEW BEST MANAGEMENT PRACTICES

Innovative technologies should be allowed and encouraged providing there is sufficient documentation as to their effectiveness and reliability. Communities can allow the use of controls not included in this Manual at their discretion, but should not do so without independently derived information concerning performance, maintenance, application requirements, and limitations.

More specifically, new BMP designs will not be accepted for inclusion in the Manual until independent pollutant removal performance monitoring data determine that the practice can meet the TSS and other selected pollutant concentration removal targets, and that the practice conforms with all necessary criteria for treatment, maintenance, and environmental impact.

4.1.2 Best Management Practice Pollutant Removal Capabilities

Best Management Practices (BMPs) are intended to provide water quality treatment for stormwater runoff. Though each of these practices provides pollutant removal capabilities, the relative capabilities vary between BMPs and for different pollutant types.

Pollutant removal capabilities for a given BMP are based on a number of factors including the physical, chemical and/or biological processes that take place in the practice and the design and size of the facility. In addition, pollutant removal efficiencies for the same BMP type and facility design can vary widely depending on the tributary land use and area, incoming pollutant concentrations, rainfall pattern, time of year, maintenance frequency, and numerous other factors.

To assist designers in evaluating the relative pollutant removal performance of the various structural control options, **Table 4.1.3-1** provides design removal efficiencies for each of the above listed BMPs. It should be noted that these values are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. A BMP design may be capable of exceeding these performances; however, the values in the table are minimum reasonable values that can be assumed to be achieved when the practice is sized, designed, constructed, and maintained in accordance with recommended specifications in this Manual.

Where the pollutant removal capabilities of an individual BMP are not deemed sufficient for a given site application, additional practices may be used in series in a "treatment train" approach. More details on using BMPs in series are provided in Subsection 4.1.6.1.

For additional information and data on the range of pollutant removal capabilities for various BMPs, refer to the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.1.3 Best Management Practice Selection

4.1.3.1 BMP SCREENING PROCESS

Outlined below is a screening process for BMPs. This process is intended to assist the site designers and engineers in selecting the most appropriate BMPs for a development site, and provides guidance on factors to consider in their location.

In general the following five criteria should be evaluated in order to select the appropriate structural control(s) or group of controls for a development:

- Stormwater Management and Treatment
- Runoff Reduction Capability
- Water Quality Performance
- Site Applicability
- Cost Considerations - both capital and maintenance

In addition, for a given site, the following factors should be considered and any specific design criteria or restrictions need to be evaluated:

- Physiographic Factors
- Soils
- Special Watershed or Stream Considerations

Finally, environmental regulations that may influence the location of a BMP on-site, or may require a permit, need to be considered. See Section 2.4 for additional information regarding permitting information.

4.1.3.2 DESIGN PROCESS

Using **Table 4.1.3-1**, the site designer can evaluate and screen the overall applicability of BMPs, as well as the constraints of the site in question. Following are details of the various screening categories and individual characteristics used to evaluate structural controls.

Stormwater Management and Treatment

The first group of columns in **Table 4.1.3-1** examines the capability of each BMP option to provide runoff reduction. The second set of columns references water quality treatment, downstream channel protection, overbank flood protection, extreme flood protection, and provides an overview of the pollutant removal performance of each BMP option when designed, constructed, and maintained according to the criteria and specifications in this Manual. The presence of a check mark indicates that the structural control can be used to meet a unified stormwater sizing criterion. An 'X' entry in the table means that the practice cannot or is not typically used to meet a unified stormwater sizing criterion. This does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one BMP may be needed at a site (e.g., a bioretention area used in conjunction with dry detention storage). A '†' entry indicates that a BMP may be able to meet the Unified Sizing Criterion depending upon size, configuration, and design constraints.

- **Runoff Reduction Volume (RR_v)** – Indicates whether a BMP reduces and/or removes a portion of the Runoff Reduction Volume (RR_v) through storage, infiltration, exfiltration, and root uptake. Runoff reduction percentages are listed in **Table 4.1.2.2** BMP Runoff Reduction Credits.
- **Water Quality Volume (WQ_v)** – Indicates whether a BMP provides treatment of the water quality volume (WQ_v).
- **Channel Protection (CP_v)** – Indicates whether the BMP can be used to provide extended detention of the channel protection volume (CP_v).
- **Overbank Flood Protection (Q_{p25})** – Indicates whether a BMP can be used to meet the overbank flood protection criteria.
- **Extreme Flood Protection (Q_f)** – Indicates whether a BMP can be used to meet the extreme flood protection criteria.
- **Total Phosphorous Removal** – Indicates the capability of a BMP to remove phosphorus in runoff, which may be of particular concern with certain downstream receiving waters.
- **Total Nitrogen Removal** – Indicates the capability of a BMP to remove nitrogen in runoff, which may also be of particular concern with certain downstream receiving waters.
- **Fecal Coliform Removal** – Indicates the capability of a BMP to remove fecal coliform and associated bacteria in runoff. This capability may be of particular focus in areas with public beaches, shellfish beds, and/or water regulatory quality criteria under the Total Maximum Daily Load (TMDL) program.
- **Metals Removal** – Indicates the capability of a BMP to remove trace metals, which may be present in stormwater runoff from designated hotspots, or where subsurface soil and/or groundwater contamination may be present. Examples of hotspots include: gas stations, convenience stores, marinas, public works storage areas, vehicle service and maintenance areas, commercial nurseries, and auto recycling facilities.

Please see the specific design criteria of each BMP for more information on the capability of each practice to treat runoff from designated hotspots.

Site Applicability

The third group of columns in **Table 4.1.3-1** provides an overview of specific site conditions or criteria that must be met for a particular BMP to be suitable. In some cases, these values are recommended values or limits that can be exceeded or reduced with proper design or depending on specific circumstances. Please see the specific criteria section of each practice for more details.

- LID/GI – Indicates that the BMP is a LID/GI structure and can be used in those applications.
- Drainage Area – Indicates the approximate minimum or maximum drainage area that is considered suitable for the BMP. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway can be permitted if more than one practice is installed. The minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), the mechanisms employed to prevent outlet clogging, and/or design variations used to maintain a permanent pool (e.g., liners).
- Space Required (% of Impervious Area) – Comparative index expresses how much space a BMP typically consumes at a site in terms of the approximate area required as a percentage of impervious area draining to the control. BMP design constraints affecting the site area consumed by the practice are also included in this column. For example, the flow path for a downspout disconnect must be 15 feet; the total area of the downspout disconnect can vary as long as the BMP meets this design constraint.
- Maximum Site Slope – Evaluates the effect of slope on the best management practice. Specifically, the slope restrictions refer to how flat the area where the facility is installed must be and/or how steep the contributing drainage area or flow length can be.
- Minimum Head (Elevation Difference) – Provides an estimate of the minimum elevation difference needed at a site (from inflow to outflow) to allow for gravity operation within the BMP.
- Water Table – Indicates the minimum depth to the seasonally high water table from the bottom, or floor, of a BMP.

Cost Considerations

The last group of columns in **Table 4.1.3-1** provides cost considerations and an estimate of the maintenance burden for each BMP option.

- Construction Cost – Structural controls are ranked according to their relative construction cost per impervious acre treated, as estimated from cost surveys.
- Maintenance – Assesses the relative maintenance effort needed for a BMP in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging), and reported failure rates. It should be noted that best management practices require routine inspection and maintenance.

Table 4.1.3-2 provides the runoff reduction values for each of the BMP Practices.

Table 4.1.3-1 BMP Selection Guide

BMP	Runoff Reduction	Stormwater Management & Treatment							Site Applicability						Cost Considerations	
	RR ***	WQ_v / TSS	CP_v	Q_{p25} / Q_f	Total Phosphorus	Total Nitrogen	Fecal Coliform	Metals	LID/GI	Drainage Area (ac)	Space Req'd (% of Im-perv. Drainage Area)	Max Site Slope	Minimum Head (Elevation Difference)	Depth to Water Table	Construction Cost	Maintenance Burden
Bioretention Basins [3,5,6]	Yes	85%	†	†	80%	60%	90%	95%	Yes	5 max	3-6%	20%	3 ft	2 ft	Med-High	Med
Bioslopes [7]	Yes	85%	†	X	60%	25%	60%	75%	Yes	N/A	N/A	5%	N/A	2 ft	Med	Med
Downspout Disconnects [2]	Yes	80%	X	X	25%	25%	N/A**	40%	Yes	2,500 ft²	Min. length of flow path 15'	6%	N/A	No restrictions	Low	Low
Dry Detention Basins [6]	No	60%	X	✓	10%	30%	N/A**	50%	No	75 max	N/A	15%	3 ft	2 ft	Low	Low
Dry Extended Detention Basins [2]	No	60%	✓	✓	10%	30%	N/A**	50%	No	No restrictions	1-3%	15%	4-8 ft	2 ft	Low	Low
Dry Wells [2]	Yes	100%	†	X	100%	100%	100%	100%	Yes	2,500 ft²	5-10%	6%	2 ft	2 ft	Med	Med
Enhanced Dry Swales [1]	Yes	80%	†	X	50%	50%	X	40%	Yes	5 max	10-20%	4%	3-5 ft	2 ft	Med	Low
Enhanced Wet Swales [1]	No	80%	†	X	25%	40%	X	20%	Yes	5 max	10-20%	4%	1 ft	Below	Med	Low
Grass Channels [1]	Minimal	50%	†	X	25%	20%	X	30%	Yes	5 max	10%	4%	<1 ft	2 ft	Low	Low
Gravity (oil-grit) Separators [2]	No	40%	X	X	5%	5%	N/A	N/A	No	5	N/A	6%	4 ft	2 ft	High	High
Green Roofs [2]	Yes	80%	X	X	50%	50%	N/A**	N/A**	Yes	N/A	No restrictions	25%	6-12 in	N/A	High	Low
Infiltration Trenches [10]	Yes	100%	†	†	100%	100%	100%	100%	Yes	5 max	2-3%	6%	1 ft	2 ft	High	High
Multi-Purpose Detention Basins [2]	No	Varies****	X	†	N/A**	N/A**	N/A**	N/A**	No	No restrictions	1-3%	15%	4-8 ft	2 ft	Low	Low
Organic Filters [2]	No	80%	†	X	60%	40%	50%	75%	Yes	10	3-5%	6%	5-8 ft	2 ft	High	High
Permeable Paver Systems [2]	Yes	80%	†	†	50%	50%	N/A**	60%	Yes	N/A	No restrictions	6%	2-4 ft	2 ft	High	High
Pervious Concrete [2]	Yes	80%	†	†	50%	65%	N/A**	60%	Yes	N/A	No restrictions	6%	2-4 ft	2 ft	High	High
Porous Asphalt (excludes OGFC) [2]	Yes	80%	†	†	50%	50%	X	60%	Yes	N/A	0%	N/A	N/A	2 ft	Med	Med
Proprietary Systems [2]	Varies	Varies****	Varies	Varies	Varies	Varies	Varies	Varies	No	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Rainwater Harvesting [2]	Based on Demand	Varies****	†	X	Varies	Varies	Varies	Varies	Yes	No restrictions	Varies	No restritions	N/A	N/A	Med	High
Regenerative Stormwater Conveyance [8]	No	80%	X	X	70%	70%	N/A**	N/A**	Yes	50 max	Varies	10%	Varies	Above	High	Med
Sand Filters [1]	No	80%	†	X	50%	25%	40%	50%	Yes	2-10 max	2-3%	6%	2-5 ft	2 ft	High	High
Site Reforestation/Revegetation [2]	No**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	Yes	N/A	10,000 ft² Min.	25%	N/A	No restrictions	Med	Low
Soil Restoration [2]	No**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	N/A**	Yes	N/A	No restrictions	10%	N/A	1.5 ft	Med	Low
Stormwater Planters / Tree Boxes [2]	Yes	80%	X	X	60%	60%	80%	N/A	Yes	2,500 ft²	5%	6%	2 ft	2 ft	High	Med
Stormwater Ponds [2]	No	80%	✓	✓	50%	30%	70%	50%	No	10-25 min	2-3%	15%	6-8 ft	2 ft (if aquifer)	Low	Low
Stormwater Wetlands – Level 1 [1]	No	80%	✓	✓	40%	30%	70%	50%	Yes	25 min	3-5%	8%	2-3 ft	2 ft (if aquifer)	Med	Med
Stormwater Wetlands – Level 2 [4]	No	85%	X	X	75%	55%	85%	60%	Yes	5 min	3-5%	Flat	2-3 ft	2 ft (if aquifer)	Med-High	Med
Submerged Gravel Wetlands [2]	No	80%	X	X	50%	20%	70%	50%	No	5	3-5%	4%	2-5 ft	No restrictions	High	High
Underground Detention [2]	No	0%	✓	✓	0%	0%	0%	0%	No	25 max	N/A	15%	4-8 ft	2 ft	High	Med
Vegetated Filter Strips [1]	Yes	60%	†	X	20%	20%	X	40%	Yes	5 max	20%	6%	<1 ft	1-2 ft	Low	Low

✓ - BMP can meet the stormwater management or treatment requirement
† - BMP may meet the stormwater management or treatment requirement depending on size, configuration, and site constraints
X - BMP may contribute but is not likely to fully meet the stormwater management or treatment requirement

* - Minimum drainage area of ten acres is required to maintain the permanent pool (unless groundwater is present).
*\- Helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates, volumes and pollutant loads
*** - Runoff reduction percentages are listed in **Table 4.1.3-2** (BMP Runoff Reduction Credits)
**** - WQ credit is to be determined on a case by case basis

Pollutant Removal References:

1: Original Georgia Stormwater Management Manual, 2001
2: Coastal Stormwater Supplement to the Georgia Stormwater Management Manual, 2009
3: Bioretention - Watershed Benefits. Low Impact Development Urban Design Tools. 04 April 2014.
4: The Next Generation of Stormwater Wetlands. EPA Wetlands and Watersheds Article Series (2008) Center for Watershed Protection
5: Bioretention Performance, Design, Construction, and Maintenance. North Carolina Cooperative Extension Service. Hunt, William. 2006
6: North Carolina Department of Environment and Natural Resources Stormwater Best Management Practices Manual. 2007
7: Washington State Department of Transportation (WSDOT) Highway Runoff Manual, 2011.
8: West Virginia Stormwater Management Design Guidance Manual, 2012
9: Georgia Department of Transportation (GDOT) Drainage Manual, 2014
10: Pollutant removal rates based on 100% infiltration with no underdrain

Table 4.1.3-2 BMP Runoff Reduction Credits

BMP	Runoff Reduction RR (%) *	BMP	Runoff Reduction RR (%) *
Bioretention Area (w/o underdrain) [1]	100%	Permeable Paver System (w/underdrain) [1]	50%
Bioretention Area (w/upturned underdrain) [1]	75%	Pervious Concrete (w/o underdrain) [1]	100%
Bioretention Area (w/underdrain) [1]	50%	Pervious Concrete (w/upturned underdrain) [1]	75%
Bioslopes (A & B hydrologic soils) [1]	50%	Pervious Concrete (w/underdrain) [1]	50%
Bioslopes (C & D hydrologic soils) [1]	25%	Porous Asphalt (w/o underdrain) [1]	100%
Downspout Disconnects (A & B hydrologic soils) [2]	50%	Porous Asphalt (w/upturned underdrain) [1]	75%
Downspout Disconnects (C & D hydrologic soils) [1]	25%	Porous Asphalt (w/underdrain) [1]	50%
Dry Detention Basins	0%	Porous Asphalt (OGFC, PEM) [3]	0%
Dry Extended Detention Basins	0%	Proprietary Systems [3]	Varies
Dry Wells 1	100%	Rainwater Harvesting [3]	Based on Demand
Enhanced Dry Swales (w/underdrain) [1]	50%	Regenerative Stormwater Conveyance	0%
Enhanced Dry Swales (w/o underdrain) [1]	100%	Sand Filters [2]	0%
Enhanced Wet Swales [2]	0%	Site Reforestation/Revegetation [1]	0%
Grass Channels (A & B hydrologic soils) [2]	25%	Soil Restoration (Can be used to remediate C & D Soils) [1]	0%
Grass Channels (C & D hydrologic soils) [1]	10%	Stormwater Planters / Tree Boxes [1]	50%
Gravity (oil-grit) Separators [1]	0%	Stormwater Ponds [2]	0%
Green Roofs [1]	60%	Stormwater Wetlands – Level 1 [2]	0%
Infiltration Trenches [1]	100%	Stormwater Wetlands – Level 2 [2]	0%
Multi-Purpose Detention Basins	0%	Submerged Gravel Wetlands [2]	0%
Organic Filters [2]	0%	Underground Detention (Not including infiltration) [2]	0%
Permeable Paver System (w/o underdrain) [1]	100%	Vegetated Filter Strips (A & B hydrologic soils) [2]	50%
Permeable Paver System (w/ upturned underdrain) [1]	75%	Vegetated Filter Strips (C & D hydrologic soils) [1]	25%

BMP pollutant removal rates and other BMP specific design criteria are listed in Table 4.1.3-1 (BMP Selection Guide)

* Runoff reduction percentages listed are maximum allowable credit values. These values, similar to other pollutant removal rates, are based on the performance and operating efficiency of the BMP.

[1]Runoff reduction percent removals are based on values from the former Georgia Stormwater Management Manual's Coastal Stormwater Supplement, 2009.

[2]Runoff reduction percent removals are based on values from the Center for Watershed Protection, 2008.

[3]Runoff reduction percent removals are not available

Additional considerations should be taken into account when designing a BMP. They include physiographic factors, soils, special watershed or stream considerations, and temperature.

Physiographic Factors

Three key factors to consider are low-relief, high-relief, and karst terrain. In the state of Georgia, low-relief (very flat) areas are primarily located in the Coastal Plain and along the Atlantic coast. High-relief (steep and hilly) areas are found throughout the Piedmont and far northern parts of the state. Karst and major carbonaceous rock areas are generally found in the western portions of the state. Special geotechnical testing requirements may be needed in karst areas. The local reviewing authority should be consulted to determine if a project is subject to terrain constraints..

- Low-relief areas need special consideration because many BMPs require a hydraulic head to move stormwater runoff through the facility.
- High-relief areas may limit the use of practices that need flat or gently sloping areas to reduce sediment and/or runoff flow velocities. In other cases high-relief terrain may impact dam heights to the point that the use of a practice becomes infeasible.
- Karst terrain can limit the use of some BMPs as the infiltration of polluted waters directly into underground streams found in karst areas may be prohibited. In addition, ponding areas may not reliably hold water in karst areas.

Soils

Key evaluation factors are based on an initial investigation of the NRCS hydrologic soils groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Special Watershed or Stream Considerations

The design of BMPs is fundamentally influenced by the nature of downstream receiving water bodies. Consequently, designers should determine the Use Classification of the watershed in which their project is located prior to design (see Georgia Department of Natural Resources Environmental Protection Division Water Quality Control Rules Chapter 391-3-6). In addition, designers should consult with appropriate review authorities to determine if their development project is subject to additional BMP criteria as a result of an adopted local watershed plan or special provision.

In some cases, higher pollutant removal or environmental performance is needed to fully protect aquatic resources and/or human health and safety within a particular watershed or receiving water. Therefore, special design criteria for a particular practice or the exclusion of one or more practices may need to be considered within these watersheds or protected areas. Examples of important watershed factors to consider include:

- **Primary and Secondary Trout Streams** – Cold and cool water streams have habitat qualities capable of supporting trout and other sensitive aquatic organisms. Therefore, the design objective for these streams is to maintain habitat quality by preventing stream warming, maintaining natural recharge, preventing bank and channel erosion, and preserving the natural riparian corridor. Some BMPs can have adverse downstream impacts on cold-water streams, and their design may need to be modified or use restricted. BMPs that result in reduced thermal and sediment loading, such as shaded or underground stormwater detention and green roof technologies should be considered where stormwater runoff may impact trout streams.
- **High Quality Streams** (High quality streams with a watershed impervious cover less than approximately 15%) – These streams may also possess high quality cool water or warm water aquatic resources and/or endangered species. The design objectives are to maintain habitat quality through the same techniques used for cold-water streams, with the exception that stream warming is not as severe of a design constraint. These streams may also be specially designated by local authorities.
- **Wellhead Protection** –Areas that recharge existing public (or known private) water supply wells present a unique management challenge. The key design constraint is to prevent possible groundwater contamination by preventing infiltration of hotspot runoff. At the same time, recharge of unpolluted stormwater is encouraged to maintain flow in streams and wells during dry weather.

- **Reservoir or Drinking Water Protection** – Watersheds that deliver surface runoff to a public water supply reservoir or impoundment are a special concern. Depending on the treatment available at the water intake, it may be necessary to achieve a greater removal rates for pollutants of concern, such as bacteria pathogens, nutrients, sediment, and/or metals. One particular management concern for reservoirs is ensuring that stormwater hotspots are adequately treated so that they do not contaminate drinking water.
- **Swimming/Shellfish** – Watersheds that drain to public swimming waters or shellfish harvesting areas require a higher level of stormwater treatment to prevent closings caused by bacterial contamination from stormwater runoff. In these watersheds, BMPs should be explicitly designed to maximize bacteria removal.
- **Temperature** – In many cases, the water running off the site may flow over an impervious surface that has absorbed the sun's heat, and can potentially cause thermal pollution to streams. Water temperatures are also increased due to shallow ponds and impoundments along a watercourse and fewer trees along streams to shade the water. This may have an adverse effect on aquatic life, particularly in trout streams as mentioned above. **Table 4.1.3-3** shows a list of the BMPs and if they can potentially reduce thermal pollution. BMPs that encourage infiltration appear to be the most effective in mitigating thermal impacts.

Additionally, Better Site Design principles (see Section 2.3 for more information), including conservation of natural buffers and stream canopy can maintain shade and reduce thermal pollution.

Table 4.1.3-3 – List of BMPs with Temperature Reduction Possibility

BMP	*Temperature Reduced?	BMP	*Temperature Reduced?
Bioretention Areas	Yes	Pervious Concrete	No
Bioslopes	Yes	Porous Asphalt	No
Downspout Disconnects	No	Proprietary Systems	No
Dry Detention Basins	No	Rainwater Harvesting	No
Dry Enhanced Swales/Wet Enhanced Swales	No	Regenerative Stormwater Conveyance	Yes
Dry Extended Detention Basins	No	Sand Filter	Yes
Dry Wells	Yes	Site Reforestation/ Revegetation	Yes
Grass Channel	Yes	Soil Restoration	Yes
Gravity (Oil-Grit) Separators	No	Stormwater Planters/Tree Boxes	Yes
Green Roofs	Yes	Stormwater Ponds	No
Infiltration Practices	Yes	Stormwater Wetlands	No
Multi-Purpose Detention Basin	No	Submerged Gravel Wetlands	Yes
Organic Filter	Yes	Underground Detention	Yes
Permeable Paver System	No	Vegetated Filter Strip	Yes

*The effects of BMPs on temperature can be dependent on many factors, including the sizing of the BMP and the presence of an underdrain.

4.1.3.3 EXAMPLE APPLICATION

A 20-acre institutional area (e.g., church and associated buildings) is being constructed in a dense urban area within metropolitan Atlanta. The existing impervious coverage of the site is 40%. The site drains to an urban stream that is highly impacted from hydrologic alterations (accelerated channel erosion). The stream channel is deeply incised; consequently, flooding is not a problem. The channel drains to an urban river that is a tributary to a phosphorus limited drinking water reservoir. Low permeability soils limit infiltration practices.

- **Objective**: Avoid additional disruptions to receiving channels and reduce pollutant loads for sediment and phosphorus to receiving waters.
- **Target Removals**: Provide stormwater management to mitigate for accelerated channel incision and reduce loadings of key pollutants by:
  - » *Sediment*: 80%
  - » *Phosphorus*: 40%
- **Activity/Runoff Characteristics**: The proposed site will have large areas of impervious surface in the form of parking and structures. However, there will be a large contiguous portion of turf grass proposed for the front of the parcel that will have a relatively steep slope (approximately 10%) and will drain to the storm drain system associated with the entrance drive. Stormwater runoff from the site is expected to exhibit fairly high sediment levels and seasonally high phosphorus levels (due to turf grass management).

While there is a downstream reservoir to consider, there are no special watershed factors or physiographic factors that preclude the use of any of the practices from the BMP list. However, due to the size of the drainage area, most stormwater ponds and wetlands are removed from consideration. In addition, the site's impermeable soils remove an infiltration trench from being considered. Vegetated filter strips and downspout disconnects could be considered for pretreatment; however, the steep slope may reduce their effectiveness and preclude their use.

To provide additional pollutant removal capabilities in an attempt to better meet the target removals, bioretention, surface sand filters, and/or perimeter sand filters can be used to treat the parking lot and driveway runoff. Bioretention provides some removal of phosphorus while improving the aesthetics of the site. Surface sand filters provide higher phosphorus removal at a comparable unit cost to bioretention, but are not as aesthetically pleasing. The perimeter sand filter is a flexible, easy to access practice (but at higher cost) that provides good phosphorus removal and high oil and grease trapping ability. A bioslope may be an ideal BMP for use in higher slope situations and should be designed to complement the site's aesthetics and accommodate pedestrian infrastructure.

Designers may consider the feasibility of using green roofs, pervious concrete, porous asphalt, and/or permeable pavers wherever possible to reduce the overall imperviousness of the property. However, the compacted subsurface soils may reduce the effectiveness of installing porous surfaces and can require the use of an extensive underdrain system that may become expensive. Soil restoration and site revegetation may be used to mitigate the effects of the urbanized soils. Installation of a green roof can increase the building's construction costs and should be considered early in the design process.

To provide overbank flood control, as well as channel protection storage, a micropool ED pond, dry extended detention basin, or multi-purpose detention basin will likely be needed, unless some downstream regional storage is available to control the overbank flood. The site drainage system can be designed so that the bioretention and/or sand filters drain to the micropool ED pond or detention basin for redundant treatment. Vegetated dry swales could also be used to convey runoff to the pond, which would provide pretreatment, runoff reduction, TSS removal, and some water quality volume reduction. Pocket wetlands, wet swales, and submerged gravel wetlands were eliminated from consideration due to the potential for nuisance conditions. Underground sand filters could also be used at the site; however, cost and aesthetic considerations were significant enough to eliminate them from consideration.

4.1.4 On-Line Versus Off-Line Best Management Practices

4.1.4.1 INTRODUCTION

Stormwater best management practices (BMPs) are designed to be either "on-line" or "off-line." On-line BMPs are designed to receive, but not necessarily control or treat, entire runoff volumes up to the Q_{p25} or Q_f event. On-line BMPs must be able to handle the entire range of storm flows. Off-line facilities are designed to receive only a specified flow rate through the use of a flow regulator (diversion structure, flow splitter, etc.). Flow regulators are typically used to divert the water quality volume (WQ_v) or runoff reduction volume (RR_v) to an off-line BMP sized and designed to treat and control the WQ_v. After the design runoff flow has been treated and/or controlled it is returned to the conveyance system. **Figure 4.1.4.1** shows an example of an off-line sand filter and an on-line enhanced dry swale.

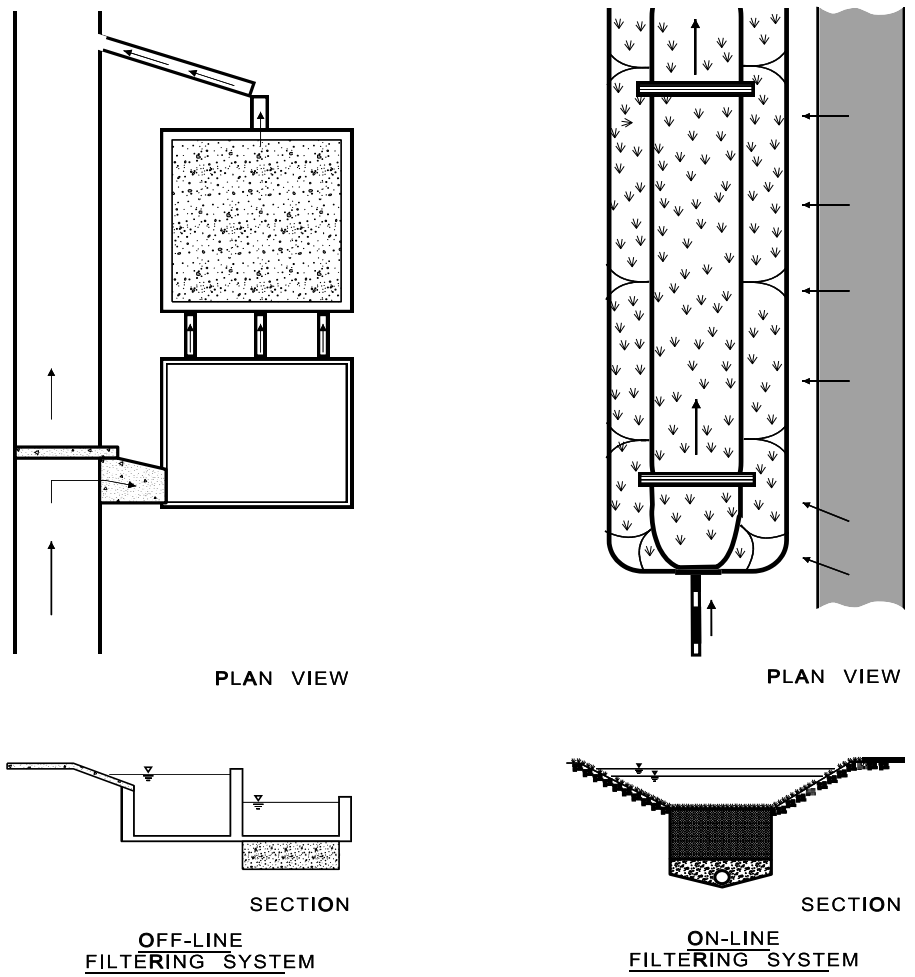


Figure 4.1.4-1 Example of On-Line versus Off-Line BMPs
(Source: CWP, 1996)

4.1.4.2 FLOW REGULATORS

Flow regulation to off-line best management practices can be achieved by either:

- Diverting the water quality volume or other specific maximum flow rate to an off-line BMP, or
- Bypassing flows in excess of the design flow rate.

The peak water quality flow rate (Q_{wq}) can be calculated using the procedure found in Subsection 3.1.7.2.

Flow regulators can be flow splitter devices, diversion structures, or overflow structures. Several examples are shown on the right and on the following pages.

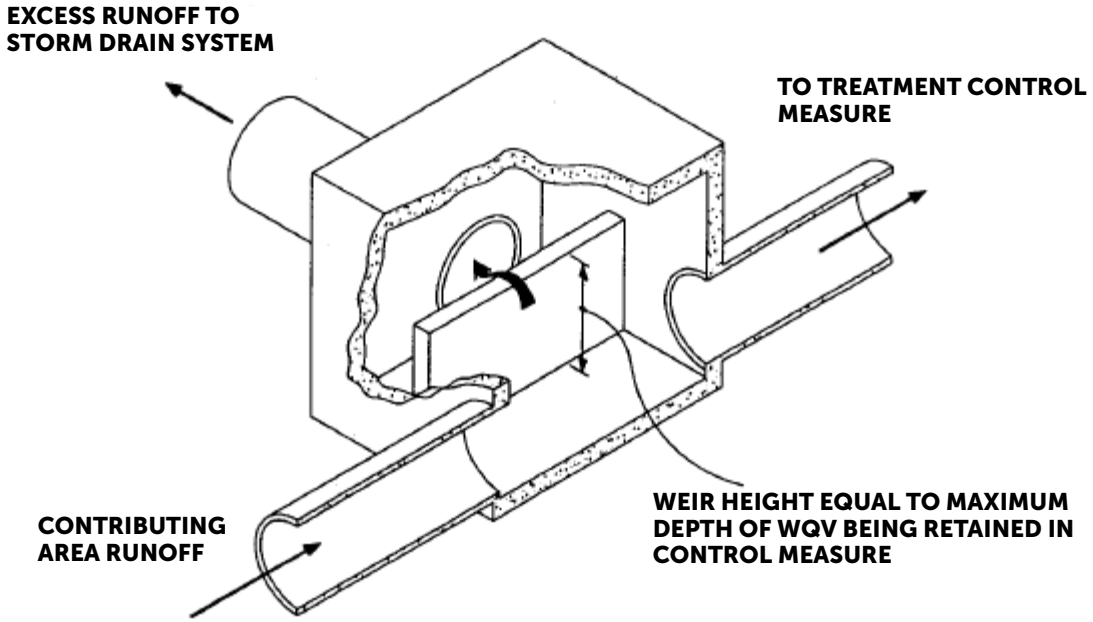


Figure 4.1.4-2 Pipe Interceptor Diversion Structure
(Source: City of Sacramento, 2000

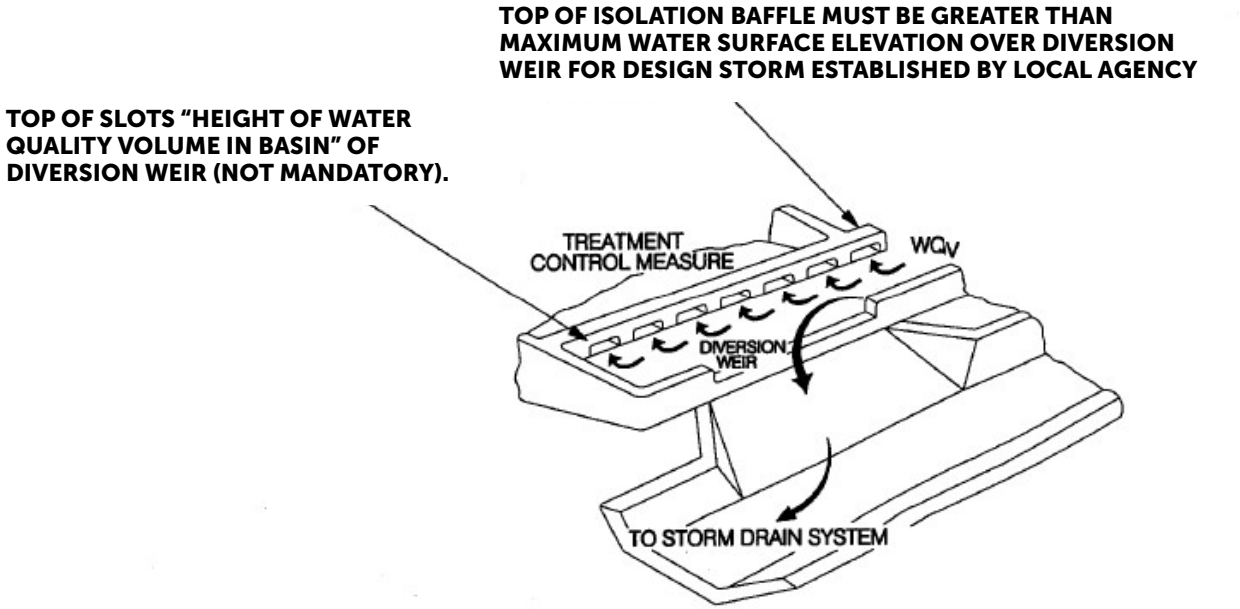


Figure 4.1.4-3 Surface Channel Diversion Structure
(Source: City of Sacramento, 2000)

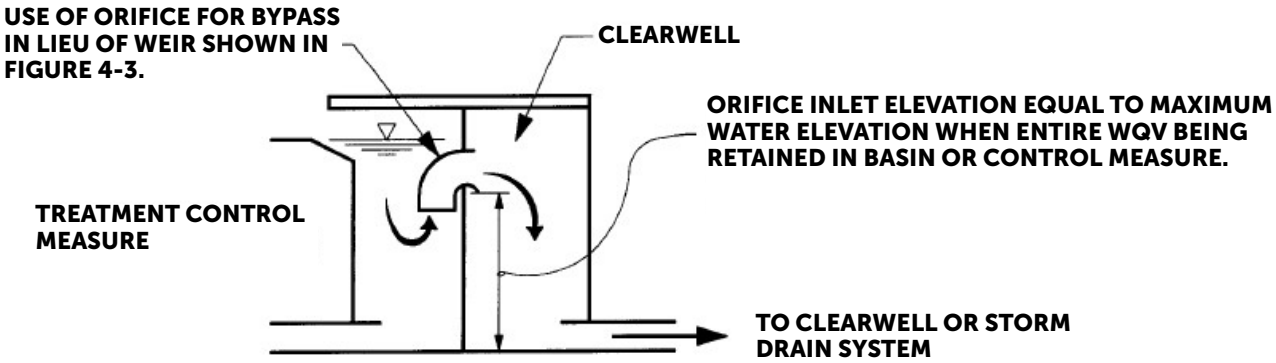


Figure 4.1.4-4 Outlet Flow Regulator
(Source: City of Sacramento, 2000)

4.1.5 Regional vs. On-site Stormwater Management

4.1.5.1 INTRODUCTION

Using individual, on-site best management practices or a treatment train of one or more BMPs for each development is the typical approach for controlling stormwater quantity and quality. The developer finances the design and construction of these controls and, initially, is responsible for all operation and maintenance.

A potential alternative approach is for a community to install a few strategically located regional stormwater BMPs in a subwatershed rather than requiring on-site controls (see **Figure 4.1.5-1**). For this Manual, regional BMPs are defined as facilities designed to manage stormwater runoff from multiple projects and/or properties through a local jurisdiction-sponsored program, where the individual properties may assist in the financing of the facility, and the requirement for on-site practices is either eliminated or reduced

4.1.5.2 ADVANTAGES AND DISADVANTAGES OF REGIONAL BEST MANAGEMENT PRACTICES

Regional stormwater facilities can be more cost-effective because it is easier and less expensive to build, operate, and maintain one large facility than several small ones. Regional stormwater facilities can also be better maintained than individual site BMPs because they are large, highly visible, and typically the responsibility of local government entities.

There are also several disadvantages to regional stormwater BMPs. In many cases, a community must provide capital construction funds for a regional facility, including the costs of land acquisition. However, if a downstream developer is the first to build, that person could be required to construct the facility and later be compensated by upstream developers for the capital construction costs and annual maintenance expenditures.

Conversely, an upstream developer may have to establish temporary control structures if the regional facility is not in place before construction. Maintenance responsibilities generally shift from the homeowner or developer to the local government when a regional approach is selected. The local government would need to establish a stormwater utility or some other program to fund and implement stormwater management facilities. Finally, a large in-stream facility can pose a greater disruption to the natural flow network and is more likely to affect wetlands within the watershed.

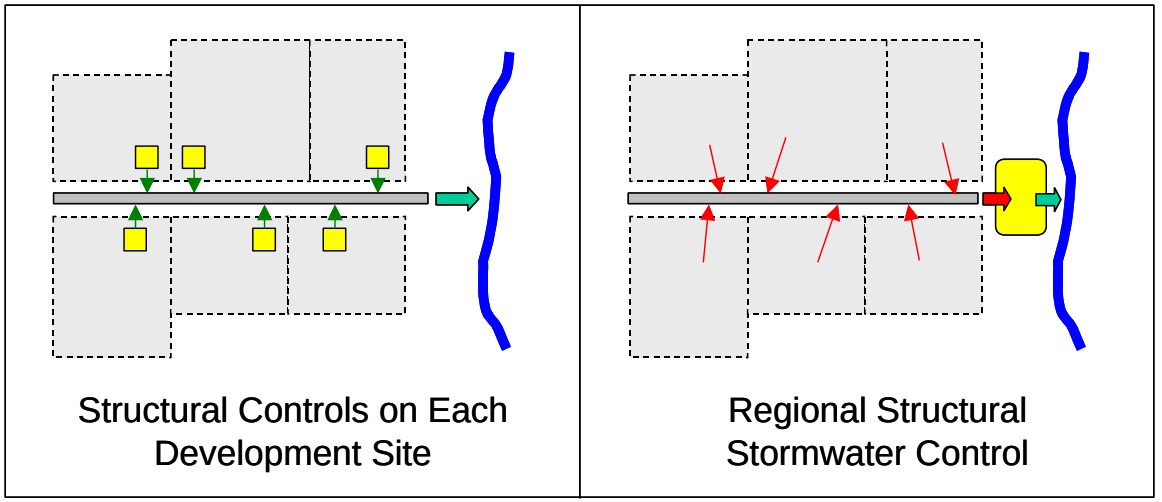


Figure 4.1.5-1 On-site versus Regional Stormwater Management

Below are summarized some of the "pros" and "cons" of regional stormwater practices.

Advantages of Regional Stormwater Management Facilities

- **Reduced Construction Costs** – Design and construction of a single regional stormwater management facility can be more cost-effective than numerous individual on-site BMPs.
- **Reduced Operation and Maintenance Costs** – Rather than multiple owners and associations being responsible for the maintenance of several stormwater facilities on their developments, it is simpler and more cost effective to establish scheduled maintenance of a single regional facility.
- **Higher Assurance of Maintenance** – Regional stormwater facilities are far more likely to be adequately maintained as they are large and have a higher visibility, and are typically the responsibility of local government.
- **Maximum Utilization of Developable Land** – Developers would be able to potentially maximize the utilization of the proposed development for the purpose intended by minimizing the land normally set aside for the construction of stormwater BMPs.
- **Retrofit Potential** – Regional facilities can be used by a community to mitigate existing developed areas that have insufficient or no best management practices for water quality and/or quantity, as well as provide for future development.
- **Other Benefits** – Well-sited regional stormwater facilities can serve as a recreational and aesthetic amenity for a community.

Disadvantages of Regional Stormwater Controls

- **Location and Siting** – Regional stormwater facilities may be difficult to site, particularly for large facilities or in areas with existing development.
- **Capital Costs** – The community must typically provide capital construction funds for a regional facility, including the costs of land acquisition.
- **Maintenance** – The local government is typically responsible for the operation and maintenance of a regional stormwater facility.
- **Need for Planning** – The implementation of regional stormwater management facilities requires substantial planning, financing, and permitting. Land acquisition must be in place ahead of future projected growth.

For in-stream regional facilities:

- **Water Quality and Channel Protection** – Without on-site water quality and channel protection, regional controls do not protect smaller streams upstream from the facility from degradation, streambank erosion, and thermal impacts. Further, diverting stormwater runoff to a stormdrain system for discharge to a regional facility eliminates the opportunity to provide local groundwater recharge and runoff reduction.
- **Ponding Impacts** – Upstream inundation from a regional facility impoundment can eliminate floodplains, wetlands, and other habitat.
- **Additional Planning** – The implementation of in-stream regional facilities requires substantial planning, permitting and increased regulatory compliance.

4.1.5.3 IMPORTANT CONSIDERATIONS FOR THE USE OF REGIONAL STORMWATER MANAGEMENT FACILITIES

If a community decides to implement a regional stormwater facility, then it must ensure that the conveyances between the individual upstream developments and the regional facility can handle the design peak flows and volumes without causing adverse impact or property damage. Full-buildout conditions in the regional facility drainage area should be used in the analysis.

In addition, unless the system consists of completely non-erodable conveyances (storm drains, pipes, concrete channels, etc.), on-site best management practices for water quality and downstream channel protection should be required for all developments within the regional facility's drainage area. Federal water quality provisions do not allow the degradation of water bodies from untreated stormwater discharges, and it is U.S. EPA policy to not allow regional stormwater facilities that would degrade stream quality between the upstream development and the regional facility. Further, without adequate channel protection, aquatic habitats and water quality in the channel network upstream of a regional facility may be degraded by streambank erosion if they are not protected from bankfull flows and high velocities. Based on these concerns, both the EPA and the U.S. Army Corps of Engineers have expressed opposition to in-stream regional stormwater control facilities. In-stream facilities should be avoided if possible and will likely be permitted on a case-by-case basis only.

It is important to note that siting and designing regional facilities should ideally be done within the context of stormwater master planning or watershed planning to be effective.

4.1.6 Using Best Management Practices in Series

4.1.6.1 STORMWATER TREATMENT TRAINS

The minimum stormwater management standards are an integrated planning and design approach, the components of which work together to limit adverse impacts of urban development on downstream waters and riparian areas. This approach is sometimes called a stormwater "treatment train". When considered comprehensively, a treatment train consists of all the design concepts, better site design practices, and BMPs that work to attain water quality and quantity goals. This is illustrated in **Figure 4.1.6-1.**

Runoff and Load Generation – The initial part of the "train" is located at the source of runoff and pollutant load generation, and consists of better site design and pollution prevention practices that reduce runoff and stormwater pollutants.

Pretreatment – The next step in the treatment train consists of pretreatment measures. These measures typically do not provide sufficient pollutant removal to meet the runoff reduction or 80% TSS reduction goal, but do provide calculable water quality benefits that may be applied towards meeting the WQ_v treatment requirement. These measures include:

- The use of stormwater better site design practices and site design credits to reduce the water quality volume (WQ_v)
- Using best management practices such as downspout disconnects, vegetated filter strips, and/or soil restoration and site revegetation to provide pretreatment and runoff reduction
- Pretreatment facilities, such as sediment forebays, on best management practices that provide storage and/or filtration of runoff



Figure 4.1.6-1 Generalized Stormwater Treatment Train

Primary Treatment and/or Quantity Control – The last step is primary water quality treatment and/or quantity (channel protection, overbank flood protection, and/or extreme flood protection) control. This is achieved through the use of one or more of the best management practices shown in **Table 4.1.1-1** as a stand-alone stormwater management practice or in series.

4.1.6.2 USE OF MULTIPLE BEST MANAGEMENT PRACTICES IN SERIES

Many combinations of best management practices in series may exist for a site. The combinations of best management practices are limited only by the need to employ measures of proven effectiveness and meet local regulatory and physical site requirements. **Figures 4.1.6-3 through 4.1.6-5** illustrate the application of the treatment train concept for: a moderate density residential neighborhood, a small commercial site, and a large shopping mall site.

In **Figure 4.1.6-3** rooftop runoff drains over grassed yards to backyard grass channels. Runoff from front yards and driveways reaches roadside grass channels. Finally, all stormwater flows drain to a micropool ED stormwater pond.

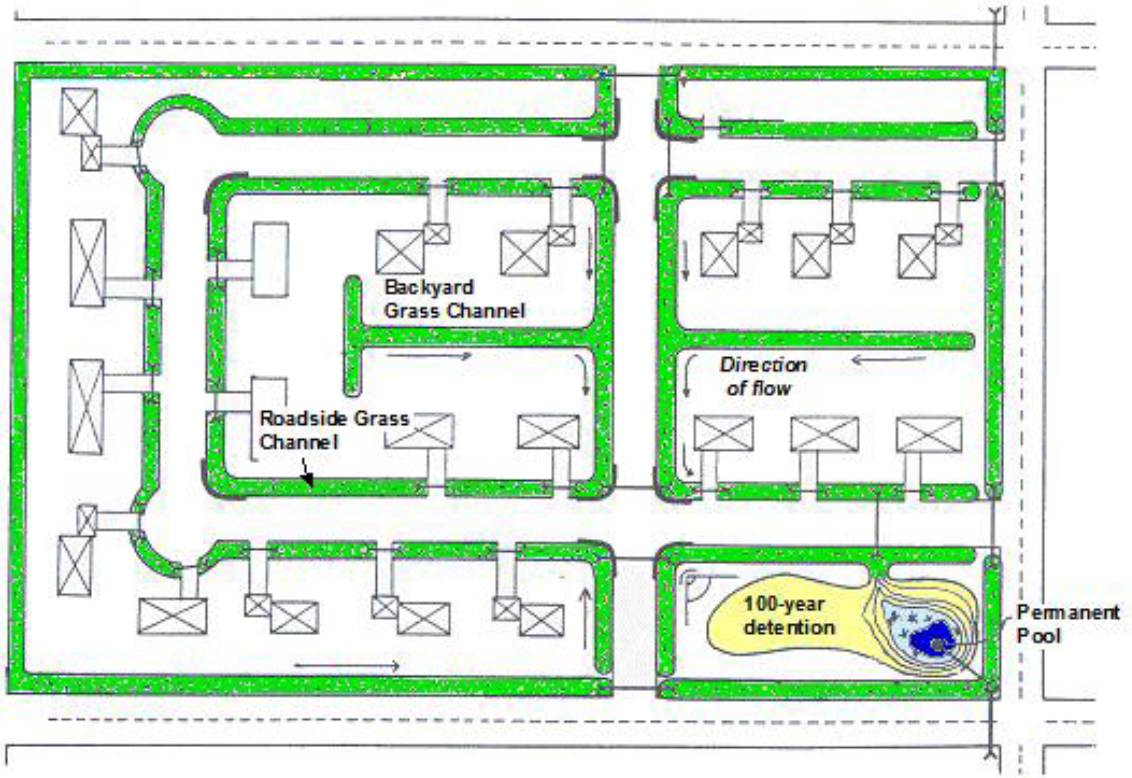


Figure 4.1.6-3 Example Treatment Train – Residential Subdivision
(Adapted from: NIPC, 2000)

A gas station and convenience store is depicted in **Figure 4.1.6-4**. In this case, the decision was made to intercept hydrocarbons and oils using a commercial gravity (oil-grit) separator located on the site prior to draining to a perimeter sand filter for removal of finer particles and TSS. No BMP for channel protection is required as the system drains to the municipal storm drain pipe system. Overbank and extreme flood protection is provided by a regional stormwater control downstream.

Figure 4.1.6-5 shows an example treatment train for a commercial shopping center. In this case, runoff from rooftops and parking lots drains to a depressed parking lot, perimeter grass channels, and bioretention areas. Slotted curbs are used at the entrances to these swales to better distribute the flow and settle out the very coarse particles at the parking lot edge for sweepers to remove. Runoff is then conveyed to a wet ED pond for additional pollutant removal and channel protection. Overbank and extreme flood protection is provided through parking lot detention.

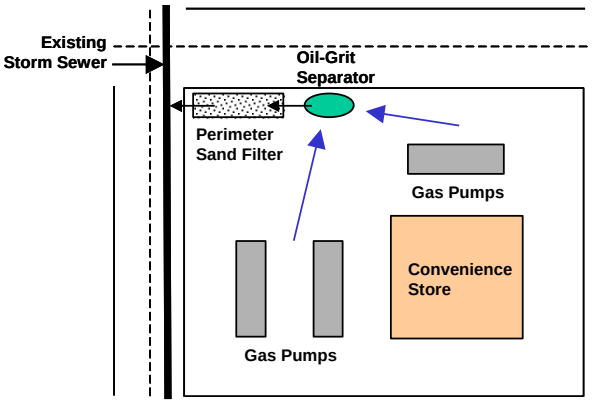


Figure 4.1.6-4 Example Treatment Train - Commercial Development

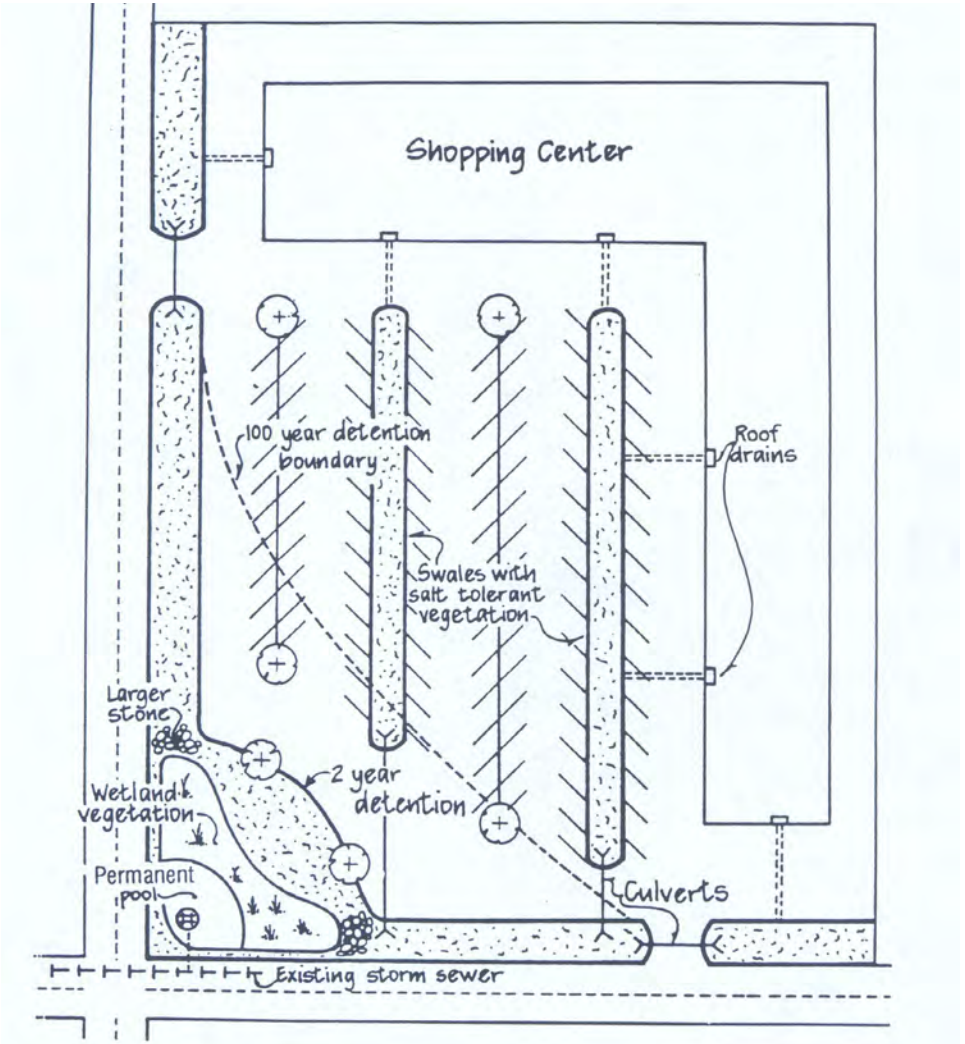


Figure 4.1.6-5 Example Treatment Train – Commercial Development
(Source: NIPC, 2000)

4.1.6.3 CALCULATION OF POLLUTANT REMOVAL FOR WATER QUALITY BEST MANAGEMENT PRACTICES IN SERIES

To estimate the pollutant removal rate of water quality based best management practices in series, the following steps are used to determine the pollutant removal:

- For each drainage area, list the BMPs in order, upstream to downstream, along with their expected average pollutant removal rates from **Table 4.1.3-1** for the pollutants of concern.
- Apply the following equation for calculation of approximate total accumulated pollution removal for BMPs in series:

Final Pollutant Removal = BMP1 removal rate + (remaining pollutant load * BMP2 removal rate) + ... for other Controls in series

4.1.7 Common BMP Components

This section provides design guidance for components commonly found in many BMPs. With any of the design guidance below, the designer is ultimately responsible for ensuring that the selection of the different elements (e.g., pipe sizes, stone depths, etc.) will not impede the proper hydraulic performance of each BMP.

4.1.7.1 PRETREATMENT

Adequate pretreatment is an essential component of many BMPs. Pretreatment facilities extend the life of BMPs and reduce maintenance frequency and effort. Pretreatment is required for some BMPs and is optional for others. For example, swales do not typically require pretreatment. However, BMPs that use filtration, infiltration, or small orifices should have pretreatment to reduce sediment and debris loading. Options for pretreatment include energy dissipation pads, forebays, and level spreaders.

4.1.7.1.1 ENERGY DISSIPATION PAD

Energy dissipation pads provide a stable inlet and dissipate flows to allow sediment and trash to settle out at or near the inlet.

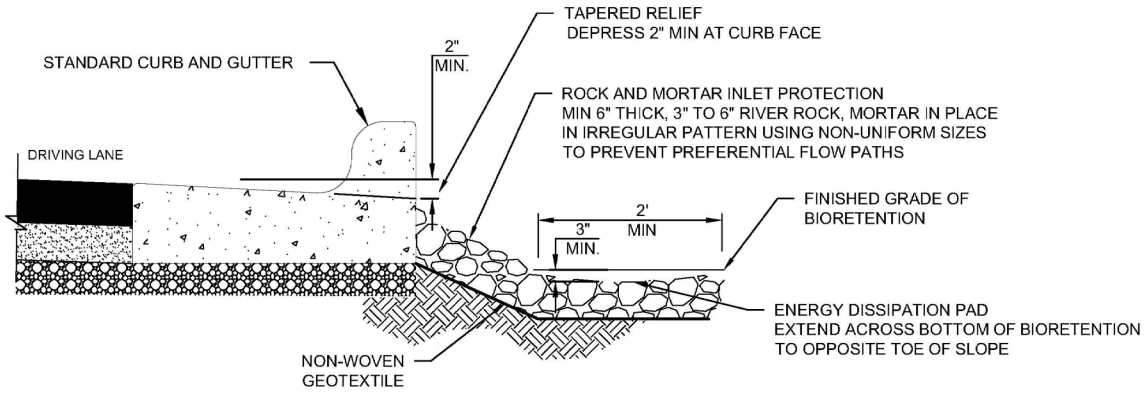


Figure 4.1.7-1 Typical Energy Dissipation Pad
(drawing courtesy of Tetra Tech)

4.1.7.1.2 FOREBAY

Forebays remove coarser suspended solids and debris, dissipate energy, and prevent erosion at the BMP inlet(s). Forebays should typically be provided at any inlet that contributes concentrated flow that is over 10% of the total flow to the BMP. A forebay is not necessary in cases where inflow to the BMP is non-erosive and enters as filtered sheet flow from a device, such as a vegetated filter strip (section 4.29).

The forebay should be designed as a separate cell and lined or armored to prevent erosion. The bottom and sides of the forebay are typically lined with woven plastic filter fabric and riprap. The overflow spillway, which is the downslope section where runoff exits the forebay and enters the BMP, is often constructed using gabion baskets or concrete in order to form a better defined spillway. It is suggested that the spillways be designed to safely convey the 10-year storm event. **Figures 4.1.7-2** and **4.1.7-3** show a typical forebay configuration.

Forebays should be sized for 0.1 inches of runoff per impervious acre of contributing drainage area. For example, assume a 2.5-acre impervious area drains to a BMP through a single inlet that requires a forebay. The forebay size should be determined as follows:

$$Forebay\ Volume = 0.1 \frac{inches}{impervious\ acre}$$

$$Forebay\ Volume = 0.1\ in \times 2.5\ ac \times \frac{1\ ft}{12\ in} \times \frac{43{,}560\ ft^2}{1\ ac}$$

$$Forebay\ Volume = 907.5\ ft^3$$

Side slopes should be limited to 2:1 or flatter where possible. Forebays should be a minimum of 3 to 4 feet deep for large scale BMPs (where the drainage area is greater than 5 acres). Forebay criteria may be reduced for smaller BMPs. Although not desirable, forebays may be eliminated for small BMPs where very minimal sediment and debris are expected and inlets are designed or determined to be non-erosive.

The forebay's pretreatment volume may be located within the main basin of the BMP and included in the calculation of the total treatment volume, if needed.

A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition. The cleanout depth should be noted on the marker.



Figure 4.1.7-2 Typical forebay configuration (in a bioretention basin)
(photo courtesy of NCDOT)



Figure 4.1.7-3 Typical forebay configuration (in a bioretention basin)
(photo courtesy of Tetra Tech)

4.1.7.1.3 LEVEL SPREADERS

Pea Gravel Diaphragm

Pea gravel diaphragms are used at edges of pavement to help maintain sheet flow as it exits the pavement and enters the filter strip or other BMP (e.g., enhanced swale, infiltration trench, bioslope). In addition, pea gravel diaphragms capture some sediment and debris which is especially important for infiltration and filtration BMPs where clogging is of greater concern.

Pea gravel diaphragms should be 1-foot wide and 2-feet deep. The inflow approach length contributing flow to the pea gravel diaphragm should be limited to 75 feet. Non-woven plastic filter fabric should be used at the bottom and sides of pea gravel diaphragms to prevent soils from migrating into the gravel. Gravel should be washed GDOT size No. 89 aggregate or ASTM equivalent. **Figure 4.1.7-4** provides an illustration of a pea gravel diaphragm.

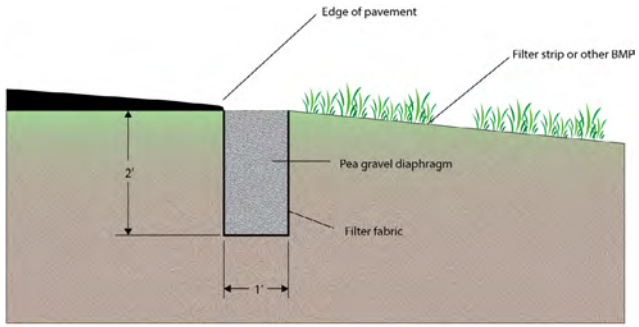


Figure 4.1.7-4 Typical pea gravel diaphragm configuration

Level Spreaders for Concentrated Flow

While pea gravel diaphragms are effective for maintaining sheet flow, level spreaders with concrete troughs are typically needed to convert concentrated flow to sheet flow. Level spreaders are typically only used in conjunction with filter strips and riparian buffers, but may be used for other BMPs as needed. Figure 4.1.7-5 provides an illustration of a typical level spreader configuration. Level spreaders should be designed to minimize the potential for erosion in downgradient areas and flow bypass systems are often needed to partially divert higher intensity storms. The erosivity of downgradient areas is a function of ground cover, slope, and soils. Flow rate is influenced by the hydrology of the contributing drainage area and the design of the flow bypass structure. The length of the level spreader can be adjusted to distribute the flow over an appropriate area.

The length of the level spreader can be determined using the same methodology for determining filter strip width. Refer to the variation of Manning's equation presented in sections 4.29.5.2 (vegetated filter strip) or 5.4.4 (general Mannings n) to determine an allowable q. This method assumes an allowable depth of flow (1 or 2 inches) that will not cause erosion in the filter strip.



Figure 4.1.7-5 Typical level spreader configuration
(photo courtesy of NCDOT)

The design storm for the peak discharge should then be determined. Typically, the flow rate associated with the water quality volume (Qwq) is used for the design of level spreaders, but may vary depending on the downgradient BMP and stormwater quality goals. Refer to section 4.29.5.2 (vegetated filter strip) for guidance on calculating Qwq. The length is then determined by taking Qwq / q. Note that a detention BMP may be used upgradient of the level spreader to control the peak flow to the level spreader, reducing the required length. Detention BMPs may also be used as flow bypass systems. Generally, level spreaders should be limited to 100 feet. It is difficult to maintain a precisely level lip for lengths in excess of 100 feet, which can cause flow to concentrate in one area of the level spreader.

Level spreaders should be a minimum of 1.5-feet deep and 2-feet wide to provide stilling of flow and allow for some sediment storage. Additional width may be desired, as shown in **Figure 4.1.7-6**, to allow maintenance equipment to enter the trough to remove sediment. Widths of 5.5 feet are generally sufficient for small equipment. The lip of the level spreader should be vertical, but the other sides can be sloped for safety (2:1) and to allow for entry by maintenance equipment (4:1). The lip of the level spreader should extend 4 inches above the downgradient ground surface to prevent vegetation from growing over the lip and causing flow to concentrate. Permanent erosion protection liners such as turf reinforcement matting (TRM), may be needed directly downgradient of the lip to stabilize the soil.

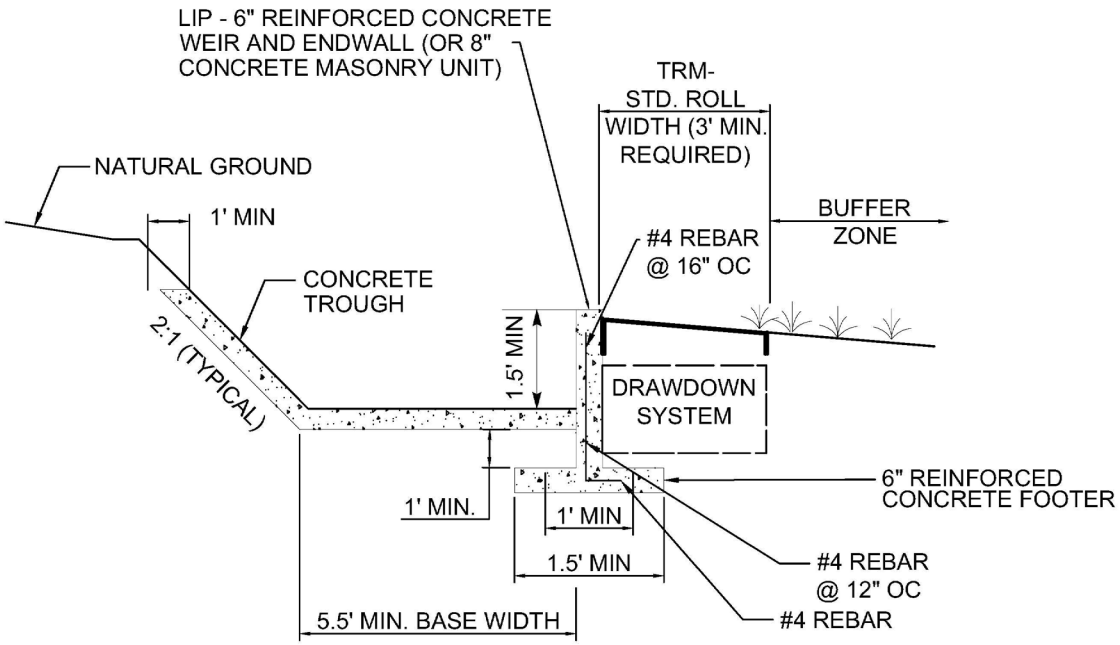


Figure 4.1.7-6 Profile view: typical level spreader details and components
(drawing courtesy of Tetra Tech)

Finally, drawdown systems may be included in the design of the trough where standing water is a concern. **Figure 4.1.7-6** shows a level spreader configuration used by the NCDOT.

4.1.7.2 FLOW BYPASS STRUCTURE

Flow bypass structures, sometimes called flow diverters or flow splitters, are often used for small-scale BMPs to prevent erosion of BMP surfaces or other modes of failure by diverting the WQv to the BMP and bypassing excess volume to another location. BMPs that typically require flow bypass structures include infiltration trenches and sand filters but they may also be used with other offline BMPs. Flow bypass structures can also be used upstream of the BMP to help reduce the size of BMP outlet control system or eliminate the need for it altogether.

Flow bypass structures can be designed for a desired volume or flow rate. A weir bypass structure, as shown in **Figures 4.1.7-7** and **4.1.7-8**, is designed to divert a given volume. All stormwater runoff is directed into the BMP, with overflow of the weir occurring when the WQv is exceeded, releasing the additional volume to the stormwater drainage system. Similarly, the bypass structure can be designed such that water backs up into the bypass structure as the water level in the BMP rises. A second outlet pipe with its invert at a higher elevation releases runoff as the WQv is exceeded. Computer modeling is recommended for the sizing and design of these structures and backwater conditions should be evaluated.

Flow bypass structures using flow rate as the controlling factor include a small diameter pipe, orifice, or similar hydraulic control device sized for the maximum water quality peak discharge that, when exceeded, directs any additional flow to the stormwater drainage system. **Figure 4.1.7-7** illustrates an example of this configuration assuming the outlet pipe to the BMP is sized to restrict flow. For these types of bypass structures, BMP outlet control systems must be provided as the BMP's capacity (volume) can be exceeded during low intensity storms.

Flow bypass structures are often prone to clogging which can result in roadway flooding. For this reason, flow bypass structures should be readily accessible for maintenance.

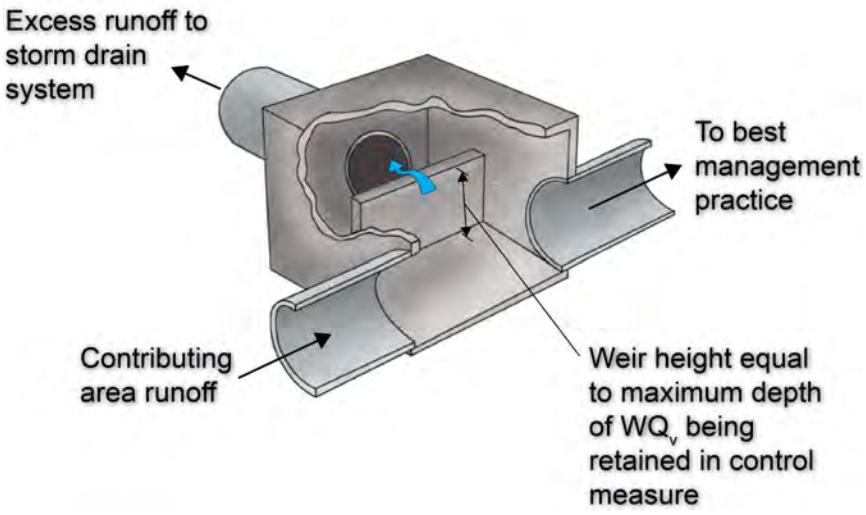


Figure 4.1.7-7 Commonly used flow bypass structure (adapted from GSMM Vol. 2)

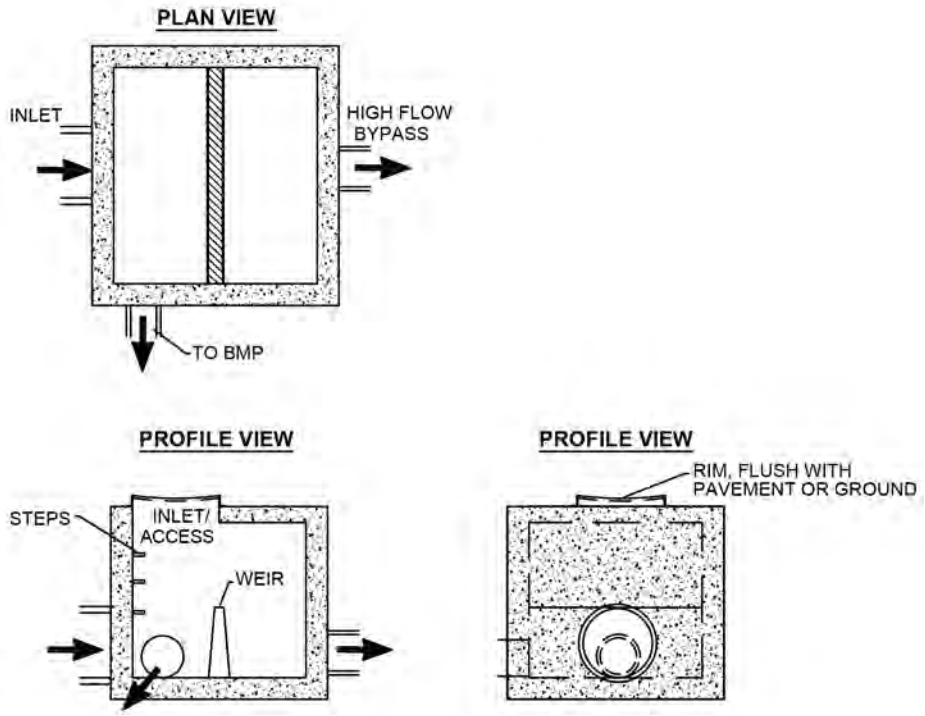


Figure 4.1.7-8 General schematic of flow bypass structure
(drawing courtesy of Tetra Tech)

4.1.7.3 UNDERDRAINS

Underdrains are perforated piping used to drain and discharge the treated stormwater from filtration BMPs. Underdrains, however, may also be included in infiltration-type BMPs as a safety measure to allow the BMP to drain in the event the BMP gets clogged or is not functioning as designed. If underdrains are provided for infiltration-type BMPs, the end at the outlet control structure shall be capped. Multiple branches of underdrain pipe may be utilized when needed. Spacing between branches should be no greater than 10 feet. The branches of the underdrain should come together within the BMP such that only one pipe enters the outlet structure or penetrates the embankment. Underdrains should generally be composed of a minimum 4-inch PVC, unless being utilized as pipe storage. Perforations are typically set at 3/8-inch diameter and spaced 6 inches on center with 4 rows running longitudinally while the pipe is placed at a minimum slope of 0.5%.

For the underdrain encasement, wash GDOT size No. 57 aggregate (or smaller) shall be used. Unless otherwise noted in the BMP specific design criteria, it is suggested that minimum dimensions of the encasement stone be 3 inches below the bottom of the pipe, 6 inches on each side of the pipe, and 6 inches above the top of the pipe.

Cleanouts should be provided at the end of each underdrain branch. Cleanouts should extend to an elevation that is appropriate for site conditions based on best professional judgment. Consideration should be given for possible inflow of stormwater should a cap become damaged or removed. Consideration should also be given to potential burial by sediment and damage by maintenance equipment.



Figure 4.1.7-9 Typical underdrain installation
(photo courtesy of NCDOT)

These criteria are typically sufficient to provide proper drainage for most BMPs; however, it is prudent to perform calculations to verify the underdrain is adequately designed. Darcy's law can be used to determine the maximum flow rate through the BMP's media. Manning's equation can then be used to verify adequate underdrain pipe diameter. Using the size, spacing, and configuration of the perforations, the orifice equation can be used to determine if the length of the underdrain pipe is sufficient. See **Figure 4.1.7-9** for an example of a typical underdrain installation.

4.1.7.4 CHOKER AND DRAINAGE LAYER

A choker layer is recommended to separate the soil media from the drainage layer. If a choker layer is used in the BMP design, it can be comprised of either a 2-3" layer of washed GDOT size No. 89 aggregate (or smaller) or a 6-inch layer of clean, washed sand. An alternative to aggregate or sand is a non-woven fabric material; however, this must be approved by Gwinnett County in advance.

Unless otherwise noted in the BMP specific design criteria, the drainage layer shall be comprised of a 6-inch layer of washed GDOT size No. 57 aggregate.

4.2 Bioretention Areas



Description: Shallow stormwater basin or landscaped area that utilizes engineered soils or native, well-draining soil and vegetation to capture and treat runoff.

LID/GI Consideration: Low land requirement, adaptable to many situations, and often a small BMP used to treat runoff close to the source.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Maximum contributing drainage area of 5 acres
- Treatment area consists of ponding area, organic/mulch layer, planting media, and vegetation
- Requires landscaping plan
- Standing water has a maximum drain time of 24 hours
- Pretreatment is required to prevent clogging of underdrains or native soil
- Ponding depth should be a maximum of 12 inches, preferably 9 inches

ADVANTAGES / BENEFITS

- Applicable to small drainage areas
- Effective pollutant removals
- Appropriate for small areas with high impervious cover, particularly parking lots
- Natural integration into landscaping for urban landscape enhancement
- Good retrofit capability
- Can be planned as an aesthetic feature and meet local planting requirements

DISADVANTAGES / LIMITATIONS

- Requires landscaping
- Not recommended for areas with steep slopes
- Medium to high capital cost
- Medium cost maintenance burden
- Soils may clog over time (may require cleaning or replacing)

MAINTENANCE REQUIREMENTS

- Inspect and repair or replace treatment area components such as mulch, plants, and scour protection, as needed
- Ensure bioretention area is draining properly so it does not become a breeding ground for mosquitos
- Remove trash and debris
- Ensure mulch is 3-4 inches thick in the practice
- Requires plant maintenance plan

POLLUTANT REMOVAL

- 85% **Total Suspended Solids**
- 95% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 80/60% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 90% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Runoff Reduction**
- ✓ **Water Quality**
- ★ **Channel Protection**
- ★ **Overbank Flood Protection**
- ★ **Extreme Flood Protection**

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L **Land Requirement**
- M/H **Capital Cost**
- M **Maintenance Burden**

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes*

Soils: *Engineered soil media is composed of sand, fines, and organic matter*

Other Considerations: Use of native plants is recommended

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

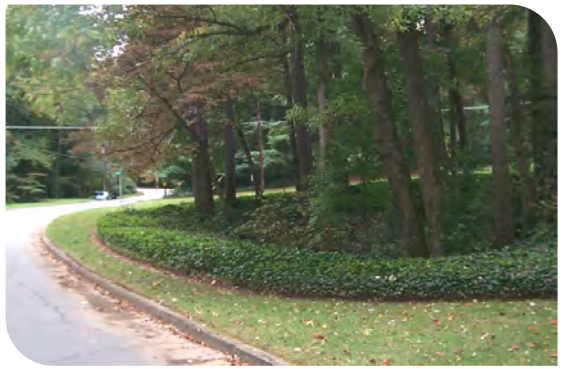
- 100% of the runoff reduction volume provided (no underdrain)
- 75% of the runoff reduction volume provided (upturned underdrain system)
- 50% of the runoff reduction volume provided (underdrain)

4.2.1 General Description

Bioretention areas are structural stormwater controls that capture and infiltrate, or at least temporarily store the water quality volume (WQ_v) using soils and vegetation in shallow basins or landscaped areas.

Bioretention areas are engineered controls that convey runoff to the "treatment area," which consists of a ponding area, organic or mulch layer, planting soil, and vegetation. If the native soils are adequate, the captured stormwater runoff will infiltrate into the surrounding soils. If not, the filtered runoff is typically collected and returned to the conveyance system, through an underdrain system. Bioretention areas slightly differ from rain gardens in that they are an engineered structure that has a larger drainage area and may include an underdrain. For additional information of designing a Rain Garden in a residential lot, see the following website: https://www.atlantawatershed.org/greeninfrastructure/atlanta-residential-gi-nov-2012022013/

There are numerous design applications for bioretention areas including along highway and roadway drainage swales, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments. A variety of bioretention areas are shown **Figure 4.2-1 through Figure 4.2-4.**









Left: **Figure 4.2-1** Landscaped Bioretention Area

Middle Left: **Figure 4.2-2** Landscaped Island

Bottom: **Figure 4.2-3** Bioretention Area near Parking Lot

Middle Right: **Figure 4.2-4** Bioretention Area after Storm

4.2.2 Stormwater Management Suitability

Bioretention areas can be designed for water quantity and quality, i.e. the removal of stormwater pollutants, depending upon the native soils. Bioretention areas can provide runoff quantity control, particularly for smaller runoff volumes such as those generated by the water quality storm event (1.2 inches). These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, bioretention areas will typically need to be used in conjunction with another control to provide channel protection, as well as overbank flood protection. Bioretention areas need to be designed and maintained to safely bypass higher flows.

- Runoff Reduction
  Bioretention areas are one of the most effective low impact development (LID) practices that can be used in Georgia to reduce post-construction stormwater runoff and improve stormwater runoff quality. Like other LID practices, they become even more effective with a higher infiltration rate of native soils. A bioretention area, with no underdrain, can be designed to provide 100% of the runoff reduction volume, if properly maintained. In order to provide runoff reduction for a bioretention area that is designed without an underdrain, a soils test or other reliable resource must indicate that the ponding area of the bioretention area will drain within 24 hours and entire bioretention area will drain within 72 hours. A bioretention area can be designed with an upturned underdrain to provide 75% of the runoff reduction volume, if properly maintained. An upturned underdrain is recommended in decent subsoils due to the clogging potential created during construction. Finally a bioretention area can be designed with an underdrain to provide 50% of the runoff reduction volume, if properly maintained.

- Water Quality
  A bioretention area is an excellent stormwater treatment practice due to its variety of pollutant removal mechanisms. Each of the components of the bioretention area is designed to perform a specific function. The grass filter strip (or grass channel) pre-treatment component reduces incoming runoff velocity and filters particulates from the runoff. The ponding area provides for temporary storage of stormwater runoff prior to its evaporation, infiltration, or uptake and provides additional settling capacity. The organic or mulch layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The planting soil in the bioretention area acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants and also serve to stabilize surrounding soils.

- Channel Protection
  For smaller sites, a bioretention area may be designed to capture the entire channel protection volume (CP_v). Given that a bioretention area facility is typically designed to completely drain over 48-72 hours, the requirement of extended detention for the 1-year, 24-hour storm runoff volume will be met. For larger sites, or where only the WQ_v is diverted to the bioretention area, another control must be used to provide CP_v extended detention.

- Overbank Flood Protection
  Another control in conjunction with a bioretention area will likely be required to reduce the post-development peak flow of the 2-25-year storms (Q_p) to pre-development levels (detention).

- Extreme Flood Protection
  Bioretention areas must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the ponding area, mulch layer and vegetation.

Credit for the volume of runoff reduced in the bioretention area may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide Runoff Reduction for Water Quality compliance, then the practice is given credit for Channel Protection and Flood Control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.2.3 Pollutant Removal Capabilities

Bioretention areas are presumed to be able to remove 85% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Other pollutants bioretention areas can remove include Phosphorus, Nitrogen, metals (such as Cadmium, Copper, Lead, and Zinc), and Pathogens (such as Fecal Coliform). A bioretention area that is undersized, poorly designed, or maintained improperly can have reduced pollutant removal performance. Proper design of the bioretention area is critical to ensure that pollutants can be properly removed from stormwater that drains into the ground or storm sewer system. Proper designs improve the quality of our environment. One of the benefits of using an Upturned Underdrain (see **Figure 4.2-6**) is that this particular type of design will increase the removal of nitrogen in the soil.

For additional information and data on pollutant removal capabilities for bioretention areas, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.2.4 Application and Site Feasibility Criteria

Bioretention areas are suitable for many types of development, from single-family residential to high-density commercial projects. Because of its ability to be incorporated in landscaped areas, the use of bioretention areas is extremely flexible whether they are placed along roadways or in areas undergoing development or re-development. Bioretention areas are an ideal stormwater control for use as roadway median strips and parking lot islands and are also good candidates for the treatment of runoff from pervious areas, such as a golf course. Bioretention areas can also be used to retrofit existing development with stormwater quantity and quality treatment capacity. Curbs are not required for this type of practice.

Because of the many design constraints including limited ponding depths and inlet velocities, bioretention areas generally have a maximum drainage area of 5 acres or less. The size of the bioretention area is generally 3-6% of the contributing drainage area but varies significantly depending on each component of the bioretention area's ability to capture and infiltrate stormwater runoff and the percent imperviousness of the drainage area.

The following criteria shall be evaluated to ensure the suitability of a bioretention area for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – 5 acres or less. If the drainage area is greater than 5 areas, the drainage area can be divided up into multiple areas with each drainage area having a bioretention area.
- **Space Required** – Rough rule of thumb of 3-6% of the contributing drainage area
- **Site Slope** – Slopes shall be a maximum of 20%, 5% preferred
- **Minimum Depth to Water Table** – A minimum separation distance of 2 feet is required between the bottom of the bioretention area and the elevation of the seasonally high water table.
- **Soils** – Native soils if they have at least 0.5 inch/hr infiltration ability. Otherwise engineered media is needed including coarse sand, silt, clay, and other organic matter. The recommended standard media depth is 36 inches, with a minimum depth of 18 inches and a maximum depth of 48 inches. A qualified, licensed professional should test the soils to determine the best depth of soil for the practice.

Other Constraints / Considerations

- **Hot spots** – Do not use for hot spot runoff.
- **Damage to existing structures and facilities** – Consideration shall be given to the impact of water exfiltrating the bioretention areas on nearby road bases.
- **Proximity** – The following is a list of specific setback requirements for the location of a bioretention area:
  - » 10 feet from building foundations
  - » 100 feet from private water supply wells
  - » 200 feet from public water supply reservoirs (measured from edge of water)
  - » 1,200 feet from public water supply wells
- **Trout Stream** – Evaluate for stream warming when an underdrain system is used.

In addition, careful consideration should be given to the potential of perched or raised groundwater levels. Provide adequate distance from building foundations or use impermeable liner on side of excavated area nearest to structure.

- **Poorly Drained Soils**—This condition minimizes the ability of bioretention areas to reduce stormwater runoff rates and volumes. One solution would be to include an underdrain system. An alternative would be to use a small stormwater wetlands or wet swales to intercept and treat stormwater runoff.
- **Flat Terrain**—May be difficult to provide adequate drainage so multiple smaller bioretention areas may be needed.
- **Shallow Water Table**—This can prevent the provision of 2 feet of clearance between the bottom of the bioretention area and the top of the water table which may cause stormwater runoff to pond in the bioretention area. Possible solutions are to minimize the depth of the planting media, or consider using stormwater ponds, wetlands, or wet swales to intercept and treat stormwater runoff.
- **Karst topography**—This condition usually warrants the use of an underdrain or impermeable liner to avoid infiltration into karst subsoils.

4.2.5 Planning and Design Criteria

Before designing the bioretention area, the following data is necessary:

- Existing and proposed site, topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.
- Infiltration testing of native soils at proposed elevation of bottom of bioretention area.

The following criteria are to be considered minimum standards for the design of a bioretention area. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.2.5.1 LOCATION AND LAYOUT

Bioretention areas vary based on site constraints such as proposed and existing infrastructure, soils, existing vegetation, contributing drainage area, and utilities. Bioretention area systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events. They shall not be used on sites with a continuous flow from groundwater, sump pumps, or other sources. Bioretention area locations shall be integrated into the site planning process and aesthetic and maintenance considerations shall be taken into account in their siting and design. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth and velocity.

4.2.5.2 GENERAL DESIGN

- A bioretention area consists of the following:
  1. A pretreatment area, usually consisting of a grass filter strip between the contributing drainage area and the ponding area or a forebay to ease maintenance of the mulch, sand, or soil layers.
  2. Ponding area containing vegetation with an engineered planting media.
  3. Organic/mulch layer to protect planting media.
  4. Native soils to infiltrate the treated runoff, (see description of infiltration trenches, Section 4.12, for infiltration criteria).
  5. Where native soils have low infiltration rates include gravel and perforated pipe underdrain system to collect runoff that has filtered through the soil layers and pipe it to the storm sewer system. An upturned underdrain system can be used, however, the system should be 12-18" below the bottom of the planted area to reduce saturated conditions in root zone.
  6. Overflow, diversion or bypass structure to safely route larger storms through or around the bioretention area.
- A bioretention area design may include some of the following:
  - » Optional level spreader to spread and filter runoff.
  - » For curbed pavements use an inlet deflector to direct flow into the practice.
  - » A splash/erosion prevention pad at the inlet to the practice.

See **Figure 4.2-5** and **Figure 4.2-6** for an overview of the various components of a bioretention area.

4.2.5.3 PHYSICAL SPECIFICATIONS/GEOMETRY

- Recommended minimum dimensions of a bioretention area are 3-6% of the total drainage area, though modeling is recommended to accurately size the area.
- The maximum recommended ponding depth of the bioretention areas is 12 inches.
- Adequate pretreatment is required. See 4.2.5.4 Pretreatment/Inlets for details. A grass filter strip or channel can be used for pretreatment. The length of the grass channel or width of the grass filter strip depends on the drainage area, land use, and channel slope. Design guidance on grass channels for pretreatment can be found in Section 4.9 (Grass Channel) and filter strips can be found in Section 4.29 (Vegetated Filter Strip). A pea gravel diaphragm flow spreader can also be used.
- The mulch layer should consist of 3 to 4 inches of triple-shredded hardwood mulch. This provides additional benefits such as removing sediment and metals and retaining soil moisture.
- If the native soils cannot suffice for the planting media used within the bioretention area planting beds, then an engineered soil mix shall be provided that meets the following specifications:
  - » **Texture**: Sandy loam or loamy sand
  - » **Sand Content**: Soils shall contain 35%-60% clean, washed sand
  - » **Topsoil Content**: Soils shall contain 20%-30% topsoil
  - » **Organic Matter Content**: Soils shall contain 10%-25% organic matter
  - » **Clay:** Soils shall contain less than 15%
  - » **Infiltration Rate**: Soils shall have an infiltration rate of at least 0.50 inches per hour (in/hr), although an infiltration rate of between 2 and 4 in/hr is preferred
  - » **Phosphorus Index (P-Index)**: Soils shall have a P-Index of less than 30
  - » **Exchange Capacity (CEC):** Soils shall have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight
  - » **pH**: Soils should have a pH of 6-8

For additional information on the soils for a Bio-retention Area, refer to Appendix D.

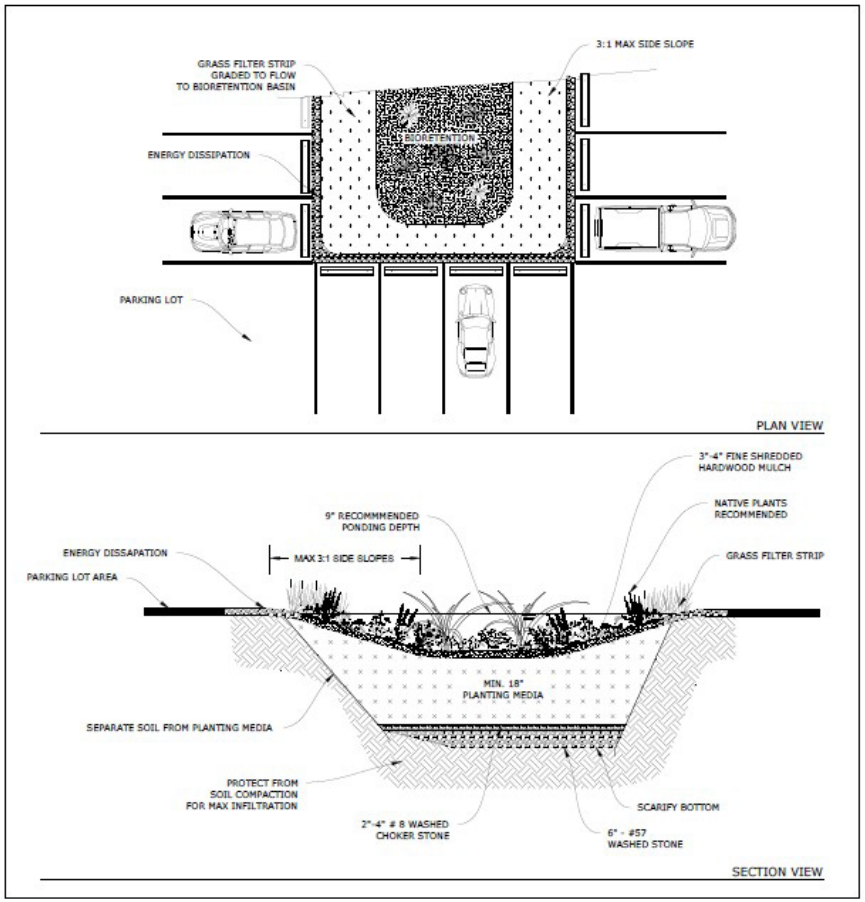


Figure 4.2.-5 Schematic of Typical Bioretention Area Without an Underdrain
(Source: AECOM 2015)

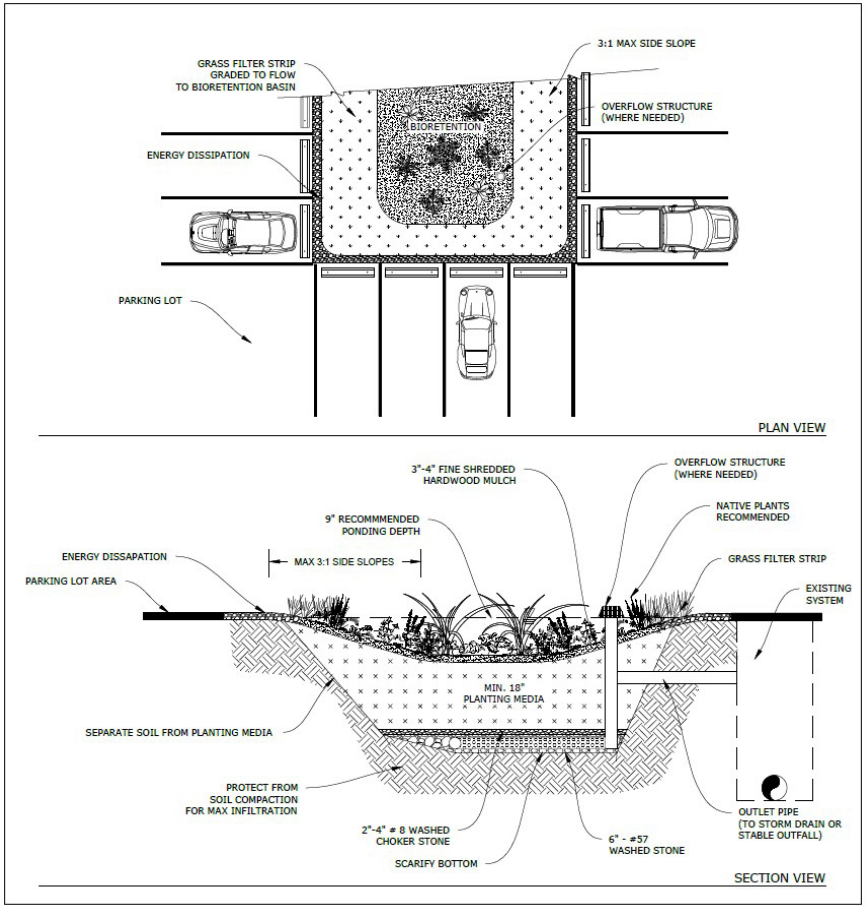


Figure 4.2.-6 Schematic of a Typical Bioretention Area with an Upturned Underdrain
(Source: AECOM, 2015)

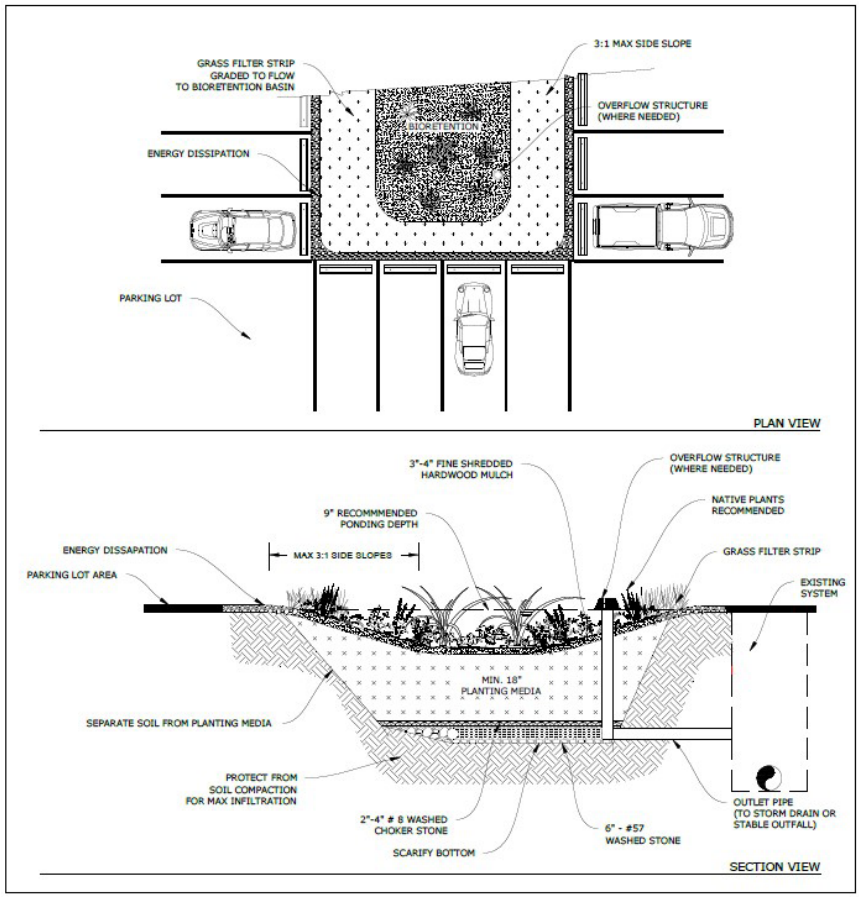


Figure 4.2.-7 Schematic of a Typical Bioretention Area with Underdrain
(Source: AECOM, 2015)

It is recommended that the underdrain collection system, to monitor the internal water levels, should be equipped with a 4-6-inch perforated PVC pipe (AASHTO M 252). The pipe should have 3/8-inch perforations, spaced at a minimum of 6-inch centers, with a minimum of 4 holes per row. The pipe is spaced at a maximum of 10 feet on center and a minimum grade of 0.5% must be maintained. Should the size of the pipe need to be bigger, a qualified licensed professional should model the area to ensure the size of the pipe is sufficient. It is recommended to separate the stone and the soil in the practice. This can be done by placing a permeable geotextile fabric between the gravel layer and the planting media. Alternatively, a stone choker layer 2-3 inches deep of #89 stone could be used to separate the practice from the soil. It is recommended that a qualified licensed professional be consulted to determine how this should be done based on the native soils and other physical properties around the practice.

4.2.5.4 PRETREATMENT/INLETS

- Adequate pretreatment is provided when a forebay, grass filter strip, or grass channel is provided.
- Inlet protection shall be designed to reduce the velocity and energy of stormwater entering the practice and prevent scour of the mulch and plantings. Inlet protection may include splash blocks, a stone diaphragm, a level spreader or another similar device.

4.2.5.5 OUTLET STRUCTURES

- Outlet structures shall be included in the design of a bioretention area configuration to ensure that larger storms can be bypassed without damaging the practice. Exceptions include small bioretention areas with flow bypass structures. Outlet configurations can include riser boxes and/or emergency spillway channels.

4.2.5.6 SAFETY FEATURES

- Bioretention areas generally do not require any special safety features, provided side slopes are maintained at 3:1 or flatter. Fencing of bioretention area facilities is not generally desired.

4.2.5.7 LANDSCAPING

- Landscaping is critical to the performance and function of bioretention areas; the vegetation filters and transpires runoff and the root systems encourage infiltration.
- Vegetation should be selected to match the look and maintenance effort desired by locals and those responsible for maintaining the facility.
- The bioretention area should be vegetated to resemble a terrestrial forest ecosystem, with a mature tree canopy, subcanopy of understory trees, shrub layer, and herbaceous ground cover. Three species each of trees, shrubs, and grass/herbaceous species should be planted to avoid creating a monoculture. When determining what trees should be planted in the bioretention area, remember that tree leaves can clog the bioretention area. Consider using trees that only drop their leaves once in the fall.
- Woody vegetation should not be specified at inflow locations.
- Plants should be installed prior to mulch.
- Choose plants based on factors such as whether they are native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Planting recommendations for bioretention area facilities are as follows:
  - » Native plant species should be preferred over non-native species.
  - » Vegetation should be selected based on a specified zone of hydric tolerance.
  - » A selection of trees with an understory of shrubs and herbaceous materials should be provided.
- Additional information and guidance on the appropriate woody and herbaceous species appropriate for bioretention areas in Georgia, and their planting and establishment, can be found in Appendix D.

4.2.5.8 CONSTRUCTION CONSIDERATIONS

- Construction equipment should be restricted from the bioretention area to prevent compaction of the native soils.
- A dense and vigorous vegetative cover must be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Otherwise the sediment from the stormwater runoff will clog the pores in the planting media and native soils.

4.2.5.9 CONSTRUCTION AND MAINTENANCE COSTS

- A budget level construction cost estimate is between $3.00 and $10.00 per square foot.
- A budget level maintenance cost estimate is between $1.50 and $3.50 per square foot annually.

4.2.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a bioretention area.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for an bioretention area. Create a rough layout of the bioretention area dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the bioretention area.**

Consider whether the bioretention area is intended to:

- » Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A. **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- » Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- » Provide a possible solution to a drainage problem
- » Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_v calculated above, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)

RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the bioretention area, use the following equation:

$$VP = (PV + VES (N))$$

Where:

VP = Volume provided (temporary storage)

PV = Ponding Volume

VES = Volume of Engineered Soils

N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pre-treatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met

When the VP $\geq$ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_v treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)
A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B) If using the practice for Water Quality treatment, determine the footprint of the bioretention area practice and the pretreatment volume required

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d) below:

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

To determine the minimum surface area of the bioretention area, use the following formula:

$$A_f = (WQ_v)\ (d_f) / [\ (k)\ (h_f + d_{f)})\ (t_f)]$$

Where:

A_f = surface area of ponding area (ft^2)
WQ_v = water quality volume (ft^3)
d_f = media depth (ft)
k = coefficient of permeability of planting media (ft/day) (use 1 ft/day for silt-loam if engineered soils is being used)
h_f = average height of water above bioretention area bed (ft)
t_f = design planting media drain time (days) (1 day is recommended maximum)

(Step 5) Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (2-25-yr, 24-hour storms), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 or Appendix B-2 for a detailed bioretention area design example

(Step 6) Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v (or RR_v) to the bioretention area.

Size low flow orifice, weir, or other device to pass Q_{wq}.

(Step 7) Size underdrain system

See Subsection 4.2.5.3 (*Physical Specifications/Geometry*)

(Step 8) Design emergency overflow

An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year storm event.

(Step 9) Prepare Vegetation and Landscaping Plan

A landscaping plan for the bioretention area should be prepared to indicate how it will be established with vegetation. See Subsection 4.2.5.7 (*Landscaping*) and Appendix D for more details.

See Appendix B-2 for a Bioretention Area Design Example

4.2.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.3 Bioslope



Description: Specialized media filtration BMP typically used in longitudinal applications to treat stormwater along an impervious area (road, parking lot, etc.).

LID/GI Consideration: Adaptable to many linear situations, and often a small BMP used to treat runoff close to the source.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Longitudinal slopes must be less than 5%
- Minimum 2 foot width
- Side slopes 3:1 or flatter; 4:1 recommended
- Length is usually the length of adjacent paved area being treated
- Sized to capture the water quality peak flow rate of discharge
- Pretreatment most commonly provided through a filter strip

ADVANTAGES / BENEFITS

- Requires minimal land
- Reduces runoff volume and velocity

DISADVANTAGES / LIMITATIONS

- Limited to sheet flow uses only
- Not suitable for embankment slopes steeper than 3:1
- Does not meet quantity control stormwater requirements

MAINTENANCE REQUIREMENTS

- Avoid damaging or rutting the permeable soil layer when mowing grass
- Remove sediment and debris from filter strip and adjacent areas

POLLUTANT REMOVAL

- 85% **Total Suspended Solids**
- 75% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 60/25% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 60% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- M Capital Cost
- M Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *No*
Drainage Area: *Contributing* upstream flow must be less than 150 feet

Soils: *No restrictions*

Other Considerations: Permeable soil layer

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- HSG A & B: 50% of the runoff reduction volume provided
- HSG C & D: 25% of the runoff reduction volume provided

4.3.1 General Description

Bioslopes (also referred to as ecology embankments) are water quality best management practices that use a permeable engineered soil media to capture and treat stormwater runoff from adjacent paved areas (see **Figure 4.3-1**). Bioslopes are typically installed along embankments or other slopes and designed to treat sheet flow stormwater runoff.

Bioslopes are designed with limited longitudinal slopes to force the flow to be slow and uniform, thus allowing for particulates to settle and limiting the effects of erosion. Once infiltrated into the highly permeable engineered soil layer, an underdrain is typically used to remove the treated stormwater from the embankment or slope. Larger flow rates, from less frequent storm events, in the form of sheet flow bypass the engineered soil media by overtopping and continuing down the embankment or slope.

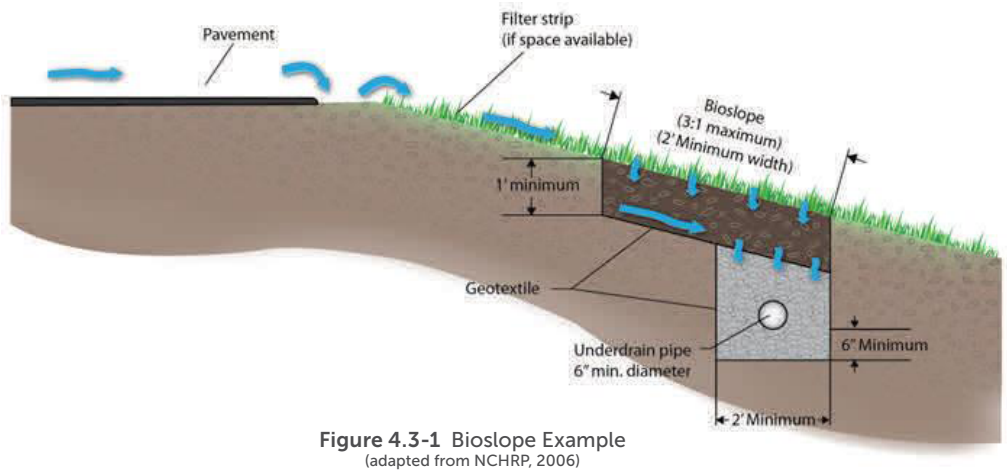


Figure 4.3-1 Bioslope Example
(adapted from NCHRP, 2006)

4.3.2 Stormwater Management Suitability

Bioslopes are designed primarily for stormwater quality and have only a limited ability to provide a small amount of channel protection volume.

- Runoff Reduction
  Bioslopes are an effective low impact development (LID) practice that can be used in Georgia to reduce post-construction stormwater runoff and improve stormwater runoff quality. Like other LID practices, they become even more effective the higher the infiltration rate of the native soils. Bioslopes can be designed to provide 50% of the runoff reduction volume for type A and B hydrologic soils or 25% of the runoff reduction volume for type C and D hydrologic soils.

- Water Quality
  Bioslopes rely primarily on filtration through an engineered media to provide removal of stormwater contaminants. The pretreatment component, commonly a vegetated filter strip, is most effective at sediment/debris removal, whereas the engineered media is capable of removing other pollutants. Subsection 4.3.3 provides median pollutant removal efficiencies that can be used for planning and design purposes.

- Channel Protection
  Generally, only the WQ_v is treated by a bioslope, so another BMP must be used to provide CP_v extended detention. However, for some smaller sites, a bioslope could provide some benefit towards detaining a portion of the full CP_v.

- Overbank Flood Protection
  Bioslopes do not provide stormwater quantity control and should be designed to safely pass overbank flood flows. Another BMP must be used in conjunction with a bioslope to reduce the post-development peak flow of the 25-year storm (Q_{p25}) to pre-development levels (detention).

- Extreme Flood Protection
  Bioslopes do not provide stormwater quantity control and should be designed to safely pass overbank flood flows. Another BMP must be used in conjunction with a bioslope to reduce the post-development peak flow of the 100-year storm (Q_f) to pre-development levels (detention).

4.3.3 Pollutant Removal Capabilities

Bioslopes are presumed to be able to remove 85% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed bioslopes can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- *Total Suspended Solids* – 85%
- *Total Phosphorus* –60%
- *Total Nitrogen* –25%
- *Fecal Coliform* – 60%
- *Heavy Metals* – 75%

For additional information and data on pollutant removal capabilities for bioslopes, see research and testing results from the Washington State Department of Transportation and published removal rates from a synthesis performed by the National Cooperative Highway Research Program.

4.3.4 Application and Feasibility Criteria

Bioslopes can be used in a variety of development types; however, they are primarily applicable to linear roadway applications where a rural (no curb and gutter) cross section is utilized. The impervious cover in the contributing drainage area is relatively small, and consists of paved areas adjacent to the embankment or slope where the practice has been installed.

Since bioslopes require a relatively small amount of land, they are more commonly selected when right-of-way availability is limited. Other practices that would be required at the bottom of the embankment or slope, such as enhanced swales or grass channels, most always require a larger amount of land. Bioslopes may not be desirable in some more aesthetically landscaped or sodded areas, due to the need for keeping the media layer free and clear of plantings and other obstructions. Only when the same infiltration rate of the media could be preserved, can grass be planted directly on top of the engineered media. This may include frequently maintained "half-cut" sod or similar vegetation.

The topography and location of a site will determine the applicability of the use of bioslopes. Overall, the topography should allow for the design of a bioslope with sufficient slope and cross-sectional area to maintain non-erosive velocities.

The following criteria should be evaluated to ensure the suitability of a bioslope for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – Contributing upstream flow must be less than 150 feet
- **Space Required** – N/A
- **Site Slope** – Typically no more than 5%
- **Minimum Head** – N/A
- **Minimum Depth to Water Table** – 2 feet required between the bottom of the media layer and the elevation of the seasonally high water table
- **Soils** – Engineered media

Other Constraints / Considerations

- **Aquifer Protection** – Exfiltration should not be allowed in hotspot areas

4.3.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a bioslope. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

4.3.5.1 LOCATION AND LAYOUT

- A bioslope should be sited such that the topography allows for the design with sufficiently mild slope and cross-sectional area to maintain non-erosive velocities.
- Bioslopes should have a maximum contributing upstream flow length of 150 feet, or less.

4.3.5.2 GENERAL DESIGN

- Bioslopes are designed to treat the WQ_v through a flow rate-based design, and to safely pass larger storm flows by checking velocities. Flow enters the bioslope via sheet flow through a pretreatment filter strip area, or a minimum 2 foot wide grass strip.
- A bioslope consists of a permeable soil mixture that overlays an underdrain system. Flow enters the media layer where it is filtered through the soil bed. Runoff is collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. **Figure 4.3-2** provides a schematic for typical components of a bioslope.

The following equation and variables are used for the sizing of a bioslope:

$$W = \frac{C\ Q_{wq}\ SF}{KL}$$

Where:

W = bioslope width (parallel with flow path) (feet)
C = conversion factor = 43,200 [(in/hr)/(ft/s)]
Q_{wq} = water quality volume peak flow (ft^3/s, refer to Subsection 3.1.7.2)
SF = safety factor equal to 1 (unitless, typical throughout Georgia)
k = infiltration rate, use long-term infiltration rate of 10 (inches/hour)
L = bioslope length (perpendicular with flow path) (feet)

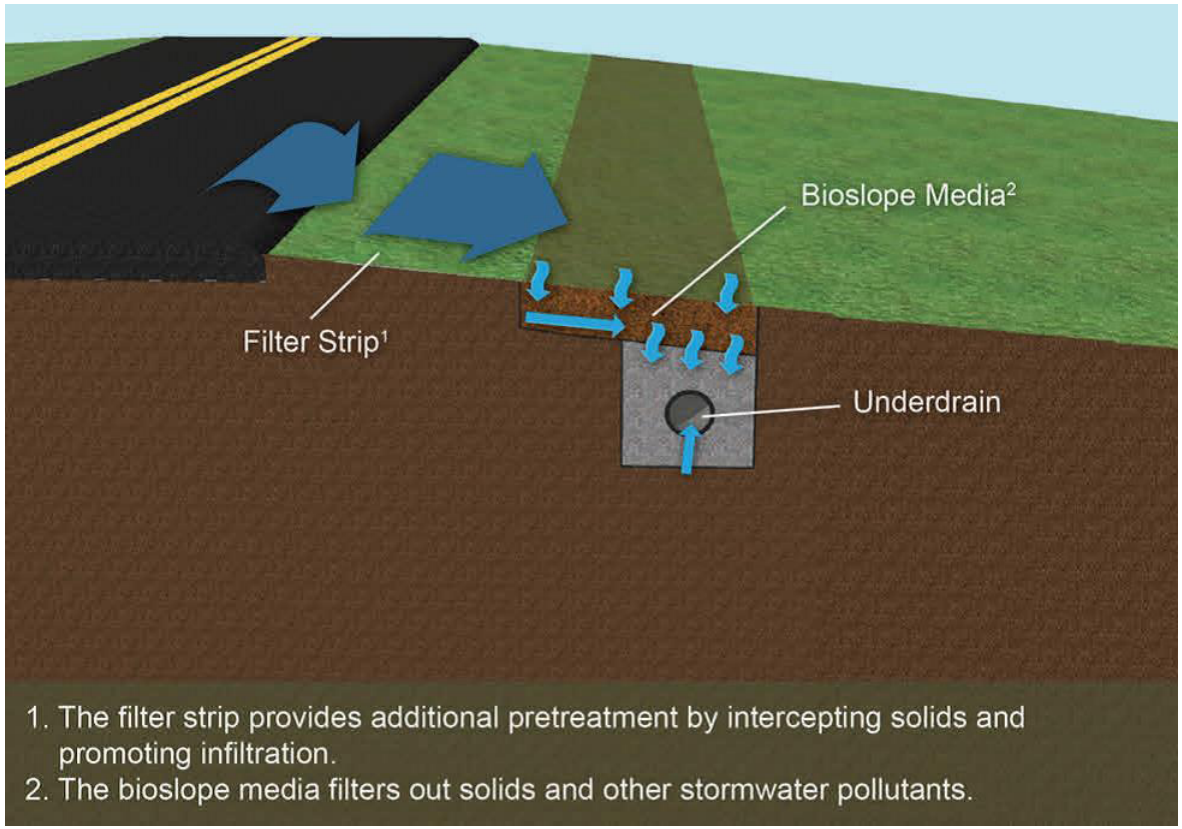


Figure 4.3-2 Schematic of Bioslope
(Source: GDOT Drainage Manual, 2014)

4.3.5.3 PHYSICAL SPECIFICATIONS/GEOMETRY

- Embankment slopes should be 3:1 or flatter. When slopes steeper than 4:1 are used, additional measures should be taken to ensure stabilization of vegetation along the slope.
- Longitudinal slopes (parallel with the embankment) should be no more than 5%.
- The area between the impervious surface, or paved area, should preferably be no more than 30 feet to avoid reconcentration of stormwater runoff creating erosion and scour through the engineered media.
- The bioslope consists of a permeable soil layer of at least 12 inches in depth, above an underdrain. The soil media should contain a mixture of crushed rock, dolomite, gypsum, and perlite as shown in **Table 4.3-1**. This mixture has an initial infiltration rate of 50 inches per hour and an infiltration rate of 28 inches per hour long-term. For sizing, an infiltration rate of 10 inches per hour is used in calculations as a factor of safety. A permeable filter fabric is placed between the media and underlying soil. Where an underdrain collection system is utilized, it should be equipped with at least a 6-inch diameter perforated PVC pipe longitudinal underdrain in a gravel layer.

Table 4.3-1 Bioslope Media Mixture

(Source: adapted from WSDOT, 2011)

Engineered Media Amendment	Quantity
Aggregate: » Washed #57 stone » No recycled material » Non-limestone material mineral aggregate	3 cubic yards (CY) (Note: 3 CY is used as a baseline for other mixture components; adjust total quantity based on bioslope dimensions)
Perlite: » Horticultural grade, free of any toxic materials » 0-30% passing US No. 18 Sieve » 0-10% passing US No. 30 Sieve	1 CY per 3 CY of mineral aggregate
Dolomite: $CaMg(CO_3)_2$ (calcium magnesium carbonate) » Agricultural grade, free of any toxic materials » 100% passing US No. 8 Sieve » 0% passing US No. 16 Sieve	10 pounds per CY of perlite
Gypsum: Non-calcined, agricultural gypsum $CaSO_4 \cdot 2H_2O$ (hydrated calcium sulfate) » Agricultural grade, free of any toxic materials » 100% passing US No. 8 Sieve » 0% passing US No. 16 Sieve	1.5 pounds per CY of perlite

4.3.5.4 PRETREATMENT/INLETS

- Where space allows, vegetated filter strips should be used as the pretreatment device for bioslopes. See Section 4.29 for more information on vegetated filter strips.
- Where space does not allow for a full width vegetated filter strip, a grassed area can still be used as pretreatment to the best extent possible.
- A pea gravel diaphragm can also be used for pretreatment where space constraints do not allow for enough of a grassed area between the bioslope and the paved surface.

4.3.5.5 OUTLET STRUCTURES

- The underdrain system should discharge to a storm drainage structure or a stable outfall.

4.3.5.6 EMERGENCY SPILLWAY

- Bioslopes must be adequately designed to safely pass flows that exceed the design storm flows.

4.3.5.7 MAINTENANCE ACCESS

- Adequate access should be provided for all bioslopes for inspection and maintenance.

4.3.5.8 LANDSCAPING

- Surrounding vegetation is typically a grassed or vegetated filter strip, Vegetation should be well established and thriving to prevent erosion and sedimentation.

4.3.5.9 ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- **Low Relief** – Ideal for embankment sheet flow conditions
- **High Relief** – Often infeasible if longitudinal slopes are greater than 5%
- **Karst** – No exfiltration of hotspot runoff from bioslopes; use impermeable liner

Soils

No additional criteria

Special Downstream Watershed Considerations

- **Aquifer Protection** – No exfiltration of hotspot runoff from bioslopes; use impermeable liner

4.3.5.10 CONSTRUCTION CONSIDERATIONS

- Construction equipment should be restricted from the bioslope area to prevent compaction of the native soils.
- A dense and vigorous vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into the bioslope. Otherwise the sediment from the stormwater runoff will clog the pores in the planting media and native soils.

4.3.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of an bioslope.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a bioslope. Create a rough layout of the bioslope dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the bioslope.**

Consider whether the bioslope is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A. **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Step 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_v calculated above, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)

RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) **Determine the storage volume of the practice and the Pre-treatment Volume**

To determine the actual volume provided in the bioslope, use the following equation:

$$VP = (PV + VES (N))$$

Where:

VP = Volume provided (temporary storage)

PV = Ponding Volume

VES = Volume of Engineered Soils

N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pre-treatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) **Determine whether the minimum storage volume was met**

When the VP $\geq$ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_v treatment method (See Step 4A).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)

1.2 = Target rainfall amount to be treated (inches)

R_V = Volumetric runoff coefficient which can be found by:

$$RV = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)

12 = Unit conversion factor (in/ft)

(Step 4B) If using the practice for Water Quality treatment, determine the length and width of the bioslope practice and the Pretreatment Volume required

Determine Bioslope Dimensions:

Refer to Subsection 3.1.7.2 and 3.1.7.5 to calculate the water quality volume peak flow rate using a reduced CN for any RR_V provided, then find either length or width using the equation in Subsection 4.3.5. In most applications, site restrictions limit the available length.

- » Longitudinal slope cannot exceed 5% (2 to 4% recommended)
- » Width should be a minimum of 2 feet
- » Ensure that side slopes are no steeper than 3:1 (4:1 recommended)

See Subsection 4.3.5.3 (*Physical Specifications / Geometry*) for more details

(Step 5) Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information

(Step 6) Size underdrain system

See Subsection 4.2.5.3 (*Physical Specifications/Geometry*)

4.3.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

Regular inspection and maintenance is critical to the effective operation of a bioslope as designed. Maintenance responsibility for a bioslope should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

4.4 Downspout Disconnects



Figure 4.4.1 Downspout Disconnect
Source: (Center for Watershed Protection)

Description: Where site characteristics permit, downspout disconnects can be used to spread rooftop runoff from individual downspouts across lawns and other pervious areas, where it is slowed, filtered and allowed to infiltrate into the native soils.

LID/GI Considerations: If properly designed, downspout disconnects can provide measurable reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Maximum length of flow path in contributing drainage areas is 75 feet
- Minimum length of flow path in pervious areas below downspout disconnects is 15 feet and equal to or greater than the length of the flow path in the contributing drainage area
- Maximum impervious rooftop drainage area to one disconnected downspout is 2,500 square feet
- Maximum slope of pervious area beneath the downspout is 6 percent
- Runoff must be conveyed as sheet flow from the downspout and across open areas to maintain proper disconnect
- Downspout disconnects should be designed to convey stormwater runoff away from buildings to prevent damage to building foundations

ADVANTAGES / BENEFITS

- Helps restore pre-development hydrology on development sites
- Reduces post-construction stormwater runoff rates, volumes and pollutant loads
- Relatively low construction cost and long-term maintenance burden
- Encourages groundwater recharge

DISADVANTAGES / LIMITATIONS

- Provides greater stormwater management benefits on sites with permeable soils (i.e., hydrologic soil group A and B soils)
- Level spreaders must be needed at the downspout to dissipate flow
- Clay soils or soils that have been compacted by construction equipment greatly reduce the effectiveness of this practice, and soil amendments may be needed

ROUTINE MAINTENANCE REQUIREMENTS

- Maintenance of areas receiving disconnected runoff is generally the same as that required for other lawn or landscaped areas.
- Areas receiving runoff should be protected from future compaction (e.g., by planting trees or shrubs along the perimeter).
- Gutters and downspouts should be kept clear of dirt, debris, vegetation, and other buildup.
- Downspout disconnects are often used in conjunction with other BMPs. Ensure that upstream and/or downstream BMPs are maintained in accordance with this manual.

POLLUTANT REMOVAL

- **80%** **Total Suspended Solids**
- **40%** **Metals** - Cadmium, Copper, Lead, and Zinc removal
- **25/25%** **Nutrients** - Total Phosphorus / Total Nitrogen removal
- **N/A** **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- **L** Land Requirement
- **L** Capital Cost
- **L** Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Not recommended*
Roadway Projects: *Not applicable*

Soils: *Disconnects should be directed over HSG A, B, or C (e.g., sands, sandy loams, loams).*

Other Considerations: Erosion and sediment control practices should not be located in vegetated areas receiving disconnected runoff. Construction vehicles and equipment should avoid areas receiving disconnected runoff to minimize disturbance and compaction.

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 50% of the RR_v conveyed to the practice (A & B hydrologic soils)
- 25% of the RR_v conveyed to the practice (C & D hydrologic soils)

4.4.1 General Description

As the name implies, a downspout disconnect is the most basic of all low impact development practices that can be used to "receive" rooftop runoff. Where site characteristics permit, they can be used to spread rooftop runoff from individual downspouts across lawns and other pervious areas, where it is slowed, filtered, and allowed to infiltrate into the soil. If properly designed, downspout disconnects can provide measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.

In order to use downspout disconnects to receive post-construction stormwater runoff, downspouts must be designed to discharge to a lawn or other pervious area (**Figure 4.4.2**). The pervious area located below the downspout disconnect should slope away from buildings and other impervious surfaces to prevent damage to building foundations and discourage rooftop runoff from entering the storm drain system.

The primary concern associated with a downspout disconnect (**Figure 4.4.3**) is the length of the flow path over the lawn or other pervious area below the disconnection point. To provide adequate residence time for stormwater runoff, the length of the flow path in the pervious area below a downspout disconnect should be equal to or greater than the length of the flow path of the contributing drainage area. If this cannot be accomplished, due to site characteristics or constraints, site planning and design teams should consider using other low impact development practices. A typical schematic for a downspout disconnect is shown in **Figure 4.4-3**.





Figure 4.4.2 Downspout Disconnects to Pervious Areas
(Source: Center for Watershed Protection)

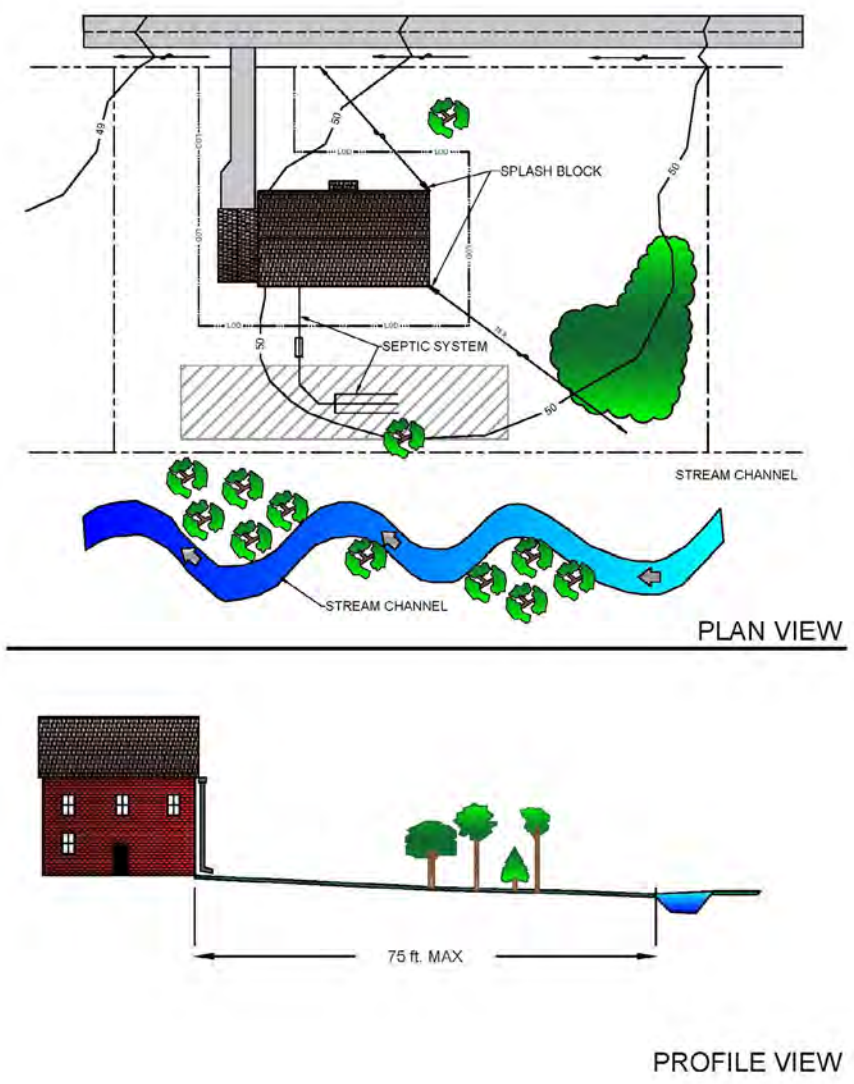


Figure 4.4-3 Schematic of Downspout Disconnect

4.4.2 Stormwater Management Suitability

- Runoff Reduction
  Runoff reduction credit can be applied to the stormwater runoff generated from the rooftop drainage area that drains to a properly designed, installed, and maintained downspout disconnect. As shown in **Table 4.1.3-2**, the runoff reduction volume (RR_v) conveyed through a downspout disconnect located on A/B or amended soils is reduced by 50%. Reduce the RR_v conveyed through a downspout disconnect located on C/D soils by 25%.

- Water Quality
  If installed as per the recommended design criteria and properly maintained, 80% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the disconnected downspout.

- Channel Protection
  No channel protection volume (CP_v) storage is provided by a disconnected downspout. Stormwater runoff generated by the impervious rooftop area and pervious receiving area should be routed to a downstream regional BMP that provides storage and treatment of the CP_v. Proportionally adjust the post-development runoff curve number (CN) to account for the runoff reduction provided by a downspout disconnect for the contributing drainage area when calculating the channel protection volume for the regional BMP.

- Overbank Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a downspout disconnect for the contributing drainage area when calculating the overbank peak discharge (Q_{p25}) on a development site.

- Extreme Flood Protection
  No Extreme Flood Protection volume is provided by a downspout disconnect. Proportionally adjust the post-development runoff curve number (CN) to account for the runoff reduction provided by a downspout disconnect for the contributing drainage area when calculating the extreme peak discharge (Q_f) on a development site.

4.4.3 Pollutant Removal Capabilities

Downspout disconnects are presumed to remove 80% of the total suspended solids (TSS) in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Other pollutants that can be removed by downspout disconnects include Phosphorus, Nitrogen, and metals (such as Cadmium, Copper, Lead, and Zinc).

In order to provide the most efficient pollutant removal, downspout disconnects should be sized with the appropriate length, width, and slope. The maximum drainage area should not be exceeded, and rooftop runoff should enter the disconnected area as sheet flow to ensure proper pollutant removal.

For additional information and data on pollutant removal capabilities for downspout disconnects, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.4.4 Application and Site Feasibility Criteria

Downspout disconnects are ideal for residential, commercial, industrial, and municipal development projects where buildings are surrounded by fairly level lawn and grass areas. Planners, designers, and developers should ensure that the pervious area beneath the downspout is at least the same length as the flow path of the contributing runoff. Additionally, disconnected stormwater runoff should not be allowed to "reconnect", or flow across impervious areas, before reaching a downstream regional BMP or being discharged off-site.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – The contributing impervious rooftop drainage area should be 2,500 square feet or less per downspout. If the total rooftop area is greater than 2,500 square feet, the rooftop can be divided up into multiple drainage areas with each drainage area flowing to a separate, properly sized, downspout disconnect.
- **Space Required** – The length of the disconnect should be a minimum of 15 feet and equal to or greater than the contributing flow path length. The length of the flow path within the contributing drainage area should be 75 feet or less.
- **Site Slope** – Slope of the pervious area below the downspout should be a maximum of 6% and a minimum of 0.5% (1% to 5% is recommended).
- **Minimum Depth to Water Table** – Separation from the water table is not required for a downspout disconnect.
- **Soils** – Disconnects should be directed over HSG A, B, or C (e.g., sands, sandy loams, loams). Clayey soils or soils that have been compacted by construction equipment greatly reduce the effectiveness of this practice, such that soil amendments may be needed.

Other Constraints / Considerations

- **Hot spots** – May be used for hot spot runoff
- **Damage to existing structures and facilities** – Downspout disconnects should be designed to convey stormwater runoff away from buildings to prevent damage to building foundations
- **Proximity** – Downspout disconnects may be used without restriction near:
  - » Private water supply wells
  - » Open water
  - » Public water supply reservoirs
  - » Public water supply wells
- **Property Lines** – Downspout disconnects may be used near property lines; however, ensure that stormwater runoff is not redirected to cause additional flooding to another homeowner.
- **Trout Stream** – Downspout disconnects help treat stormwater for pollutants and reduce the volume and velocity of runoff. Therefore, downspout disconnects are an effective BMP for use where trout streams or other protected waters may receive stormwater runoff.
- **Poorly Drained Soils** – Downspout disconnects may be used with poorly drained soils; however, less runoff reduction will be provided in these cases.
- **Flat Terrain** – Downspout disconnects require minimal slope to treat and convey stormwater runoff; therefore, they may be used in areas of flatter terrain.
- **Shallow Water Table** – Downspout disconnects may be used with a shallow water table.

4.4.5 Planning and Design Criteria

Before designing the downspout disconnect, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- The proposed site design including, buildings, parking lots, sidewalks, stairs, handicapped ramps, and landscaped areas
- Architectural roof plan for rooftop pitches and downspout locations
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Information about downstream BMPs and receiving waters
- Design data from nearby storm sewer structures

The following criteria are to be considered minimum standards for the design of a downspout disconnect. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.4.5.1 LOCATION AND LAYOUT

- Downspout disconnects should be located where there is at least 15 linear feet of managed turf, grass, lawn, or landscaped area at the receiving end of the downspout.
- Disconnects should not be upstream of an impervious area, which will allow rooftop runoff to "reconnect". Locate disconnects upstream of vegetated or forested areas, regional BMPs, and/or stormwater drainage systems.
- The slope of the pervious receiving area should be between 0.5% and 6%, with 1% to 5% slopes being ideal.
- Ensure that the length of each disconnected area is equal to or greater than the contributing flow path of the rooftop runoff.
- The length of the contributing flow path should no greater than 75 feet.
- Rooftop runoff should enter the disconnected pervious area as sheetflow. Level spreaders should be used at the discharge end of the downspout to dissipate energy and spread out the flow.

4.4.5.2 GENERAL DESIGN

A level (0.5 % to 6% slope) managed turf, grass, lawn, or landscaped area at the receiving end of the downspout, between 15 and 75 feet long. Downspout disconnects can be constructed on HSG A, B, C or D soils.

4.4.5.3 LANDSCAPING

- Vegetation commonly planted in the pervious areas located below downspout disconnects includes turf, shrubs, trees, and other herbaceous vegetation. Although managed turf is most commonly used, site planning and design teams are encouraged to use trees, shrubs and/or other native vegetation to help establish mature native plant communities in the pervious areas located below downspout disconnects.
- Methods used to establish vegetative cover within the pervious area below a downspout disconnect should achieve at least 75 percent vegetative cover within one year of installation.
- To help prevent soil erosion and sediment loss, landscaping should be provided immediately after the downspout disconnect has been completed. Temporary irrigation may be needed to quickly establish vegetative cover within the pervious areas below downspout disconnects.

4.4.5.4 CONSTRUCTION CONSIDERATIONS

To help ensure that downspout disconnects are properly installed on a development site, planning and design teams should consider the following recommendations:

- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used within the pervious areas located below downspout disconnects.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of the pervious areas located below downspout disconnects during and after construction.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted within the pervious area located below a downspout disconnect.

4.4.5.5 CONSTRUCTION AND MAINTENANCE COSTS

Construction and maintenance of areas receiving disconnected runoff is generally no different than that required for other lawn or landscaped areas. Soil amendments may be required for downspout disconnects constructed on HSG C or D soils or on previously compacted areas, such as gravel driveways or grassed parking areas.

4.4.6 Design Procedures

(Step 1) **Determine the goals and primary function of the downspout disconnect.**

Consider whether the downspout disconnect is intended to:

- Meet a runoff reduction* target or water quality (treatment) target.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Provide a possible solution to a drainage problem.

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the downspout disconnect has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the downspout disconnect should be centered on the restrictions/requirements, goals, targets, and primary function(s) of a downspout disconnect. By considering the primary function, as well as, topographic and soil conditions, the design elements of the downspout disconnect can be determined (i.e. planting media, outlet, etc.).

(Step 2) **Determine if the development site and conditions are appropriate for the use of a downspout disconnect.**

Consider the application and site feasibility criteria in this chapter to determine if site conditions are suitable for a downspout disconnect. Ensure that the drainage area and ground surface slope do not exceed the maximum criteria. Calculate the drainage area flow path and determine if the disconnected pervious area is of equal or greater length. Finally, review the NRCS data and perform site and geotechnical investigations, if necessary, to determine soil type and condition.

Complete Steps 3A and 3B for a runoff reduction approach, or skip Step 3 and complete Step 4 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume.**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 3B) **If using the practice for Runoff Reduction, apply the BMP Runoff Reduction Credit to the Runoff Reduction Volume calculated in Step 3A.**

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the downspout disconnect – either 50% for HSG A/B soils, or 25% for HSG C/D soils. If the practice meets the 2500 square foot rooftop restriction, the minimum and maximum slope requirement, and the 15 – 75 foot flow path requirement then a credit of 50% or 25% (depending upon soil type) of the runoff volume to this practice is awarded. This volume reduction can be used to calculate a reduced CN for CP_v, Q_{p25}, and Q_f calculations.

Multiply the Runoff Reduction Credit by the Runoff Reduction Volume (RR_v)

$$RR_v \times \text{Runoff Reduction Credit (\%)} = RR_v \text{ (Credited)}$$

Where:

RR_v = Runoff Reduction Volume conveyed to the practice

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

RR_v (Credited) = Runoff Reduction Volume provided (ft^3)

(Step 4) **Calculate the Target Water Quality Volume.**

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)

1.2 = Target rainfall amount to be treated (inches)

R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)

12 = Unit conversion factor (in/ft)

(Step 5) **Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information.**

(Step 6) **Prepare a site vegetation and planting plan.**

A planting plan for the downspout disconnect area should be prepared to indicate how it will be established with vegetation.

See Subsection 4.4.5.3 (*Landscaping*) and Appendix D for more details.

4.4.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.5 Dry Detention Basins



Description: A surface storage basin or facility designed to provide water quality treatment and water quantity control through detention of stormwater runoff. Dry detention basins differ from dry extended detention (ED) basins (Section 4.6) in that they do not provide 24-hour detention of the channel protection volume (CP_v).

LID/GI Considerations: While dry detention basins are primarily used for storage and control of larger storm events, their use as a BMP contributes to a site's overall perviousness and aesthetics. The open grassed area of a dry detention basin can be used for multiple purposes, such as landscaped or recreational areas. Additionally, dry detention basins dissipate energy in the stormwater runoff it receives and provide opportunities for some sedimentation of suspended solids.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Embankments should be less than 20 feet in height and should have side slopes no steeper than 3:1 (horizontal to vertical).
- The depth of the basin should not exceed 10 feet.
- Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height.
- All embankments must be designed to State of Georgia guidelines for dam safety.
- Storage volumes greater than 100 acre-feet are subject to the requirements of the Georgia Safe Dams Act (Georgia Annotated Code 12-5-370) unless the facility is excavated to provide this volume.
- The dry detention basin bottom should be graded toward the outlet to prevent standing water conditions.
- The outfall(s) of dry detention basins should always be stabilized to prevent scour.
- An emergency spillway should be provided to safely convey large flood events.

ADVANTAGES / BENEFITS

- Moderate removal rate of urban pollutants
- High community acceptance
- Useful for water quality treatment and flood control
- Dry detention basins can serve multiple use purposes on a development site.

DISADVANTAGES / LIMITATIONS

- Potential for thermal impacts/downstream warming
- Dam height restrictions for high relief areas
- Detention basin drainage can be problematic for low relief terrain.

ROUTINE MAINTENANCE REQUIREMENTS

- Remove debris from inlet and outlet structures
- Maintain side slopes and outlet structure
- Remove invasive vegetation
- Monitor sediment accumulation and remove periodically

POLLUTANT REMOVAL

- 60% **Total Suspended Solids**
- 50% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 10/30% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ★ Water Quality
- ● Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- M **Land Requirement**
- L **Capital Cost**
- L **Maintenance Burden**

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Not recommended*
Roadway Projects: *Yes*

Soils: *Dry detention basins can be used with almost all soils and geology, with minor design adjustments for regions of karst topography or in rapidly percolating soils, such as sand.*

Other Considerations: In order to convey low flows through dry detention basins, designers should provide a pilot channel. Plantings on the bank of the detention pond to provide shade around the pilot channel and the basin outlet or designing the pilot channel as a grass channel can reduce thermal impacts.

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided

4.5.1 General Description

Dry detention basins are surface facilities intended to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts. These facilities temporarily detain stormwater runoff, releasing the flow over a period of time. They are designed to completely drain following a storm event and are normally dry between rain events. See **Figure 4.5-1** for a typical dry detention basin schematic.

Dry detention basins provide limited pollutant removal benefits and are not intended for runoff reduction. Detention-only facilities should be used in a treatment train approach with other BMPs that provide runoff reduction, additional water quality treatment, and channel protection (see Subsection 4.1.6).

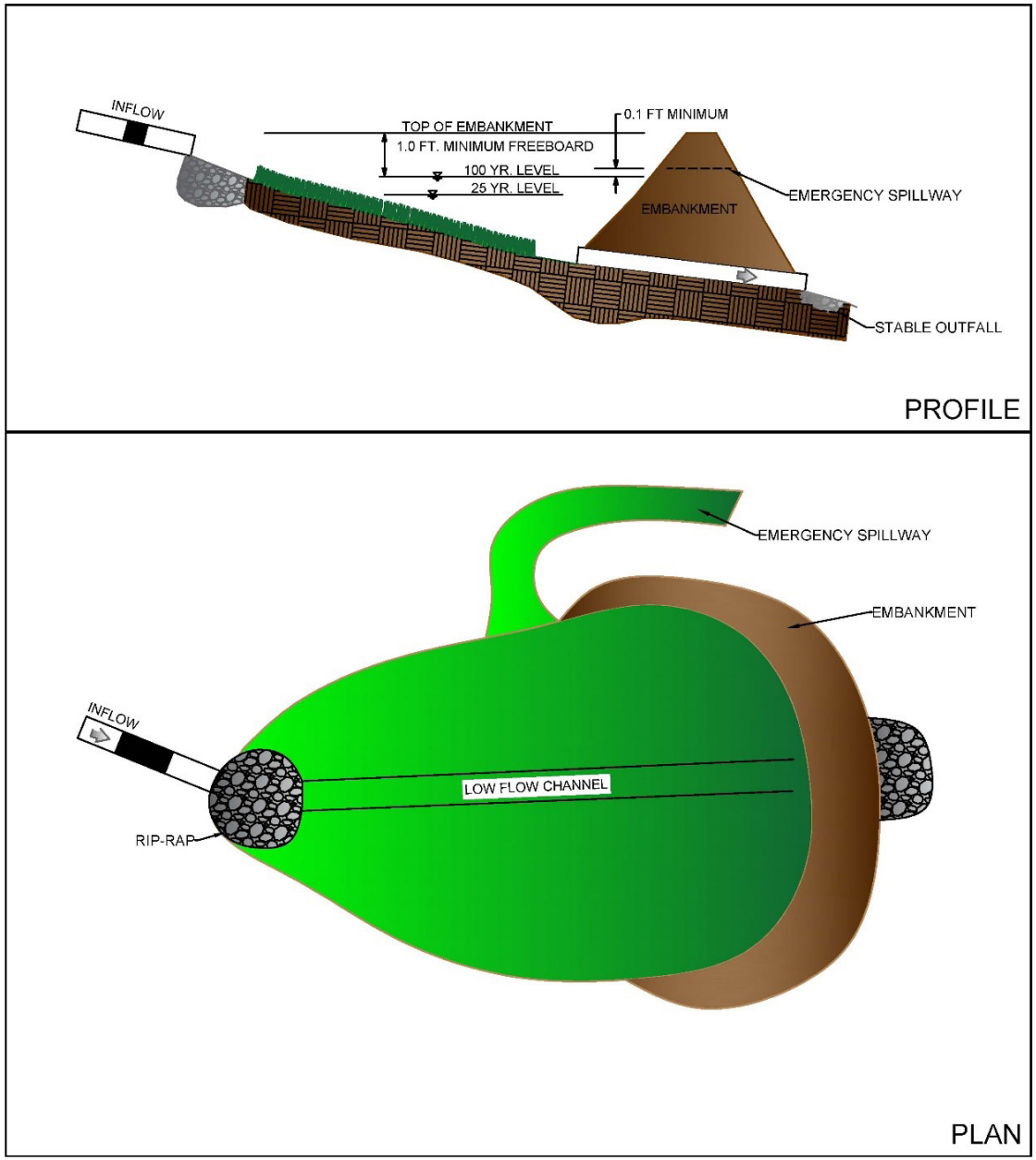


Figure 4.5-1 Schematic of Dry Detention Basin

4.5.2 Stormwater Management Suitability

- Runoff Reduction
  Another BMP should be used in a treatment train with dry detention basins to provide runoff reduction as they are not designed to provide RR_V as a stand-alone BMP.

- Water Quality
  If installed as per the recommended design criteria and properly maintained, 60% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the dry detention basin. Another BMP should be used in a treatment train with dry detention basins to provide the additional required water quality treatment.

- Channel Protection
  Dry detention basins are not generally used to store and treat the channel protection volume (CP_v). A dry extended detention basin (Section 4.6) should be used if the CP_v must be treated within the facility.

- Overbank Flood Protection
  Dry detention basins are intended to provide overbank flood protection (peak flow reduction of the 2-25-year storms, Q_{p2-25}).

- Extreme Flood Protection
  Dry detention basins can be designed to control the extreme flood (100-year, Q_f) storm event.

4.5.3 Pollutant Removal Capabilities

Dry detention basins are presumed to remove 60% of the total suspended solids (TSS) load in typical urban post development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Although they can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. Other pollutants that dry detention basins can remove include Phosphorus, Nitrogen, and metals (such as Cadmium, Copper, Lead, and Zinc).

For additional information and data on pollutant removal capabilities for dry detention basins, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.5.4 Application and Site Feasibility Criteria

Dry detention basins have traditionally been one of the most widely used stormwater BMPs. Dry detention basins can easily be designed for flood control, and this is actually the primary purpose of most detention basins in the ground today. However, if pollutant removal efficiency is an important consideration, then dry detention basins may not be the most appropriate choice.

The following criteria shall be evaluated to ensure the suitability of dry detention basins for meeting stormwater management objectives on a site.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **YES**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – In general, dry detention basins should be used on sites with a minimum drainage area of 10 acres.
- **Space Required** – Approximately of 2-3% of the contributing drainage area.
- **Site Slope** – Dry detention basins can be used on sites with slopes up to about 15%.
- Vegetated and rip rap embankments should be less than 20 feet in height and have side slopes no steeper than 3:1 (horizontal to vertical).
- **Minimum Depth to Water Table** – The base of the detention facility shall not intersect the groundwater table

- **Soils** – Dry detention basins can be used in almost all soils and geology, with minor design adjustments for regions of karst (i.e., limestone) topography or in rapidly percolating soils, such as sand. In these areas, detention basins should be designed with an impermeable liner to prevent groundwater contamination or sinkhole formation.

Other Constraints / Considerations

- **Hot spots** – Dry detention basins can accept runoff from stormwater hotspots, but need significant separation from groundwater when used for this purpose.
- **Damage to existing structures and facilities** – Dry Detention basins should be designed to safely store and/or bypass the overbank flood (Q_{p25}) and extreme flood (Q_f) storms to prevent overflow or failure, which may cause damage to site structures and facilities.
- **Proximity** – The following is a list of specific setback requirements for the location of a dry detention basin:
  - » 10 feet from building foundations
  - » 10 feet from property lines
  - » 100 feet from private water supply wells
  - » 100 feet from open water (measured from edge of water)
  - » 200 feet from public water supply reservoirs (measured from edge of water)
  - » 1,200 feet from public water supply wells
- **Trout Stream** – In cold water streams, dry detention basins should be designed to detain stormwater for a relatively short time (i.e., less than twelve hours) to minimize the potential amount of stream warming that occurs in the practice. In addition, careful consideration should be given to the potential of perched or raised groundwater levels.
- **Poorly Drained Soils** – Poorly draining soils do not generally inhibit a dry detention basin's ability to temporarily store and treat stormwater runoff and completely drain between rain events, as the bottom of the BMP is sloped to provide for flow.
- **Flat Terrain** – The local slope should be relatively flat in order to maintain reasonably flat side slopes
- **Shallow Water Table** – Except for the case of hot spot runoff, the only consideration regarding ground water is that the base of the detention facility should not intersect the ground water table.

4.5.5 Planning and Design Criteria

Before designing dry detention basins, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as depth to the seasonally high groundwater level.

The following criteria are to be considered minimum standards for the design of a dry detention basin. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

4.5.5.1 LOCATION AND LAYOUT

Dry detention basins should be located downstream of other BMPs providing runoff reduction and/or additional treatment of the water quality volume (WQ_v). See Subsection 4.1.6 for more information on the use of multiple BMPs in a treatment train.

4.5.5.2 GENERAL DESIGN

- Dry detention basins are sized to provide storage and control for multiple rain events, including:
  - » Storage of the water quality volume (WQ_v);
  - » Temporary storage of the volume of runoff required to provide overbank flood (Q_{p25}) protection (i.e., reduce the post-development peak flow of the 2-25-year storm event to the pre-development rate);
  - » Control of the 100-year storm (Q_f), if required.
- Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 3.3 (*Storage Design*) for procedures on the design of detention storage.
- Storage volumes greater than 100 acre-feet are subject to the requirements of the Georgia Safe Dams Act (Georgia Annotated Code 12-5-370) unless the facility is excavated to this depth.
- No more than 50% of the basin perimeter may be a wall of any type unless a drive is provided to the bottom of the pond. The drive shall be a minimum of 15 feet wide with a maximum slope of 20%.
- If the developer desires to install a fence around a detention facility, it shall be a minimum 4-foot high fence of durable material, with a 12-foot wide access gate. The fence shall be contained within an easement and outside the detention facility's slopes and/or walls. This easement is for inspection purposes, more width may be necessary for maintenance purposes.

4.5.5.3 PHYSICAL SPECIFICATIONS/GEOMETRY

- Vegetated embankments should be less than 20 feet in height and shall have side slopes no steeper than 3:1 (horizontal to vertical). Riprap-protected embankments must also be no steeper than 3:1. Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to State of Georgia guidelines for dam safety.
- Dam heights greater than 25 feet or a storage volume greater than 100 acre-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated to this depth.
- The depth of the basin should not exceed 10 feet.
- Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions.
- Designing dry detention basins with a high length to width ratio (i.e., at least 1.5:1) and incorporating other design features to maximize the flow path effectively increases detention time by eliminating the potential of flow to short circuit the basin. Designing basins with relatively flat side slopes can also help to lengthen the effective flow path.
- While there is no minimum slope requirement, enough elevation drop is needed from the basin inlet to the basin outlet to ensure that flow can move through the system.
- A low flow or pilot channel across the facility bottom from the inlet to the outlet is recommended to convey low flows and prevent standing water conditions. To prevent stream warming, designers should place landscaping to provide shade around the pilot channel and the basin outlet. Designing the pilot channel as a grass channel also reduces thermal impacts. A minimum slope of 1% is recommended for grass swales and 0.5% for armored pilot channels.
- Maintenance access must be provided for all dry detention basins. The width of this maintenance access must be a minimum of 15 feet with a maximum slope of 5:1.

4.5.5.4 PRETREATMENT/INLETS

- Inflow channels are to be stabilized with flared aprons, or the equivalent.
- Pretreatment for a dry detention basin is usually provided by a sediment forebay. The sediment forebay should be sized to 0.1 inches of runoff per impervious acre of contributing drainage area for dry detention basins
- Pretreatment may also be provided by using a grass filter strip, pea gravel diaphragm, or grass channel. Where filter strips are used, 100% of the contributing runoff should flow across the filter strip. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

4.5.5.5 OUTLET STRUCTURES

- For a dry detention basin, the outlet structure is sized for Qp25 control (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. Small outlets that will be prone to clogging or difficult to maintain are not acceptable.
- If either the Water Quality (WQ) or the Channel Protection (CP) Orifice is less than 4.0 inches, use table below to set orifice diameter:

WQ/CP Orifice Diameter from Design (inches)	WQ/CP Orifice Diameter to use (inches)
0.50 < X < 0.75	0.50
0.75 < X < 1.00	0.75
1.00 < X <1.25	1.00
1.25 < X < 1.50	1.25
1.50 < X < 1.75	1.50
1.75 < X < 2.00	1.75
2.00 < X < 2.50	2.00
2.50 < X < 3.00	2.50
3.00 < X < 3.50	3.00
3.50 < X < 4.00	3.50

- Orifices smaller than 3 inches in diameter shall have internal orifice protection such as a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket. An orifice smaller than 15 inches in diameter shall be protected by a trash rack.
- Seepage control or anti-seep collars should be provided for all outlet pipes.
- Unless the 100-year maximum flow velocity in a conduit through a dam forming a pond or a lake is less than 10 feet per second, and the hydraulic grade line for the 100-year condition is at or below the crown of the conduit for at least 90 percent of its length, the conduit must be equal or superior to Class V reinforced concrete pipe in its structural characteristics.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.

4.5.5.6 SAFETY FEATURES

- An emergency spillway should be included in the dry detention basin design to safely pass the extreme flood flow. The spillway prevents basin water levels from overtopping the embankment and causing structural damage. The emergency spillway must be designed to State of Georgia guidelines for dam safety and located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1.5 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood, to the lowest point of the dam embankment, not counting the emergency spillway. A safety bench shall be provided for embankments greater than 10 feet in height and having a side slope steeper than 3:1. For large basins, the safety bench shall extend no less than 15 feet outward from the normal water edge to the toe of the basin side slope. The slope of the safety bench shall not exceed 6%.
- Stormwater should be conveyed to and from dry detention basins safely and to minimize erosion potential.
- If a structure is 25 feet in height or more (measured from the natural bed of the stream or water course measured at the downstream toe or the lowest elevation of the outside limit of the barrier (whichever is lower) to the maximum water storage elevation) or has an impounding capacity at maximum water storage elevation of one hundred (100) acre-feet or more, the structure is considered a dam and is subject to the requirements of the Georgia Safe Dams Act.
- Designs of non-earthen dams shall not include planned structure overtopping for emergency overflows.
- Non earthen pond dam structures shall be constructed of monolithic wall materials. Walls shall extend from the toe of exterior fill slope into the pond's earthen embankment a distance 4 times the depth of the 100 year ponding limits.

4.5.5.7 LANDSCAPING

- Designers shall provide a vegetated buffer around the dry detention basin and select plants within the detention zone (i.e., the portion of the basin up to the elevation where stormwater is detained) that can withstand both wet and dry periods. The side slopes of dry basins should be relatively flat to reduce safety risks.
- Plantings should be designed not to conflict with the current drainage of the basin.
- All trees should be kept away from any drainage structures to allow for maintenance access and repairs as needed. There are to be no trees or woody vegetation on the dam, the downward slope of the dam, within 15 feet of the toe of the embankment, or within 25 feet of the principal spillway structure.
- Within a detention basin, all stumps are to be removed, and all debris is to be removed. Shrubs may be allowed to remain on the top of the embankment only upon certification of the survivability of the vegetation, under both wet and dry conditions. There are to be no trees or woody vegetation on the side slopes of the detention basin.
- Detention slopes that are disturbed are to be grassed. The ground cover within the basin shall be well established with all exposed areas covered prior to the end of the maintenance period.

4.5.5.8 CONSTRUCTION CONSIDERATIONS

Construction equipment should be restricted from the dry detention basin to prevent compaction of soils.

4.5.5.9 CONSTRUCTION AND MAINTENANCE COSTS

Construction costs associated with dry extended detention basins range considerably and are based on a cost per unit area treated. One study evaluated the cost of all basin systems (Brown and Schueler, 1997). Adjusting for inflation using a RSMeans Construction Cost Index, the cost of dry ED basins can be estimated with the equation:

$$C = 22.7V^{0.760}$$

Where:

C = Total construction cost including design and permitting cost

V = Total volume required to control the 10-year storm (cubic ft)

Using this equation, typical construction costs are:

$ 76,200 for a 1 acre-foot basin

$ 438,000 for a 10 acre-foot basin

$ 2,530,000 for a 100 acre-foot basin

Dry ED basins are typically less costly than stormwater (wet) basins, for example, that would provide equivalent flood storage, as less excavation is required.

4.5.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a dry detention basins.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a dry detention basin. Create a rough layout of the dry detention basin dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the dry detention basin.**

Consider whether the dry detention basin is intended to:

- » Meet a water quality (treatment) target. See Step 3 to size the BMP utilizing the water quality treatment approach.
- » Provide a possible solution to a drainage problem
- » Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3) **Calculate the Target Water Quality Volume**

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)

1.2 = Target rainfall amount to be treated (inches)

R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)

12 = Unit conversion factor (in/ft)

(Step 4) **Size flow diversion structure, if needed**

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the dry detention basins facility. Size low flow orifice, weir, or other device to pass Q_{wq}.

(Step 5) **Determine pretreatment volume.**

A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the basin. The forebay should be sized to contain 0.1 inch per impervious acre of contributing drainage.

(Step 6) **Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P2-25} (2-25-yr, 24-hour storms), and Q_f (100-yr, 24-hour storm).**

(Step 7) **Compute WQ_v orifice release rate and size WQ_v orifice.**

- Size a water quality orifice to release the calculated WQ_v.
- The WQ_v elevation is then determined from the stage-storage relationship. The invert of the WQ_v orifice is located at the water quality detention elevation, and the orifice is sized to allow for temporary storage of the water quality storage volume
- The water quality orifice should be adequately protected from clogging by an acceptable external trash rack.

(Step 8) **Design embankment(s) and spillway(s).**

Size emergency spillway, calculate the 100-year, 24-hour storm water surface elevation, set the top of the embankment elevation, and analyze safe passage of the Q_f. Set the invert elevation of the emergency spillway 0.1 foot above the 100-year, 24-hour storm water surface elevation.

(Step 9) **Investigate potential basin hazard classification**

Design and construction of the detention facility may be required to meet the Georgia Dam Safety standards.

(Step 10) **Prepare a site vegetation and landscaping plan.**

A vegetation scheme for the dry detention basin should be prepared to indicate how the basin bottom, side slopes, and embankment will be stabilized and established with vegetation.

4.5.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.6 Dry Extended Detention Basins



Description: A surface storage basin or facility designed to provide water quality treatment and water quantity control through extended detention (ED) of stormwater runoff. Dry ED basins differ from dry detention basins in that they provide 24-hour detention of the channel protection volume (CP_v).

LID/GI Considerations: Similar to dry detention, dry ED basins contribute to a site's overall perviousness and aesthetics. The open grassed area of a dry ED basin can also be used for multiple purposes, such as landscaped or recreational areas.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Embankments should be less than 20 feet in height and should have side slopes no steeper than 2:1 (horizontal to vertical) although 3:1 is preferred.
- The depth of the basin should not exceed 10 feet.
- Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height.
- All embankments must be designed to State of Georgia guidelines for dam safety.
- Storage volumes greater than 100 acre-feet are subject to the requirements of the Georgia Safe Dams Act (Georgia Annotated Code 12-5-370) unless the facility is excavated to this depth.
- The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions.
- The outfall of dry ED basins should always be stabilized to prevent scour.
- An emergency spillway should be provided to safely convey large flood events.

ADVANTAGES / BENEFITS

- Moderate removal rate of urban pollutants
- High community acceptance
- Useful for water quality treatment, channel protection, and flood control
- Dry ED basins can serve multiple purposes on a development site.
- Settling pools within the dry ED basin mitigate potential thermal impacts.

DISADVANTAGES / LIMITATIONS

- Dam height restrictions for high relief areas
- Drainage from the ED basin can be problematic for low relief terrain.

ROUTINE MAINTENANCE REQUIREMENTS

- Remove debris from inlet and outlet structures
- Maintain side slopes and outlet structure
- Remove invasive vegetation
- Monitor sediment accumulation and remove periodically

POLLUTANT REMOVAL

- **60%** **Total Suspended Solids**
- **50%** **Metals** - Cadmium, Copper, Lead, and Zinc removal
- **10/30%** **Nutrients** - Total Phosphorus / Total Nitrogen removal
- **N/A** **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ★ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- **M** Land Requirement
- **L** Capital Cost
- **L** Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Not recommended*
Roadway Projects: *Yes*

Soils: *Dry ED basins can be used with nearly all soils and geology, with minor design adjustments for regions of karst topography or in rapidly percolating soils, such as sand.*

Other Considerations: In order to convey low flows through dry ED basins, designers should provide a pilot channel. Designers should provide shade around the pilot channel and the basin outlet to prevent stream warming.

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided

4.6.1 General Description

Dry ED basins are surface facilities intended to provide for the temporary storage and treatment of stormwater runoff to reduce downstream water quality and water quantity impacts. These facilities temporarily detain stormwater runoff, releasing the flow over a period of time. They are designed to completely drain within 24 – 72 hours after a storm event and are normally dry between rain events. A typical schematic for a dry ED basin is shown in **Figure 4.6-1**. Dry ED basins provide downstream channel protection through extended detention of the channel protection volume (CP_v). Dry ED basins are intended to provide overbank flood protection (peak flow reduction of the 25-year, 24-hour storm, Q_{p25}) and can be designed to control the extreme flood (100-year, 24-hour, Q_f) storm event.

Dry ED basins provide limited pollutant removal benefits and are not intended for runoff reduction. Dry ED-basins should be used in a treatment train approach with other BMPs that provide runoff reduction and/or additional water quality treatment (see Subsection 4.1.6).

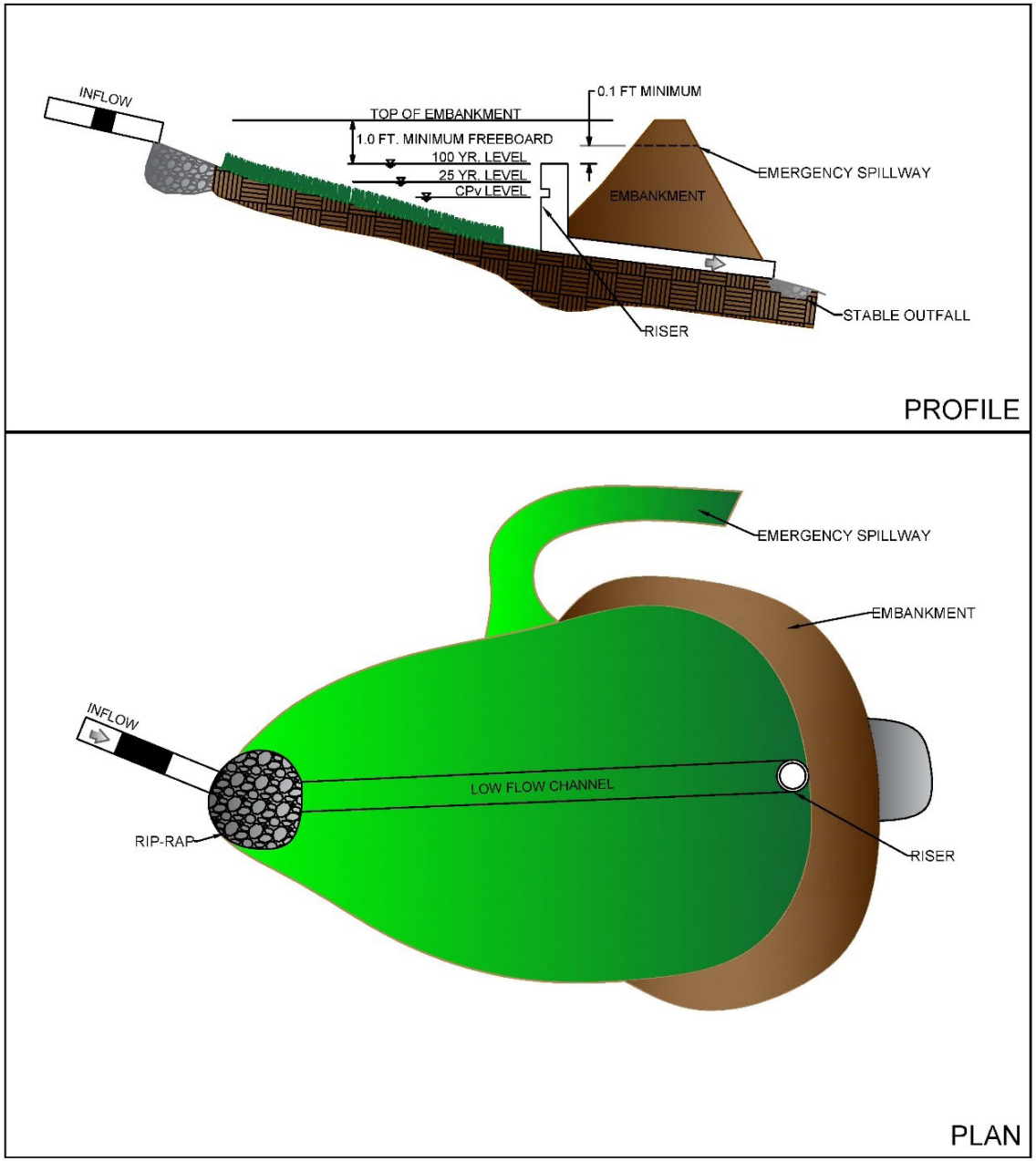


Figure 4.6-1 Schematic of dry ED Basin

4.6.2 Stormwater Management Suitability

- Runoff Reduction
  Another BMP should be used in a treatment train with dry ED basins to provide runoff reduction as they are not designed to provide RR_V as a stand-alone BMP.

- Water Quality
  If installed as per the recommended design criteria and properly maintained, 60% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the dry ED basin. Another BMP should be used in a treatment train with dry ED basins to provide the additional required water quality treatment.

- Channel Protection
  Dry ED basins can be sized to store the Channel Protection volume (CP_v) and to completely drain over 24-72 hours, meeting the requirement of extended detention of the 1-year, 24-hour stormwater runoff volume.

- Overbank Flood Protection
  Dry ED basins are intended to provide overbank flood protection (peak flow reduction of the 2-25-year, 24-hour storm, Q_{p2-25}).

- Extreme Flood Protection
  Dry ED basins can be designed to control the extreme flood (100-year, 24-hour storm, Q_f) rainfall event.

4.6.3 Pollutant Removal Capabilities

Dry ED basins are presumed to remove 60% of the total suspended solids (TSS) load in typical urban post development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Although they can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. Other pollutants that dry ED basins can remove include Phosphorus, Nitrogen, and metals (such as Cadmium, Copper, Lead, and Zinc).

For additional information and data on pollutant removal capabilities for dry ED basins, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.6.4 Application and Site Feasibility Criteria

A dry ED basin temporarily stores runoff and releases that runoff at a controlled rate over a specified period of time. By definition, dry ED basins are dry structures during non-precipitation periods. Dry ED basins are capable of providing water quality improvement, downstream flood control, channel erosion control, and mitigation of post-development runoff to pre-development levels. A dry ED facility improves runoff quality primarily through the gravitational settling of pollutants.

The following criteria should be evaluated to gage the suitability of dry ED basins for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **YES**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – In general, dry ED basins should be used on sites with a minimum drainage area of 10 acres.

- **Space Required** – Roughly 2-3% of the contributing drainage area.

- **Site Slope** – Dry ED basins can be used on sites with slopes up to about 15%.

- Vegetated and rip rap embankments should be less than 20 feet in height and should have side slopes no steeper than 2:1 (horizontal to vertical), although 3:1 is preferred.

- **Minimum Depth to Water Table** – Except for the case of hotspot runoff, the only consideration regarding groundwater is that the base of the dry ED basin should not intersect the groundwater table.

- **Soils** – Dry ED basins can be used in nearly all soils and geology, with minor design adjustments for regions of karst (i.e., limestone) topography or in rapidly percolating soils, such as sand. In these areas, dry ED basins should be designed with an impermeable liner to prevent groundwater contamination or sinkhole formation.

Other Constraints / Considerations

- **Hot spots** – Dry ED basins can accept runoff from stormwater hotspots, but need significant separation from groundwater when used for this purpose.
- **Damage to existing structures and facilities** – Dry ED basins should be designed to safely store and/or bypass the overbank flood (Q_{p25}) and extreme flood (Q_f) event to prevent overflow or failure, which may cause damage to site structures and facilities.
- **Proximity** – The following is a list of specific setback requirements for the location of dry ED basins:
  - » 10 feet from building foundations
  - » 10 feet from property lines
  - » 100 feet from private water supply wells
  - » 100 feet from open water (measured from edge of water)
  - » 200 feet from public water supply reservoirs (measured from edge of water)
  - » 1,200 feet from public water supply wells
- **Trout Stream** – Dry ED basins should not be used where receiving water temperature is a concern. In addition, careful consideration should be given to the potential for perched or raised groundwater levels.
- **Poorly Drained Soils** – Poorly draining soils do not inhibit a dry ED basin's ability to temporarily store and treat stormwater runoff and completely drain within 24-72 hours.
- **Flat Terrain** – The local slope needs to be relatively flat in order to maintain reasonably flat side slopes. While there is no minimum slope requirement, enough elevation drop is needed from the basin inlet to the basin outlet to ensure that flow can move through the facility.
- **Shallow Water Table** – Except for the case of hot spot runoff, the only consideration regarding ground water is that the base of the dry ED basin should not intersect the ground water table.

4.6.5 Planning and Design Criteria

Before designing dry ED basins, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews.
- Impervious and pervious areas. Other means may be used to determine land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems, as well as depth to the seasonally high groundwater table.

The following criteria are to be considered minimum standards for the design of a dry ED basin. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.6.5.1 LOCATION AND LAYOUT

Dry ED basins are to be located downstream of other BMPs providing runoff reduction and/or treatment of the water quality volume (WQ_v). See Subsection 4.1.6 for more information on the use of multiple BMPs in a treatment train.

4.6.5.2 GENERAL DESIGN

- Dry ED basins are sized to provide storage and control for multiple rain events, including:
  - » Storage of the water quality volume (WQ_v)
  - » 24-hour storage of the channel protection volume (CP_v)
  - » Temporary storage of the volume of runoff required to provide overbank flood (Q_{p25}) protection (i.e., reduce the post-development peak flow of the 2-25-year storm event to the pre-development rate), and
  - » Control of the 100-year storm (Q_f), if required.
- Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 3.3 (Storage Design) for procedures on the design of detention storage.
- Storage volumes greater than 100 acre-feet are subject to the requirements of the Georgia Safe Dams Act (Georgia Annotated Code 12-5-370) unless the facility is excavated to this depth.
- No more than 50% of the basin perimeter may be a wall of any type unless a drive is provided to the bottom of the pond. The drive shall be a minimum of 15 feet wide with a maximum slope of 20%.
- If the developer desires to install a fence around a detention facility, it shall be a minimum 4-foot high fence of durable material, with a 12-foot wide access gate. The fence shall be contained within an easement and outside the detention facility's slopes and/or walls. This easement is for inspection purposes, more width may be necessary for maintenance purposes.

4.6.5.3 PHYSICAL SPECIFICATIONS/GEOMETRY

- Vegetated embankments should be less than 20 feet in height and shall have side slopes no steeper than 3:1 (horizontal to vertical). Riprap-protected embankments must also be no steeper than 3:1. Geotechnical slope stability analysis is recommended for embankments greater than 10 feet in height and is mandatory for embankment slopes steeper than those given above. All embankments must be designed to State of Georgia guidelines for dam safety.
- The depth of the basin should not exceed 10 feet.
- Dam heights greater than 25 feet or a storage volume greater than 100 acre-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated to this depth.
- Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage and prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions.
- Designing dry ED basins with a high length to width ratio (i.e., at least 1.5:1) and incorporating other design features to maximize the flow path effectively increases the detention time in the system by eliminating the potential of flow to short circuit the basin. Designing basins with relatively flat side slopes can also help to lengthen the effective flow path.
- While there is no minimum slope requirement, enough elevation drop is needed from the basin inlet to the basin outlet to ensure that flow can move through the facility.
- A low-flow or pilot channel across the facility bottom from the inlet to the outlet is recommended to convey low flows and prevent standing water conditions. In order to prevent stream warming, designers should place landscaping to provide shade around the pilot channel and the basin outlet. A minimum slope of 1% is recommended for grass swales and 0.5% for armored pilot channels.
- Maintenance access must be provided for all dry ED basins. The width of this maintenance access must be a minimum of 15 feet with a maximum slope of 5:1.

4.6.5.4 PRETREATMENT/INLETS

- Inflow channels are to be stabilized with flared aprons, or the equivalent.
- Pretreatment for a dry ED basin is usually provided by a sediment forebay. The sediment forebay should be sized for 0.1 inches per impervious acre of contributing drainage area.
- Pretreatment may also be provided by using a grass filter strip, pea gravel diaphragm, or grass channel. Where filter strips are used, 100% of the contributing runoff should flow across the filter strip. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

4.6.5.5 OUTLET STRUCTURES

- For a dry ED basin, the outlet structure is sized for Q_{p25} control (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.
- If either the Water Quality (WQ) or the Channel Protection (CP) Orifice is less than 4.0 inches, use table below to set orifice diameter:

WQ/CP Orifice Diameter from Design (inches)	WQ/CP Orifice Diameter to use (inches)
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1.00 < X <1.25	1.00
1.25 < X < 1.50	1.25
1.50 < X < 1.75	1.50
1.75 < X < 2.00	1.75
2.00 < X < 2.50	2.00
2.50 < X < 3.00	2.50
3.00 < X < 3.50	3.00
3.50 < X < 4.00	3.50

- Orifices smaller than 3 inches in diameter shall have internal orifice protection such as a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket. An orifice smaller than 15 inches in diameter shall be protected by a trash rack.
- Seepage control or anti-seep collars should be provided for all outlet pipes.
- Unless the 100-year maximum flow velocity in a conduit through a dam forming a pond or a lake is less than 10 feet per second, and the hydraulic grade line for the 100-year condition is at or below the crown of the conduit for at least 90 percent of its length, the conduit must be equal or superior to Class V reinforced concrete pipe in its structural characteristics.
- Riprap, plunge pools or pads, or other energy dissipaters are to be placed at the end of the outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance from the dry ED basin.

4.6.5.6 SAFETY FEATURES

- An emergency spillway should be included in the dry ED basin design to safely pass the extreme flood flow. The spillway prevents water levels from overtopping the embankment and causing structural damage. The emergency spillway must be designed to State of Georgia guidelines for dam safety and must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1.5 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood, to the lowest point of the dam embankment, not counting the emergency spillway. A safety bench shall be provided for embankments greater than 10 feet in height and having a side slope steeper than 3:1. For large basins, the safety bench shall extend no less than 15 feet outward from the normal water edge to the toe of the basin side slope. The slope of the safety bench shall not exceed 6%.
- Stormwater should be conveyed to and from dry ED basins safely and to minimize erosion potential.
- Dam heights greater than 25 feet or a storage volume greater than 100 acre-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated to this depth.
- Designs of non-earthen dams shall not include planned structure overtopping for emergency overflows.
- Non earthen pond dam structures shall be constructed of monolithic wall materials. Walls shall extend from the toe of exterior fill slope into the pond's earthen embankment a distance 4 times the depth of the 100 year ponding limits.

4.6.5.7 LANDSCAPING

- Designers shall provide a vegetated buffer around dry ED basins, selecting plants within the detention zone (i.e., the portion of the basin up to the elevation where stormwater is detained) that can withstand both wet and dry periods. The side slopes of dry ED basins should be relatively flat to reduce safety risks.
- Plantings should be designed not to conflict with the current drainage of the basin.

- All trees should be kept away from any drainage structures to allow for maintenance access and repairs as needed. There are to be no trees or woody vegetation on the dam, the downward slope of the dam, within 15 feet of the toe of the embankment, or within 25 feet of the principal spillway structure.
- Within a detention basin, all stumps are to be removed, and all debris is to be removed. Shrubs may be allowed to remain below this ponding elevation only upon certification of the survivability of the vegetation, under both wet and dry conditions. There are to be no trees or woody vegetation on the side slopes of the detention basin.
- Detention slopes that are disturbed are to be grassed. The ground cover within the basin shall be well established with all exposed areas covered prior to the end of the maintenance period.

4.6.5.8 CONSTRUCTION CONSIDERATIONS

Construction equipment should be restricted from the dry ED basin to prevent compaction of native soils.

4.6.5.9 CONSTRUCTION AND MAINTENANCE COSTS

Construction costs associated with dry extended detention basins range considerably and are based on a cost per unit area treated. One study evaluated the cost of all basin systems (Brown and Schueler, 1997). Adjusting for inflation using a RSMeans Construction Cost Index, the cost of dry ED basins can be estimated with the equation:

$$C = 22.7V^{0.760}$$

Where:

C = Total construction cost including design and permitting cost
V = Total volume required to control the 10-year storm (cubic feet)

Using this equation, typical construction costs are:

$ 76,200 for a 1 acre-foot basin
$ 438,000 for a 10 acre-foot basin
$ 2,530,000 for a 100 acre-foot basin

Dry ED basins are typically less costly than stormwater (wet) basins, for example, that would provide equivalent flood storage, as less excavation is required.

4.6.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of dry extended detention basins.**
Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a dry extended detention basin. Create a rough layout of the dry extended detention basin dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the dry extended detention basin.**
Consider whether the dry extended detention basin is intended to:

- Meet a water quality (treatment) target. See Step 3 to size the BMP utilizing the water quality treatment approach.
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3) **Calculate the Target Water Quality Volume**
Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the dry extended detention basins facility.

Size low flow orifice, weir, or other device to pass Q_{wq}.

(Step 5) Determine pretreatment volume.

A sediment forebay is provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the basin. The forebay should be sized to contain 0.1 inch per impervious acre of contributing drainage.

(Step 6) Calculate the CP_v (1-yr, 24-hour storm), Q_{P2-25} (2-25-yr, 24-hour storms), and Q_f (100-yr, 24-hour storm) flow rates and volumes.

(Step 7) Design embankment(s) and spillway(s).

Size the emergency spillway, calculate the 100-year water surface elevation, set the top of the embankment elevation, and analyze safe passage of the Q_f. Set the invert elevation of the emergency spillway 0.1 foot above the 100-year water surface elevation.

(Step 8) Investigate potential basin hazard classification.

The design and construction of the dry ED basin may be required to meet the Georgia Dam Safety standards.

(Step 9) Prepare a site Vegetation and Landscaping Plan.

A vegetation scheme for the dry ED basin should be prepared to indicate how the basin bottom, side slopes and embankment will be stabilized and established with vegetation. The use of native vegetation is highly recommended for these facilities.

4.6.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.7 Dry Wells



(Source: City of Portland, OR, 2008)

Description: Dry wells are low impact development practices that are located below the surface of development sites. They consist of shallow excavations, typically filled with stone, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils.

LID/GI Considerations: Use of a dry well decreases the post construction runoff volume from a site, decreasing the pollutant load as well as thermal and erosive impacts to receiving waters. Dry wells are installed underground, which allows for multiple uses of development space.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Dry wells should be designed to completely drain within 24 hours of the end of a rainfall event.
- There should be at least 2 feet of separation distance between the bottom of a dry well and the top of the water table.
- Dry wells should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed throughout the stone reservoir.

ADVANTAGES / BENEFITS

- Helps restore pre-development hydrology on development sites
- Reduces post-construction stormwater runoff rates, volumes, and pollutant loads
- Well-suited for use on urban development sites

DISADVANTAGES / LIMITATIONS

- Can only be used to "receive" runoff from small drainage areas of 2,500 square feet or less
- Should not be used on development sites that have soils with infiltration rates of less than 0.5 inches per hour

ROUTINE MAINTENANCE REQUIREMENTS

- A dry well and its components shown in Figure 4.7-1 must be inspected and maintained at least annually.
- Replace gravel when more than 6 inches of sediment has accumulated.
- Inspect after major storm events to ensure water does not pond for more than 48 hours. If extended ponding occurs, the gravel may need to be replaced.

POLLUTANT REMOVAL

- 100% **Total Suspended Solids**
- 100% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 100/100% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 100% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- M Capital Cost
- M Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Not recommended*

Soils: *Dry wells should be considered for use on development sites where fine sediment (e.g., clay, silt) loads will be relatively low, as high sediment loads will cause them to clog and fail. Permeable soils with a water table low enough to provide for the infiltration of stormwater runoff are recommended.*

Other Considerations: *Dry wells should not be located beneath a driveway, parking lot or other impervious surface.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 100% runoff reduction volume

4.7.1 General Description

Dry wells (also known as seepage pits and French drains) are low impact development practices that are located below the surface of development sites. They consist of shallow excavations, typically filled with stone, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils (**Figure 4.7-1**). If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.

As infiltration-based low impact development practices, dry wells are limited to use in areas where the soils are permeable enough and the water table is low enough to provide for the infiltration of stormwater runoff. They should only be considered for use on development sites where fine sediment (e.g., clay, silt) loads will be relatively low, as high sediment loads will cause them to clog and fail. In addition, dry wells should be carefully sited to avoid potential contamination of water supply aquifers.

The primary concern associated with the design of a dry well is its storage capacity, which directly influences its ability to reduce stormwater runoff rates, volumes, and pollutant loads. Site planning and design teams should strive to design dry wells that can accommodate the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event).

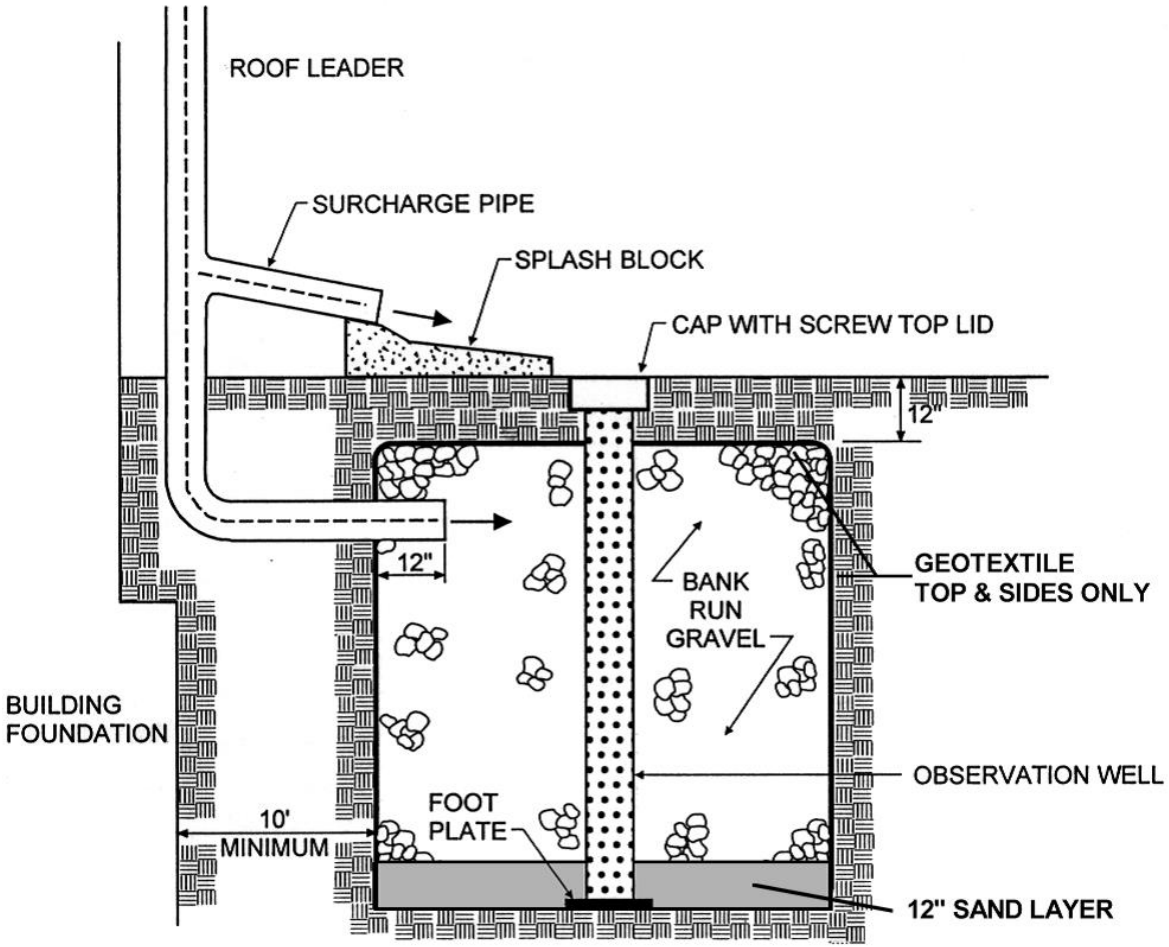


Figure 4.7-1: Dry Well
(Source: Maryland Department of the Environment, 2000)

If this cannot be accomplished due to site characteristics or constraints, site planning and design teams should consider using dry wells in combination with other runoff reducing low impact development practices, such as bioretention areas (Section 4.2) and rainwater harvesting (Section 4.19), to supplement the stormwater management benefits provided by the dry wells.

4.7.2 Stormwater Management Suitability

The Center for Watershed Protection (Hirschman et al., 2008) recently documented the ability of dry wells to reduce annual stormwater runoff volumes and pollutant loads on development sites, as follows:

- Stormwater Runoff Reduction
  Subtract 100% of the storage volume provided by a dry well from the runoff reduction volume (RR_v) conveyed through the dry well.
- Water Quality Protection
  If installed as per the recommended design criteria and properly maintained, 100% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the dry well.
- Channel Protection
  Proportionally adjust the post-development runoff curve number (CN) to account for the runoff reduction provided by a dry well when calculating the channel protection volume (CP_v) on a development site (See Subsection 3.1.7.5).
- Overbank Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a dry well when calculating the overbank peak discharge (Q_{p25}) on a development site (See Subsection 3.1.7.5).
- Extreme Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a dry well when calculating the extreme peak discharge (Q_f) on a development site (See Subsection 3.1.7.5).

4.7.3 Pollutant Removal Capabilities

Dry wells are presumed to remove 100% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Dry wells also remove 100% of the Phosphorus, Nitrogen, metals (such as Cadmium, Copper, Lead, and Zinc), and fecal coliform in contributing runoff.

In order to provide the most efficient pollutant removal, dry wells should be constructed in permeable soils of hydrologic soil group A or B. The maximum drainage area and site surface slope should not be exceeded to ensure proper pollutant removal.

For additional information and data on pollutant removal capabilities for dry wells, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.7.4 Application and Site Feasibility Criteria

Dry wells can be used to treat stormwater runoff on a wide variety of development sites, including residential, commercial, and institutional development sites in rural, suburban, and urban areas. Although they are particularly well-suited to receive rooftop runoff, they can also be used to receive stormwater runoff from other small drainage areas, such as local streets and roadways, driveways, small parking areas, and disturbed pervious areas (e.g., lawns, parks, community open spaces). When compared with other low impact development practices, dry wells have a moderate construction cost, a moderate maintenance burden, and require only a small amount of surface area.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – The size of the contributing drainage area should be 2,500 square feet or less.
- **Space Required** – Dry well surface area requirements vary according to the size of the contributing drainage area and the infiltration rate of the soils in which the dry well is located. In general, dry wells require about 5-10% of the size of their contributing drainage areas.
- **Flow Path** – The length of flow path in contributing drainage areas should be 150 feet or less in pervious drainage areas and 75 feet or less in impervious drainage areas.
- **Site Slope** – Although dry wells may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed throughout the stone reservoir.
- **Minimum Depth to Water Table** – 2 feet
- **Minimum Head** – 2 feet
- **Soils** – Dry wells should be designed to completely drain within 24 hours of the end of a rainfall event. Consequently, dry wells generally should not be used on development sites that have soils with infiltration rates of less than 0.50 inches per hour (i.e., hydrologic soil group C and D soils).

Other Constraints / Considerations

- **Hot spots** – May be used for hot spot runoff
- Damage to existing structures and facilities – Dry wells should not be used in areas where their operation may create a risk for basement flooding, interfere with subsurface sewage disposal systems, or affect other underground structures.
- Dry wells should be designed so that overflow drains away from buildings to prevent damage to building foundations.
- **Proximity** – Dry wells may be used without restriction, except within:
  - » 10 feet from building foundations
  - » 10 feet from property lines
  - » 100 feet from private water supply wells
  - » 1,200 feet from public water supply wells
  - » 100 feet from septic systems
  - » 100 feet from surface waters
  - » 400 feet from public water supply surface waters
- **Trout Stream** – Use of a dry well reduces a site's runoff pollutant load, as well as the volume and velocity of stormwater runoff. Therefore, dry wells are an effective BMP for use where trout streams or other protected waters may receive stormwater runoff.
- **Poorly drained soils, such as hydrologic soil groups C and D** – Limits the ability of dry wells to reduce stormwater runoff rates, volumes, and pollutant loads. Dry wells should not be used on development sites that have soils with infiltration rates of less than 0.5 inches per hour (i.e., hydrologic soil group C and D soils). Use other low impact development practices, such as rainwater harvesting (Section 4.19), to "receive" stormwater runoff in these areas.
- **Well drained soils, such as hydrologic soil groups A and B** – Enhance the ability of dry wells to reduce stormwater runoff rates, volumes, and pollutant loads, but may allow stormwater pollutants to reach groundwater aquifers with greater ease. Rooftop runoff is relatively clean, so this should not prevent the

use of dry wells, even at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers. However, rooftop runoff should not be allowed to comingle with runoff from other impervious surfaces in these areas if it will be sent to a dry well.

- Flat Terrain – Does not influence the use of dry wells. In fact, dry wells should be designed with slopes that are as close to flat as possible.
- Shallow Water Table – In certain areas it may be difficult to provide 2 feet of clearance between the bottom of the dry well and the top of the water table. This may occasionally cause stormwater runoff to pond in the bottom of the dry well. Ensure that the distance from the bottom of the dry well to the top of the water table is at least 2 feet. Reduce the depth of the stone reservoir in dry wells to 18 inches, if necessary.

4.7.5 Planning and Design Criteria

Before designing the dry well, the following data is needed:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- The proposed site design, including buildings, parking lots, sidewalks, stairs, handicapped ramps, and landscaped areas
- Architectural roof plan for rooftop pitches and downspout locations
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Information about downstream BMPs and receiving waters
- Design data from nearby storm sewer structures
- Water surface elevation of nearby water systems as well as the depth to the seasonally high groundwater table

The following criteria are to be considered minimum standards for the design of a dry well. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

4.7.5.1 LOCATION AND LAYOUT

- Dry wells should be located in a lawn or other disturbed pervious area and should be designed so that the top of the dry well is located as close to the surface as possible. Dry wells should not be located beneath a driveway, parking lot, or other impervious surface.
- Although dry wells may be installed on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed throughout the stone reservoir.
- Dry wells should be used on development sites that have underlying soils with an infiltration rate of 0.50 inches per hour or greater, as determined by NRCS soil survey data and subsequent field testing.
- Although the number of infiltration tests needed on a development site will ultimately be determined by the local development review authority, at least one infiltration test is recommended for each dry well that will be used on the development site.
- Since clay lenses or any other restrictive layers located below the bottom of a dry well will reduce soil infiltration rates, infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed dry well.

- The depth from the bottom of a dry well to the top of the water table should be at least 2 feet to prevent nuisance ponding and ensure proper operation of the dry well.
- If used to receive rooftop runoff, dry wells should be preceded by a leaf screen installed in the gutter or downspout. This will prevent leaves and other large debris from clogging the dry well.
- If used to receive non-rooftop runoff, dry wells should be preceded by a pea gravel diaphragm or equivalent level spreader device (e.g., concrete sills, curb stops, curbs with sawteeth cut into them) and a vegetated filter strip that is designed according to the planning and design criteria provided in Section 4.29.
- Consideration should be given to the stormwater runoff rates and volumes generated by larger storm events (e.g., 25-year, 24-hour storm event) to help ensure that these larger storm events are able to safely bypass the dry well. An overflow, such as a vegetated filter strip (Section 4.29) or grass channel (Section 4.9), should be designed to convey the stormwater runoff generated by these larger storm events safely out of the dry well.

4.7.5.2 GENERAL DESIGN

- Dry wells should be used to receive stormwater runoff from small drainage areas of 2,500 square feet or less. The stormwater runoff rates and volumes from larger contributing drainage areas typically become too large to be properly treated by a dry well.
- The length of the flow path within the contributing drainage area should be 150 feet or less for pervious drainage areas and 75 feet or less for impervious drainage areas. In contributing drainage areas with longer flow paths, stormwater runoff tends to become shallow, concentrated flow (Claytor and Schueler, 1996), which can significantly reduce the stormwater management benefits that dry wells can provide. In these situations, bioretention areas (Section 4.2) and infiltration practices (Section 4.12) should be used to "receive" post-construction stormwater runoff.
- Dry wells should be designed to provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event).
- Dry wells should be designed to completely drain within 24 hours of the end of a rainfall event. Where site characteristics allow, it is preferable to design dry wells to drain within 12 hours of the end of a rainfall event to help prevent the formation of nuisance ponding conditions.
- Broader, shallower dry wells perform more effectively by distributing stormwater runoff over a larger surface area. However, a minimum depth of 18 inches is recommended for all dry well designs to prevent them from consuming a large amount of surface area on development sites. Whenever practical, the depth of dry wells should be kept to 36 inches or less.
- Dry wells should be filled with clean, washed stone. The stone used in the dry well should be 1.5 to 2.5 inches in diameter, with a void space of approximately 40% (e.g., GA DOT No. 3 Stone). Unwashed aggregate contaminated with soil or other fine particulates may not be used in the dry well. Underlying native soils should be separated from the dry well stone by a thin, 2 to 4 inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or ASTM D 448 size No. 89, 3/8" to 1/16"). The choker stone should be placed between the dry well stone and the underlying native soils.
- The top and sides of the dry well should be lined with a layer of appropriate permeable filter fabric. The filter fabric should be a non-woven geotextile with a permeability that is greater than or equal to the infiltration rate of the surrounding native soils. The top layer of the filter fabric should be located 6 inches from the top of the excavation, with the remaining space filled with appropriate landscaping. This top layer serves as a sediment barrier and, consequently, will need to be replaced over time. Site planning and design teams should ensure that the top layer of filter fabric can be readily separated from the filter fabric used to line the sides of the dry well.

- An observation well should be installed in every dry well. An observation well consists of a 4 to 6 inch perforated PVC (AASHTO M 252) pipe that extends to the bottom of the dry well. The observation well can be used to observe the rate of drawdown within the dry well following a storm event. It should be installed along the centerline of the dry well, flush with the elevation of the surface of the dry well. A visible floating marker should be provided within the observation well and the top of the well should be capped and locked to prevent tampering and vandalism.

4.7.5.3 PRETREATMENT/INLETS

Pretreatment and inlet protection need to be designed to reduce the velocity and energy of stormwater entering the practice and prevent scour of the mulch and plantings. Pretreatment and inlet protection may include splash blocks, a stone diaphragm, a level spreader, or similar device.

4.7.5.4 OUTLET STRUCTURES

Outlet structures should be included in the design of a dry well to ensure that larger storms can be bypassed without damaging the practice. See Section 3.4 (*Outlet Structures*) for more guidance regarding the proper design and installation of an outlet structure.

4.7.5.5 CONSTRUCTION AND MAINTENANCE COSTS

- The cost of a dry well varies based on the size. Typically, a small residential dry well costs between $1,350-$1,700.
- Larger dry wells can cost between $11,250-$16,900.
- Costs for downstream infiltration trenches or regional BMPs can be found in their respective sections in this manual.

4.7.7.6 SAFETY FEATURES

Dry wells generally do not require any special safety features, provided side slopes are maintained at 3:1 or flatter. Fencing of dry wells is not generally desirable.

4.7.5.7 LANDSCAPING

- The landscaped area above the surface of a dry well may be covered with pea gravel (i.e., ASTM D 448 size No. 8, 3/8" to 1/8"). This pea gravel layer provides sediment removal and additional pretreatment upstream of the dry well and can be easily removed and replaced when it becomes clogged.
- Alternatively, a dry well may be covered with an engineered soil mix, such as that prescribed in Appendix D, and planted with managed turf or other herbaceous vegetation. This may be an attractive option when dry wells are placed in disturbed pervious areas (e.g., lawns, parks, and community open spaces).

4.7.5.8 CONSTRUCTION CONSIDERATIONS

To help ensure that dry wells are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- If dry wells will be used to receive non-rooftop runoff, they should only be installed after their contributing drainage areas have been completely stabilized. To help prevent dry well failure, stormwater runoff may be diverted around the dry well until the contributing drainage area has been stabilized.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of dry wells before, during, and immediately after construction. This can typically be accomplished by clearly delineating dry wells on all development plans and, if necessary, protecting them with temporary construction fencing.
- Excavation for dry wells should be limited to the width and depth specified in the development plans. Excavated material should be placed away from the excavation so as not to jeopardize the stability of the side walls.
- The native soils along the bottom of the dry well should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the choker stone and dry well stone.
- The sides of all excavations should be trimmed of large roots that will hamper the installation of the permeable filter fabric used to line the sides and top of the dry well.

4.7.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a dry well.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a dry well. Create a rough layout of the dry wells dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the dry well.**

Consider whether the dry well is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A. **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume.**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_v calculated above, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)
RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the dry well, use the following equation:

$$VP = (PV + VES (N))$$

Where:

VP = Volume provided (temporary storage)
PV = Ponding Volume
VES = Volume of Engineered Soils
N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour.

(Step 3C) Determine whether the minimum storage volume was met.

When the VP ≥ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_v treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume.

Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2) (R_v) (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)
A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B) **If using the practice for Water Quality treatment, determine the footprint of the dry well practice.**
The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d) below:

(a) Using WQ_v, compute CN.
(b) Compute time of concentration using the TR-55 method.
(c) Determine appropriate unit peak discharge from time of concentration.
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

To determine the minimum surface area of the dry well, use the following formula:

$$A_f = (WQ_v)\ (d_f) \ / \ [\ (k)\ (h_f + d_f)\ (t_f)]$$

Where:

A_f = surface area of ponding area (ft^2)
WQ_v = water quality volume (ft^3)
d_f = rock depth (ft)
k = coefficient of permeability of rock (ft/day)
h_f = average height of water above dry well bed (ft)
t_f = design rock drain time (days) (1 day is the recommended maximum)

(Step 5) **Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information.**

(Step 6) **Size the flow diversion structure, if needed.**
If the contributing drainage area to dry well exceeds the water quality treatment and/or storage capacity, flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v (or RR_v) to the dry well.
Size low-flow orifice, weir, or other device to pass Q_{wq}.

(Step 7) **Design emergency overflow facilities.**
An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year, 24-hour storm event.

(Step 8) **Prepare a site Vegetation and Landscaping Plan.**
A landscaping plan for the dry well should be prepared to indicate how it will be established with vegetation.
See Subsection 4.7.5.7 (*Landscaping*) and Appendix D for more details.

4.7.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.8 Dry Enhanced Swales/Wet Enhanced Swales



Description: Vegetated open channels that are explicitly designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means.

LID/GI Consideration: Adaptable to many linear situations, and often a small BMP used to treat runoff close to the source.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Longitudinal slopes must be less than 4%
- Bottom width of 2 to 8 feet
- Side slopes 2:1 or flatter; 4:1 recommended
- Convey the 25-year storm event with a minimum of 6 inches of freeboard

ADVANTAGES / BENEFITS

- Combines stormwater treatment with runoff conveyance system
- Less expensive than curb and gutter
- Reduces runoff velocity

DISADVANTAGES / LIMITATIONS

- Higher maintenance than curb and gutter systems
- Cannot be used on steep slopes
- Possible resuspension of sediment
- Potential for odor / mosquitoes (wet swale)

MAINTENANCE REQUIREMENTS

- Maintain grass heights of approximately 4 to 6 inches (dry swale)
- Remove sediment from forebay and channel

POLLUTANT REMOVAL (DRY SWALE)

- 80% **Total Suspended Solids**
- 40% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/50% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

POLLUTANT REMOVAL (WET SWALE)

- 80% **Total Suspended Solids**
- 20% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 25/40% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- M Land Requirement
- M Capital Cost
- L Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *No*
Drainage Area: *5 acres max*

Soils: *No restrictions*

Other Considerations:

- Permeable soil layer (dry swale)
- Wetland plants (wet swale)

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- Dry Swale: 100% of the runoff reduction volume provided (no underdrain)
- Dry Swale: 50% of the runoff reduction volume provided (underdrain)
- Wet Swale: 0% of the runoff reduction volume provided

4.8.1 General Description

Enhanced swales (also referred to as bioswales, *vegetated open channels*, or *water quality swales*) are conveyance channels engineered to capture and treat the water quality volume (WQ_v) for a drainage area. They differ from a normal drainage channel or swale through the incorporation of specific features that enhance stormwater pollutant removal effectiveness.

Enhanced swales are designed with limited longitudinal slopes to force the flow to be slow and shallow, thus allowing for particulates to settle and limiting the effects of erosion. Berms and/or check dams installed perpendicular to the flow path promote settling and infiltration.

There are two primary enhanced swale designs, the *dry swale* and the *wet swale* (or *wetland channel*). Below are descriptions of these two designs:

- **Dry Swale** – The dry swale is a vegetated conveyance channel designed to include a filter bed of prepared soil that may overlay an underdrain system. Dry swales are sized to allow the entire WQv to be filtered or infiltrated through the bottom of the swale. Because they are dry most of the time, they are often the preferred option in residential settings.
- **Wet Swale** – The wet swale is a vegetated channel designed to retain water or marshy conditions that support wetland vegetation. A high water table or poorly drained soils are necessary to retain water. The wet swale essentially acts as a linear shallow wetland treatment system, where the WQ_v is retained.

Dry and wet swales are not to be confused with a filter strip or grass channel, which are not considered acceptable for meeting the TSS removal performance goal by themselves. Ordinary grass channels are not engineered to provide the same treatment capability as a well-designed dry swale with filter media. Filter strips are designed to accommodate overland flow rather than channelized flow and can be used as stormwater credits to help reduce the total water quality treatment volume for a site. Both of these practices may be used for pretreatment or included in a "treatment train" approach where redundant treatment is provided. Please see a further discussion of these types of BMPs in Sections 4.28 and 4.9, respectively.



Enhanced Dry Swale



Enhanced Wet Swale

Figure 4.8-1 Enhanced Swale Examples

4.8.2 Stormwater Management Suitability

Enhanced swale systems are designed primarily for stormwater quality and have only a limited ability to provide channel protection or to convey higher flows to other controls.

- Runoff Reduction
  Dry swales, with no underdrain, can be designed to provide 100% of the runoff reduction volume, if properly maintained. In order to provide runoff reduction for a dry enhanced swale that is designed without an underdrain, a soils test or other reliable resource must indicate that the ponding area of the dry swale will drain within 24 – 48 hours. A dry swale area can also be designed with an underdrain to provide 50% of the runoff reduction volume, if properly maintained. Wet enhanced swales do not provide runoff reduction volume.

- Water Quality
  Dry swale systems rely primarily on filtration through an engineered media to provide removal of stormwater contaminants. Wet swales achieve pollutant removal both from sediment removal and biological removal. Subsection 4.8.3 provides median pollutant removal efficiencies that can be used for planning and design purposes.

- Channel Protection
  Generally only the WQ_v is treated by a dry or wet swale, and another BMP must be used to provide CP_v extended detention. However, for some smaller sites, a swale may be designed to capture and detain the full CP_v.

- Overbank Flood Protection
  Enhanced swales must provide flow diversion and/or be designed to safely pass overbank flood flows. Another BMP must be used in conjunction with an enhanced swale system to reduce the post-development peak flow of the 25-year storm (Q_{p25}) to pre-development levels (detention).

- Extreme Flood Protection
  Enhanced swales must provide flow diversion and/or be designed to safely pass extreme storm flows. Another BMP must be used in conjunction with an enhanced swale system to reduce the post-development peak flow of the 100-year storm (Q_f) if necessary.

4.8.3 Pollutant Removal Capabilities

Both the dry and wet enhanced swale are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed swales can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- *Total Suspended Solids* – 80%
- *Total Phosphorus* – Dry Swale 50% / Wet Swale 25%
- *Total Nitrogen* – Dry Swale 50% / Wet Swale 40%
- *Fecal Coliform* – insufficient data
- *Heavy Metals* – Dry Swale 40% / Wet Swale 20%

For additional information and data on pollutant removal capabilities for enhanced dry and wet swales, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.8.4 Application and Feasibility Criteria

Enhanced swales can be used in a variety of development types; however, they are primarily applicable to residential and institutional areas of low to moderate density where the impervious cover in the contributing drainage area is relatively small, and along roads and highways. Dry swales are mainly used in moderate to large lot residential developments, small impervious areas (parking lots and rooftops), and along rural highways. Wet swales tend to be used for highway runoff applications, small parking areas, and in commercial developments as part of a landscaped area.

Because of their relatively large land requirement, enhanced swales are generally not used in higher density areas. In addition, wet swales may not be desirable for some residential applications, due to the presence of standing and stagnant water, which may create nuisance odor or mosquito problems.

The topography and soils of a site will determine the applicability of the use of one of the two enhanced swale designs. Overall, the topography should allow for the design of a swale with sufficient slope and cross-sectional area to maintain non-erosive velocities. The following criteria should be evaluated to ensure the suitability of an enhanced swale for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – 5 acres maximum
- **Space Required** – Approximately 10 to 20% of the tributary impervious area
- **Site Slope** – Typically no more than 4% channel slope
- **Minimum Head** – Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet for dry swale; 1 foot for wet swale
- **Minimum Depth to Water Table** – 2 feet required between the bottom of a dry swale and the elevation of the seasonally high water table, if an aquifer or treating a hotspot; wet swale is below water table or placed in poorly drained soils
- **Soils** – Engineered media for dry swale

Other Constraints / Considerations

- **Aquifer Protection** – Exfiltration should not be allowed in hotspot areas

4.8.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of an enhanced swale system. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.

4.8.5.1 LOCATION AND LAYOUT

- A dry or wet swale should be sited such that the topography allows for the design of a channel with sufficiently mild slope (unless small drop structures are used) and cross-sectional area to maintain non-erosive velocities.
- Enhanced swale systems should have a contributing drainage area of 5 acres or less.
- Swale siting should also take into account the location and use of other site features, such as buffers and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape.
- A wet swale can be used where the water table is at or near the soil surface, or where there is a sufficient water balance in poorly drained soils to support a wetland plant community.

4.8.5.2 GENERAL DESIGN

Both types of enhanced swales are designed to treat the WQv through a volume-based design, and to safely pass larger storm flows. Flow enters the channel through a pretreatment forebay. Runoff can also enter along the sides of the channel as sheet flow through a flow spreader, such as a pea gravel trench along the top of the bank.

- Dry Swale
  A dry swale system consists of an open conveyance channel with a filter bed of permeable soils that may overlay an underdrain system. Flow passes into and is detained in the main portion of the channel where it is filtered through the soil bed. Runoff may be collected and conveyed by a perforated pipe and gravel underdrain system to the outlet. **Figure 4.8-2** provides a plan view and profile schematic for the design of a dry swale system.

- Wet Swale
  A wet swale or wetland channel consists of an open conveyance channel which has been excavated to the water table or to poorly drained soils. Check dams are used to create multiple wetland "cells," which act as miniature shallow marshes. **Figure 4.8-3** provides a plan view and profile schematic for the design of a wet swale system.

4.8.5.3 PHYSICAL SPECIFICATIONS/GEOMETRY

- Channel slopes between 1% and 2% are recommended unless topography necessitates a steeper slope, in which case 6- to 12-inch drop structures can be placed to limit the energy slope to within the recommended 1 to 2% range. Energy dissipation will be required below the drops. Spacing between the drops should not be closer than 50 feet. Depth of the storage volume at the downstream end should not exceed 18 inches.

- Dry and wet swales should have a bottom width of 2 to 8 feet to ensure adequate filtration. Wider channels can be designed, but should contain berms, walls, or a multi-level cross section to prevent channel braiding or uncontrolled sub-channel formation.

- Dry and wet swales are parabolic or trapezoidal in cross-section and are typically designed with moderate side slopes no greater than 2:1 for ease of maintenance and side inflow by sheet flow (4:1 or flatter recommended).

- Dry and wet swales should maintain a maximum WQ_v ponding depth of 18 inches at the end point of the channel. A 12-inch average depth should be maintained.

- The peak velocity for the 2-year storm must be non-erosive for the soil and vegetative cover provided.

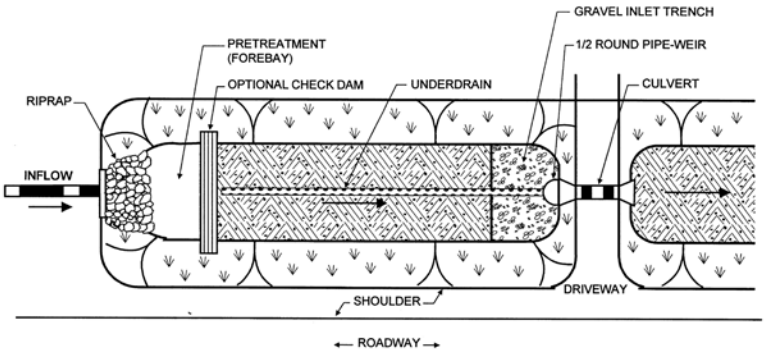
- If the system is on-line, channels should be sized to convey runoff from the overbank flood event (Q_{p25}) safely with a minimum of 6 inches of freeboard and without damage to adjacent property.

Dry Swale

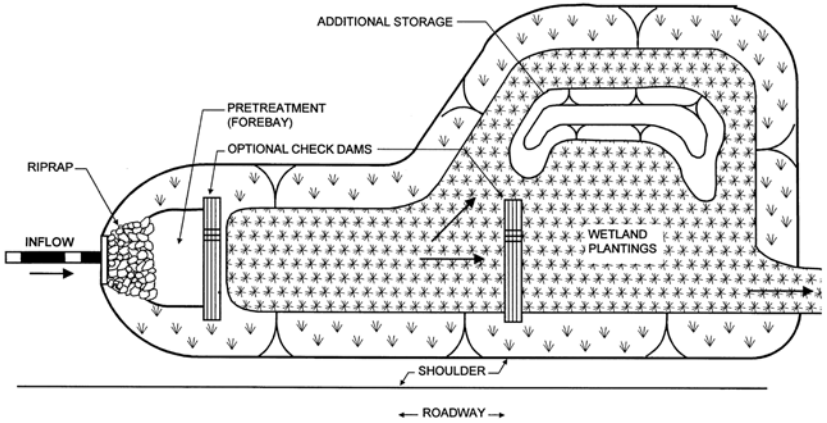
- Dry swale channels are sized to store and infiltrate the entire water quality volume (WQ_v) with less than 18 inches of ponding and allow for full filtering through the permeable soil layer. The maximum ponding time is 48 hours, though a 24-hour ponding time is more desirable.

- The dry swale consists of a permeable soil layer of at least 30 inches in depth, above an underdrain. The soil media should have an infiltration rate of at least 1 foot per day (1.5 feet per day maximum) and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil. Where an underdrain collection system is utilized, it should be equipped with at least a 4-inch diameter perforated PVC pipe (AASHTO M 252) longitudinal underdrain in a gravel layer.

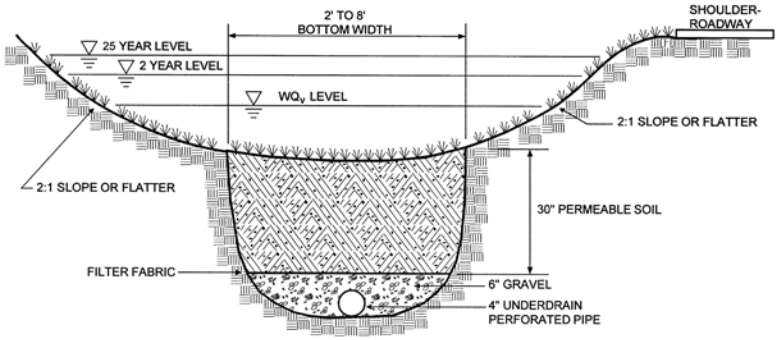
- The channel and underdrain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and shall be scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.



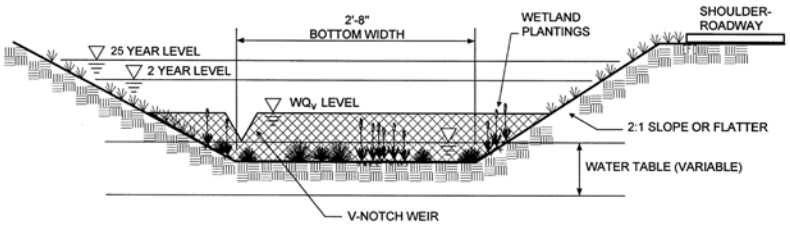
PLAN VIEW



PLAN VIEW



SECTION



PROFILE

Figure 4.8-2 Schematic of Dry Swale
(Source: Center for Watershed Protection)

Figure 4.8-3 Schematic of Wet Swale
(Source: Center for Watershed Protection)

Wet Swale

- Wet swale channels are sized to retain the entire water quality volume (WQ_v) with less than 18 inches of ponding at the maximum depth point.
- Check dams can be used to achieve multiple wetland cells. V-notch weirs in the check dams can be utilized to direct low flow volumes.

4.8.5.4 PRETREATMENT/INLETS

- Inlets to enhanced swales must be provided with energy dissipators such as riprap.
- Pretreatment of runoff in both a dry and wet swale system is typically provided by a sediment forebay located at the inlet. The pretreatment volume should be equal to 0.1 inches per impervious acre. This storage is usually obtained by providing check dams at pipe inlets and/or driveway crossings.
- Enhanced swale systems that receive direct concentrated runoff may have a 6-inch drop to a pea gravel diaphragm flow spreader at the upstream end of the control.
- Vegetated filter strips and gentle side slopes should be provided along the top of channels to provide pretreatment for lateral sheet flows.

4.8.5.5 OUTLET STRUCTURES

Dry Swale

Outlet protection must be used at any discharge point from a dry swale to prevent scour and downstream erosion. The underdrain system should discharge to the storm drainage infrastructure or a stable outfall.

Wet Swale

Outlet protection must be used at any discharge point from a wet swale to prevent scour and downstream erosion.

4.8.5.6 EMERGENCY SPILLWAY

Enhanced swales must be adequately designed to safely pass flows that exceed the design storm flows.

4.8.5.7 MAINTENANCE ACCESS

Adequate access should be provided for all dry and wet swale systems for inspection and maintenance.

4.8.5.8 SAFETY FEATURES

Ponding depths should be limited to a maximum of 18 inches.

4.8.5.9 LANDSCAPING

Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel. **Table 4.8-1** below provides a number of grass species that perform well in the stressful environment of an open channel BMP. In addition, wet swales may include other wetland species (see plant list in Section 5 of Appendix D). Select plant material capable of salt tolerance in areas that may include high salt levels.

Table 4.8-1: Common Grass Species for Dry and Wet Enhanced Swales

Common Name	Scientific Name	Notes
Bermuda Grass	Cynodon dactylon	
Big Bluestem	Andropogon gerardii	Not for wet swales
Creeping Bentgrass	Agrostis palustris	
Red Fescue	Festuca rubra	Not for wet swales
Reed Canary Grass	Phalaris arundinacea	Wet swales
Redtop	Agrostis alba	
Smooth Brome	Bromus inermis	Not for wet swales
Switch Grass	Panicum virgatum	

Note 1: These grasses are sod-forming and can withstand frequent inundation, and are thus ideal for swale or channel environments. Most are salt-tolerant as well.
Note 2: Where possible, one or more of these grasses should be in the seed mixes.

The following information is specific guidance for wet swales:

Wet Swale

- Emergent vegetation should be planted, or wetland soils may be spread on the swale bottom for seed stock.
- Where wet swales do not intercept the groundwater table, a water balance calculation should be performed to ensure an adequate water budget to support the specified wetland species. See Subsection 3.1.8 for guidance on water balance calculations.

4.8.5.10 ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- **Low Relief** – Reduced need for use of check dams
- **High Relief** – Often infeasible if slopes are greater than 4%
- **Karst** – No exfiltration of hotspot runoff from dry swales; use impermeable liner

Soils

No additional criteria

Special Downstream Watershed Considerations

- **Aquifer Protection** – No exfiltration of hotspot runoff from dry swales; use impermeable liner.

4.8.5.11 CONSTRUCTION CONSIDERATIONS

- Construction equipment should be restricted from the enhanced swale area to prevent compaction of the native soils.
- A dense and vigorous vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Otherwise the sediment from the stormwater runoff will clog the pores in the planting media and native soils.

4.8.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of an enhanced swale.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for an enhanced swale. Create a rough layout of the enhanced swale dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the enhanced swale and if a dry or wet swale is desired.**

Consider whether the enhanced swale is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.).

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Step 4 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_V calculated above, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)

RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the enhanced swale, use the following equation:

$$VP = (PV + VES (N))$$

Where:

VP = Volume provided (temporary storage)

PV = Ponding Volume

VES = Volume of Engineered Soils

N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pre-treatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met.

When the VP $\geq$ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_V treatment method (See Step 4).

(Step 4) **Calculate the Target Water Quality Volume**

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Site area (total drainage area) (ft^2)
12 = Unit conversion factor (in/ft)

Using the WQ_V calculated above, determine the actual size and Volume of the Practice (VP) as shown in Step 3B. Note that VP, calculated using the formula shown in Step 3B, should be greater than or equal to WQ_V.

(Step 5) **If applicable, calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information.**

(Step 6) **Determine the length and channel base width of the enhanced swale practice and the Pretreatment Volume required.**

Determine Swale Dimensions:
Size bottom width, depth, length, and slope necessary to store VP, with less than 18 inches of ponding at the downstream end.

- Slope cannot exceed 4% (1 to 2% recommended)
- Bottom width should range from 2 to 8 feet
- Ensure that side slopes are no greater than 2:1 (4:1 recommended)

See Subsection 4.8.5.3 (*Physical Specifications / Geometry*) for more details

(Step 7) **Compute number of check dams (or similar structures) required to detain the RR_V or WQ_V, as applicable**

(Step 8) **Calculate draw-down time**

Dry swale: Planting soil should pass a maximum rate of 1.5 feet in 24 hours and must completely filter the ponded volume within 48 hours (24 hours preferred).
Wet swale: Must hold the WQ_V.

(Step 9) **Check 2-year and 25-year velocity erosion potential and freeboard**

Check for erosive velocities and modify design as appropriate. Provide 6 inches of freeboard.

(Step 10) **Design overflow weir or orifice at downstream berm, headwall, or checkdam.**

(Step 11) Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v (or RR_v) to the best management practice.

Size low flow orifice, weir, or other device to pass Q_{wq}.

(Step 12) Size underdrain system

See Subsection 4.2.5.3 (*Physical Specifications/Geometry*)

(Step 13) Design emergency overflow

An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year storm event.

(Step 14) Design inlets, sediment forebay(s), and underdrain system (dry swale)

See Subsection 4.8.5.4 through 4.8.5.8 for more details.

(Step 15) Prepare Vegetation and Landscaping Plan

A landscaping plan for a dry or wet swale should be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation.

See Subsection 4.8.5.9 (*Landscaping*) and Appendix D for more details.

See Appendix B-5 for an Enhanced Swale Design Example

4.8.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

Regular inspection and maintenance is critical to the effective operation of an enhanced swale as designed. Maintenance responsibility for an enhanced swale should be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.

4.9 Grass Channel



Description: Grass channels designed to enhance water quality through the settling of suspended solids.

LID/GI Considerations: If properly incorporated into overall site design, grass channels can help to reduce the impacts of impervious cover and partially infiltrate runoff with pervious soils. Grass channels can complement the natural landscape while providing aesthetic benefits.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Can be used as part of the runoff conveyance system to provide pretreatment
- Can act to partially infiltrate runoff from small storm events if underlying soils are pervious
- Less expensive than curb and gutter systems
- Shall not be used on slopes greater than 4% (1-2% slopes recommended)
- Potential for bottom erosion and sediment resuspension
- Standing water may not be acceptable in some areas
- Contributing drainage area less than 5 acres
- Minimum residence time of 5 minutes
- Water quality rainfall event flow velocity less than 1.0 ft/s and flow depth less than 4 inches
- Side slopes are 3:1 or flatter
- Minimum soil infiltration rate of 0.50 in/hr
- Minimum 2-foot clearance from groundwater table

ADVANTAGES / BENEFITS

- Lower cost
- Reduces runoff from impervious areas
- Ideal for linear environments (along roadways)
- Stormwater collection and conveyance
- Aesthetic benefits
- Well suited for linear environments, interchanges, and facilities
- May be contained within the roadway right-of-way

DISADVANTAGES / LIMITATIONS

- Cannot achieve the 80% TSS removal target alone; must be used in series with other BMPs for removal credit
- Limitations for drainage area, flow, velocity, and flow depth
- Design dependent on existing site conditions and topography

ROUTINE MAINTENANCE REQUIREMENTS

- Provides access to BMP and appropriate components
- Sediment cleanout, trash and debris removal, revegetation, and repair of erosion must be completed as necessary to maintain functionality

POLLUTANT REMOVAL

- 50% **Total Suspended Solids**
- 30% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 25/20% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Runoff Reduction**
- ★ **Water Quality**
- ★ **Channel Protection**
- ● **Overbank Flood Protection**
- ● **Extreme Flood Protection**

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L **Land Requirement**
- L **Capital Cost**
- L **Maintenance Burden**

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes*
Other Considerations: Curb and gutter replacement

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 25% of the RR_v conveyed to the practice (A & B hydrologic soils)
- 10% of the RR_v conveyed to the practice (C & D hydrologic soils)

4.9.1 General Description

Grass channels, also termed "biofilters," settle suspended solids and other pollutants through filtration, infiltration, and biofiltration. Grass channels are also able to help meet runoff velocity targets for the water-quality design storm of small drainage areas. Vegetative practices offer a method to manage pollution while conveying stormwater runoff. Grass channels are well-suited to a number of applications and land uses, including treating runoff from roads and other impervious surfaces. They can also be used in a variety of ways including, but not limited to, a single BMP, a pretreatment to another BMP, or in a "treatment train".

Grass channels differ from enhanced dry swales in that they do not have an engineered filter media to enhance pollutant removal capabilities and therefore have a lower pollutant removal rate than dry enhanced swales. Grass channels are different from conventional roadside ditches in that they are designed for water quality purposes and help increase residence time while decreasing velocities. When properly incorporated into an overall site design, grass channels can reduce impervious cover, accent the natural landscape, and provide aesthetic benefits while removing pollutants.

When designing a grass channel, the two primary considerations are channel capacity and minimizing erosion. Runoff velocity shall not exceed 1.0 foot per second during the peak discharge associated with the water quality design rainfall event, and the total length of a grass channel should provide at least 5 minutes of residence time. To enhance water quality treatment, grass channels must have broader bottoms, lower slopes and denser vegetation than most drainage channels. Additional treatment can be provided by placing check-dams across the channel below pipe inflows, and at various other points along the channel.

4.9.2 Stormwater Management Suitability

Grass channels, a form of 'biofilter,' are trapezoidal or parabolic shaped vegetated channels that work to enhance water quality through the settling of suspended solids through filtration, infiltration, and biofiltration.

- Runoff Reduction
  Grass channels are an effective low impact development (LID) practices that can be used in Georgia to reduce post-construction stormwater runoff and improve water quality. Like other LID practices, they become more effective with higher infiltration rates of native soils. A grass channel can be designed to provide 25% of the runoff reduction volume for type A and B hydrologic soils or 10% of the runoff reduction volume for type C and D hydrologic soils. Performance is dependent on vegetation density and contact time for settling, filtration, and infiltration.

- Water Quality
  Grass channel can be used to remove a variety of pollutants from stormwater runoff' they are typically used as the pre-treatment component of a larger "treatment train" to reduce incoming runoff velocities and filter out particulates.

- Channel Protection
  For smaller sites, a grass channel may be designed to capture the entire channel protection volume (CP_v). Given that a grass channel facility is typically designed to completely drain within 48-72 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, or where only the WQ_v is diverted to the grass channel, another practice must be used to provide CP_v extended detention.

- Overbank Flood Protection
  Another practice used in conjunction with a grass channel will likely be required to reduce the post-development peak flow of the 25-year, 24-hour storm (Q_p) to pre-development levels (detention).

- Extreme Flood Protection
  Grass channels must provide flow diversion and/or be designed to safely pass extreme storm flows while protecting vegetation.

Credit for the volume of runoff reduced in the grass channel may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide Runoff Reduction for Water Quality compliance, then the practice is given credit for Channel Protection and Flood Control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.9.3 Pollutant Removal Capabilities

Pollutant removal from grass channels is highly variable and depends primarily on the density of vegetation and contact time for filtration and infiltration. These, in turn, depend on soil and vegetation type, slope, and contact time. Research on fecal coliform removal has been inconclusive, but suggests that grass channels are generally not considered to be effective BMPs for treating bacterial loads.

For additional information and data on pollutant removal capabilities for grass channels, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.9.4 Application and Site Feasibility Criteria

Grass channels are best suited to treating smaller drainage areas of 5 acres or less. Flow must enter the practice as sheet flow spread out over the width (long dimension normal to flow) of the channel. For longer flow paths, special provision must be made to ensure design flows spread evenly across the filter strip.

Grass channels shall have a side slope of 3:1 or flatter. The maximum flow depth through the channel during the peak discharge associated with the water quality design rainfall event shall be no more than 4 inches. The base width of the channel should be 2-6 feet to ensure a sufficient filtering surface for water quality treatment, and the maximum width prevents braiding, which is the formation of small channels within the channel bottom. The bottom width is a dependent variable in the calculation of velocity based on Manning's equation. If a larger channel is needed, the use of a compound cross section is recommended. The depth from the bottom of the channel to the groundwater should be at least 2 feet to prevent a moist channel bottom, or contamination of the groundwater.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – 5 acres or less. If the practice is used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.
- **Side Slope** – Slopes of the channel shall be 3:1 or flatter.
- **Longitudinal Slope** - Between 1-4%; slopes between 1-2% recommended.
- **Base Width** - Between 2-6 feet.
- **Minimum Depth to Water Table** – A separation distance of 2 foot is recommended between the bottom of the vegetated filter strip and the elevation of the seasonally high water table.
- **Runoff Velocities** – Most not be erosive. Maximum flow velocity of 1.0 ft/s or less is recommended.

Other Constraints / Considerations

Location Requirements – The following is a list of specific setback requirements for the location of a grassed swale:

- Grass channels shall only be used on soils that can sustain a dense grass cover with high retardance. Designers shall choose a grass that can withstand relatively high velocity flows at the entrances of the BMP and both wet and dry periods. See Appendix D for a list of appropriate grasses for use in Georgia.
- Grass channels shall not be used on soils with infiltration rates less than 0.50 inches per hour.
- Minimum setback requirements:
  - » From a property line – 10 feet
  - » From a building foundation – 25 feet
  - » From a private well – 100 feet
  - » From a public water supply well – 1,200 feet
  - » From a septic system tank/leach field – 100 feet
  - » From surface waters – 100 feet
  - » From surface drinking water sources – 400 feet (100 feet for a tributary)

- A grass channel should accommodate the peak flow for the water quality design storm Q_{wq} (see Subsection 3.1.7).
- Incorporation of check dams within the channel will increase retention time.
- A 5-minute residence time is recommended for the water quality peak flow. Residence time may be increased by reducing the slope of the channel, increasing the wetted perimeter, or planting a denser grass (raising the Manning's n).

See Section 5.4 (*Open Channel Design*) for more information and specifications on the design of grass channels.

Grass Channels for Pretreatment

A number of other BMPs, including bioretention areas and infiltration trenches, may utilize a grass channel as a pretreatment measure. The length of the grass channel depends on the drainage area, land use, and channel slope. **Table 4.9.1** provides sizing guidance for grass channels for a 1-acre drainage area. The minimum grassed channel length should be 20 feet.

Table 4.9-1: Grass Channel Sizing Guidance

Source: Claytor and Schueler, 1996

Parameter	≤ 33% Impervious		Between 34% and 66% Impervious		≥ 67% Impervious	
Slope (max =4%)	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%
Grass channel minimum length* (feet) *assumes 2-foot wide bottom width	25	40	30	45	35	50

4.9.5 Planning and Design Criteria

Before designing the grass channel, the following data is necessary:

- Existing and proposed site, topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structure(s).
- Infiltration testing of native soils at the proposed elevation of bottom of grass channel.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.

The following criteria are to be considered minimum standards for the design of a grass channel. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.9.5.1 LOCATION AND LAYOUT

Grass channels vary based on site constraints such as proposed and existing infrastructure, soils, existing vegetation, contributing drainage area, and utilities. Grass channels are designed for intermittent flow and must be allowed to drain between rain fall events and should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources. Grass channel locations should be integrated into the site planning process, with aesthetic and maintenance considerations taken into account in their siting and design.

4.9.6 Design Procedures

(Step 1) **Determine the goals and primary function of the grass channel**

Consider whether the grass channel is intended to:

- » Meet water quality (treatment) target.
- » Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v))
- » Provide a possible solution to a drainage problem

Check with local officials and other agencies to determine if there are any additional watershed restrictions that may apply. In addition, consider if the grass channel has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the grass channel should be centered on the restrictions/requirements, goals, targets, and primary function(s) of a grass channel. By considering the primary function, as well as, topographic and soil conditions, the design elements of the grass channel can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

(Step 2) **Determine if the development site and conditions are appropriate for the use of a grass channel.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a grass channel. Create a rough layout of the grass channel dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 3) **Calculate the Target Water Quality Volume.**

Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) **Calculate the channel width based on an assumed channel flow depth:**

$$W = (n*Q)/(1.49*D^{5/3}*S^{1/2})$$

Where:

W = minimum bottom channel width (ft)
n = Manning's roughness coefficient
Q = peak runoff from the WQ_v rain event (cfs). See Subsection 3.1.7.2.
D = flow depth (ft)
S = slope (%)

(Step 5) Calculate the minimum length (feet) of the grass channel using a 5-minute (300 seconds) residence time:

$$V = Q/(W*D)$$

$$L = V \times (300 \text{ seconds})$$

Where:

L = minimum length of channel (ft)
V = velocity through the channel (ft/s)

(Step 6) Modify base width value and channel slope until the flow depth is less than 4 inches and the flow velocity is less than 1 ft/sec.

(Step 7) Confirm the channel can pass the local design requirements with required freeboard.

(Step 8) Calculate the Stormwater Runoff Reduction Volume conveyed to the practice
Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)
A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 9) Calculate RR_v credited
Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

$$RR_v \text{ (credited)} = RR_v \text{ (RR\%)}$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
RR_v (credited) = Runoff Reduction Volume credited by this practice (ft^3)
RR_V = RR_v conveyed to the practice

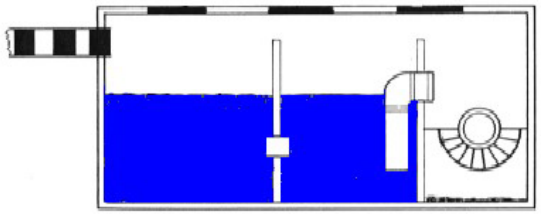
(Step 10) If Steps 5 and 6 are met, then downstream calculations can be performed with adjusted CN using the runoff reduction volume credited. Refer to Subsection 3.1.7.5.

(Step 11) Prepare Vegetation and Landscaping Plan
A landscaping plan for the grass channel should be prepared to indicate how it will be established with vegetation.
See Appendix D for more details.

4.9.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.10 Gravity (Oil-Grit) Separator



Description: An oil-grit separator is a device designed to remove suspended solids, oil, grease, debris, and floatables from stormwater runoff through gravitational settling, hydrodynamic separation, and trapping of pollutants. Oil-grit separators are also called gravity separators or oil-water separators.

LID/GI Considerations: Gravity oil-grit separators are not considered low impact development or green infrastructure. However, for ultra-urban development projects or stormwater retrofit designs, oil-grit separators may be one of few design options for removal of total suspended solids and/or pollutants from stormwater runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Gravity separators are typically used for drainage areas of less than 5 acres.
- Limit the contributing drainage area to any individual gravity separator to have 1 acre or less of impervious cover.
- The total wet storage of the gravity separator unit should be at least 400 cubic feet per contributing impervious acre.
- The minimum depth of permanent pools should be 4 feet.
- Horizontal velocity through the separation chamber should be 1-3 ft/min or less.
- No velocities in the device should exceed the entrance velocity.
- A trash rack should be included in the design to capture floating debris, preferably near the inlet chamber.

ADVANTAGES / BENEFITS

- Well-suited for use on urban development sites, where larger or above-ground BMPs are not an option, or for stormwater retrofit projects
- Can be used as pretreatment for other BMPs
- Can replace a conventional junction or inlet structure
- Multiple inlets can connect to a single unit.
- Some designs require minimal drop between inlet and outlet.

DISADVANTAGES / LIMITATIONS

- Dissolved pollutants are not effectively removed by oil-grit separators.
- Oil-grit separators alone cannot achieve the 80% TSS removal target.
- Frequent maintenance is required.
- Performance is dependent on design and frequency of inspection and cleanout of unit.
- Some designs may require a confined space entry for inspection, maintenance, and repairs.

ROUTINE MAINTENANCE REQUIREMENTS

- Maintenance requirements for a proprietary system should be obtained from the manufacturer.
- Frequency of inspection and maintenance is dependent on land use, climate, and design of the gravity separator.
- Failure to provide adequate inspection and maintenance can result in the resuspension of accumulated solids.
- Proper disposal of oil, solids, and floatables removed from the gravity separator must be ensured.

POLLUTANT REMOVAL

- 40% **Total Suspended Solids**
- N/A **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 5/5% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ★ Water Quality
- ● Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L **Land Requirement**
- H **Capital Cost**
- H **Maintenance Burden**

Residential Subdivision Use: *NO*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Not recommended*

Soils: Gravity oil-grit separator systems can be installed in almost any soil or terrain.

Other Considerations: Install as an off-line device unless the separator can be sized to handle a small drainage area. Also, consider installing a manhole on the downstream side to provide easy access for sampling of effluent.

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% Runoff Reduction Credit is provided by this practice.

4.10.1 General Description

Gravity oil-grit separators are hydrodynamic separation devices that are designed to remove grit, heavy sediments, oil, grease, debris, and floatable matter from stormwater runoff through gravitational settling and trapping. Gravity separator units contain a permanent pool of water and typically consist of an inlet chamber, separation and storage chamber, a bypass chamber, and an access port for maintenance purposes (see Figure 4.10-1). Runoff enters the inlet chamber where heavy sediments and solids drop to the bottom. The flow moves into the main gravity separation chamber, where further settling of suspended solids takes place. Oil and grease are skimmed and stored in a waste oil storage compartment for future removal. After moving into the outlet chamber, the clarified runoff is then discharged.

The performance of these systems is based primarily on the relatively low solubility of petroleum products in water and the difference between their specific gravities. Gravity separators are not designed to separate other products, such as solvents, detergents, or dissolved pollutants. The typical gravity separator unit may be enhanced with a pretreatment swirl concentrator chamber, oil draw-off devices that continuously remove the accumulated light liquids, and flow control valves regulating the flow rate through the facility.

Gravity separators are often used in commercial, industrial, and transportation land uses and are intended primarily as a pretreatment measure for high-density or ultra-urban sites, or for use in hydrocarbon hotspots, such as gas stations and areas with high vehicular traffic. However, gravity separators cannot be used for the removal of dissolved or emulsified oils and pollutants such as coolants, soluble lubricants, glycols and alcohols.

Since resuspension of accumulated sediments is possible during heavy storm events, gravity separator units are typically installed off-line. Gravity separators are available as prefabricated proprietary systems from a number of different commercial vendors.

4.10.2 Stormwater Management Suitability

- Runoff Reduction
  Gravity oil-grit separators do not provide stormwater volume runoff reduction. Another BMP should be used in a treatment train with gravity oil-grit separators to provide runoff reduction. See Subsection 4.1.6 for more information about using BMPs in series.

- Water Quality
  If installed as per the recommended design criteria and properly maintained, 40% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the gravity oil-grit separator. Another BMP should be used in a treatment train with gravity oil-grit separators to provide the additional required water quality treatment. (See Subsection 4.1.6.)

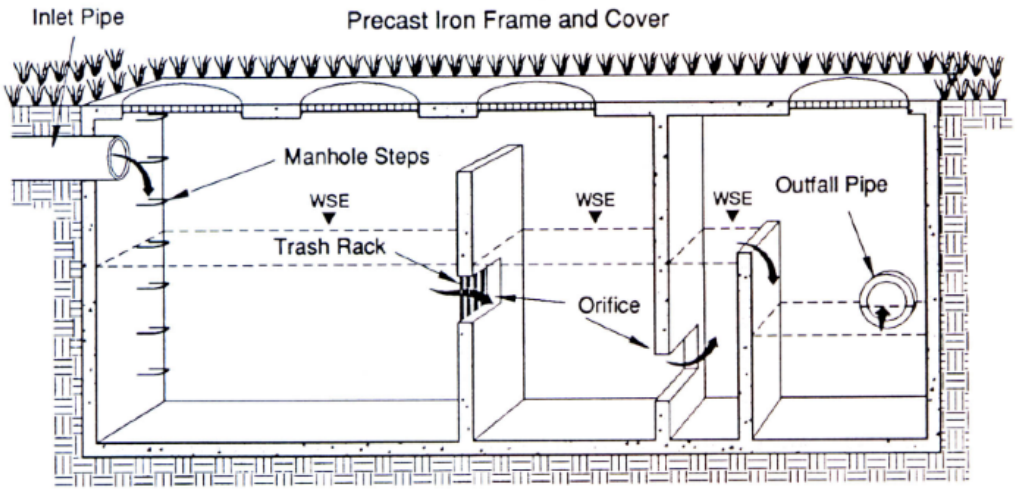


Figure 4.10-1 Schematic of an Example Gravity (Oil-Grit) Separator
(Source: NVRC, 1992[1])

- **Channel Protection**
  Gravity oil-grit separators do not provide channel protection. Another BMP should be used in a treatment train with gravity oil-grit separators to provide channel protection. (See Subsection 4.1.6.) Additionally, the gravity oil-grit separator should be designed off-line or with a bypass for higher flows.

- **Overbank Flood Protection**
  Gravity oil-grit separators do not provide overbank flood protection. Another BMP should be used in a treatment train with gravity oil-grit separators to provide overbank flood protection. Additionally, the gravity oil-grit separator should be designed off-line or with a bypass for higher flows. (See Subsection 3.1.5.)

- **Extreme Flood Protection**
  Gravity oil-grit separators do not provide extreme flood protection. Another BMP should be used in a treatment train with gravity oil-grit separators to provide extreme flood protection. Additionally, the gravity oil-grit separator should be designed off-line or with a bypass for higher flows. (See Subsection 3.1.5.)

4.10.3 Pollutant Removal Capabilities

Testing of gravity oil-grit separators has shown that they can remove between 40-50% of the TSS loading when used in an off-line configuration (Curran, 1996 and Henry, 1999). Gravity oil-grit separators also provide removal of debris, hydrocarbons, trash, and other floatables. They provide only minimal removal of nutrients and organic matter.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- *Total Suspended Solids* – 40%
- *Total Phosphorus* – 5%
- *Total Nitrogen* – 5%
- *Fecal Coliform* – insufficient data
- *Heavy Metals* – insufficient data

Actual field testing data and pollutant removal rates from an independent source should be obtained before using a proprietary gravity separator system.

4.10.4 Application and Site Feasibility Criteria

Conventional oil-grit separators contain a permanent pool of water and typically consist of an inlet chamber, separation and storage chamber, a bypass chamber, and an access port for maintenance purposes. Runoff enters the inlet chamber where heavy sediments and solids drop to the bottom. Then the flow moves into the main separation chamber, where further settling of suspended solids takes place. Oil and grease are skimmed and stored in a waste oil storage compartment for future removal. After moving into the outlet chamber, the clarified runoff is then discharged to the site's stormwater conveyance system.

A wide variety of separator systems are commercially-available in a variety of layouts, for which vendors have design data and procedures. Oil-grit separators are sized based on a design flow rate, the Water Quality Peak Flow Rate (Q_{wq}). This differs from how other stormwater BMPs are sized.

General Feasibility

- Suitable for Residential Subdivision Usage – NO
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Stormwater Control – NO

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – Gravity oil-grit separators are typically used for drainage areas less than 5 acres. It is recommended that the contributing area to any individual gravity separator be limited to 1 acre or less of impervious cover.
- The total wet storage of the gravity separator unit should be at least 400 cubic feet per contributing impervious acre.
- **Space Required** – Gravity oil-grit separators are installed underground; therefore, minimal surface area is required for the device.
- Adequate maintenance access to each chamber must be provided for inspection and cleanout of a gravity separator unit.
- **Site Slope** – Gravity oil-grit separators may be installed on sites with slopes up to 6%.
- A minimum 20 foot wide maintenance right-of-way or drainage easement shall be provided for the oil-grit separator from any public right-of-way. The maintenance access easement shall have a maximum slope of no more than 15% and shall have a minimum unobstructed drive path width of 12 feet, appropriately stabilized to withstand maintenance equipment and vehicles. The right-of-way shall be located such that maintenance vehicles and equipment can access the oil-grit separator.
- **Minimum Depth to Water Table** – 2 feet
- **Minimum Head** – 4 feet (The depth of the permanent pools shall be a minimum of 4 feet.)
- **Soils** – Gravity separator systems can be installed in almost any soil or terrain.
- Provide the listing of manufacturer recommendations for additional site design constraints

Other Constraints/Considerations

- **Hot spots** – Gravity oil-grit separators are well-suited for hot spot runoff
- Damage to existing structures and facilities:
  - » Gravity oil-grit separators may increase the risk of flooding within a basement, affecting underground sewage pipes, or cause adverse effect to other underground structures.
  - » Gravity oil-grit separators should be designed so that overflow drains away from buildings to avoid causing damage to building foundations.
- **Trout Stream** – Gravity oil-grit separators will not reduce thermal impacts of stormwater runoff, nor are they effective at removing soluble pollutants. Therefore, they are not considered an effective means of protecting trout streams. However, in urban and highly developed areas or with a stormwater retrofit, gravity oil-grit separators may be an effective BMP for total suspended solids removal and hydrocarbons.
- **Poorly Draining Soils** – Poorly draining soils do not inhibit a gravity oil-grit separator's ability to temporarily store and treat stormwater runoff.
- **Flat Terrain** – Flat terrain and low site slopes do not interfere with the operation of a gravity oil-grit separator.
- **Shallow Water Table** – Review manufacturer's instructions regarding groundwater elevation. Anti-flotation calculations may be required when large open chambers are installed at or below the water table.

4.10.5 Planning and Design Criteria

Before designing the gravity oil-grit separator, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- Impervious and pervious areas. Other means may be used to determine the land use data
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Design data from nearby storm sewer structures
- Water surface elevation of nearby water systems and depth to seasonally high groundwater

The following criteria are to be considered minimum standards for the design of a gravity oil-grit separator. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.10.5.1 LOCATION AND LAYOUT

Gravity oil-grit separators should be located upstream or downstream of other BMPs providing runoff reduction, additional treatment of the water quality volume (WQ_v), channel protection volume (CP_v), overbank flood protection (Q_{P25}), and extreme flood protection (Q_f). See Subsection 4.1.6 for more information on the use of multiple BMPs in a treatment train.

4.10.5.2 GENERAL DESIGN

- The use of gravity (oil-grit) separators shall be limited to the following applications:
  - » Pretreatment for other BMPs
  - » High-density, ultra-urban, or other space-limited development sites
  - » Hotspot areas where the control of grit, floatables, oil, and/or grease are required
- Gravity separators are rate-based devices. This contrasts with most other stormwater BMPs, which are sized based on capturing and treating a specific volume.
- Horizontal velocity through the separation chamber shall be limited to 1-3 ft/min or less. No velocities in the device shall exceed the entrance velocity.

4.10.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

- The design criteria and specifications of a proprietary gravity separator unit shall be obtained from the manufacturer, and submitted with the Stormwater Site Plan.
- The separation chamber shall provide for three separate storage volumes:
  - » A volume for separated oil storage at the top of the chamber
  - » A volume for settled solids accumulation at the bottom of the chamber
  - » A volume required to give adequate flow-through detention time for separation of oil and sediment from the stormwater flow.
- Gravity separator units shall be designed to bypass runoff flows in excess of the design flow rate. Some designs have built-in high flow bypass mechanisms. Other designs require a diversion structure or flow splitter ahead of the device in the drainage system. An adequate outfall must be provided.
- A trash rack shall be included in the design to capture floating debris, preferably near the inlet chamber to prevent debris from becoming oil impregnated.
- A gravity separator design will provide an oil draw-off mechanism that empties to a separate chamber or storage area.
- Gravity separator units shall be watertight to prevent possible groundwater contamination.

4.10.5.4 PRETREATMENT/INLETS

- Gravity oil-grit separators are typically used for pretreatment in a hotspot area or where floatable debris and pollutants should be removed prior to additional treatment.
- Inlets sizing, slope, and invert placement shall be sized based on manufacturer's recommendations for flow rate, volume, and structure size.

4.10.5.5 OUTLET STRUCTURES

An important consideration when designing an oil-grit separator system for a site is how to bypass large storm events that exceed the design flow capacity around the separator without damaging the unit, exceeding the design flow capacity, or resuspending collected pollutants. Since resuspension of accumulated sediments and oil droplets is possible during heavy storm events, oil-grit separator units are typically installed off-line with a bypass to minimize pollutant wash-out or resuspension in these instances.

The outlet from the gravity separator needs to be able to convey stormwater leaving the gravity separator as well as the bypassed discharge without eroding the surrounding area. Typically the high flow outlet will discharge at a higher elevation than the low flow outlet.

4.10.5.6 SAFETY FEATURES

- The deep inverts, open void sections, and sometimes larger pipe diameters into and out of oil-grit separators may present a fall or entrapment hazard. It is recommended that gravity oil-grit separators be constructed with manhole covers and/or grate lids with locking mechanisms. Structural loading calculations, such as H-20 loading for traffic areas, should be performed when sizing and installing gravity oil-grit separators.
- Some oil-grit separators are considered confined spaces. Additional training may be required to perform work inside the units.

4.10.5.7 CONSTRUCTION CONSIDERATIONS

- Contributing drainage areas to the gravity oil-grit separator should be stabilized with appropriate erosion and sediment control devices, such as with temporary or permanent seeding before runoff can enter a newly installed-device.
- Newly installed gravity oil-grit separators should be inspected prior to being placed in service. Remove sediment and debris that may have been collected during delivery and installation.
- A minimum 20-foot wide maintenance right-of-way or drainage easement shall be provided for the oil-grit separator from any public right-of-way.

4.10.5.8 CONSTRUCTION AND MAINTENANCE COSTS

- Material and installation costs for gravity oil-grit separators can vary based on the size, location, treatment requirements, and manufacturer.
- Typically, gravity oil-grit separator systems range from approximately $5,000-$6,000 for a small catch basin or manhole insert type design to approximately $40,000 for a multi-chamber, high-volume, high-flow device.

4.10.6 Design Procedures

In general, site designers should perform the following design procedures when designing a gravity oil-grit separator.

(Step 1) **Determine the goals and primary functions of the gravity oil-grit separator.**

- » A gravity oil-grit separator can be designed to provide pre-treatment of settled solids, oil, grease, debris, and floatables.
- » An oil-grit separator may also be used to provide some treatment of the water quality volume (WQ_v).
- » Check with local officials and other agencies to determine if there are any additional watershed restrictions that may apply. In addition, consider if the oil-grit separator has any site-specific design conditions or criteria. List any other requirements that may apply to or affect the design.

(Step 2) **Determine if the development site and conditions are appropriate for the use of a gravity oil-grit separator.**
Consider the application and site feasibility criteria in this chapter to determine if site conditions are suitable for a gravity oil-grit separator. Create a rough layout of the device dimensions taking into consideration existing trees, utility lines, power and telephone poles, roadways, sidewalks, curbs, and other obstructions.

(Step 3) **Compute runoff control volumes and rates.**
Oil-grit separators are typically sized based on the Water Quality peak flow rate (Q_{wq}). See Subsection 3.1.7.2 for more information on calculating the Q_{wq}. This differs from how other stormwater BMPs are sized. Refer to manufacturer instructions and tools to design the gravity oil-grit separator based on the appropriate design flow rate and volumes.

(Step 4) **Compute outlet release rate and size outlet.**

- » Use manufacturer-recommend design methods to determine the size, slope, and invert of the device outlet.
- » Ensure downstream receiving BMPs and/or storm drain systems can receive the volume and rate of stormwater flow from the gravity oil-grit separator and/or bypass system.
- » A hydraulic grade analysis should be performed to ensure that the receiving stormwater system can accept the flow, and that the oil-grit separator does not create a hydraulic head jump that exceeds the elevation of the upstream system.

4.10.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.11 Green Roof



Description: Green roofs represent an alternative to traditional impervious roof surfaces. They typically consist of underlying waterproofing and drainage materials and an overlying engineered growing media that is designed to support plant growth. Stormwater runoff is captured and temporarily stored in the engineered growing media, where it is subjected to the hydrologic processes of evaporation and transpiration with any remaining stormwater conveyed back into the storm drain system. This allows green roofs to provide measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.

LID/GI Considerations: Green roofs are an excellent method for reducing site impervious area, stormwater runoff volumes, pollutant loads, and thermal impacts of development. Green roofs provide outdoor areas and species habitat in developed and highly urbanized areas. The use of green roofs reduces the amount of ground surface area required to treat stormwater runoff, maximizing development space.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Engineered growing media should be a light-weight mix containing about 15% organic material.
- Waterproofing materials should be protected from root penetration by an impermeable root barrier.
- Extensive green roofs may be installed on rooftops with slopes of up to 25%, while intensive green roofs are generally recommended to be installed with slopes less than 10%.
- It is suggested that a minimum slope of 1% exist. For roofs with slopes of less than 2%, it is recommended to place a geotextile and a drainage layer beneath the growing media.
- The use of extensive green roof systems (2"-6" deep growing media) should be considered prior to the use of more complex and expensive intensive green roof systems.
- A landscaping plan should be prepared for all green roofs. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.

ADVANTAGES / BENEFITS

- Helps reduce post-construction stormwater runoff rates, volumes, and pollutant loads without consuming valuable land
- Particularly well-suited for use on urban development and redevelopment sites
- Use of green roofs allows for more development space on a project site.

DISADVANTAGES / LIMITATIONS

- Can be difficult to establish vegetation in the harsh growing conditions found on rooftops.
- The roof structure must be capable of supporting the additional weight (live and dead load) of a green roof. Additional support, such as trusses, may be necessary for redevelopment projects to existing structures.

ROUTINE MAINTENANCE REQUIREMENTS

- Inspect green roof for dead or dying vegetation. Dead vegetation should be removed along with any woody vegetation. Plant replacement vegetation as needed.
- Inspect waterproof membrane for leaks. Repair as needed.
- Remove invasive vegetation.
- Monitor sediment accumulation and remove periodically.

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- N/A **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/50% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ● Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- L Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *No*

Soils: *Planting media should meet design recommendations.*

Other Considerations: *Drainage systems for the roof (gutters, downspouts, etc.) must be capable of handling large rainfall events.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 60% of the runoff reduction volume provided

4.11.1 General Description

Green roofs (also known as *vegetated roofs* or *eco-roofs*) represent an alternative to traditional impervious roof surfaces. They typically consist of underlying waterproofing and drainage materials and an overlying engineered growing media that is designed to support plant growth (**Figure 4.11-1**). Stormwater runoff is captured and temporarily stored in the engineered growing media, where it is subjected to the hydrologic processes of evaporation and transpiration, with any excess runoff conveyed back into the storm drain system. This allows green roofs to provide measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.

There are two different types of green roof systems: intensive green roof systems and extensive green roof systems. Intensive green roof systems (also known as *rooftop gardens*) have a thick layer of engineered growing media (i.e., 12-24 inches) that supports a diverse plant community that may include trees (**Figure 4.11-2**). Extensive green roof systems typically have a much thinner layer of engineered growing media (i.e., 2-6 inches) that supports a plant community that is comprised primarily of drought tolerant vegetation (e.g., sedums, succulent plants) (**Figure 4.11-3**).

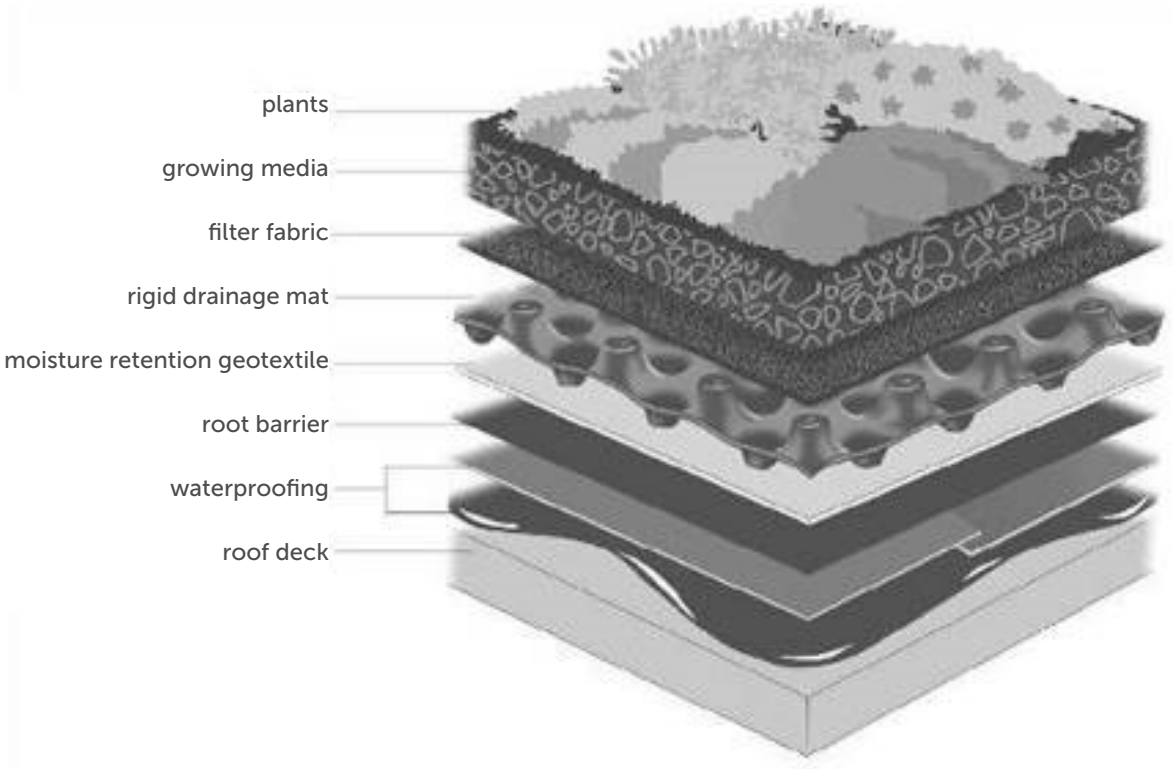


Figure 4.11-1: Components of a Green Roof System
(Source: Carter et al., 2007)

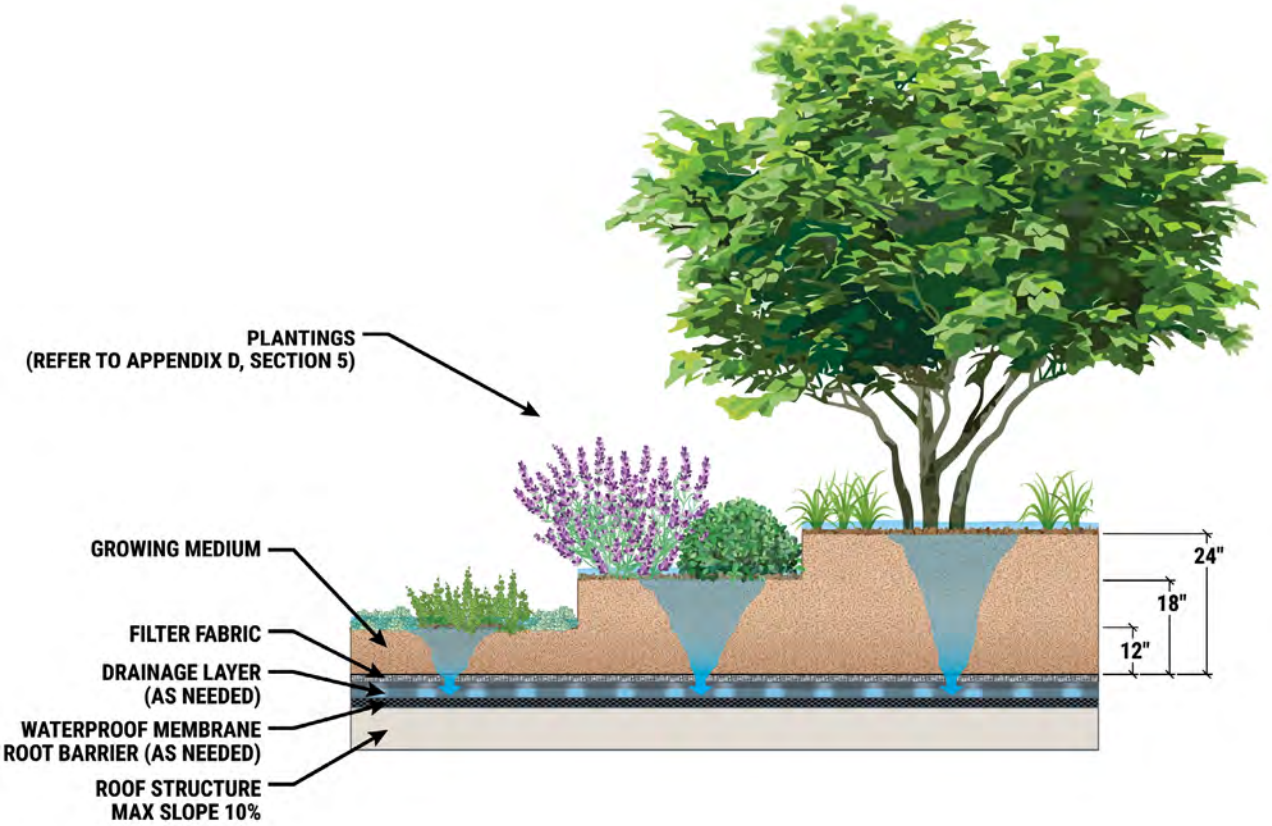


Figure 4.11-2: Intensive Green Roof System

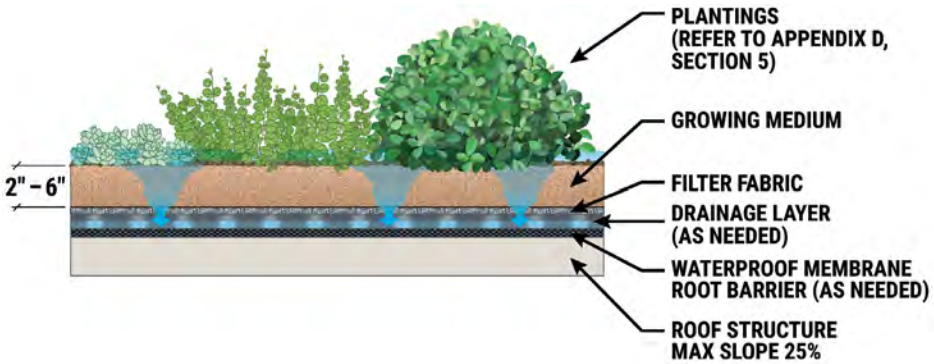


Figure 4.11-3: Extensive Green Roof System

Extensive green roof systems, which can cost up to twice as much as traditional impervious roof surfaces, are much lighter and less expensive than intensive green roof systems. Consequently, it is recommended that the use of extensive green roof systems be considered prior to the use of intensive green roof systems.

Extensive green roof systems typically contain multiple layers of roofing materials (**Figure 4.11-1**), and are designed to support plant growth while preventing stormwater runoff from ponding on the roof surface. Green roof systems are designed to drain stormwater runoff vertically through the engineered growing media and then horizontally through a drainage layer that is sloped towards an outlet. They are designed to require minimal long-term maintenance and, if the right plants are selected to populate the green roof, should not need supplemental irrigation or fertilization after an initial vegetation establishment period.

4.11.2 Stormwater Management Suitability

The Center for Watershed Protection (Hirschman et al., 2008) recently documented the ability of green roofs to reduce annual stormwater runoff volumes and pollutant loads on development sites.

- Runoff Reduction
  Runoff reduction credit can be applied to the green roof contributing drainage area if properly designed, installed, and maintained. As shown in **Table 4.1.3-2**, the runoff reduction volume (RRv) conveyed to a green roof may be reduced by 60%

- Water Quality
  If installed as per the recommended design criteria and properly maintained, 80% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the green roof.

- Channel Protection
  No channel protection volume (CP_v) storage is provided by a green roof. Stormwater runoff generated by the contributing impervious rooftop area and pervious green roof should be routed to a downstream regional BMP that provides storage and treatment of the CP_v. Proportionally adjust the post-development runoff curve number (CN) to account for the runoff reduction provided by a green roof when calculating the CP_v for the regional BMP. See Subsection 3.1.7.5 for more information about curve number reduction.

- Overbank Flood Protection
  No overbank flood protection volume storage is provided by a green roof. Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a green roof when calculating the overbank peak discharge (Q_{p25}) on a development site. See Subsection 3.1.7.5 for more information about curve number reduction.

- Extreme Flood Protection
  No extreme flood protection volume storage is provided by a green roof. Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a simple green roof for the contributing drainage area when calculating the extreme peak discharge (Q_f) on a development site. See Subsection 3.1.7.5 for more information about curve number reduction.

4.11.3 Pollutant Removal Capabilities

Green roofs are presumed to remove 80% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Green roofs remove 50% total Phosphorus and 50% total Nitrogen from stormwater. Green roofs are not presumed to remove fecal coliform or metals such as Cadmium, Copper, Lead, and Zinc.

In order to provide the most efficient pollutant removal, green roofs should be designed according to the criteria provided in this section. For additional information and data on pollutant removal capabilities for green roofs, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.11.4 Application and Site Feasibility Criteria

Green roofs can be used on a wide variety of development sites in rural, suburban, and urban areas. They are especially well-suited for use on commercial, institutional, municipal, and multi-family residential buildings on urban and suburban development and redevelopment sites. When compared with other low impact development practices, green roofs have a relatively high construction cost, a relatively low maintenance burden, and no additional surface area requirements beyond that which will be covered by the green roof. Although they can be expensive to install, green roofs are often a component of "green buildings," such as those that achieve certification in the Leadership in Energy and Environmental Design (LEED) Green Building Rating System.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area –** Green roofs should only be used to replace traditional impervious roof surfaces. They should not be used to treat any stormwater runoff generated elsewhere on the development site.
- **Space Required** – Green roofs require 100% of their contributing drainage areas.
- **Site Slope** – Although green roofs may be installed on rooftops with slopes of up to 25%, they are not recommended for use on rooftops with slopes greater than 10%.
- **Minimum Depth to Water Table** – Separation from the water table is not applicable to a green roof.
- **Minimum Head** – 6-12 inches
- **Soils** – An appropriate engineered growing media, consisting of approximately 80% lightweight inorganic material, 15% organic material, and 5% sand, should be used in green roof systems.

Other Constraints / Considerations

- **Hot spots –** May not be used for hot spot runoff
- **Damage to existing structures and facilities** – When designing a green roof, site planning and design teams must not only consider the stormwater storage capacity of the green roof, but also the structural capacity of the rooftop itself. To support a green roof, a rooftop must be designed to support an additional 15 to 30 pounds per square foot (psf) of load. Consequently, a structural engineer or other qualified professional should be involved with the design of a green roof to ensure that the rooftop itself has enough structural capacity to safely support the green roof system.
- **Proximity** – Green roofs may be used without restriction near:
  - » Private water supply wells
  - » Open water
  - » Public water supply reservoirs
  - » Public water supply wells
  - » Property Lines – Green roofs may be used near property lines; however, ensure that stormwater runoff is not redirected onto an adjacent owner's property. Stormwater runoff should remain on the property where it was generated until it is discharged to downstream receiving waters, a municipal stormwater system, or to the pre-construction point of discharge.
- **Trout Stream** – Green roofs help to treat stormwater for pollutants and reduce the volume and velocity of runoff. Therefore, green roofs are an effective BMP for use where trout streams or other protected waters may receive stormwater runoff.

Green roofs can be used without restriction, where there is flat terrain, low site slopes, and shallow water tables.

4.11.5 Planning and Design Criteria

Before designing the green roof, the following data is necessary:

- Architectural roof plan with rooftop pitches and downspout locations
- The proposed site design, including, buildings, parking lots, sidewalks, stairs and handicapped ramps, and landscaped areas for downspout discharge locations and bypass outfalls
- Information about downstream BMPs and receiving waters

The following criteria are to be considered minimum standards for the design of a green roof. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.11.5.1 LOCATION AND LAYOUT

- Green roof systems should be designed to provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). The required dimensions of a green roof system are governed by several factors, including the hydraulic conductivity and moisture retention capacity of the engineered growing media and the porosity of the underlying drainage layer. Site planning and design teams are encouraged to consult with green roof manufacturers and/or materials suppliers to design green roof systems that provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event).
- During the design of a green roof system, site planning and design teams should consider not only the storage capacity of the green roof, but also the structural capacity of the rooftop itself. A structural engineer or other qualified professional should be involved with the design of a green roof to ensure that the rooftop itself has enough structural capacity to support the green roof system.
- Green roofs should not be used to treat any stormwater runoff generated elsewhere on the development site.

4.11.5.2 GENERAL DESIGN

- All green roofs should be designed in accordance with the ASTM International Green Roof Standards (ASTM, 2005a, ASTM, 2005b, ASTM, 2005c, ASTM, 2005d, ASTM, 2006).
- Extensive green roofs may be installed on rooftops with slopes of up to 25%, while Intensive green roofs are generally recommended to be installed with slopes less than 10%.
- Supplemental measures, such as battens, may be needed to ensure stability against sliding on rooftops with slopes of greater than 10%.All green roof systems should include a waterproofing layer that will prevent stormwater runoff from damaging the underlying rooftop. Waterproofing materials typically used in green roof installations include reinforced thermoplastic and synthetic rubber membranes.
- The waterproofing layer should be protected from root penetration by an impermeable, physical root barrier. Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals, or chemicals that may leach into post-construction stormwater runoff should not be used.
- A drainage layer should be placed between the root barrier and the engineered growing media. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, recycled polyethylene) that are capable of both retaining water and providing efficient drainage when the layer becomes saturated. The required depth of the drainage layer will be governed by the required storage capacity of the green roof system and by the structural capacity of the rooftop itself. An appropriate engineered growing media, consisting of approximately 80% lightweight inorganic materials, 15% organic matter (e.g., well-aged compost), and 5% sand, should be installed above the drainage layer. The engineered growing media should have a maximum water retention capacity of approximately 30%.
- To prevent clogging within the drainage layer, the engineered growing media should be separated from the drainage layer by a layer of permeable filter fabric. The filter fabric should be a non-woven geotextile with a permeability that is greater than or equal to the hydraulic conductivity of the overlying engineered growing media.

- For extensive green roofs, the engineered growing media should be between 4-6 inches deep, unless synthetic moisture retention materials (e.g., drainage mat with moisture storage "cups") are placed directly beneath the engineered growing media layer. When synthetic moisture retention materials are used, a 2 inch deep engineered growing media layer shall be used.
- To assist in conveying runoff to the building drainage system, a semi-rigid, plastic geo-composite drain or mat layer should be included in the design of a green roof. If the roof is flat, a perforated network may be necessary to help rainfall drain properly.
- Extend the roof flashing 6 inches above engineered growing media and protect by counter flashing.
- All media depths used for either intensive or extensive green roof systems, shall support plant growth.

4.11.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

The drainage area of a green roof is comprised of the green roof itself. No additional stormwater runoff should be allowed to "run on" to the green roof with the exception of walking paths or vegetation access ways incorporated into the green roof design.

4.11.5.4 PRETREATMENT/INLETS

Green roofs are designed to directly receive rainfall. Pretreatment and inlets are not required.

4.11.5.5 OUTLET STRUCTURES

An outlet (e.g., scupper and downspout) should be provided to convey stormwater runoff out of the drainage layer and off of the rooftop when the drainage layer becomes saturated.

4.11.5.6 SAFETY FEATURES

- Consideration should be given to the stormwater runoff rates and volumes generated by larger storm events (e.g., 25-year, 24-hour storm event) to design green roofs that are able to safely convey or bypass these flows. An overflow system, such as a traditional rooftop drainage system with inlets set slightly above the elevation of the surface of the green roof, should be designed to convey the stormwater runoff generated by these larger storm events safely off of the rooftop.
- Runoff shall flow through and exit green roof systems without damaging or eroding the roof system or carrying media or vegetative material from the system and shall not cause erosion of soil at the roof system outlets or ground level in the vicinity of the outlet. Roof system discharges shall be conveyed to a non-erodable outlet area adequate to convey the design flow. Overflow structures should be capable of passing the 2-year, 24-hour design storm without inundating the roof.

4.11.5.7 LANDSCAPING

- A landscaping plan should be prepared for all green roofs. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- When developing a landscaping plan, site planning and design teams are encouraged to consult with a botanist, landscape architect, or other qualified professional to identify plants that will tolerate the harsh growing conditions found on rooftops in Georgia. Planting recommendations for green roofs include:
  - » Drought- and full sun-tolerant vegetation that requires minimal irrigation after establishment
  - » Low maintenance vegetation that is self-sustaining and does not require mowing, trimming or the use of fertilizers, pesticides, or herbicides
  - » Vegetation that is fire resistant and able to withstand heat, cold, and high winds
- Since sedum and succulent plants possess many of the characteristics listed above, they are recommended for use on green roof systems installed in Georgia. Herbs, forbs, grasses, and other groundcovers may be used, but these plants typically have higher watering and maintenance requirements.
- Methods used to establish vegetative cover on a green roof should achieve at least 75 percent vegetative cover one year after installation.

4.11.5.8 CONSTRUCTION CONSIDERATIONS

To help ensure that green roofs are properly installed on a development site, site planning and design teams should consider the following recommendations:

- Care should be given to avoid damage to the waterproofing membrane during installation of the green roof. If the integrity of the membrane is compromised in a manner that may cause leaks or roof damage, the area should be identified and repaired. Visually inspect for damage and test the membrane for water tightness prior to installation of the engineered growing media.
- If the roof is sloped, stabilization measures may be required before installing the green roof to prevent soil from sliding down the roof. Some situations may allow the stabilization measures to be incorporated into the roof structure.
- Install the green roof according to the manufacturer's instructions. Usually the root barrier layer, walkway, and irrigation system are installed first.
- To help prevent compaction of the engineered growing media, heavy foot traffic should be kept off of green roof surfaces during and after construction.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted on a green roof.

4.11.5.9 CONSTRUCTION AND MAINTENANCE COSTS

- Extensive green roofs can range from roughly $5-$20 per square foot.
- Intensive green roofs can range from roughly $20-$80 per square foot.
- Although the cost per square foot of a green roof is notably higher than a regular roof, green roofs have been reported to save costs associated with energy consumption and increasing the lifespan of the roof.

4.11.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a green roof.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a green roof. Create a rough layout of the green roof dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the green roof.**

Consider whether the green roof is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Step 4 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the R_V calculated, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)
RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) **Determine the storage volume of the practice and the Pretreatment Volume**

To determine the actual volume provided in the green roof, use the following equation:

$$VP = (PV + VES\ (N))$$

Where:

VP = Volume provided (temporary storage)
PV = Ponding Volume
VES = Volume of Engineered Soils
N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

(Step 3C) **Determine whether the minimum storage volume was met.**

When the VP ≥ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_V treatment method (See Step 4).

(Step 4) **Calculate the Target Water Quality Volume**

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Site area (total drainage area) (ft^2)
12 = Unit conversion factor (in/ft)

Using the WQ_V calculated above, determine the actual size and Volume of the Practice (VP) as shown in Step 3B. Note that VP, calculated in Step 3B, should be greater than or equal to WQ_V.

(Step 5) Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information.

(Step 6) Prepare Site Vegetation and Landscaping Plan.
Vegetation is critical to the function and appearance of any green roof. Therefore landscaping plans should be provided according to the guidance in Subsection 4.11.5.7 (*Landscaping*) and Appendix D.

4.11.7 Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.12 Infiltration Practices



Description: Infiltration practices, which may also be classified as a runoff reducing low impact development practices, are shallow excavations, typically filled with stone or an engineered soil mix, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes and pollutant loads.

LID/GI Considerations: Because infiltration practices allow more infiltration to the soil surrounding the practice than other BMPs, they are considered a LID/GI Control. This helps restore a sites natural hydrology.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Pretreatment should be provided upstream of all infiltration practices
- Infiltration practices should be designed to completely drain within 72 hours of the end of a rainfall event
- Underlying native soils should have an infiltration rate of 0.5 in/hr or more
- The distance from the bottom of an infiltration practice to the top of the water table should be 2 feet or more
- Facilities include an excavated trench (2-10 foot depth) filled with stone media (1.5-2.5 inch diameter), as well as pea gravel and sand filter layers
- A pretreatment device is recommended upstream from the practice
- Observation wells are used to monitor percolation and performance of the practice
- Infiltration practices must not be placed under pavement or concrete

ADVANTAGES / BENEFITS

- Considered a LID-GI control
- Provides for groundwater recharge
- Good for small sites with porous soils
- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads
- Can be integrated into development plans as attractive landscaping features

DISADVANTAGES / LIMITATIONS

- Can only be used to manage runoff from relatively small drainage areas of 5 acres or less
- Should not be used to "receive" stormwater runoff that contains high sediment loads
- Potential for groundwater contamination
- High clogging potential; should not be used on sites with fine-particle soils (clays or silts) in drainage areas
- Significant setback requirements
- Restrictions in karst areas
- Geotechnical testing required, two borings per practice

ROUTINE MAINTENANCE REQUIREMENTS

- Keep practice free of trash, debris, and dirt
- Inspect area for ponding water
- If structures become clogged, remove aggregate, wash and replace
- Can be susceptible to clogging, so locate in stabilized areas (i.e. not in tree canopy)
- Keep observation well easily and safely accessible
- Remove sediment from forebay or other pretreatment practice
- Replace pea gravel layer as needed

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ★ Overbank Flood Protection
- ★ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- H Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*

Other Considerations: *Highly applicable for roadway projects*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 100%- Runoff Reduction Volume

POLLUTANT REMOVAL

- 100% **Total Suspended Solids**
- 100/100% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 100% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 100% **Pathogens** – Fecal Coliform

4.12.1 General Discussion

Infiltration practices are excavations typically filled with stone to create an underground reservoir for stormwater runoff (see **Figure 4.12-1**). This runoff volume gradually exfiltrates through the bottom and sides of the trench into the subsoil over a three-day period and eventually reaches the water table. By diverting runoff into the soil, an infiltration practice not only treats the water quality volume, but also helps to preserve the natural water balance on a site through groundwater recharge to preserve baseflow. Due to this fact, infiltration systems are limited to areas with highly porous soils where the water table and/or bedrock are located well below the bottom of the trench. In addition, infiltration practices must be carefully sited to avoid the potential for groundwater contamination.

Infiltration practices are not intended to trap sediment and must always be designed with a sediment forebay and grass channel for concentrated flow or filter strip for sheet flow, or other appropriate pretreatment measures to prevent clogging and failure. Due to their high potential for failure, these facilities must only be considered for sites where upstream sediment control can be ensured.

Although infiltration practices can provide significant reductions in post-construction stormwater runoff rates, volumes and pollutant loads, they have historically experienced high rates of failure due to clogging caused by poor design, poor construction and neglected maintenance. If infiltration practices are to be used on a development site, great care should be taken to ensure that they are adequately designed, carefully installed and properly maintained over time. They should only be applied on development sites that have permeable soils (i.e., hydrologic soil group A and B soils) and that have a water table and confining layers (e.g., bedrock, clay lenses) that are located at least two feet below the bottom of the trench or basin.

There are two major variations of infiltration practices, namely infiltration trenches and infiltration basins. A brief description of each of these design variants is provided below:

- **Infiltration Trenches**: Infiltration trenches are excavated trenches filled with stone. Stormwater runoff is captured and temporarily stored in the stone reservoir, where it exfiltrates into the surrounding and underlying native soils. Infiltration trenches can be used to manage post-construction stormwater runoff from contributing drainage areas of up to 2 acres and should only be used on development sites where sediment loads can be kept relatively low.
- **Infiltration basins** are shallow, landscaped excavations filled with an engineered soil mix. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration while infiltrating into the surrounding soils. They are essentially non-underdrained bioretention areas (Section 4.2), and should also only be used on development sites where sediment loads can be kept relatively low. It should be noted that this example is only one method.

4.12.2 Stormwater Management Suitability

Infiltration practices can be designed for water quantity, but they are mostly used for water quality, i.e. the removal of stormwater pollutants, depending upon the native soils. Infiltration practices can provide runoff quantity control, particularly for smaller runoff volumes such as the runoff volume generated by the water quality storm event (1.2 inches). These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, infiltration practices will typically need to be used in conjunction with another control to provide channel protection, as well as overbank flood protection. Infiltration practices need to be designed and maintained to safely bypass higher flows.

- Runoff Reduction
  Like other LID practices, infiltration practices become more effective with higher infiltration rates of native soils. An infiltration practice can be designed to provide 100% of the runoff reduction volume, if properly maintained. In order to provide runoff reduction with an infiltration practice that is designed without an underdrain, the infiltration practice should drain within 72 hours.

- Water Quality
  The infiltration practice is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the infiltration practice is designed to perform a specific function. The grass filter strip (for sheet flow) or grass channel or forebay (for concentrated flow) pre-treatment component reduces incoming runoff velocity and filters particulates from the runoff. The planting soil or rock in the infiltration practice acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants.

- Channel Protection
  For smaller sites, an infiltration practice may be designed to capture the entire channel protection volume (CP_v). Given that an infiltration practice is typically designed to completely drain over 48-72 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, or where only the WQ_v is diverted to the infiltration practice, another practice must be used to provide CP_v extended detention.

- Overbank Flood Protection
  Although relatively rare, on some development sites, an infiltration practice can be designed to attenuate the overbank peak discharge (Q_{p2-25}).

- Extreme Flood Protection
  Although relatively rare, on some development sites, an infiltration practice can be designed to attenuate the extreme peak discharge (Q_f).

Credit for the volume of runoff reduced in the infiltration practice may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide Runoff Reduction for Water Quality compliance, then the practice is given credit for Channel Protection and Flood Control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.12.3 Pollutant Removal Capabilities

Infiltration practices are presumed to be able to remove 80% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Infiltration practices can also remove Phosphorus, Nitrogen, metals, and pathogens. An undersized, poorly designed and/or neglected infiltration practice may have reduced pollutant removal performance. Proper design of infiltration practices is critical to ensure that pollutants are properly removed from stormwater runoff. Due to clogging issues, Infiltration Practices should not be used for removing sediment or other coarse material.

For additional information and data on pollutant removal capabilities for infiltration practices, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.12.4 Application and Site Feasibility Criteria

Infiltration practices can be used to manage post-construction stormwater runoff on development sites in rural, suburban and urban areas where the soils have adequate permeability and the water table is low enough to provide for the infiltration of stormwater runoff. They are generally suited for medium-to-high density residential, commercial and institutional developments. Infiltration practices should be considered for use on development sites where the

- Subsoil is sufficiently permeable to provide a reasonable infiltration rate.

- Fine sediment (e.g., clay, silt) loads will be relatively low, as high sediment loads will cause them to clog and fail.

- The water table is low enough to prevent groundwater contamination that could potentially contaminate water supply aquifers.
- Impervious areas where there are not high levels of fine particles (clay/silt soils) in the runoff.

Infiltration practices can either be used to capture sheet flow or concentrated flow from a drainage area. Due to their relatively narrow shape, infiltration practices can be adapted to many different types of sites, such as in retrofit situations. Unlike some other structural stormwater practices, infiltration practices can easily fit into the margin, perimeter, or other unused areas of developed sites.

To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Infiltration practices shall not be used for manufacturing or industrial sites, where there is a potential for high concentrations of soluble pollutants and heavy metals. In addition, infiltration shall not be considered for areas with a high pesticide concentration. Infiltration practices shall not be installed in areas with karst geology.

The following criteria should be evaluated to ensure the suitability of an infiltration practice for meeting stormwater management objectives on a site.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – Maximum of 5 acres. Although infiltration practices can be used to manage stormwater runoff from contributing drainage areas as large as 5 acres in size, contributing drainage areas of between 2,500 square feet and 2 acres are preferred.
- **Space Required** – Will vary depending on the depth of the practice. In general, infiltration practices require about 5% of the size of their contributing drainage areas.
- **Site Slope** – No more than 6% slope (for pre-construction facility footprint). However, they should be designed with slopes that are as close to flat as possible.
- **Minimum Head** – Unless a shallow water table is found on the development site, all infiltration practices should be designed to be at least 36 inches deep. Infiltration basins may be designed with a maximum ponding depth of 12 inches, although a ponding depth of 9 inches is recommended to help prevent nuisance ponding conditions. Unless a shallow water table is found on the development site, all infiltration basin planting beds should be at least 36 inches deep.
- **Minimum Depth to Water Table** – A minimum of two feet is required between the bottom of the infiltration practice and the elevation of the seasonally high water table.
- **Soils** – Infiltration practices should be designed to completely drain within 72 hours of the end of a rainfall event. Consequently, infiltration practices generally should not be used on development sites that have soils with infiltration rates of less than 0.5 inches per hour (i.e., hydrologic soil group C and D soils).

Other Constraints/Considerations

- **Aquifer Protection** – No hotspot runoff allowed; meet setback requirements in design criteria.
- **Poorly Draining Soils**— this condition minimizes the ability of an infiltration practice to reduce stormwater runoff rates, volumes, and pollutant loads. Infiltration practices should not be used on development sites that have soils with infiltration rates of less than 0.5 inches per hour (i.e., hydrologic soil group C and D soils). Another consideration would be to use other low impact development and stormwater management practices, such as rainwater harvesting (Section 4.19) and underdrained bioretention areas (Section 4.2), to manage post-construction stormwater runoff in these areas.

- **Well-Draining Soils**—this condition enhances the ability of infiltration practices to reduce stormwater runoff rates, volumes and pollutant loads, but may allow stormwater pollutants to reach groundwater aquifers with greater ease. A potential solution is to avoid the use of infiltration-based stormwater management practices, including infiltration practices, at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers, unless adequate pretreatment is provided upstream. Another potential solution is to use bioretention areas (Section 4.2) or dry enhanced swales (Section 4.6) with liners and underdrains at stormwater hotspots and in areas known to provide groundwater recharge to water supply aquifers.
- **Flat Terrain**—does not negatively influence the infiltration practice. In fact, infiltration practices should be designed with slopes that are as close to flat as possible.
- **Shallow Water Table**—it may be difficult to provide two feet of clearance between the bottom of the infiltration practice and the top of the water table, which may occasionally cause stormwater runoff to pond in the bottom of the infiltration practice. There are several potential solutions to this problem:
  - » Ensure that the distance from the bottom of the infiltration practice and the top of the water table is at least 2 feet.
  - » Reduce the depth of the stone reservoir in infiltration practices to no less than18 inches.
  - » Reduce the depth of the planting bed in infiltration basins to no less than 18 inches.
  - » Use stormwater ponds (Section 4.25), stormwater wetlands (Section 4.26), or grass channel (Section 4.9), instead of infiltration practices to intercept and treat stormwater runoff in these areas.

4.12.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of an infiltration practice. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.12.5.1 LOCATION AND LAYOUT

- Infiltration practices should be used on development sites that have underlying soils with an infiltration rate of 0.5 inches per hour (in/hr) or greater, as determined by NRCS soil survey data and subsequent field testing. See Appendix D for additional information on the field infiltration test protocol. Note that soil testing should be approved by the local development review authority prior to testing.
- Infiltration practices should have a contributing drainage area of 5 acres or less, with 2 acres or less being preferred.
- There should be at least 24 inches between the bottom of the infiltration practice and the elevation of the seasonally high water table.
- Clay lenses, bedrock or other restrictive layers below the bottom of the trench will reduce infiltration rates unless excavated.
- Minimum setback requirements for infiltration practice facilities (when not specified by local ordinance or criteria):
  - » From a property line – 10 feet
  - » From a building foundation – 25 feet
  - » From a private well – 100 feet
  - » From a public water supply well – 1,200 feet
  - » From a septic system tank/leach field – 100 feet
  - » From surface waters – 100 feet
  - » From surface drinking water sources – 400 feet (100 feet for a tributary)
- To reduce the potential for costly maintenance and/or system reconstruction, it is strongly recommended that the trench be located in an open space, with the top of the structure as close to the ground surface as possible. Infiltration practices should not be located beneath paved surfaces, such as parking lots.
- Infiltration practices are designed for intermittent flow and must be allowed to drain for reaeration of the surrounding soil between rainfall events. They must not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

4.12.5.2 GENERAL DESIGN

A well-designed infiltration practice consists of:

1. Excavated a shallow trench or basin backfilled with sand, coarse stone, and pea gravel;
2. Appropriate pretreatment measures; and
3. One or more observation well to show how quickly the trench basin dewaters or to determine if the practice is clogged.

4.12.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

- Infiltration practices should be designed to completely drain within 72 hours of the end of a rainfall event. Where site characteristics allow, it is preferable to design infiltration practices to drain within 48 hours of the end of a rainfall event to help prevent the formation of nuisance ponding conditions.
- Infiltration practice depths should be between 3-8 feet, to provide for easier maintenance. The width of a trench should be less than 25 feet.
- The surface area required is calculated based on the practice depth, soil infiltration rate, aggregate void space, and fill time (this will need to be modeled).
- The bottom slope of an infiltration practice should be flat across its length and width to evenly distribute flows, encourage uniform infiltration through the bottom, and reduce the risk of clogging.
- Stone aggregate used in the trench should be washed, bank-run gravel, 1.5-2.5 inches in diameter with a void space of about 40% (GADOT No.3 Stone). Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 should be used in calculations, unless aggregate specific data exist.
- An observation well shall be installed in every infiltration practice, at a spacing of at least 1 observation well/100 feet of trench length. There shall be no less than one observation well per infiltration practice. An observation well consists of a 4 to 6 inch perforated PVC (AASHTO M 252) pipe that extends to the bottom of the infiltration practice. The observation well can be used to observe the rate of drawdown within the infiltration practice following a storm event. It should be installed along the centerline of the infiltration practice, flush with the elevation of the surface of the infiltration practice. A visible floating marker should be provided within the observation well and the top of the well should be capped and locked to prevent tampering and vandalism.
- Infiltration systems shall not be constructed until all construction areas draining to them are fully stabilized.
- If an infiltration practice is proposed to be installed in structural fill, adjacent to a structure, or adjacent to a retaining wall the designer shall submit a signed and sealed geotechnical report that addresses, as a minimum, the following:
  - » Compaction requirements and allowances for infiltration into the structural fill.
  - » Global stability of all walls with specific allowances for saturation zones and offset distances from the infiltration practice and the wall.
  - » Structural integrity of all structures with specific allowances for saturation zones and offset distances from the infiltration practice and the structure.
  - » Infiltration rates required for the practice including procedures for obtaining those infiltration rates in the structural fill.
- Minimum setback requirements:
  - » From a property line – 10 feet
  - » From a septic system tank/leach field – 100 feet
  - » From surface waters – 100 feet
  - » From surface drinking water sources – 400 feet (100 feet for a tributary)
  - » From retaining walls with height greater than 4 feet – 20 feet minimum.
- Since clay lenses or any other restrictive layers located below the bottom of an infiltration practice will reduce soil infiltration rates, infiltration testing should be conducted within any confining layers that are found within 4

feet of the bottom of a proposed infiltration practice.

- Infiltration practices should be located in an open pervious area and should be designed so that the top of the practice is located as close to the surface as possible. Infiltration practices should not be located beneath a driveway, parking lot or other impervious surface.
- Broader, shallower infiltration practices perform more effectively by distributing stormwater runoff over a larger surface area. However, a minimum depth of 36 inches is recommended for all infiltration practices to prevent them from consuming a large amount of surface area on development sites. Whenever practical, the depth of infiltration practices should be kept to 60 inches or less.
- Underlying native soils should be separated from the stone reservoir by a thin, 2-4 inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or ASTM D 448 size No. 89, 3/8" to 1/16") or a 6-inch layer of clean, washed sand. The choker stone or sand should be placed between the stone reservoir and the underlying native soils.
- Consideration shall be given to the stormwater runoff rates and volumes generated by larger storm events (e.g., 25-year, 24-hour storm event) to help ensure that these larger storm events are able to safely bypass the infiltration practice. An overflow system shall be designed to convey the stormwater runoff generated by these larger storm events safely out of the infiltration practice. Methods that can be used to accommodate the stormwater runoff rates and volumes generated by these larger storm events include:
  - » Using storm drain inlets set slightly above the elevation of the surface of an infiltration practice to collect excess stormwater runoff. This will create some ponding on the surface of the infiltration practice, but can be used to safely convey excess stormwater runoff over the surface of the practice.
  - » Using yard drains or storm drain inlets set at the maximum ponding depth of an infiltration basin to collect excess stormwater runoff.
  - » Using a spillway with an invert set slightly above the elevation of maximum ponding depth to convey stormwater runoff generated by larger storm events safely out of an infiltration basin.
  - » Placing a perforated pipe (e.g., underdrain) near the top of the stone reservoir or planting bed to provide additional conveyance of stormwater runoff after the infiltration practice has been filled.

4.12.5.4 PRETREATMENT/INLETS

- Pretreatment practices are required to be used in conjunction with an infiltration practice to prevent clogging and failure.
- For an infiltration practice receiving sheet flow from an adjacent drainage area, the pretreatment system should consist of a vegetated filter strip (refer to Section 4.29).
- For concentrated flow, pretreatment should consist of a sediment forebay, vault, plunge pool, or similar sedimentation chamber (with energy dissipaters) sized to a minimum of 10% of the water quality volume (WQ_v). Exit velocities from the pretreatment chamber must be non-erosive for the 2-year, 24-hour design storm.

4.12.5.5 OUTLET STRUCTURES

Outlet structures are not required for infiltration practices.

4.12.5.6 EMERGENCY SPILLWAY

A non-erosive overflow channel or pipe shall be provided to safely pass flows that exceed the storage capacity of the infiltration practice to a stabilized downstream area or watercourse.

4.12.5.7 MAINTENANCE ACCESS

- Adequate access should be provided to an infiltration practice for inspection and maintenance.
- Include access roads and ramps for appropriate equipment to all applicable components of the infiltration practice (observation well, forebay, etc.).
- Provide space to safely exit and enter public roads (if necessary).

4.12.5.8 SAFETY FEATURES

In general, infiltration practices are not likely to pose a physical threat to the public and do not need to be fenced.

4.12.5.9 LANDSCAPING

- Infiltration practices should fit into and blend with the surrounding area. Native grasses are preferable, if compatible. A basin may be covered with permeable topsoil and planted with grass in a landscaped area.
- The landscaped area above the surface of an infiltration practice may also be covered with pea gravel (i.e., ASTM D 448 size No. 8, 3/8" to 1/8"). This pea gravel layer provides sediment removal and additional pretreatment upstream of the infiltration practice and can be easily removed and replaced when it becomes clogged.
- Alternatively, an infiltration practice may be covered with an engineered soil mix, such as that prescribed for an infiltration basin, and planted with managed turf or other herbaceous vegetation. This may be an attractive option when infiltration practices are placed in disturbed pervious areas (e.g., lawns, parks and community open spaces).
- A landscaping plan should be prepared for all infiltration basins. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- Vegetation commonly planted in infiltration basins includes native trees, shrubs and other herbaceous vegetation. When developing a landscaping plan, site planning and design teams should choose vegetation that will be able to stabilize soils and tolerate the stormwater runoff rates and volumes that will pass through the infiltration basin. Vegetation used in infiltration basins should also be able to tolerate both wet and dry conditions. See Appendix D for a list of grasses and other plants that are appropriate for use in infiltration practices installed in the state of Georgia.
- A mulch layer, consisting of 2-4 inches of fine shredded hardwood mulch or shredded hardwood chips, should be included on the surface of an infiltration basin.
- Methods used to establish vegetative cover within an infiltration basin should achieve at least 75% vegetative cover one year after installation.
- To help prevent soil erosion and sediment loss, landscaping should be provided immediately after an infiltration practice has been installed. Temporary irrigation may be needed to quickly establish vegetative cover within an infiltration basin.
- The soils used within infiltration basin planting beds should be an engineered soil mix that meets the following specifications:
  - **Texture:** Sandy loam or loamy sand should be used.
  - **Sand Content:** Soils should contain 85%-88% clean, washed sand.
  - **Topsoil Content:** Soils should contain 8%-12% topsoil.
  - **Organic Matter Content:** Soils should contain 3%-5% organic matter.
  - **Infiltration Rate:** Soils should have an infiltration rate of at least 0.25 inches per hour (in/hr), although an infiltration rate of between 1 and 2 in/hr is preferred.
  - **Phosphorus Index (P-Index):** Soils should have a P-Index of less than 30.
  - **Exchange Capacity (CEC):** Soils should have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight.
  - **pH:** Soils should have a pH of 6-8.
- The organic matter used within an infiltration basin planting bed should be a well-aged compost that meets the specifications outlined in Appendix D.

4.12.5.10 ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- **Low Relief** – No additional criteria.
- **High Relief** – Maximum site slope of 6%.
- **Karst** – Not suitable without adequate geotechnical testing.

Special Downstream Watershed Considerations- No additional criteria

4.12.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of an infiltration practice.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for an infiltration practice. Create a rough layout of the infiltration practice dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the infiltration practice.**

Consider whether the infiltration practice is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A. **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_v = (P)\ (R_v)\ (A) / 12$$

Where:

RR_v = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_v calculated, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)

RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the infiltration practice, use the following equation:

$$VP = (PV + VES (N))$$

Where:

VP = Volume provided (temporary storage)

PV = Ponding Volume

VES = Volume of Engineered Soils

N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pre-treatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met.

When the VP $\geq$ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_v treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)
A = Site area (total drainage area) (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B) If using the practice for Water Quality treatment, determine the footprint of the infiltration practice and the Pretreatment Volume required.

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d):

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

The required dimensions of an infiltration practice that will be filled with a planting media can be determined using the following equation, which is based on Darcy's Law:

$$A_{in} = (WQ_v)(d_{in}) / [(k_{in})(h_{in} + d_{in})(t_{drain})]$$

Where:

A_{in} = surface area of infiltration basin (ft^2)
WQ_v = Water Quality Volume, calculated in Step 4 (ft^3)
d_{in} = depth of infiltration basin planting bed (ft) (use 3 feet or more, unless a shallow water table is found on the development site)
k_{in} = coefficient of permeability of infiltration basin planting bed (ft/day) (use kin = 0.5 ft/day for engineered soil mix specified)
h_{in} = average height of ponded water above infiltration basin (ft) (use 50% of maximum ponding depth)
t_{drain} = design infiltration basin drain time (days) (use 72 hours or less)

(Step 5) Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P2-25} (2-25-yr, 24-hour storms), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information.

(Step 6) Size flow diversion structure, if needed.

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v (or RR_v) to the infiltration practice.

(Step 7) Size the underdrain system.

See Subsection 4.12.5.3 (*Physical Specifications/Geometry*)

(Step 8) **Design the emergency overflow system.**
An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year, 24-hour storm event.

(Step 9) **Prepare Vegetation and Landscaping Plan.**
A landscaping plan for an infiltration practice should be prepared to indicate how it will be established with vegetation. See Subsection 4.12.5.9 (*Landscaping*) and Appendix D for more details.
See Appendix B-4 for an Infiltration Trench Design Example

4.12.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.13 Multi-Purpose Detention Areas



Description: A facility designed primarily for another purpose, such as parking lots and rooftops that can provide water quantity control through detention of stormwater runoff.

LID/GI Consideration: Low land requirement, adaptable to many situations, and often a BMP used to treat runoff close to the source.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Must be designed to minimize potential safety risks, potential property damage, and inconvenience to the facility's primary purposes
- Adequate grading and drainage must be provided to allow full use of facility's primary purposes following a storm event
- Maximum depth of detention ponding in a parking lot should be 6 inches
- Must have a minimum slope of 0.5% towards the outlet, 1% or greater is recommended. Maximum slope shall be 5%

ADVANTAGES / BENEFITS

- Allows for multiple uses of site areas and reduces the need for downstream detention facilities
- Used in conjunction with water quality BMPs
- Adequate grading and drainage must be provided to allow full use of facility's primary purposes following a storm event

DISADVANTAGES / LIMITATIONS

- Controls for stormwater quantity only – not intended to provide water quality treatment
- Restrictions in ponding depths

ROUTINE MAINTENANCE REQUIREMENTS

- Keep practice free of trash, debris, and dirt
- Inspect area for excessive ponding of water
- Remove sediment as needed

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ★ Water Quality*
- ● Channel Protection
- ★ Overbank Flood Protection
- ★ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits
* WQ credit is to be determined on a case by case basis

IMPLEMENTATION CONSIDERATIONS

- (L) Land Requirement
- (L) Capital Cost
- (L) Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *No*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% Runoff Reduction Credit is provided by this practice

4.13.1 General Description

Multi-purpose detention facilities are site areas primarily used for one or more specific activities that are also designed to provide for the temporary storage of stormwater runoff to reduce downstream water quantity impacts. Example of multi-purpose detention areas include:

- Parking Lots
- Rooftops
- Sports Fields
- Recessed Plazas

Multi-purpose detention areas are normally dry between rain events, and by their very nature must be useable for their primary function the majority of the time. As such, multi-purpose detention areas should not be used for extended detention.

Multi-purpose detention areas are not intended for water quality treatment and must be used in a treatment train approach with other BMPs that provide treatment of the WQ_v (see Section 4.1).

4.13.2 Design Criteria and Specifications

Location

- Multi-purpose detention areas can be located upstream or downstream of other BMPs providing treatment of the water quality volume (WQ_v). See Section 4.1 for more information on the use of multiple BMPs in a treatment train.

General Design

- Multi-purpose detention areas may be sized to temporarily store a portion or all of the volume of runoff required to provide overbank flood ($Q_{p2\text{-}25}$) protection (i.e., reduce the post-development peak flow of the 2-25-year storm events to the pre-development rate) and control the 100-year storm (Q_f) if required. Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 3.3 (*Storage Design*) for procedures on the design of detention storage.
- All multi-purpose detention facilities must be designed to minimize potential safety risks, potential property damage, and inconvenience to the facility's primary purposes. Emergency overflows are to be provided for storm events larger than the design storm. The overflow must not create an adverse impact to downstream properties or the conveyance system.

Parking Lot Storage

- Parking lot detention can be implemented in areas where portions of large, paved lots can be temporarily used for runoff storage without significantly interfering with normal vehicle and pedestrian traffic. Parking lot detention can be created in two ways: by using ponding areas along sections of raised curbing, or through depressed areas of pavement at drop inlet locations.
- The maximum depth of detention ponding in a parking lot, except at a flow control structure, should be 6 inches for a 10-year, 24-hour storm, and 9 inches for a 100-year, 24-hour storm. The maximum depth of ponding at a flow control structure is 12 inches for a 100-year, 24-hour storm.
- Fire lanes used for emergency equipment must be free of ponding water for runoff events up to the extreme storm (100-year) event.
- Flows are typically backed up in the parking lot using a raised inlet.
- Detention ponding areas are to be drained within 30 minutes after the peak inflow occurs.

Rooftop Storage

- Rooftops can be used for detention storage as long as the roof support structure is designed to address the weight of ponded water and is sufficiently waterproofed to achieve a minimum service life of 30 years. All rooftop detention designs must meet Georgia State Building Code and local building code requirements.
- The minimum pitch of the roof area subject to ponding is 0.25 inches per foot.
- The rooftop storage system must include another mechanism for draining the ponding area in the event that the primary outlet is clogged.
- See Section 4.11 for information and guidance on Green Roof practices.

Sports Fields

- Athletic facilities such as football fields, soccer fields, and tracks can be used to provide stormwater detention. This is accomplished by constructing berms around the facilities, which in essence creates very large and shallow detention basins. Outflow can be controlled through the use of an overflow weir or other appropriate control structure. Proper grading must be performed to ensure complete drainage of the facility.

Public Plazas

- In high-density areas, recessed public common areas such as plazas and pavilions can be utilized for stormwater detention. These areas can be designed to flood no more than once or twice annually, and provide important open recreation space during the rest of the year.
- Consult the design criteria for the dry detention basins (see Subsection 4.5.6, *Dry Detention Basins*) for the Multi-purpose Detention Basins sizing and design steps.

4.13.3 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.14 Organic Filter



Description: Design variant of the surface sand filter using organic materials in the filter media.

LID/GI Consideration: BMP used to treat runoff close to the source.

KEY CONSIDERATIONS

DESIGN CRITERIA
- Minimum head requirement of 5 to 8 feet
- Maximum contributing drainage area of 10 acres

ADVANTAGES / BENEFITS
- Applicable to small drainage areas
- Good for highly impervious areas
- High pollutant removal capability
- Removal of dissolved pollutants is greater than sand filters due to cation exchange capacity

DISADVANTAGES / LIMITATIONS
- Intended for hotspot, space-limited applications, or for areas requiring enhanced pollutant removal capability
- High maintenance burden
- Filter may require more frequent maintenance than most of the other stormwater BMPs
- Severe clogging potential if exposed soil surfaces exist upstream

ROUTINE MAINTENANCE REQUIREMENTS
- Inspect for clogging – rake first inch of sand
- Remove sediment from forebay and chamber
- Replace organic filter media as needed

POLLUTANT REMOVAL

80% **Total Suspended Solids**

75% **Metals** - Cadmium, Copper, Lead, and Zinc removal

60/40% **Nutrients** - Total Phosphorus / Total Nitrogen removal

50% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- H Maintenance Burden

Residential Subdivision Use: *No*
High Density/Ultra-Urban: *Yes*
Special Considerations: *Hotspot areas*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT
- 0% of the runoff reduction volume provided

4.14.1 General Description

The organic filter is a design variant of the surface sand filter, which uses organic materials such as leaf compost or a peat/sand mixture as the filter media. The organic material enhances pollutant removal by providing adsorption of contaminants such as soluble metals, hydrocarbons, and other organic chemicals.

As with the surface sand filter, an organic filter consists of a pretreatment chamber, and one or more filter cells. Each filter bed contains a layer of leaf compost or the peat/sand mixture, followed by filter fabric and a gravel/perforated pipe underdrain system. The filter bed and subsoils can be separated by an impermeable polyliner or concrete structure to prevent movement into groundwater.

Organic filters are typically used in high-density applications, or for areas requiring an enhanced pollutant removal ability. Maintenance is typically higher than the surface sand filter facility due to the potential for clogging. In addition, organic filter systems have a higher head requirement than sand filters.

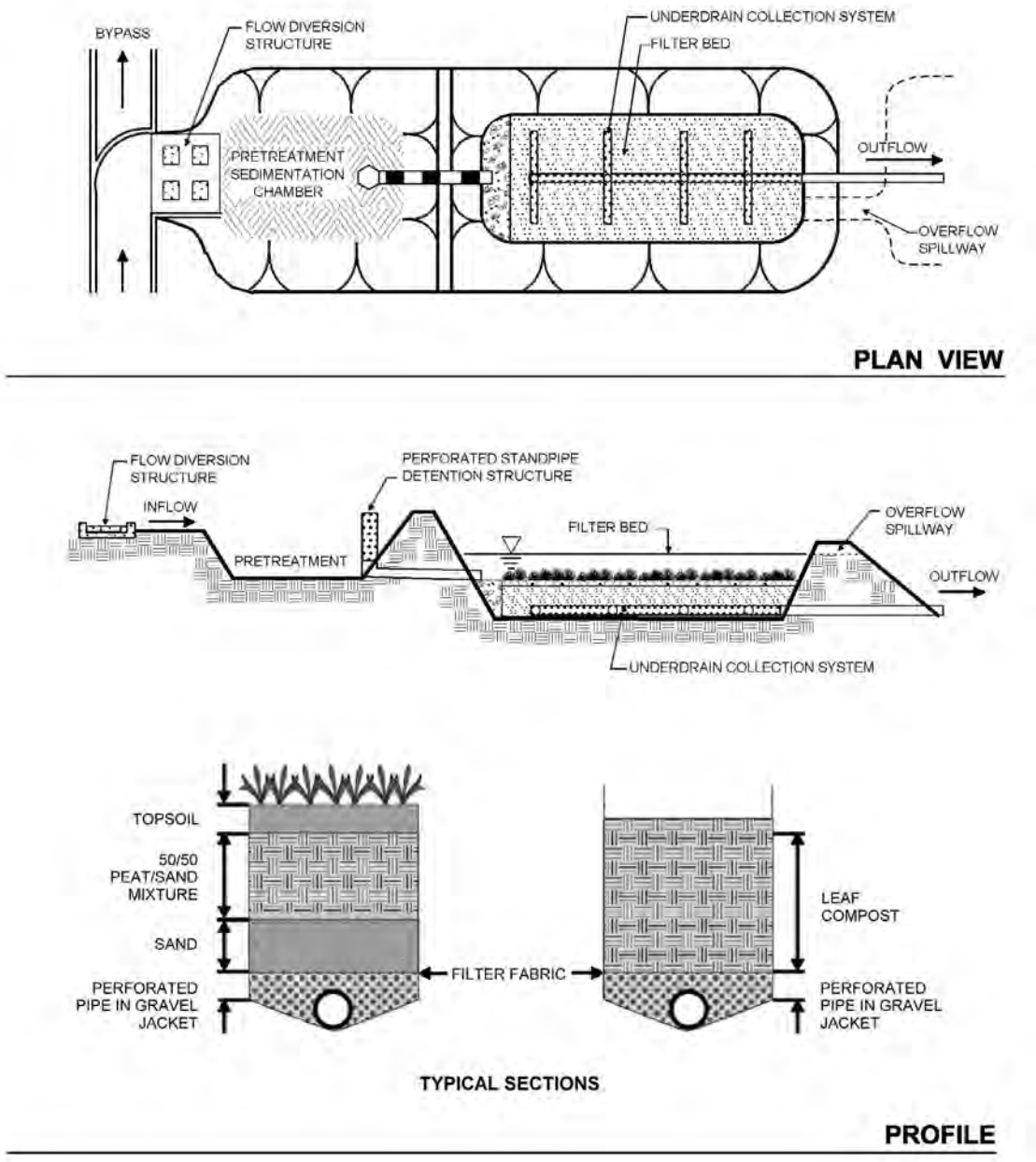
4.14.2 Pollutant Removal Capabilities

Peat/sand filter systems provide good removal of bacteria and organic waste metals.
The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- *Total Suspended Solids* – 80%
- *Total Phosphorus* – 60%
- *Total Nitrogen* – 40%
- *Fecal Coliform* – 50%
- *Heavy Metals* – 75%

4.14.3 Design Criteria and Specifications

- Organic filters are typically used on relatively small sites (up to 10 acres), to minimize potential clogging.
- The minimum head requirement (elevation difference needed at a site from the inflow to the outflow) for an organic filter is 5 to 8 feet.
- Organic filters can utilize a variety of organic materials as the filtering media. Two typical media bed configurations are the peat/sand filter and compost filter (see **Figure 4.14-1**). The peat filter includes an 18-inch 50/50 peat/sand mix over a 6-inch sand layer and can be optionally covered by 3 inches of topsoil and vegetation. The compost filter has an 18-inch compost layer. Both variants utilize a gravel underdrain system.
- The type of peat used in a peat/sand filter is critically important. Fibric peat in which undecomposed fibrous organic material is readily identifiable is the preferred type. Hemic peat containing more decomposed material may also be used. Sapric peat made up of largely decomposed matter should not be used in an organic filter.
- Typically, organic filters are designed as "off-line" systems, meaning that the water quality volume (WQ_v) is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Stormwater flows greater than the WQ_v are diverted to other BMPs or downstream using a diversion structure or flow splitter.
- Consult the design criteria for the surface sand filter (see Subsection 4.21.4, *Sand Filters*) for the organic filter sizing and design steps.

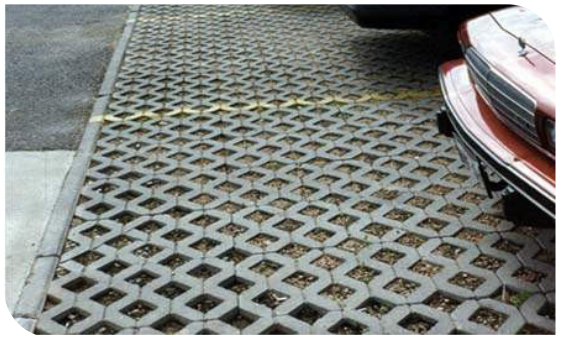


4.14.4 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

Figure 4.14-1 Schematic of Organic Filter
(Source: Center for Watershed Protection)

4.15 Permeable Paver Systems



Description: A pavement surface composed of structural units with void areas that are filled with pervious materials such as gravel, sand, or grass turf. Permeable paver systems are installed over a gravel base course that provides structural support and stores stormwater runoff that infiltrates through the system into underlying permeable soils.

LID/GI Consideration: A permeable paver system provides water quality benefits in addition to groundwater recharge and a reduction in stormwater volume. The use of permeable paver systems should result in a reduction of impervious area on a site.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Intended for low traffic areas, or for residential or overflow parking applications, not ideal for areas with a tree canopy
- Aesthetically pleasing
- Americans with Disabilities Act (ADA) compliance should be met for all accessible areas
- Should be a minimum of two feet above the natural water table
- Should be a minimum of 15 feet away from buildings

ADVANTAGES / BENEFITS

- Surface flow reduction of peak flows, volume, and stormwater runoff
- High level of pollutant removal
- Aesthetic pleasing options
- Reusable product
- Longer life than traditional pavement
- Decreases impermeable area

DISADVANTAGES / LIMITATIONS

- High cost compared to conventional pavements
- Potential for high failure rate if not adequately maintained or used in unstabilized areas
- Geotechnical analysis of soils required
- Ineffective under tree canopy, due to clogging
- Requires specialized knowledge for proper installation

ROUTINE MAINTENANCE REQUIREMENTS

- High maintenance requirements
- Weed and remove grass out of bricks/blocks as necessary (unless concrete grid pavers are used)
- Sweep or vacuum the pavers as necessary

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- 60% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/50% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ★ Overbank Flood Protection
- ★ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- H Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes*

Other Considerations: *Overflow parking, driveways, & related uses*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 100% of the runoff reduction credit if an underdrain is not used
- 75% of the runoff reduction credit if an upturned underdrain is used
- 50% of the runoff reduction credit if an underdrain is used

4.15.1 General Description

Modular permeable paver systems are structural units with regularly inter dispersed void areas used to create a load-bearing pavement surface. The void areas are filled with pervious materials (gravel) to create a system that can infiltrate stormwater runoff. Permeable paver systems provide water quality benefits in addition to groundwater recharge and a reduction in stormwater volume. The use of permeable paver systems should result in a reduction of impervious area on a site.

There are many different types of modular permeable paver systems available from different manufacturers, including both pre-cast and mold in-place concrete blocks, concrete grids, interlocking bricks, and plastic mats with hollow rings or hexagonal cells (see **Figure Page 1**).

Modular permeable paver systems are typically placed on a gravel (stone aggregate) base course. Runoff infiltrates through the permeable paver surface into the gravel base course, which acts as a storage reservoir as it exfiltrates runoff to the underlying soil. The infiltration rate of the soils in the subgrade must be adequate to support drawdown of the entire runoff capture volume within 48-72 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils, which could affect the soils' infiltration capability.

Modular permeable paver systems are typically used in low-traffic areas with low to no tree coverage such as:

- Parking pads in parking lots
- Overflow parking areas
- Residential driveways
- Residential street parking lanes
- Recreational trails
- Golf cart and pedestrian paths
- Emergency vehicle and fire access lanes

A major drawback is the cost and complexity of modular permeable paver systems compared to conventional pavements. Permeable paver systems require a very high level of construction workmanship to ensure that they function as designed. In addition, there is the difficulty and cost of rehabilitating the surfaces when they become clogged. Therefore, consideration of permeable paver systems should include the construction and maintenance requirements and costs.

4.15.2 Stormwater Management Suitability

Permeable paver systems can be designed for water quantity, but they are mostly used for water quality, i.e. the removal of stormwater pollutants, depending upon the native soils. Permeable paver systems can provide runoff quantity control, particularly for smaller runoff volumes such as the runoff volume generated by the water quality storm event (1.2 inches). These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, permeable paver systems will typically need to be used in conjunction with another control to provide channel protection, as well as overbank flood protection. Permeable paver systems need to be designed and maintained to safely bypass higher flows.

- Runoff Reduction
  Like other LID practices, permeable paver systems become more effective with higher infiltration rates of native soils. A permeable paver system can be designed to provide 100% of the runoff reduction volume, if properly maintained.

- Water Quality
  The permeable paver system is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the permeable paver system is designed to perform a specific function. The grass filter strip (for sheet flow) or grass channel or forebay (for concentrated flow) pre-treatment component reduces incoming runoff velocity and filters particulates from the runoff. The planting soil or rock in the permeable paver system acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants.

- Channel Protection
  For smaller sites, a permeable paver system may be designed to capture the entire channel protection volume (CP_v). Given that a permeable paver system is typically designed to completely drain over 48-72 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, or where only the WQ_v. is diverted to the permeable paver system, another practice must be used to provide CP_v extended detention.

- Overbank Flood Protection
  Although relatively rare, on some development sites, a permeable paver system can be designed to attenuate the overbank peak discharge (Q_{p2-25}).

- Extreme Flood Protection
  Although relatively rare, on some development sites, a permeable paver system can be designed to attenuate the extreme peak discharge (Q_f).

Credit for the volume of runoff reduced in the permeable paver system may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide runoff reduction for water quality compliance, then the practice is given credit for channel protection and flood control requirements by allowing the designer to compute an Adjusted CN (see Section 3.1.7.5 for more information).

4.15.3 Pollutant Removal Capabilities

As they provide for the infiltration of stormwater runoff, permeable paver systems have a high removal of both soluble and particulate pollutants, since they become trapped, absorbed or broken down in the underlying soil layers. Due to the potential for clogging, permeable paver surfaces should not be used for the removal of sediment or other coarse particulate pollutants.

For additional information and data on pollutant removal capabilities for permeable pavers, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.15.4 Design Criteria and Specifications

- Permeable paver systems can be used where the underlying in-situ subsoils have an infiltration rate of at least 0.5 inches per hour. Therefore, permeable paver systems are not suitable on sites with hydrologic group D or most group C soils, or soils with a high (>30%) clay content. During construction and preparation of the subgrade, special care must be taken to avoid compaction of soils.

- Permeable paver systems should typically be used in applications where the pavement receives tributary runoff only from impervious areas. The ratio of the contributing impervious area to the permeable paver surface area shall be no greater than 3:1.

- If runoff is coming from adjacent pervious areas, those areas must be fully stabilized to reduce sediment loads and prevent clogging of the permeable paver surface.

- The subsoil of the permeable paver systems shall have a slope of 0% and the surface shall have a slope of no more than 0.5%. Surface slopes shall be 5% or less.

- Shall not be constructed over fill soils.

- If an infiltration practice is proposed to be installed in structural fill, adjacent to a structure, or adjacent to a retaining wall the designer shall submit a signed and sealed geotechnical report that addresses, as a minimum, the following:
  - » Compaction requirements and allowances for infiltration into the structural fill.
  - » Global stability of all walls with specific allowances for saturation zones and offset distances from the infiltration practice and the wall.
  - » Structural integrity of all structures with specific allowances for saturation zones and offset distances from the infiltration practice and the structure.
  - » Infiltration rates required for the practice including procedures for obtaining those infiltration rates in the structural fill.

- Minimum setback requirements:
  - » From a property line – 10 feet
  - » From a septic system tank/leach field – 100 feet

  - » From surface waters – 100 feet
  - » From surface drinking water sources – 400 feet (100 feet for a tributary)
  - » From retaining walls with height greater than 4 feet – 20 feet minimum
- A minimum of 2 feet of clearance is required between the bottom of the gravel base course and underlying bedrock or the seasonally high groundwater table.
- Permeable paver systems should be sited at least 15 feet down gradient from buildings and
- 100 feet away from drinking water wells.
- An appropriate modular permeable paver should be selected for the intended application. A minimum of 40% of the surface area should consist of open void space. If it is a load bearing surface, then the pavers should be able to support the maximum load.
- The permeable paver infill is selected based upon the intended application and required infiltration rate. Masonry sand (such as ASTM C-33 concrete sand or GADOT Fine Aggregate Size No. 10) has a high infiltration rate (8 in/hr) and should be used in applications where no vegetation is desired. A sandy loam soil has a substantially lower infiltration rate (1 in/hr), but will provide for growth of a grass ground cover.
- A 1-inch top course (filter layer) of sand (ASTM C-33 concrete sand or GADOT Fine Aggregate Size No. 10) underlain by filter fabric is placed under the permeable pavers and above the gravel base course.
- The gravel base course should be designed to store at a minimum the water quality volume (WQ_v). The stone aggregate used should be washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40% (GADOT No.3 Stone). Aggregate contaminated with soil should not be used. A porosity value (void space/total volume) of 0.32 should be used in design calculations.
- The gravel base course must have a minimum depth of 12 inches. The following equation can be used to determine if the depth of the storage layer (gravel base course) needs to be greater than the minimum depth:

$$RR_V = A\ [(p1)(d1)]$$

Where:
RR_V - Runoff reduction volume (ft^3)
A - area of permeable paver system (ft^2)
p1 - porosity of base layer (% void)
d1 - depth of base layer (ft)
Note that this formula works for surfaces with a 0% slope.

- The upper surface of the subgrade should be lined with filter fabric or an 8-inch layer of sand (ASTM C-33 concrete sand or GADOT Fine Aggregate Size No. 10) and be completely flat to promote infiltration across the entire surface.
- Permeable paver system designs must use some method to convey larger storm rainfall event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but also accepting bypass flows that are too large to be infiltrated by the permeable paver system. This also helps to address concerns about handling flows when the paver system is clogged.
- For the purpose of sizing downstream conveyance and structural control system, permeable paver surface areas can be assumed to be 40% impervious. In addition, credit can be taken for the runoff volume infiltrated from other impervious areas using the methodology described in Section 3.1.

4.15.5 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a permeable paver system.**
Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a permeable paver systems. Create a rough layout of the permeable paver systems dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the permeable paver system.**
Consider whether the permeable paver system is intended to:

- » Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- » Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- » Provide a possible solution to a drainage problem
- » Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.).

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**
Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_V calculated, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)

RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the permeable paver system, use the following equation:

$$VP = (PV + VES (N))$$

Where:

VP = Volume provided (temporary storage)

PV = Ponding Volume

VES = Volume of Engineered Soils

N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pre-treatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met.

When the VP $\geq$ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_V treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Site area (total drainage area) (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B) If using the practice for Water Quality treatment, determine the footprint of the infiltration practice and the Pretreatment Volume required.

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d) below:

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

To determine the minimum surface area of the permeable paver system, use the following formula:

$$A_f = (WQ_v)(d_g + d_{es}) / [(k_g * d_g * t_g) + (k_{es} * d_{es} * t_{es})]$$

Where:

A_f = surface area of permeable paver system (ft^2)
WQ_v = Water Quality Volume (ft^3)
d_g = gravel depth
d_{es} = engineered soil layer depth (ft)
k_g = coefficient of permeability for gravel (ft/day)
k_{es} = coefficient of permeability for engineered soil (ft/day)
t_g = drain time of gravel (days)
t_{es} = drain time of engineered soil (days)

(Step 5) Calculate the adjusted curve numbers for CP_v (1-yr, 24-hour storm), Q_{P2-25} (2-25-yr, 24-hour storms), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information.

(Step 6) Design system outlets

Determine which type of outlet design will be used for the permeable paver system. There are two types of outlet design that are generally used if infiltration is not possible without additional assistance. They are an underdrain system and overflow system. The underdrain system should include a series of perforated pipes that run longitudinal with the pavers to remove additional stormwater runoff that could not otherwise infiltrate into the surrounding soil. An overflow system directs water that cannot be infiltrated into the subsoil and moves it to another location, for instance another BMP or storm sewer system.

(Step 7) Erosion and Sediment Control/Base Protection

Determine the stormwater discharges to the construction site that could potentially erode and clog the system. Take the proper steps to stabilize the site and prevent erosion when construction begins.

(Step 8) Select Permeable Paver System and finalize design

Select the most appropriate paver system based on the specific site conditions. Finalize the design the of the practice. Make sure that the soil is stabilized by using filter fabric or other method as determined by the designer.

4.15.6 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs should include considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.16 Pervious Concrete



Description: Pervious concrete is a mixture of coarse aggregate, Portland cement and water that allows for rapid infiltration of water and overlays a stone aggregate reservoir. This reservoir provides temporary storage as runoff infiltrates into underlying permeable soils and/or out through an underdrain system.

LID/GI Consideration: Since pervious concrete is often designed primarily for stormwater quantity, but can also provide runoff quality control when used as an integral part of the stormwater management system plan, it can be considered an LID/GI control.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Refer to ACI 522 Report on Pervious Concrete for design considerations
- Construction recommended by National Ready Mixed Concrete Association (NRMCA) certified personnel as specified in ACI 522.1
- Typically used for low volume auto traffic areas, or for overflow parking applications
- Not recommended on sites with low permeability soils, wellhead protection zones, or water supply aquifer recharge areas
- Although not typical, pervious concrete can be designed to accommodate heavier vehicles under certain circumstances
- Americans with Disabilities Act (ADA) compliance should be met for all accessible areas

ADVANTAGES / BENEFITS

- Provides reductions in runoff volume, stormwater runoff, and impervious area
- Helps minimize size of detention ponds
- Particularly well suited in capturing "first flush" water quality volume
- Reduces standing water on pavement
- May help to reduce stormwater management costs

DISADVANTAGES / LIMITATIONS

- Somewhat higher installation cost than for conventional pavement
- Infiltration testing of existing soils may be required
- Not typically recommended for areas with heavy traffic or trucks.
- Not recommended under tree canopy

ROUTINE MAINTENANCE REQUIREMENTS

- Keep concrete free of trash, debris, and dirt
- Use street sweepers or vacuum trucks to clean pervious concrete as needed
- Keep grass surrounding the area trimmed and remove grass clippings from area
- Occasional pressure washing may be necessary

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- 60% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/65% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ★ Overbank Flood Protection
- ★ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- H Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*

Other Considerations: *Overflow parking, driveways, & related uses*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 100% of the runoff reduction credit if an underdrain is not used
- 75% of the runoff reduction credit if an upturned underdrain is used
- 50% of the runoff reduction credit if an underdrain is used

4.16.1 General Description

Pervious concrete (also referred to as *enhanced porosity concrete, porous concrete, Portland cement pervious pavement* and *pervious pavement*) is a subset of a broader family of pervious pavements including porous asphalt, and various kinds of grids and paver systems. Pervious concrete is generally regarded to have a greater ability than permeable asphalt to maintain its porosity in hot weather and thus is provided as a limited application control. Please see **Figure 4.16-1** for typical applications.

Past failures have been attributed to poor design, inadequate construction techniques, soils with low permeability, heavy vehicular traffic and poor maintenance. However, pervious concrete has experienced increasing success in Georgia due to advancements in concrete mix designs, installation techniques and maintenance acceptance. In particular, wider acceptance of the NRMCA Pervious Concrete Contractor certification program (as required by ACI 522) has led to improved contractor performance

Pervious concrete consists of a specially formulated mixture of Portland cement, uniform, open graded course aggregate, and water. The concrete layer has a high permeability, such that the underlying permeable soil layer allows rapid percolation of rainwater through the surface and into the layers beneath. The void space in pervious concrete is in the 15-22% range, as opposed to 3-5% for conventional pavements. The permeable surface is placed over a layer of open-graded gravel and crushed stone. The void spaces in the stone act as a storage reservoir for runoff.

Pervious concrete is often designed primarily for stormwater quantity (i.e. the removal of stormwater volume). However, it can provide runoff quality control, when used as an integral part of the stormwater management system plan. Pervious concrete systems can be designed to capture and infiltrate the water quality volume (WQ_v) and the channel protection volume (CP_v) as well as providing an infiltration option for overbank protection and extreme flood protection.

Modifications or additions to the standard design have been used to pass flows and volumes in excess of the water quality volume, or to increase storage capacity and treatment. These include but are not limited to:

- Placing a perforated pipe near the top of the crushed stone reservoir to pass excess flows after the reservoir is filled
- Providing surface detention storage in a parking lot, adjacent swale, or detention pond with suitable overflow conveyance
- Connecting the stone reservoir layer to a stone filled trench
- Adding a sand layer and perforated pipe beneath the stone layer for filtration of the water quality volume
- Placing an underground detention tank or vault system beneath the layers





Figure 4.16-1 Typical Pervious Concrete System Applications
(Photos by Bruce Ferguson, Don Wade)

In order to meet water quality standards (WQv) and accommodate extended detention requirements for the CP_v, the minimum drawdown time should be 24 hours. Longer drawdown is acceptable as necessary to infiltrate, bypass or detain and release larger storm events with a maximum drawdown time of 3 days. Undue compaction, which could affect the soils' infiltration capability, should be avoided.

Pervious concrete systems are typically used in low-traffic areas such as:

- Parking pads in parking lots
- Overflow parking areas
- Residential street parking lanes
- Recreational trails
- Golf cart and pedestrian paths
- Emergency vehicle and fire access lanes

It is required that subsoil slopes should be equal to or less than 0.5% slope. Surface slopes shall be 5% or less, with 2% maximum slope preferable. The seasonally high water table or bedrock shall be a minimum of two feet below the bottom of the pervious concrete.

Pervious concrete has the positive characteristics of volume reduction due to infiltration, groundwater recharge, and an ability to blend into the normal urban landscape relatively unnoticed. It also allows a reduction in the cost of other stormwater infrastructure, which may offset the greater upfront capital cost of pervious (versus impervious) concrete.

Like other infiltration controls, pervious concrete should not be used in areas that experience high rates of wind erosion or in drinking water aquifer recharge areas.

4.16.2 Stormwater Management Suitability

Pervious concrete can provide runoff quantity control, particularly for smaller runoff volumes such as the runoff volume generated by the water quality storm event (1.2 inches). These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, pervious concrete will typically need to be used in conjunction with another control to provide channel protection, as well as overbank flood protection.

- Runoff Reduction
  Like other LID practices, pervious concrete becomes more effective with higher infiltration rates of native soils. Pervious concrete can be designed to provide 100% of the runoff reduction volume, if properly maintained.
- Water Quality
  Pervious concrete provides some amount of pollutant removal, but is not well suited for removing sediment due to the sediment potentially clogging the pores within the pervious concrete.
- Channel Protection
  For smaller sites, the pervious concrete may be designed to capture the entire channel protection volume (CP_v). Given that the storage volume under the pervious concrete is typically designed to completely drain over 48-72 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, or where only the WQ_v. is diverted to the pervious concrete, another practice must be used to provide CP_v extended detention.
- Overbank Flood Protection
  Although relatively rare, on some development sites, pervious concrete can be designed to attenuate the overbank peak discharge (Q_{p2-25}).
- Extreme Flood Protection
  Although relatively rare, on some development sites, pervious concrete can be designed to attenuate the extreme peak discharge (Q_f).

Credit for the volume of runoff reduced in pervious concrete may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide runoff reduction for water quality compliance, then the practice is given credit for channel protection and flood control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.16.3 Pollutant Removal Capabilities

As they provide for the infiltration of stormwater runoff, pervious concrete systems have a high removal rate for both soluble and particulate pollutants, which become trapped, absorbed or broken down in the underlying soil layers. Due to the potential for clogging, pervious concrete surfaces should not be used for the removal of sediment or other coarse particulate pollutants.

For additional information and data on pollutant removal capabilities for pervious concrete, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the national Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

Pollutant removal can be improved through routine vacuuming, sweeping, and high pressure washing of pervious concrete systems, maintaining a drainage time of at least 24 hours, pretreating the runoff, having organic material in the subsoil, and using clean washed aggregate (EPA, 1999).

4.16.4 Application and Site Feasibility Criteria

Pervious concrete is suitable for many types of development, from single-family residential to high-density commercial projects. Though not often used for heavily traveled roads, it is well suited for alleys, driveways, and parking lots.

The following criteria shall be evaluated to ensure the suitability of pervious concrete for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Site Slope** – Slopes shall be a maximum of 5%.
- If an infiltration practice is proposed to be installed in structural fill, adjacent to a structure, or adjacent to a retaining wall the designer shall submit a signed and sealed geotechnical report that addresses, as a minimum, the following:
  - » Compaction requirements and allowances for infiltration into the structural fill.
  - » Global stability of all walls with specific allowances for saturation zones and offset distances from the infiltration practice and the wall.
  - » Structural integrity of all structures with specific allowances for saturation zones and offset distances from the infiltration practice and the structure.
  - » Infiltration rates required for the practice including procedures for obtaining those infiltration rates in the structural fill.
- Minimum setback requirements:
  - » From a property line – 10 feet
  - » From a septic system tank/leach field – 100 feet
  - » From surface waters – 100 feet
  - » From surface drinking water sources – 400 feet (100 feet for a tributary)
  - » From retaining walls with height greater than 4 feet – 20 feet minimum
- **Minimum Depth to Water Table** – A separation distance of 2 feet is recommended between the bottom of the rock storage area of the pervious concrete and the elevation of the seasonally high water table.
- **Soils** – Native soils if they have at least 0.5 inch/hr infiltration ability.

Other Constraints/Considerations

- **Hot spots** – Do not use for hot spot runoff.
- **Damage to existing structures and facilities** – Consideration should be given to the impact of water exfiltrating the pervious concrete.
- **Proximity** – The following is a list of specific setback requirements for the location of pervious concrete:
  - » 10 feet from building foundations
  - » 100 feet from private water supply wells
  - » 200 feet from public water supply reservoirs (measured from edge of water)
  - » 1,200 feet from public water supply wells
- **Trout Stream** – Evaluate for stream warming when an underdrain system is used.
- **Poorly Drained Soils**—This condition minimizes the ability of pervious concrete to reduce

stormwater runoff rates and volumes. One solution would be to include an underdrain system.

- **Shallow Water Table**—This can prevent the provision of 2 feet of clearance between the bottom of the pervious concrete and the top of the water table which may cause stormwater runoff to pond in the storage layer of the pervious concrete.

In addition, careful consideration should be given to the potential of perched or raised groundwater levels. Provide adequate distance from building foundations or use impermeable liner on side of excavated area nearest to structure.

4.16.5 Planning and Design Criteria

- Pervious concrete systems can be used where the underlying in-situ subsoils have an infiltration rate greater than 0.5 inches per hour. Infiltration rates for in-situ soils should be determined through geotechnical investigation prior to design of the system. During construction and preparation of the subgrade, over compaction of soils should be avoided. Refer to ACI 522 for compaction recommendations.
- Pervious concrete systems should typically be used in applications where the pavement receives tributary runoff only from impervious areas. It is required that the ratio of tributary impervious area to the area of the pervious concrete system shall be a maximum of 1:1. Pervious concrete systems should be sized for a minimum drawdown time of 24 hours and a maximum drawdown time of 3 days.
- Tributary runoff from adjacent pervious areas is not recommended. However, if it is necessary for runoff to come from adjacent pervious areas, those areas are to be fully stabilized to reduce sediment loads and prevent clogging of the pervious surface. Pretreatment using dry or wet enhanced swales or vegetated filter strips for removal of course sediments is recommended and continued maintenance of these areas will be required. (see Sections 4.6 and 4.29)
- A minimum of two feet of clearance is required between the bottom of the gravel base course and underlying bedrock or the groundwater table.
- Pervious concrete systems should be sited at least 10 feet down-gradient from buildings and 100 feet away from drinking water wells.
- To protect groundwater from potential contamination, runoff from designated hotspot land uses or activities must not be infiltrated. Pervious concrete should not be used on manufacturing or industrial sites, where there is potential for high concentrations of soluble pollutants and heavy metals. In addition, pervious concrete should not be considered for areas with high pesticide concentrations. Pervious concrete is also not suitable in areas with karst geology without adequate geotechnical testing and approval by qualified individuals and in accordance with local requirements.
- Pervious concrete systems can be used independently or in conjunction with other stormwater management system components to effectively infiltrate, bypass, or detain and time-release all required storm events..
- For the purpose of sizing downstream conveyance and structural control system, pervious concrete surface areas can be estimated as 35% impervious.
- For treatment control, the design volume should be, at a minimum, equal to the water quality volume. The water quality storage volume is contained in the surface layer and the aggregate reservoir. The storm duration (fill time) is normally short compared to the infiltration rate of the sub-grade, so storage duration of two hours can be used for design purposes. The total storage volume in a layer is equal to the percent of void space times the volume of the layer.

- The cross-section typically consists of two layers, as shown in **Figure 4.16-2**. The aggregate reservoir can sometimes be avoided or minimized if the sub-grade is sandy and there is adequate time to infiltrate the necessary runoff volume into the sandy soil without by-passing the water quality volume. A description for each of the layers is presented below:
  - » **Pervious Concrete Layer** – The pervious concrete layer consists of an open-graded concrete mixture usually ranging from depths of 6 – 15 inches depending on required bearing strength and pavement design requirements. Pervious concrete can be assumed to contain 18 percent voids (porosity = 0.18) for design purposes. Thus, for example, a 6 inch thick pervious concrete layer would hold 1.08 inches of rainfall. Refer to ACI 522R (most current version) for recommendations on mix proportioning for pervious concrete. See the GCPA specifications (referenced) as well.
  - » **Reservoir Layer** – The reservoir gravel base course consists of washed, bank-run gravel, 1.5 2.5 inches in diameter with a void space of about 40% (GADOT No.3 Stone). The depth of this layer depends on the desired storage volume, which is typically the water quality volume (WQv) at a minimum. Typical depths for the reservoir layer range from 2-4 feet. Aggregate contaminated with soil shall not be used. A porosity value (void space/ total volume) of 0.40 should be used in calculations unless aggregate-specific data exist.



Figure 4.16-2 Pervious Concrete System Section
(Modified From: LAC 2000

  - » **Filter Fabric** – Filter fabric can be used is certain applications, as site conditions warrant. General guidance for the use of filter fabrics is below. Actual use should be under the guidance of a Georgia licensed engineer.
  - » **Geotextiles** consisting of permeable materials should line the sides of the aggregate base to prevent migration of adjacent soils into it and subsequent permeability and storage capacity reduction. Geotextiles are not recommended under the aggregate base in an infiltration design because they can accumulate fine particulates that inhibit infiltration.

» Geomembranes consisting of impermeable materials should be used to accomplish the following:

- Provide a barrier on the side and bottom of the aggregate base in a detention design to prevent infiltration into the subgrade typically due to soil instability, the presence of stormwater hotspots, or potential for groundwater contamination. Geomembrane barriers reduce the credit for TSS removal from 85% to 70%.
- Line the sides of the aggregate base whenever structure foundations of conventional pavement are 20 feet or less from the permeable pavement (to avoid the risk of structural damage due to seepage). The use of geomembranes for this purpose will not reduce credit for TSS removal in the system.

» Geogrids may be used on top of subgrade soils for additional structural support, especially in very weak, saturated soils. All manufacturer requirements must be followed in design and installation of geogrids.

» **Underlying Soil** – Pervious concrete systems cannot be used in fill soils. The underlying soil should have an infiltration capacity of at least 0.50 in/hr. as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5000 square feet, with a minimum of two borings per practice (taken within the proposed limits of the facility). Test borings are recommended to determine the soil classification, seasonal high ground water table elevation, impervious substrata, and an initial estimate of permeability. Often a double-ring infiltrometer test is done at subgrade elevation to determine the impermeable layer, and, for safety, one-half the measured value is allowed for infiltration calculations.

- The pit excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench to avoid jeopardizing the stability of the trench sidewalls. The bottom of the excavated trench should not be loaded so as to cause compaction, and should be scarified prior to placement of reservoir base material. The sides of the trench should be trimmed of all large roots. The sidewalls should be uniform with no voids and scarified prior to backfilling. All pervious concrete systems should be protected during construction and constructed after upstream areas are stabilized.
- An observation well consisting of perforated PVC pipe 4-6 inches in diameter should be placed at the downstream end of the facility and protected during site construction. The well should be used to determine actual infiltration rates for use in final design of the pervious concrete system.
- A warning sign should be placed at the facility that states, "Pervious Paving used on this site to reduce pollution. Do not resurface with non-pervious material. Call (XXX) XXX-XXXX for more information."
- Details of construction of the concrete layer are beyond the scope of this manual. However, construction by NRMCA certified personnel, following the guidelines of ACI 522R and ACI 522.1, is recommended.

4.16.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of the pervious concrete.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for pervious concrete. Create a rough layout of the pervious concrete dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the pervious concrete.**

Consider whether the pervious concrete is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A. **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_v calculated, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)
RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the pervious concrete, use the following equation:

$$VP = (VBL) * (N)$$

Where:

VP = Volume provided (temporary storage)
VBL = Volume of Base Layer
N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity. Most gravel has a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pretreatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met.

When the VP $\geq$ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_v treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Site area (total drainage area) (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B) If using the practice for Water Quality treatment, determine the footprint of the pervious concrete and the Pretreatment Volume required

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d) below:

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

To determine the minimum surface area of the pervious concrete, use the following formula:

$$A_f = (WQ_v)(d_{pc} + d_{rl})/[(k_{pc} * d_{pc} * t_{pc})+(k_{rl} * d_{rl} * t_{rl})]$$

Where:

A_f = surface area of pervious (ft^2)
WQ_v = Water Quality Volume (ft^3)
d_{pc} = pervious concrete depth (ft)
d_{rl} = reservoir layer depth (ft)
k_{pc} = coefficient of permeability for pervious concrete (ft/day)
k_{rl} = coefficient of permeability for reservoir layer (ft/day)
t_{pc} = drain time of pervious concrete (days)
t_{rl} = drain time of reservior layer (days)

(Step 5) Size underdrain system (if applicable)

See Subsection 4.2.5.3 (*Physical Specifications/Geometry*)

4.16.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.17 Porous Asphalt



Description: Porous asphalt is asphalt with reduced sands or fines and larger void spaces, which allow water to drain through it. Porous asphalt allows water to infiltrate into the subsoil below through the paved surface and base layer. This aggregate base layer acts as a structural layer and container to temporarily hold stormwater.

LID/GI Consideration: Porous asphalt can be used to reduce the effective impervious area on a site, therefore reducing the design volumes and peak discharges that must be controlled. Porous asphalt can also eliminate problems with standing water, provide groundwater recharge, control erosion of streambeds and riverbanks, and facilitate pollutant removal.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Intended for low-traffic areas, or for residential or overflow parking applications
- Not ideal for areas with a tree canopy or high-traffic flow
- Soil infiltration rate of 0.5 in/hr or greater is required if no underdrain is present
- Aesthetically pleasing
- Americans with Disabilities Act (ADA) compliance should be met for all accessible areas
- Not appropriate as water quality treatment BMP for drainage discharged from other areas

ADVANTAGES / BENEFITS

- Surface flow reduction of peak flows, volume, and stormwater runoff
- Can be used as a pretreatment for other BMPs for pollutants other than TSS
- High level of pollutant removal other than TSS
- Decreases impermeable area

DISADVANTAGES / LIMITATIONS

- Potential for high failure rate if not adequately maintained or if used in unstabilized areas
- Not recommended for areas with sediment-laden runoff that can clog porous pavement
- Subgrade cannot be over-compacted
- Construction must be sequenced to avoid compaction and clogging of the pavement.

ROUTINE MAINTENANCE REQUIREMENTS

- Sweep or vacuum the asphalt to increase pavement life and avoid clogging
- Keep contributing drainage area free of debris and address any areas of erosion

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- 60% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/50% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ★ Overbank Flood Protection
- ★ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L **Land Requirement**
- M **Capital Cost**
- M **Maintenance Burden**

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes*

Soils: *Not recommended for use with hydrologic soils group 'D' and 'C' without underdrain.*

Other Considerations: *Overflow parking, driveways, & related uses*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 100% of the runoff reduction credit if an underdrain is not used
- 75% of the runoff reduction credit if an upturned underdrain is used
- 50% of the runoff reduction credit if an underdrain is used

4.17.1 General Description

Porous asphalt is an asphalt driving surface that permits the infiltration of water through the pavement and into underlying soils. Porous asphalt can be used to reduce the effective impervious area on a site, therefore reducing the design volumes and peak discharges that must be controlled. This will allow a reduction in the cost of other stormwater infrastructure, which may offset the greater placement cost. Porous asphalt can also eliminate problems with standing water, provide for groundwater recharge, control erosion of streambeds and riverbanks, facilitate pollutant removal, reduce thermal pollution of receiving waters, and provide for a more aesthetically pleasing site.

Porous asphalt consists of open-graded coarse aggregate, bonded together by asphalt cement, with sufficiently interconnected voids to make it highly permeable to water (see **Figure 4.17-1**). Porous asphalt is best applied in areas that experience low amounts of vehicle traffic and have little to no tree coverage, including:

- Parking pads in parking lots
- Overflow parking areas
- Residential driveways
- Residential street parking lanes
- Recreational trails
- Golf cart and pedestrian paths
- Emergency vehicle and fire access lanes
- Plazas

Porous asphalt is not recommended and may not be approved for use in areas that experience high amounts of traffic volume, heavy loads, or areas with high amounts of sediment runoff (i.e. construction areas).

A major drawback of this BMP is the cost and complexity of porous asphalt compared to conventional pavements. Porous asphalt requires a very high level of construction workmanship to ensure that it functions as designed. In addition, there is the difficulty and cost of rehabilitating porous asphalt surfaces should they become clogged. Therefore, consideration of porous asphalt should include the construction and maintenance requirements and costs.

Porous asphalt is designed primarily for impervious area reduction and the subsequent reduction in stormwater treatment volumes and peak discharges, particularly for smaller storm events. These include:

- Placing a perforated pipe near the top of the crushed stone reservoir to pass the excess flows after the reservoir is filled
- Connecting the stone reservoir layer to a stone-filled trench
- Adding a sand layer and perforated pipe beneath the stone layer for filtration of the water quality volume

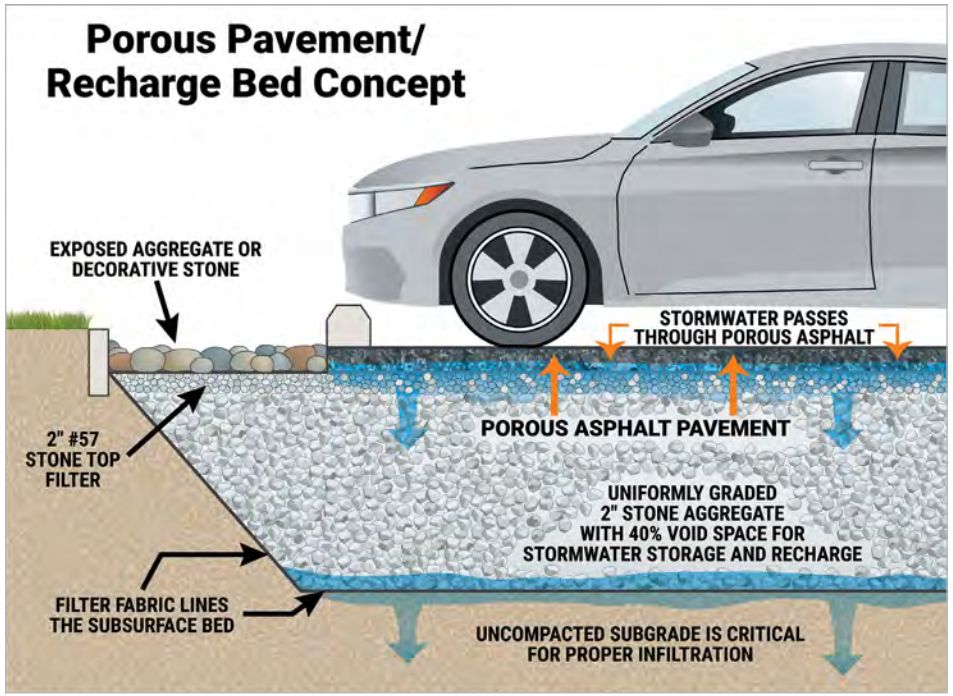


Figure 4.17-1

Porous asphalt is typically placed on a gravel (stone aggregate) base course. Runoff infiltrates through the porous asphalt into the gravel base course, which acts as a storage reservoir as it exfiltrates to the underlying soil. The infiltration rate of the soils in the subgrade must be adequate to support drawdown of the entire runoff capture volume within 24-48 hours. Special care must be taken during construction to avoid undue compaction of the underlying soils, which could affect the soils' infiltration capability.

Another type of porous asphalt is called open-graded friction course (OGFC). OGFC is a thin permeable layer of asphalt that encompasses a support structure consisting of uniform, coarse aggregate with minimal fines, and serves as an overlay for conventional asphalt pavements. OGFC has a high void content that creates permeability, allowing for the infiltration of stormwater runoff.

4.17.2 Stormwater Management Suitability

Porous asphalt can provide runoff quantity control, particularly for smaller runoff volumes such as the runoff volume generated by the water quality storm event (1.2 inches). These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, porous asphalt will typically need to be used in conjunction with another control to provide channel protection, as well as overbank flood protection.

- Runoff Reduction
  Like other LID practices, porous asphalt becomes more effective with higher infiltration rates of native soils. Porous asphalt can be designed to provide 100% of the runoff reduction volume, if properly maintained.
- Water Quality
  Porous asphalt provides some amount of pollutant removal, but is not well suited for removing sediment due to the sediment potentially clogging the pores within the porous asphalt.
- Channel Protection
  For smaller sites, the porous asphalt may be designed to capture the entire channel protection volume (CP_v). Given that the storage volume under the porous asphalt is typically designed to completely drain over 48-72 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, or where only the WQ_v. is diverted to the porous asphalt, another practice must be used to provide CP_v extended detention.is diverted to the porous asphalt, another practice must be used to provide CP_v extended detention.
- Overbank Flood Protection
  Although relatively rare, on some development sites, porous asphalt can be designed to attenuate the overbank peak discharge (Q_{p2-25}).
- Extreme Flood Protection
  Although relatively rare, on some development sites, porous asphalt can be designed to attenuate the extreme peak discharge (Q_f).

Credit for the volume of runoff reduced in porous asphalt may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide runoff reduction for water quality compliance, then the practice is given credit for channel protection and flood control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.17.3 Pollutant Removal Capabilities

As it provides for the infiltration of stormwater As porous asphalt provides infiltration of stormwater runoff, it has a high removal rate for both soluble and fine particulate pollutants, which can be trapped, absorbed, or broken down in the underlying soil layers. Due to the potential for clogging, porous asphalt should not be used for the removal of sediment or other coarse particulate pollutants. Maintenance efforts and frequency is directly related to the amount of accumulated or trapped sediment. OGFC has a TSS removal of 50%. There is not sufficient data for nutrients, fecal coliform, or metal removal rates to be determined.

For additional information and data on pollutant removal capabilities for porous asphalt and OGFC, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.17.4 Application and Site Feasibility Criteria

Porous asphalt is suitable for many types of development, from single-family residential to high-density commercial projects. Though not often used for heavily traveled roads, it is well suited for alleys, driveways, and parking lots.

The following criteria should be evaluated to ensure the suitability of porous asphalt for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Site Slope** – Slopes shall be a maximum of 5%.
- If an infiltration practice is proposed to be installed in structural fill, adjacent to a structure, or adjacent to a retaining wall the designer shall submit a signed and sealed geotechnical report that addresses, as a minimum, the following:
  - » Compaction requirements and allowances for infiltration into the structural fill.
  - » Global stability of all walls with specific allowances for saturation zones and offset distances from the infiltration practice and the wall.
  - » Structural integrity of all structures with specific allowances for saturation zones and offset distances from the infiltration practice and the structure.
  - » Infiltration rates required for the practice including procedures for obtaining those infiltration rates in the structural fill.
- Minimum setback requirements:
  - » From a property line – 10 feet
  - » From a septic system tank/leach field – 100 feet
  - » From surface waters – 100 feet
  - » From surface drinking water sources – 400 feet (100 feet for a tributary)
  - » From retaining walls with height greater than 4 feet – 20 feet minimum
- **Minimum Depth to Water Table** – A separation distance of 2 feet is recommended between the bottom of the rock storage area of the porous asphalt and the elevation of the seasonally high water table.
- **Soils** – Native soils if they have at least 0.5 inch/hr infiltration ability.

Other Constraints / Considerations

- **Hot spots** – Do not use for hot spot runoff.
- **Damage to existing structures and facilities** – Consideration should be given to the impact of water exfiltrating the porous asphalt.
- **Proximity** – The following is a list of specific setback requirements for the location of porous asphalt:
  - » 10 feet from building foundations
  - » 100 feet from private water supply wells
  - » 200 feet from public water supply reservoirs (measured from edge of water)
  - » 1,200 feet from public water supply wells
- **Trout Stream** –Evaluate for stream warming when an underdrain system is used.
- **Poorly Drained Soils**— This condition minimizes the ability of porous asphalt to reduce stormwater runoff rates and volumes. One solution would be to include an underdrain system.
- **Shallow Water Table**— This can prevent the provision of 2 feet of clearance between the bottom of the porous asphalt and the top of the water table which may cause stormwater runoff to pond in the storage layer of the porous asphalt.

In addition, careful consideration should be given to the potential of perched or raised groundwater levels. Provide adequate distance from building foundations or use impermeable liner on side of excavated area nearest to structure.

4.17.5 Planning and Design Criteria

- The detailed design of porous asphalt is beyond the scope of this Manual. Refer to The National Asphalt Pavement Associations' *Porous Asphalt Pavements for Stormwater Management: Design, Construction and Maintenance Guide* for detailed design guidance.
- Porous asphalt systems can be used where the underlying in-situ subsoils have an infiltration rate of at least 0.5 inches per hour. During construction and preparation of the subgrade, special care must be taken to avoid compaction of the soils.

- Porous asphalt should typically be used in applications where the pavement receives tributary runoff only from impervious areas. It is required that the ratio of the contributing impervious area to the porous asphalt surface area shall be no greater than 3:1. Porous asphalt systems should be sized for a minimum drawdown time of 24 hours and a maximum drawdown time of 3 days.
- If runoff is coming from adjacent pervious areas, those areas are to be fully stabilized to reduce sediment loads and prevent clogging of the porous asphalt surface.
- It is recommended that the subsoil of the porous asphalt have a slope of 0% and the surface have a slope 0.5% or less, if possible.
- A minimum of 2 feet of clearance is required between the bottom of the gravel base course and underlying bedrock or the groundwater table.
- To protect groundwater from potential contamination, runoff form designated hotspot land uses or activities must not be infiltrated. Porous asphalt should not be used for manufacturing or industrial sites, where there is potential for high concentrations of soluble pollutants and heavy metals. In addition, porous asphalt is not suitable in areas with karst geology without adequate geotechnical testing and approval by qualified individuals and in accordance with local requirements.
- Porous asphalt can be used independently or in conjunction with other stormwater management system components to effectively infiltrate, bypass, or detain and time-release all required storm events.
- The surface of the subgrade should be lined with or an 8-inch layer of sand (ASTM C-33 concrete sand or GADOT Fine Aggregate Size No. 10) and completely flat to promote infiltration across the entire surface.
- Porous asphalt must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that are too large to be infiltrated by the porous asphalt. This would also address situations in which the surface clogs.
- In addition, credit can be taken for the runoff volume infiltrated from other impervious areas using the methodology in Section 3.1.
- For the purpose of sizing downstream conveyance and structural control system, porous asphalt surface areas can be estimated as 35% impervious.
- The cross-section typically consists of two layers. The aggregate reservoir can sometimes be avoided or minimized if the sub-grade is sandy and there is adequate time to infiltrate the necessary runoff volume into the sandy soil without by-passing the water quality volume. A description for each of the layers is presented below:
  - » **Porous Asphalt Layer** – The porous asphalt layer consists of a porous mixture of asphalt. This layer is usually 4-8 inches deep depending on the required bearing strength, pavement design requirements, and manufacturer's specifications.
  - » **Reservoir Layer** –The reservoir gravel base course consists of washed, bank-run gravel, 1.5-2.5 inches in diameter with a void space of about 40% (GADOT No.3 Stone). The depth of this layer depends on the desired storage volume, which is typically the water quality volume (WQ_v) at a minimum. Typical depths for the reservoir layer range from 2-4 feet. Aggregate contaminated with soil should not be used. A porosity value (void space/total volume) of 0.40 should be used in calculations unless aggregate-specific data exist.
  - » **Filter Fabric** – Filter fabric can be used in certain applications, as site conditions warrant. General guidance for the use of filter fabrics is below. Actual use should be under the guidance of a Georgia licensed engineer. Geotextiles consisting of permeable materials should line the sides of the aggregate base to prevent migration of adjacent soils into it, which may lead to permeability and storage capacity reduction.
  - » Geotextiles consisting of permeable materials should line the sides of the aggregate base to prevent migration of adjacent soils into it, which may lead to permeability and storage capacity reduction.

    Geotextiles are not recommended under the aggregate base in an infiltration design because they can accumulate fine particulates that inhibit infiltration.

- Geogrids may be used on top of subgrade soils for additional structural support, especially in very weak, saturated soils. All manufacturer requirements must be followed in design and installation.
- Underlying Soil – Porous asphalt should not generally be used in fill soils. The underlying soil should have an infiltration capacity of at least 0.50 in/hr, as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Test borings are recommended to determine the soil classification, seasonal high groundwater table elevation, and impervious substrata, to produce an initial estimate of permeability. Often a double-ring infiltrometer test is done at subgrade elevation to determine the impermeable layer.
- Pit excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench as to not jeopardize the stability of the trench sidewalls. The bottom of the excavated trench should not be loaded in a way that causes compaction, but should be scarified prior to placement of reservoir base material. The sides of the trench should be trimmed of all large roots. The sidewalls should be uniform with no voids and scarified prior to backfilling. All porous asphalt systems should be protected during site construction and constructed after upstream areas have been stabilized.
- An observation well consisting of perforated PVC pipe 4-6 inches in diameter should be placed at the downstream end of the practice and protected during construction. The well should be used to determine actual infiltration rates for use in final design of the porous asphalt system.
- A warning sign should be placed at the facility that states, "Porous pavement used on this site to reduce pollution. Do not resurface with non-porous material. Call (XXX) XXX-XXXX for more information."
- If OGFC is used, consult the *GDOT Manual on Drainage Design for Highways* for design specifications.

4.17.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of the porous asphalt.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for porous asphalt. Create a rough layout of the porous asphalt dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the porous asphalt.**

Consider whether the porous asphalt is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) Calculate the Stormwater Runoff Reduction Target Volume

Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_V calculated, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v\ (target) / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)
RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the porous asphalt, use the following equation:

$$VP = (VBL) * (N)$$

Where:

VP = Volume provided (temporary storage)
VBL = Volume of Base Layer
N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most gravel has a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pretreatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met.

When the VP $\geq VP_{MIN}$, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP $< VP_{MIN}$, then the BMP must be sized according to the WQ_V treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Site area (total drainage area) (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B)If using the practice for Water Quality treatment, determine the footprint of the infiltration practice and the Pretreatment Volume required.

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d below):

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

To determine the minimum surface area of the pervious concrete, use the following formula:

$$A_f = (WQ_v)(d_{pc} + d_{rl})/[(k_{pc} * d_{pc} * t_{pc})+(k_{rl} * d_{rl} * t_{rl})]$$

Where:

A_f = surface area of pervious (ft^2)
WQ_v = Water Quality Volume (ft^3)
d_{pc} = porous asphalt depth (ft)
d_{rl} = reservoir layer depth (ft)
k_{pc} = coefficient of permeability for porous asphalt (ft/day)
k_{rl} = coefficient of permeability for reservoir layer (ft/day)
t_{pc} = drain time of porous asphalt (days)
t_{rl} = drain time of reservior layer (days)

(Step 5) Size underdrain system (if applicable)
See Subsection 4.2.5.3 (*Physical Specifications/Geometry*)

4.17.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for inspection and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.18 Proprietary Systems

Description: Proprietary systems are manufactured stormwater BMPs and treatment systems available from commercial vendors; these systems are designed to treat stormwater runoff and/or provide water quantity control.

LID / GI Consideration: Proprietary systems may be considered to be low impact development or green infrastructure practices.

Note: It is the policy of this Manual not to recommend any specific commercial vendors for proprietary systems. However, this subsection is being included in order to provide communities with a rationale for approving the use of a proprietary system or practice in their jurisdictions.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Design criteria, such as drainage area, slope, soils, flow velocity, storage area, permanent pool depth, and inlet/outlet considerations are based on manufacturer recommendations.

ADVANTAGES / BENEFITS

- Proprietary systems can be chosen or designed for a site's specific stormwater runoff characteristics and/or design constraints.
- Often, proprietary systems are well-suited for use on urban development sites where larger or above-ground BMPs are not an option, or for stormwater retrofit projects.
- Can be used as pretreatment for other BMPs
- Can replace a conventional junction or inlet structure
- Some designs require minimal drop between inlet and outlet.

DISADVANTAGES / LIMITATIONS

- Dissolved pollutants may not be effectively removed by proprietary systems.
- Proprietary systems may not achieve the 80% TSS removal target alone.
- Performance is dependent on design and maintenance of individual units.

ROUTINE MAINTENANCE REQUIREMENTS

- Maintenance requirements for a proprietary system should be obtained from the manufacturer.
- Frequency of inspection and maintenance is dependent on land use, climatological conditions, and the system's design.
- Failure to provide adequate inspection and maintenance can result in the re-suspension of accumulated solids.
- Ensure maintenance access to proprietary systems when designing each site.

STORMWATER MANAGEMENT SUITABILITY

- ★ Runoff Reduction
- ★ Water Quality
- ★ Channel Protection
- ★ Overbank Flood Protection
- ★ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- varies Land Requirement
- varies Capital Cost
- varies Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes*

Soils: *Proprietary systems can be installed in almost any structure, soil, or terrain.*

Other Considerations: *Install as an off-line device unless the system can be sized to handle a small drainage area.*

RUNOFF REDUCTION CREDIT

- Runoff reduction is not typically provided by proprietary systems.

4.18.1 General Description

There are many types of commercially-available proprietary stormwater BMPs for both water quality treatment and quantity control. These systems include:

- Hydrodynamic systems such as gravity and vortex separators
- Filtration systems
- Catch basin media inserts
- Chemical treatment systems
- Package treatment plants
- Prefabricated detention structures

Many proprietary systems are useful on small sites and space-limited areas where there is not enough land or room for other stormwater treatment alternatives. Proprietary systems can be used as pretreatment in a treatment train. However, proprietary systems are often more costly than other alternatives and may have high maintenance requirements. Perhaps the largest difficulty in using a proprietary system is the lack of adequate independent performance data, particularly for use in Georgia conditions. Below are general guidelines that should be followed before considering the use of a proprietary commercial system.

4.18.2 Approval for Using Proprietary Systems

A proprietary system shall have a demonstrated ability to meet the stormwater management goals and uses for which it is intended. This means that the system shall provide:

1. Independent third-party scientific verification of the ability of the proprietary system to meet water quality treatment objectives and/or to provide water quantity control (channel or flood protection)
2. A proven record of longevity in the field
3. Proven ability to function in Georgia conditions (e.g., climate, rainfall patterns, soil types)

For a propriety system to meet (1) above for water quality goals, the following monitoring criteria shall be met for supporting studies:

- Samples shall be taken for at least 15 storm events.
- The study shall be independent or independently verified (i.e., may not be conducted by the vendor or designer without third-party verification).
- The study shall be conducted in the field, as opposed to laboratory testing.
- Field monitoring shall be conducted using standard protocols that require proportional sampling both upstream and downstream of the device.
- Concentrations reported in the study shall be flow-weighted.
- The propriety system or device shall have been in place for at least one year at the time of monitoring.

Although local data is preferred, data from other regions can be accepted as long as the design accounts for local conditions.

Gwinnett County may submit a proprietary system to further scrutiny based on the performance of similar practices. A poor performance record or high failure rate is valid justification for not allowing the use of a proprietary system or device.

As an example for a proprietary system evaluation guideline, the Metropolitan North Georgia Water Planning District has developed the *Post-Construction Stormwater Technology Assessment Protocol (PCSTAP).*

Introduction

These guidelines, however, were not intended to be testing protocols or procedures for evaluating the performance of a proprietary technology or product. Furthermore, the lack of consistent review and evaluation of monitoring and performance data has been a source of frustration for local governments, vendors and the development community.

As local governments are being asked to review and approve emerging stormwater treatment technologies, a consistent testing protocol and a process for evaluating and accepting proprietary stormwater treatment systems is necessary.

The objective of this protocol is to provide local governments and other entities with an assessment tool to use, if they so choose, as a starting point for evaluating a particular technology's effectiveness in removing pollutants from stormwater runoff for an intended application and to compare test results with vendor performance claims.

Purpose

This document's primary purpose is to establish a testing protocol and process for evaluating and reporting on the performance and appropriate uses of proprietary stormwater treatment technologies and systems for addressing post-construction stormwater runoff. It is not intended for use in evaluation of erosion and sedimentation control technologies or products for use during construction or land-disturbing activities. See the Georgia Soil & Water Conservation Commission's *Manual for Sedimentation and Erosion Control in Georgia* for information on assessing E&S technologies.

Stormwater treatment technologies and products that have been tested according to this protocol can receive consideration to have their results evaluated and made available publicly on the Metro Water District website (www.northgeorgiawater.org). The review of vendor data and subsequent determinations and public dissemination is not intended to be an approval process or an endorsement of any product by the Metropolitan North Georgia Water Planning District. Purchasers and users of any technologies or products presented by a manufacturer or other entity using this protocol should make their own independent analyses and evaluations concerning the usefulness or value of any stormwater technologies or combinations of technologies in considering whether to use any particular technology or product for post-construction stormwater treatment. Local governments and other entities are free to use this information as part of their process to evaluate the suitability of these technologies or products.

Note: The current protocol is only set-up for collecting information on TSS removal. The protocol may be updated in the future to also provide information and evaluation on run-off reduction volumes.

For the latest protocol and other information, see: www.northgeorgiawater.org.

Gwinnett County Procedure for Approval to Use a Proprietary BMP

Approval of a proprietary BMP (i.e. one not included in this manual), must obtain written approval issued by the Department of Water Resources (DWR). The review and approval/denial will be provided to the applicant within 21 days of a submittal to the Department of Water Resources of a complete application. If the application is not complete it will be returned to the applicant, and the re-submittal will restart at the 21-day period. There are two avenues to obtain this approval: 1) a Development General Approval with Conditions, or 2) a Development Specific Approval. The processes for each approval type are noted below.

Development General Approval with Conditions

Any party may apply for written approval for use of a proprietary BMP (i.e. one not included in this manual), in unincorporated Gwinnett County. This is known as a Development General Approval with Conditions. The applicant must acquire, a development general written approval, issued by the DWR, stating that the proprietary BMP is approved for use in unincorporated Gwinnett County, under certain conditions.

Consistent with the PCSTAP mentioned previously, which encourages Gwinnett County to conduct its own independent analysis and evaluation of any concurrence issued under that protocol, the DWR has established the following three step process to obtain local approval to use a proprietary BMP in unincorporated Gwinnett County, under certain specified conditions. These steps are as follows:

1) Obtain Metropolitan North Georgia Water Planning District's Post-Construction Stormwater Technology Assessment Protocol (PCSTAP) Concurrence; The applicant must supply proof of concurrence with the PCSTAP issued by the Metropolitan North Georgia Water Planning District.
2) Submit a General Application to Gwinnett County for Local Analysis and Evaluation; A request to use a proprietary device in unincorporated Gwinnett County, under certain specified conditions, must be made in writing to the DWR. The applicant may be required to pay a fee so that the DWR can have the design reviewed by an independent expert or panel of experts. The application, at a minimum, shall include the following information:
    a. Justification for use of the proposed proprietary device
    b. Summary description of the proprietary device
    c. Description of design
    d. Anticipate useful life of the proprietary device
    e. Minimum and maximum flows (drainage area) that the proprietary device can handle
    f. Pollutants that are removed by the BMP
    g. Pollutant removal efficiency

h. Standard Proprietary device design drawings
i. Example Proprietary device design calculations
j. Technology limitations, including site characteristic limitations, and operating condition requirements
k. Monitoring data documenting water quality benefits and pollutant removal efficiencies.
l. Monitoring data statistical analysis
m. Maintenance program, including actions and intervals, with projected costs and blank inspection forms
n. Safety and aesthetic considerations
o. A description of the particle size distribution (PSD) used in the assessment of the proprietary device.
p. A description of where the monitoring was completed, and if not within Gwinnett County, a detailed description of why the conditions at the monitoring site should be considered equivalent to local conditions
q. A copy of the full PCSTAP submittal to the Metropolitan North Georgia Water Planning District and a copy of any of the Metro District's written assessment of results.

3) Local Analysis and Evaluation Completed by Gwinnett County:
   a. DWR will call a meeting of the GCSMM Committee to review the submittal. This committee consists of County employees from P&D, DWR and GC DOT, who work in the field of Stormwater. The GCSMM Committee may also seek feedback and comment from the Stormwater Technical Advisory Committee, or other experts, as necessary.
   b. GCSMM Committee will review the submittal and assess whether submitted materials, including the PCSTAP review, is adequate and complete. If they do not agree with the Metro District's written assessment results, or the application is otherwise lacking in detail to allow a full assessment for use of the proprietary device under local conditions, the GCSMM Committee may request further documentation, testing or monitoring.
   c. The GCSMM Committee will assess whether the proprietary device, if installed in unincorporated Gwinnett County, is likely to meet the mandatory performance standards established within this manual.
   d. he GCSMM Committee will assess whether the proprietary device can be reasonably maintained by an end user for the term of its useful life.
   e. The GCSMM Committee will recommend approval or denial and refer such recommendation, with the results of their review, to the DWR Department Director for a decision. The GCSMM Committee may also recommend additional monitoring, or other requirements considered necessary to ensure the protection of water quality and long-term maintenance viability. Such additional requirements may include, but not be limited to, the following:
      i. Where provided monitoring data is not considered to be equivalent to local conditions, additional monitoring of the proprietary device under local conditions may be requested. Such additional monitoring would be conducted consistent with the methods contained within the PCSTAP. Approval to install the device as a pilot installation could also be recommended.
   f. The DWR Director shall issue a letter of approval or denial to the applicant. Approvals may be issued with site specific requirements or conditions.

Decisions of the DWR Director may be appealed to the Stormwater Authority. Appeals must be in writing and provide clear, concise reasoning as to why the appeal should be granted. The decision of the Stormwater Authority will be final.

DWR may complete monitoring of installed proprietary devices and use any data obtained during such monitoring to inform decisions on the approval for use of proprietary devices.

DWR will maintain a record of proprietary devices that have been approved for installation. Proprietary devices that consistently perform well and meet design claims may be considered for inclusion in the Design Manual.

The approval of the proprietary device may also be revoked if any of the following conditions are met: the device was removal from Metropolitan North Georgia Water Planning District's Post-Construction Stormwater Technology

Assessment Protocol (PCSTAP) Concurrence, the device is not able to be maintained per the application, the device has been substantially changed or altered since the original approval, or the device is no longer operating as designed (i.e., device needs significant design changes).

Development Specific Approval

Any development permit application, which proposes the use of a proprietary BMP (ie. one not included in this manual), must include as a part of the submittal, a development specific written approval, issued by the Department of Water Resources, stating that the proprietary BMP is approved for use at that specific development.

Consistent with the PCSTAP mentioned previously, which encourages Gwinnett County to conduct its own independent analysis and evaluation of any concurrence issued under that protocol, the DWR has established the following three step process to obtain local approval to use a proprietary BMP at a particular development. These steps are as follows:

1. Obtain Metropolitan North Georgia Water Planning District's Post-Construction Stormwater Technology Assessment Protocol (PCSTAP) Concurrence; The applicant must supply proof of concurrence with the PCSTAP issued by the Metropolitan North Georgia Water Planning District.
2. Submit an Application to Gwinnett County for Local Analysis and Evaluation; A request to use a proprietary device at a particular development must be made in writing to the DWR. The applicant may be required to pay a fee so that the DWR can have the design reviewed by an independent expert or panel of experts. The application, at a minimum, shall include the following information:
   a. Justification for use of the proposed proprietary device
   b. Summary description of the proprietary device
   c. Description of design
   d. Anticipate useful life of the proprietary device
   e. Minimum and maximum flows (drainage area) that the proprietary device can handle
   f. Pollutants that are removed by the BMP
   g. Pollutant removal efficiency
   h. Proprietary device design drawings for the development
   i. Proprietary device design calculations for the development
   j. Technology limitations, including site characteristic limitations, and operating condition requirements
   k. Monitoring data documenting water quality benefits and pollutant removal efficiencies
   l. Monitoring data statistical analysis
   m. Maintenance program, including actions and intervals, with projected costs and blank inspection forms
   n. Safety and aesthetic considerations
   o. A description of the particle size distribution (PSD) used in the assessment of the proprietary device and a description of the expected PSD at the development site
   p. A description of where the monitoring was completed, and if not within Gwinnett County, a detailed description of why the conditions at the monitoring site should be considered equivalent to local conditions
   q. A copy of the full PCSTAP submittal to the Metropolitan North Georgia Water Planning District and a copy of any of the Metro District's written assessment of results.
3. Local Analysis and Evaluation Completed by Gwinnett County:
   a. DWR will call a meeting of the GCSMM Committee to review the submittal. This committee consists of County employees from P&D, DWR and GC DOT, who work in the field of Stormwater. The GCSMM Committee may also seek feedback and comment from the Stormwater Technical Advisory Committee, or other experts, as necessary.
   b. GCSMM Committee will review the submittal and assess whether submitted materials, including the PCSTAP review, is adequate and complete. If they do not agree with the Metro District's written assessment results, or the application is otherwise lacking in detail to allow a full assessment for use of the proprietary device under local conditions, the GCSMM Committee may request further documentation, testing or monitoring.
   c. The GCSMM Committee will assess whether the proprietary device, as proposed for use in the development, is likely to meet the mandatory performance standards established within this manual.

d. The GCSMM Committee will assess whether the proprietary device, as proposed for use in the development, can be reasonably maintained by an end user for the term of its useful life.
e. The GCSMM Committee will recommend approval or denial and refer such recommendation, with the results of their review, to the DWR Department Director for a decision. The GCSMM Committee may also recommend additional monitoring, maintenance, surety, or other requirements considered necessary to ensure the protection of water quality and long term maintenance viability. Such additional requirements may include, but not be limited to, the following:
    i. Where provided monitoring data is not considered to be equivalent to local conditions, additional monitoring of the proprietary device under local conditions may be requested. Such additional monitoring would be conducted consistent with the methods contained within the PCSTAP. Approval to install the device as a pilot installation could also be recommended.
f. The DWR Director shall issue a letter of approval or denial to the applicant. Approvals may be issued with site specific requirements or conditions.

Each use of the proprietary device will require another application for an assessment to determine its suitability for the specific location and site characteristics. .

4.18.3 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for inspection and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.19 Rainwater Harvesting



(Source: Jones and Hunt, 2008)

Description: Rainwater harvesting is the ancient stormwater management practice of intercepting, diverting and storing stormwater runoff for later use. In a typical rainwater harvesting system, rainfall is collected from a gutter and downspout system, screened and "washed" and conveyed into an above- or below-ground storage tank or cistern. Once captured, stored water may be used for non-potable indoor or outdoor uses. In some cases, treatment may be required for indoor uses. If properly designed, rainwater harvesting systems can significantly reduce post-construction stormwater runoff rates, volumes and pollutant loads on development sites. Rainwater harvesting also helps reduce the demand on public water supplies, which, in turn, helps protect aquatic resources, such as groundwater aquifers, from drawdown. If using non-potable water, the system needs to comply with state and local plumbing codes.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Rainwater harvesting systems should be sized based on the size of the contributing drainage area, local rainfall patterns and projected demand for harvested rainwater
- Pretreatment should be provided upstream of all rainwater harvesting systems to prevent leaves and other debris from clogging the system
- *Georgia Rainwater Harvesting Guidelines (2009)*

ADVANTAGES / BENEFITS

- May reduce water bill
- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads
- Can be used on almost any development site
- Reduces demand on public water supplies, which helps protect groundwater aquifers from drawdown and seawater intrusion
- Allows beneficial reuse of stormwater

DISADVANTAGES / LIMITATIONS

- Stored rainwater should be used on a regular basis to maintain system storage capacity
- A pump may be required if rainwater harvesting system is below ground
- Not aesthetically pleasing in some cases
- If the system is inside, plumbing codes may be required. See Georgia Amendments to the International Plumbing Code (latest version)
- Should not be used with tar, gravel, and/or asbestos shingled roofs

ROUTINE MAINTENANCE REQUIREMENTS

- Drain and clean out aboveground cistern
- Inspect health of vegetation receiving harvested rainwater to determine watering needs
- Remove leaves and debris from grated and screened inlet
- Inspect for erosion around the overflow discharge and repair as necessary
- Check for algae growth inside the cistern; if found, treat water to remove the algae
- Check pumping system to ensure it is working properly

POLLUTANT REMOVAL

- varies **Total Suspended Solids**
- varies **Metals** - Cadmium, Copper, Lead, and Zinc removal
- varies **Nutrients** - Total Phosphorus / Total Nitrogen removal
- varies **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ★ Runoff Reduction
- ★ Water Quality
- ★ Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ based on demand

IMPLEMENTATION CONSIDERATIONS

- L **Land Requirement**
- M **Capital Cost**
- H **Maintenance Burden**

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*

Other Considerations: *Trees near catchment area may cause clogging in the system.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- Varies based on demand

4.19.1 General Description

Rainwater harvesting is the ancient stormwater management practice of intercepting, diverting and storing rainfall for later use. In a typical rainwater harvesting system (**Figure 4.19-1**), rainfall is collected from a gutter and downspout system, screened, "washed," and conveyed into an above- or below-ground storage tank or cistern. Once captured stored water may be used for non-potable indoor or outdoor uses. If properly designed, rainwater harvesting systems can significantly reduce post-construction stormwater runoff rates, volumes and pollutant loads on development sites.

There are two basic types of rainwater harvesting systems:

1. Systems that are used to supply water for non-potable outdoor uses, such as landscape irrigation, car and building washing and firefighting; and
2. Systems that are used to supply water for non-potable indoor uses, such as laundry and toilet flushing.

Rainwater harvesting systems used to supply water for non-potable indoor uses are more complex and require separate plumbing, pressure tanks, pumps and backflow preventers. Additionally, the use of harvested rainwater for non-potable indoor uses may be restricted in some areas of Georgia, due to existing "development rules." Developers and their site planning and design teams are encouraged to consult with the local development review authority if they are interested in using harvested rainwater for non-potable indoor uses. If indoor non-potable use is planned, filtration followed by disinfection is required, and there are additional system components not pictured in **Figure 4.19-1**.

Whether it is used to supply water for non-potable indoor or outdoor uses, a well-designed rainwater harvesting system typically consists of five major components (**Figure 4.19-2**), including the collection and conveyance system (e.g., gutter and downspout system), pretreatment devices (e.g., leaf screens, first flush diverters, roof washers), the storage tank or cistern, the overflow pipe (which allows excess stormwater runoff to bypass the storage tank or cistern) and the distribution system (which may or may not require a pump, depending on site characteristics). When designing a rainwater harvesting system, site planning and design teams should consider each of these components, as well as the size of the contributing drainage area, local rainfall patterns and projected water demand, to determine how large the cistern or storage tank must be to provide enough water for the desired non-potable indoor or outdoor use.

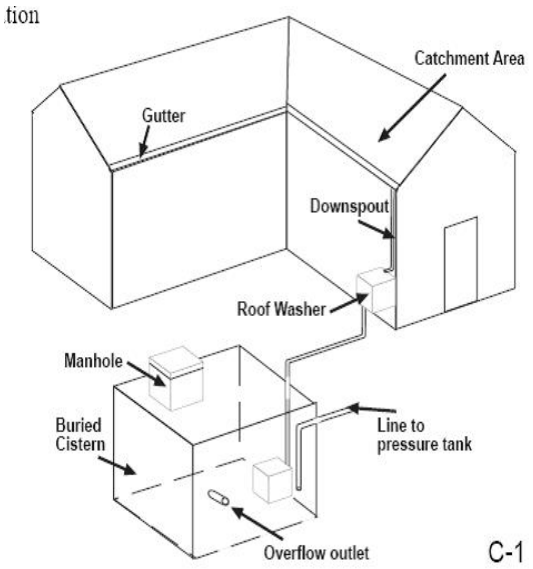


Figure 4.19-1: Rainwater Harvesting System
(Source: Rupp, 1998)



Figure 4.19-2: Major Components of a Rainwater Harvesting System
(Source: Jones and Hunt, 2008)

4.19.2 Stormwater Management Suitability

The Center for Watershed Protection (Hirschman et al., 2008) recently documented the ability of rainwater harvesting systems to reduce annual stormwater runoff volumes and pollutant loads on development sites. Consequently, this low impact development practice has been assigned quantifiable stormwater management "credits" that can be used to help satisfy the stormwater management criteria presented in this manual:

- Runoff Reduction
  Subtract 75% of the storage volume provided by a rainwater harvesting system from the runoff reduction volume (RR_v) captured by the system.
- Water Quality
  Through the achieved runoff reduction volume provided by this practice, 100% of the pollutants associated with the achieved RR_v are removed. Pollutant removal rates are otherwise not provided for this practice.
- Channel Protection
  Proportionally adjust the post-development runoff curve number (CN) to account for the runoff reduction provided by a rainwater harvesting system when calculating the channel protection volume (CP_v).
- Overbank Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a rainwater harvesting system when calculating the overbank peak discharge (Q_{p25}) on a development site.
- Extreme Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a rainwater harvesting system when calculating the extreme peak discharge (Q_f) on a development site.

Only 75% of the storage volume provided by a rainwater harvesting system can be subtracted from the runoff reduction volume (RRv) that is captured by the system due to the fact that some of the harvested rainwater may not be used between consecutive storm events.

In order to "receive" stormwater runoff and be eligible for these "credits," it is recommended that rainwater harvesting systems satisfy the planning and design criteria outlined below.

Credit for the volume of runoff reduced in the rainwater harvesting system may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide Runoff Reduction for Water Quality compliance, then the practice is given credit for Channel Protection and Flood Control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.19.3 Pollutant Removal Capabilities

The amount of pollutant removal varies and is based on the type of rainwater harvesting system used.

For additional information on data and pollutant removal capabilities for rainwater harvesting systems, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org, the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org, and the Georgia Rainwater Harvesting Guidelines (2009).

4.19.4 Application and Site Feasibility Criteria

The criteria listed in **Table 4.19-1** should be evaluated to determine whether or not a rainwater harvesting system is appropriate for use on a development site. It is important to note that rainwater harvesting systems have few constraints that impede their use on development sites.

Table 4.19-1: Factors to Consider When Evaluating the Overall Feasibility of Using a Rainwater Harvesting System on a Development Site

Site Characteristic	Criteria
Drainage Area	No restrictions
Area Required	Varies according to the size of the contributing drainage area and the dimensions of the rain tank or cistern used to store the harvested rainwater.
Slope	No restrictions, although placing rainwater harvesting systems at higher elevations may reduce or eliminate pumping requirements.
Minimum Head	N/A
Minimum Depth to Water Table	N/A
Water Table	N/A
Soils	N/A

Site Applicability

Rainwater harvesting systems can be used on a wide variety of development sites in rural, suburban and urban areas. They are especially well suited for use on commercial, institutional, municipal and multi-family residential buildings on urban and suburban development and redevelopment sites. When compared with other low impact development practices, rainwater harvesting systems have a moderate construction cost, a relatively high maintenance burden and require a relatively small amount of surface area. Although they can be expensive to install, rainwater harvesting systems are often a component of "green buildings," such as those that achieve certification in the Leadership in Energy and Environmental Design (LEED) Green Building Rating System. Refer to the *Georgia Rainwater Harvesting Guidelines (2009)* document for a detailed discussion of beneficial reuse and associated rule and requirements of harvested rainwater.

4.19.5 Planning and Design Criteria

The following criteria should be considered minimum standards for the design of a rainwater harvesting system. Consult with the local authority to determine if there are any variations to these criteria or additional standards that must be met.

4.19.5.1 LOCATION AND LAYOUT

Rainwater harvesting systems may be installed on nearly any development site. However, placing storage tanks or cisterns at higher elevations may reduce or eliminate pumping requirements

4.19.5.2 GENERAL DESIGN

- Distribution systems may be gravity fed or may include a pump to provide the energy necessary to convey harvested rainwater from the storage tank to its final destination. Rainwater harvesting systems used to provide water for non-potable outdoor uses typically use gravity to feed watering hoses through a tap and spigot arrangement.
- Staff working on larger sites may use vehicles to transport stormwater storage containers to specific sites for watering outside of the immediate vicinity of the collection area.
- Rain barrels (i.e., small storage tanks capable of storing less than 100 gallons of stormwater runoff) rarely provide enough storage capacity to accommodate the stormwater runoff volume generated by the target runoff reduction rainfall event. Consequently, they should not be used as part of a rainwater harvesting system, except on small drainage areas of 2,500 square feet or less in size.

4.19.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

Rainwater harvesting systems should be designed to provide at least enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). The required size of a rainwater harvesting system is governed by several factors, including the size of the contributing drainage area, local rainfall patterns and projected demand for harvested rainwater. Site planning and design teams should calculate the projected water demand and then conduct water balance calculations, based on the size of the contributing drainage area and local precipitation data, to size a rainwater harvesting system.

A rainwater harvesting model, such as the one provided by North Carolina State University (NCSU, 2008) at: http://www.bae.ncsu.edu/topic/waterharvesting, can be used to design a rainwater harvesting system, provided that the precipitation data being used in the model reflects local rainfall patterns and distributions and has been approved by the local development review authority prior to use.

4.19.5.4 PRETREATMENT/INLETS

Pretreatment is needed to remove debris, dust, leaves and other materials that accumulate on rooftops, and may cause clogging within a rainwater harvesting system. Pretreatment devices that may be used include leaf screens, roof washers and first-flush diverters, each of which are described briefly below:

- **Leaf Screens**: Leaf screens are mesh screens installed either in the gutter or downspout that are used to remove leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to work effectively. If not regularly maintained, they can become clogged and prevent rainwater from flowing into the storage tank.
- **First Flush Diverters**: First flush diverters direct the initial pulse of stormwater runoff away from the storage tank and into an adjacent pervious area. While leaf screens effectively remove larger debris such as leaves and twigs from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and animal feces.
- **Roof Washers***:* Roof washers are placed just ahead of storage tanks and are used to filter small debris from the harvested rainwater. Roof washers consist of a small tank, usually between 25-50 gallons in size, with leaf strainers and filters with openings as small as 30 microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis. Without regular maintenance, they may not only become clogged and prevent rainwater from entering the storage tank, but may become breeding grounds for bacteria and other pathogens.

Rooftop drainage systems (e.g., gutter and downspout systems) should be designed as they would be for a building designed without a rainwater harvesting system. Drainage system components leading to the cistern should have a minimum slope of 2% to ensure that harvested rainwater is actually conveyed into the storage tank.

4.19.5.5 OUTLET STRUCTURES

- An overflow pipe should be provided to allow stormwater runoff to bypass the storage tank or cistern when it reaches its storage capacity. The overflow pipe should have a conveyance capacity that is equal to or greater than that of the inflow pipe and should direct excess stormwater runoff to another low impact development practice, such as a vegetated filter strip (Section 4.29), grass channel (Section 4.9) or bioretention areas (Section 4.2).
- All overflow pipes should be directed away from buildings to prevent damage to building foundations

4.19.5.6 SAFETY FEATURES

- Storage tanks (also known as cisterns) are the most important and often the most expensive component of a rainwater harvesting system. Storage tanks can be constructed from a variety of materials, including wood, plastic, fiberglass, concrete, and galvanized metal. Site planning and design teams should choose an appropriate cistern for the intended application and should ensure that it has been sealed with a water safe, non-toxic substance.
- All storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algae growth. They should also be screened to discourage mosquito breeding and reproduction, but should be accessible for use, cleaning, inspection and maintenance.
- The quality of harvested rainwater will vary according to the rooftop material. For example, water harvested from certain types of rooftops, such as those constructed of asphalt, tar, gravel and treated wood shingles, should be avoided or only be used for non-potable outdoor uses, as these materials may leach toxic compounds into stormwater runoff.

4.19.5.7 LANDSCAPING

Landscaping requirements for the rainwater harvesting system is generally minimal. Rainwater harvesting systems typically drain to planted vegetation as a method of watering. Vegetation should be non-invasive and native plants. During dry periods, additional watering may be necessary to keep plants healthy. Check with local jurisdictions for any restrictions on using harvested rainwater.

4.19.5.8 CONSTRUCTION CONSIDERATIONS

To help ensure that rainwater harvesting systems are successfully installed on a development site, site planning and design teams should consider the following recommendations:

- Rainwater harvesting systems may be installed on development and redevelopment sites after building rooftops and their drainage systems (e.g., gutter and downspout systems) have been constructed.

4.19.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of rainwater harvesting**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for rainwater harvesting. Create a rough layout of the rainwater harvesting dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of rainwater harvesting.**

Consider whether the rainwater harvesting is intended to:

- Meet a runoff reduction* target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

If the rainwater harvesting system will be used to supply water for toilet and/or urinal flushing, provide filtering and treatment in accordance with the Georgia Rainwater Harvesting Guidelines (2009) and the plumbing features in accordance with the Georgia Amendments to the International Plumbing Code (latest version).

Complete Step 3A, 3B, and 3C for a runoff reduction approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$RR_v = (P)\ (R_v)\ (A) / 12$$

Where:

RR_v = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

The runoff reduction percentage (or credit) provided by the practice should be determined by the local jurisdiction. As guidance, if the demand for the harvested rainwater volume (VP_{Demand}) is ≥ VP and VP ≥ VP_{MIN}, then the RR% should 100%.

Using the RR_V calculated above, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)
RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) **Determine the storage volume of the practice and the Pretreatment Volume**
The actual volume provided (VP) for rainwater harvesting is equal to the size of the rainwater harvesting tank.

(Step 3C) **Determine whether the minimum storage volume was met**
When $VP_{Demand} \geq VP_{MIN}$ and VP ≥ $VP_{MIN,}$ then the Runoff Reduction requirements are met.

(Step 4) **Determine the drainage area from the roof and required RR_V to each downspout**
Assess roof to determine the percentage of the entire roof and the specific area of the roof that drains to each downspout. Use this area along with the RR_V calculation in Step 3 to estimate the volume for each downspout.

(Step 5) **Determine the number and size of the systems**
Based on the volume calculated in Step 4, determine site constrains, cistern costs, and appropriate size of the rainwater harvesting system.

(Step 6) **Size the overflow structure**
Calculate the peak roof runoff rate to each downspout for the 2-, 10-, and 100-year storm events. Size the overflow for each cistern so that it can pass the larger storm events. The overflow should be designed in such a way that the discharge does not cause any erosion or scour.

(Step 7) **Select and size treatment components, as needed, when the harvested rainwater will be used to supply water for toilet and/or urinal flushing.**

4.19.7 Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.20 Regenerative Stormwater Conveyance



Description: Regenerative stormwater conveyance (RSC) provides treatment, infiltration and conveyance through the combination of sand, wood chips, native vegetation, riffles (with either cobble rocks or boulders), and shallow pools. RSCs are designed to convey water while minimizing the effects of erosion.

LID/GI Considerations: By repairing and restoring eroded and damaged drainage channels by mimicking natural drainage patterns, regenerative stormwater conveyance provide water quality volume treatment for total suspended solids dissolved pollutants, while also providing mitigation of thermal impacts of stormwater runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Ideally, channel slopes should be less than 10%; however, RSC designs can be adapted for slopes exceeding 10%.
- Natural drainage patterns should be matched as closely as possible.
- Stabilize the outfall from the RSC to receiving waters.
- RSCs can be designed to receive runoff from up to 50 acres, however typical drainage areas range from 10-30 acres.
- The storage volume of the pools should be large enough and include storage volume above the seasonally high groundwater table so that the practice is not inundated by groundwater.
- Pools should drain to their design (ponding) levels within 72 hours from the end of a storm event.
- The outlet of the storage facility should be sloped to prevent conditions that promote standing water.
- RSC should not be used to treat runoff from hot spots.

ADVANTAGES / BENEFITS

- When designed correctly, RSCs are safe and aesthetically pleasing and may potentially increase the natural value of the site.
- RSC systems provide high total suspended solids and soluble pollutant removal rates.
- Effective at restoring highly eroded areas such as outfalls, ditches, and channels.

DISADVANTAGES / LIMITATIONS

- RSC is a new type of BMP and significant data is not available making performance of the BMP uncertain.
- RSCs are unfamiliar to most designers due to the recent use of this practice.
- Design of RSC is an iterative practice.
- Construction of an RSC system can be time and labor intensive.

ROUTINE MAINTENANCE REQUIREMENTS

- There are intensive maintenance requirements during establishment of the practice
- Check for erosion or "end-cutting" of weirs and riffle structures and stable water levels in pools.
- Remove invasive vegetation.
- Bare or eroding areas in the contributing drainage area or around the RSC channel should be immediately stabilized.
- Remove and replace dead plants.
- Once every 2 to 3 years, remove accumulated sediment in pools.
- Prune and weed the practice four times per year.

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ✓ Water Quality
- ● Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- (M) Land Requirement
- (H) Capital Cost
- (M) Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Not recommended*
Roadway Projects: *Yes*

Soils: *RSC systems can be installed in hydrologic soil group A, B, C, or D soils.*

Other Considerations: *Vegetation is essential to the function of RSC systems. The use of native plants is recommended.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% Runoff Reduction Credit is provided by this practice

POLLUTANT REMOVAL

- (80%) **Total Suspended Solids**
- (70/70%) **Nutrients** - Total Phosphorus / Total Nitrogen removal
- (N/A) **Metals** - Cadmium, Copper, Lead, and Zinc removal
- (N/A) **Pathogens** – Fecal Coliform

4.20.1 General Description

Regenerative stormwater conveyance (RSC) systems are BMPs that are designed to restore incised and eroded channels, ditches, and intermittent (ephemeral) streams. They are constructed with a series of shallow pools, riffles, cascades, weirs, and outfalls that dissipate stormwater runoff energy and allow for temporary ponding, internal storage, and infiltration. The temporary ponding area of a RSC provides settling time for total suspended solids. The wood chip/sand layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants, and also serve to stabilize the surrounding soils. See **Figure 4.20-1** for a design schematic of a regenerative stormwater conveyance system.

For additional information about the design, construction and pollutant removal provided by RSC systems, visit the Maryland Department of Natural Resources website.

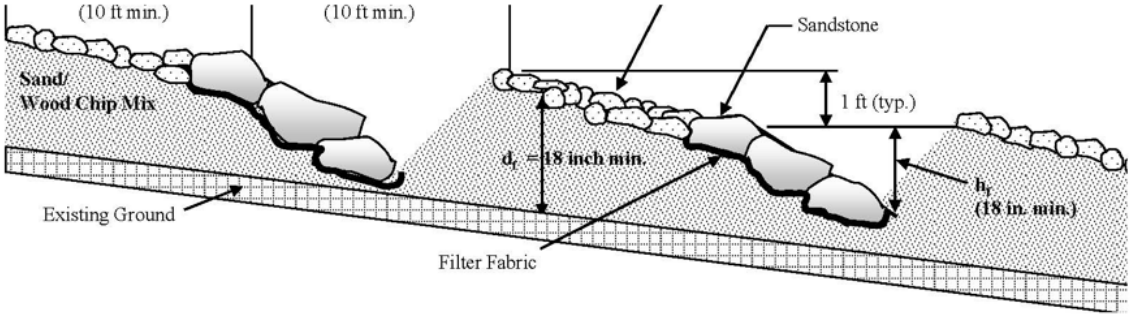


Figure 4.20-1 Typical RSC Profile
(Source: Anne Arundel County, Maryland, June 2009)

4.20.2 Stormwater Management Suitability

- Runoff Reduction
  RRSC systems are not designed to provide runoff reduction. The substrate provides storage and gradual release, especially of 'first flush' events. RSC systems must be installed as part of a treatment train with other BMPs that provide runoff reduction, if it is desired.

- Water Quality
  If installed as per the recommended design criteria and properly maintained, 80% total suspended solids removal can be applied to the water quality volume (WQ_v) flowing to the RSC system. In addition, RSC is effective at removing 70% of the total phosphorus and nitrogen found in the water. RSC is not effective at removing metal or pathogens from the water.

- Channel Protection
  RSC systems do not provide channel protection. Another BMP should be used in a treatment train with RSC systems to provide channel protection or runoff reduction. (See Subsection 4.1.6.)

- Overbank Flood Protection
  RSC systems do not provide overbank flood protection. Another BMP should be used in a treatment train with RSC systems to provide overbank flood protection or runoff reduction.

- Extreme Flood Protection
  RSC systems do not provide extreme flood protection. Another BMP should be used in a treatment train with RSC systems to provide extreme flood protection or runoff reduction.

4.20.3 Pollutant Removal Capabilities

Regenerative stormwater conveyance systems are presumed to be able to remove 80% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Other pollutants that RSC systems can remove include Phosphorus and Nitrogen. Metals, including Cadmium, Copper, Lead, and Zinc, and Pathogens, such as Fecal Coliform, are not presumed to be removed by a RSC system. See **Table 4.1.2-3** for pollutant removal rates.

4.20.4 Application and Site Feasibility Criteria

Regenerative stormwater conveyance systems are usually used to retrofit or repair an existing channel. They can be designed to receive stormwater runoff from up to 50 acres, usually highly impervious. They can also be designed for new construction projects and roadway designs when site conditions allow. Although an RSC system can receive relatively high volume and rates of runoff, they are not considered for control of the CP_v, Q_{p25}, and Q_f. Designers should consider the importance of native herbaceous and woody vegetation in the function of an RSC system, and ensure that the development area can support the necessary landscaping.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – 50 acres or less, but typically 10-30 acres
- **Space Required** – A rough rule of thumb is that RSC systems comprise approximately 0.5–3% of the contributing drainage area.
- **Site Slope** – Drainage channel slopes should be 10% or less.
- **Minimum Depth to Water Table** – Shallow ponding areas should include storage volume above the seasonally high groundwater table to allow for temporary ponding in a majority of the pools and storage of the water quality volume.
- **Soils** – RSC systems can be installed in hydrologic soil group A, B, C or D soils.

Other Constraints/Considerations

- **Hot spots** – RSC systems should not be used for hot spot runoff.
- **Damage to existing structures and facilities** – Ensure that runoff through the RSC system is conveyed in a safe, non-erosive manner to minimize damage to existing structures and facilities.
- **Proximity** – The following is a list of specific setback requirements for the location of a regenerative stormwater conveyance system:
  - 10 feet from building foundations
  - 10 feet from property lines
  - 100 feet from private water supply wells
  - 200 feet from public water supply reservoirs (measured from edge of water)
  - 1,200 feet from public water supply wells
- **Trout Stream** –The ponding and settling functions provided by RSC systems allow for a reduction of the thermal impacts and pollutant loads of runoff from highly urbanized areas.
- **Poorly Drained Soils and Shallow Water Table** — RSC systems may be installed in any soil type and where there is a shallow water table as long as the shallow pools of an RSC system drain to the designed ponding levels within 72 hours of a rain event.
- **Flat Terrain** – Adequate slope from inlet to outfall of the RSC system must be provided to generate flow.

4.20.5 Planning and Design Criteria

Before designing the regenerative stormwater conveyance system, assess site conditions to determine its applicability. Check with the local stormwater authority to ensure that RSC is applicable to the particular site. The following information is needed prior to initiating design:

- Existing and proposed site and location maps and field reviews
- Topographic map with 1-foot minimum contour intervals
- Existing and proposed impervious and pervious areas
- Dimensions and profiles of existing drainage channels for retrofit projects
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Design data from nearby storm sewer structures
- Average and 10 and 100 year water surface elevation of nearby water systems and depth to the seasonally high groundwater
- Infiltration testing of native soils at the proposed bottom elevation of the RSC system

The following criteria are to be considered ***minimum*** *standards for the design of a regenerative stormwater conveyance system. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.*

4.20.5.1 LOCATION AND LAYOUT

RSC systems are best used to restore ecological functions to an existing eroded ditch, outfall, channel, or ephemeral stream. RSC systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events.

4.20.5.2 GENERAL DESIGN

- A RSC consists of the following:
  1. A sequence of pools, riffles, and cascades to assist in treating, detaining, and conveying storm flow.
  2. Organic/mulch layer to protect planting media.
  3. Native soils to infiltrate the treated runoff, (see description of infiltration trenches, Section 4.12, for infiltration criteria).
  4. A grade control structure and settling pool should be used if the slope of the channel is greater than 5%.
- A RSC design may include some of the following:
  - » Pretreatment maybe required to keep sediment and large debris out of the practice.
  - » A series of riffle cobbles and boulders, shallow pools, and sand and wood chips.

4.20.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

- Recommended total length of grade control structures and pools is less than 10 feet.
- The invert of the upstream elevation of the grade control structure should be 1 foot higher than the elevation of the downstream grade control structure.
- The width of the grade control structure should be 8-20 times the depth of the grade control structure. 10 feet preferred.
- The West Virginia design manual recommends using the following equation to determine the length of the grade control structure for RSC:

$$L_{GCS} = L_{pool} = \frac{L_{RSC\ Path}}{\frac{\Delta E}{2}}$$

Where:

L_{GCS} = Length of grade control structure
L_{pool}=Length of pool
$L_{RSC\ Path}$=Length of the RSC flow path
ΔE=Change in elevation of the RSC practice.

- Four inches should be the maximum depth of flow going over the grade control structure.
- Cascades should have a maximum slope of 2H:1V, a maximum vertical drop of 5 feet, and followed by three pools instead of the usual one.
- Pool widths should be greater than the width of the grade control structure.
- Sand layer should be a mixture of sand and wood chips with a ratio of 4:1. This layer should run along the length of the RSC system. To stabilize the sand layer, 1 foot of bank-run gravel should be placed below the sand layer. A 1 foot layer of gravel should be placed on top of the sand layer to stabilize the grade control structures. Maximum width of the sand bed is 14 feet.
- The velocity of the water going through the pool should be less than 4 ft/s.
- The mulch layer should consist of 3 to 4 inches of triple-shredded hardwood mulch. This provides additional benefits such as removing sediment and metals and retaining soil moisture.
- Footer boulders should be inserted 6 inches lower than the invert of the pool.
- Flow velocity going through the RSC should be less than the maximum allowable velocity for the cobble size that was selected, use **Table 4.20-1** to size the cobble stones based on the velocity of flow.

Table 4.20-1: Cobble Diameter Based on Flow Velocity

Cobble diameter, inches	Allowable velocity (ft/s)
4	5.8
5	6.4
6	6.9
7	7.4
8	7.9
9	8.4
10	8.8
11	9.2
12	9.6
15	10.4

- If the native soils are not suitable for planting, then an engineered soil mix should be provided that meets the following specifications:
  - **Texture**: Sandy loam or loamy sand
  - **Sand Content**: Soils should contain 35%-60% clean, washed sand
  - **Topsoil Content**: Soils should contain 20%-30% topsoil
  - **Organic Matter Content**: Soils should contain 10%-25% organic matter
  - **Clay**: Soils should contain less than 15%
  - **Infiltration Rate**: Soils should have an infiltration rate of at least 0.50 inches per hour (in/hr), although an infiltration rate of between 2 and 4 in/hr is preferred
  - **Phosphorus Index (P-Index)**: Soils should have a P-Index of less than 30
  - **Exchange Capacity (CEC)**: Soils should have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight
  - **pH**: Soils should have a pH of 6-8
  - For additional information on the soils for a Regenerative Stormwater Conveyance, refer to Appendix D.

4.20.5.4 PRETREATMENT/INLETS

A grass filter strip or channel can be used for pretreatment. The length of the grass channel or width of the grass filter strip depends on the drainage area, land use, and channel slope. Design guidance on grass channels for pretreatment can be found in Section 4.9 (*Grass Channel*) and filter strips can be found in Section 4.29 (*Vegetated Filter Strip*).

4.20.5.5 OUTLET STRUCTURES

The outlet of the RSC should end with an outlet pool with a grade control structure just upstream of the outlet pool. The outlet pool elevation should match the existing grade.

4.20.5.6 SAFETY FEATURES

RSC generally does not require any special safety features, and fencing the RSC facility is not generally desired.

4.20.5.7 LANDSCAPING

- Landscaping is critical to the performance and function of the RSC; the vegetation filters and transpires runoff and the root systems encourage infiltration.
- Vegetation should be selected to match the look and maintenance effort desired by the local community and those responsible for maintaining the facility.
- The RSC should be vegetated to resemble a terrestrial forest ecosystem, with a mature tree canopy, subcanopy of understory trees, shrub layer, and herbaceous ground cover. Three species each of trees, shrubs, and grass/herbaceous species should be planted to avoid creating a monoculture.
- Woody vegetation should not be specified at inflow locations.
- Plants should be installed prior to mulch.
- Choose plants based on factors such as whether they are native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Planting recommendations for RSCs are as follows:
  - » Native plant species should be specified over non-native species.
  - » Vegetation should be selected based on a specified zone of hydric tolerance.
  - » A selection of trees with an understory of shrubs and herbaceous materials should be provided.

Additional information and guidance on the appropriate woody and herbaceous species appropriate for RSC in Georgia, and their planting and establishment, can be found in Appendix D.

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4.20.5.8 CONSTRUCTION CONSIDERATIONS

- Construction equipment should be restricted from the regenerative stormwater conveyance system to prevent compaction of the native soils.
- A dense and vigorous vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Otherwise sediment from the stormwater runoff will clog the pores in the planting media and native soils.

4.20.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a RSC.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a RSC. Create a rough layout of the RSC dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the RSC.**

Consider whether the RSC is intended to:

- Meet the water quality (treatment) target. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 3.
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of this method.

(Step 3) **Calculate the Target Water Quality Volume**

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

Using the WQ_V calculated above, determine the actual size and Volume of the Practice (VP) as shown in Step 4. Note that VP_{TOTAL}, calculated in Step 4, must be greater than or equal to WQ_V.

(Step 4) **Determine the storage volume of the practice and the Pre-treatment Volume.**

The total volume provided (VP) is calculated by the following equation:

$$VP_{TOTAL} = VP_{SAND} + \Sigma\, VP_{POOLS}$$

Where:

VP_{TOTAL} = Total volume provided by the RSC system

VP_{SAND} = Volume provided in the sand layer

VP_{POOLS} = Volume provided in the pools throughout the RSC system

To determine the volume provided for the sand layer in the RSC, use the following equation:

$$VP_{SAND} = (VSB)^* (N)$$

Where:

VP_{SAND} = Volume provided in sand layer

VSB = Volume of Sand Bed

N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the sand used. Most sand has a porosity value of 0.40.

To determine the volume provided for the shallow pools in the RSC, use the following equation:

$$VP_{POOLS} = (V_{POOL_1}) + (V_{POOL_2}) + (V_{POOL_3}) + \ldots$$

Where:

VP_{POOLS} = Volume provided in the pools throughout the RSC system

V_{POOL} = Volume of a single storage pool

(Step 5) **Determine whether the WQ_v was met.**

When the $VP_{Total} \geq WQ_v$, then proceed to Step 6.

When the $VP_{Total} < WQ_v$, then proceed to Step 7.

(Step 6) **Design grade control structure, pools, and cascades as described in Subsection 4.20.5. Design and Planning Criteria.**

(Step 7) **Prepare Vegetation and Landscaping Plan.**

A landscaping plan for a dry or wet swale should be prepared to indicate how the RSC system will be stabilized and established with vegetation.

See Subsection 4.20.5.7 (*Landscaping*) and Appendix D for more details.

4.20.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.21 Sand Filters



Description: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and, typically, an underdrain collection system.

LID/GI Consideration: Sand filters have low land requirement and may be incorporated to complement the natural landscape.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Typically requires 2 to 6 feet of head, depending on the type of sand filter
- Maximum contributing drainage area of 10 acres for surface sand filter; 2 acres for perimeter sand filter
- Sand filter media with underdrain system

ADVANTAGES / BENEFITS

- Applicable to small drainage areas
- Good for highly impervious areas
- Good retrofit capability

DISADVANTAGES / LIMITATIONS

- High maintenance burden
- Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas
- Relatively costly
- Possible odor problems

MAINTENANCE REQUIREMENTS

- Inspect for clogging – rake first inch of sand
- Remove sediment from forebay and chamber
- Replace sand filter media as needed

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- 50% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/25% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 40% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ✓ Water Quality
- ★ Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice

★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- (L) Land Requirement
- (H) Capital Cost
- (H) Maintenance Burden

Residential Subdivision Use: *No*
High Density/Ultra-Urban: *Yes*
Drainage Area: *2-10 acres max.*

Soils: *No restrictions*

Other Considerations: Typically needs to be combined with other controls to provide water quantity control

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided
- Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

4.21.1 General Description

Sand filters (also referred to as filtration basins) are BMPs that capture and temporarily store stormwater runoff and pass it through a filter bed of sand. Most sand filter systems consist of two-chamber structures. The first chamber is a sediment forebay or sedimentation chamber, which removes floatables and heavy sediments. The second is the filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. The filtered runoff is typically collected and returned to the conveyance system, though it can also be partially or fully exfiltrated into the surrounding soil in areas with porous soils.

Because they have few site constraints beside head requirements, sand filters can be used on development sites where the use of other structural controls may be precluded. However, sand filter systems can be relatively expensive to construct and maintain.

There are two primary sand filter system designs, the surface sand filter and the perimeter sand filter. Below are descriptions of these filter systems:

- **Surface Sand Filter** – The surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a filter bed chamber. This system can treat drainage areas up to 10 acres in size and is most commonly located off-line. Surface sand filters can be designed as an excavation with earthen embankments or as a concrete or block structure.
- **Perimeter Sand Filter** – The perimeter sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. The system consists of a sedimentation chamber and a sand bed filter. Runoff flows into the structure through a series of inlet grates located along the top of the control.

A third design variant, the underground sand filter, is intended primarily for extremely space limited and highly dense areas and is thus only considered when local communities allow. Underground sand filters require additional planning for access, maintenance, and incorporation with the stormwater management plan.



Surface Sand Filter



Perimeter Sand Filter

Figure 4.21-1 Sand Filter Examples

4.21.2 Stormwater Management Suitability

Sand filter systems are designed primarily as off-line systems for stormwater quality (i.e., the removal of stormwater pollutants) and will typically need to be used in conjunction with another BMP to provide downstream channel protection, overbank flood protection, and extreme flood protection, if required. However, under certain circumstances, filters can provide limited runoff quantity control, particularly for smaller storm events. If used for smaller drainage areas, or used to provide limited quantity control, sand filters could be used as an on-line system provided proper design planning for erosion and scour is considered.

- Runoff Reduction Volume
  Another BMP should be used in a treatment train with sand filters to provide runoff reduction as they are not designed to provide RR_V as a stand-alone BMP.

- Water Quality
  In sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration and adsorption. The filtration process effectively removes suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants. Surface sand filters with a grass cover have additional opportunities for bacterial decomposition as well as vegetation uptake of pollutants, particularly nutrients. Subsection 4.21.3 provides median pollutant removal efficiencies that can be used for planning and design purposes.

- Channel Protection
  For smaller sites, a sand filter may be designed to capture the entire channel protection volume CP_v in either an off- or on-line configuration. Given that a sand filter system is typically designed to completely drain over 40 hours, the time requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites –or– where only the WQ_v is diverted to the sand filter facility, another structural control must be used to provide CP_v extended detention.

- Overbank Flood Protection
  Another BMP must be used in conjunction with a sand filter system to reduce the post-development peak flow of the 25-year, 24-hour storm (Q_p) to pre-development levels (detention).

- Extreme Flood Protection
  Sand filter facilities must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the filter bed and facility.

4.21.3 Pollutant Removal Capabilities

Both the surface and perimeter sand filters are presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed sand filters can reduce TSS removal performance.

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- *Total Suspended Solids* – 80%
- *Total Phosphorus* – 50%
- *Total Nitrogen* – 25%
- *Fecal Coliform* – 40%
- *Heavy Metals* – 50%

For additional information and data on pollutant removal capabilities for sand filters, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.21.4 Application and Site Feasibility Criteria

Sand filter systems are well suited for highly impervious areas where land available for BMPs is limited. Sand filters should primarily be considered for new construction or retrofit opportunities for commercial, industrial, and institutional areas where the sediment load is relatively low, such as: parking lots, driveways, loading docks, gas stations, garages, airport runways/taxiways, and storage yards. Sand filters may also be feasible and appropriate in some multi-family or higher density residential developments.

To avoid rapid clogging and failure of the filter media, the use of sand filters should be avoided in areas with less than 50% impervious cover, or high sediment yield sites with clay/silt soils. Special attention should also be given to the topsoil and sod layers, if being used (See **Figure 4.21-2**).

The following basic criteria should be evaluated to ensure the suitability of a sand filter facility for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **NO**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – 10 acres maximum for surface sand filter; 2 acres maximum for perimeter sand filter
- **Space Required** – Function of available head at site
- **Site Slope** – No more than 6% slope across filter location
- **Minimum Head** – Elevation difference needed at a site from the inflow to the outflow: 5 feet for surface sand filters; 2 to 3 feet for perimeter sand filters
- **Minimum Depth to Water Table** – For a surface sand filter with exfiltration (earthen structure), 2 feet are required between the bottom of the sand filter and the elevation of the seasonally high water table
- **Soils** – No restrictions; Group "A" soils generally required to allow exfiltration (for surface sand filter earthen structure)

Other Constraints/Considerations

- **Aquifer Protection** – Do not allow exfiltration of filtered hotspot runoff into groundwater
- **Landscaping** -
  - ❑ Check with your local review authority to see if the planning of a grass cover or turf over a sand filter is allowed.
  - ❑ Do not plant trees or provide shade within 15 feet of filtering area or where leaf litter will collect and clog filtering area.
  - ❑ Do not locate plants to block maintenance access to the facility.
  - ❑ Sod areas with heavy flows that are not stabilized with erosion control mats.
  - ❑ Divert flows temporarily from seeded areas until stabilized.
  - ❑ Planting on any area requiring a filter fabric should include material selected with care to insure that no tap roots will penetrate the filter fabric.

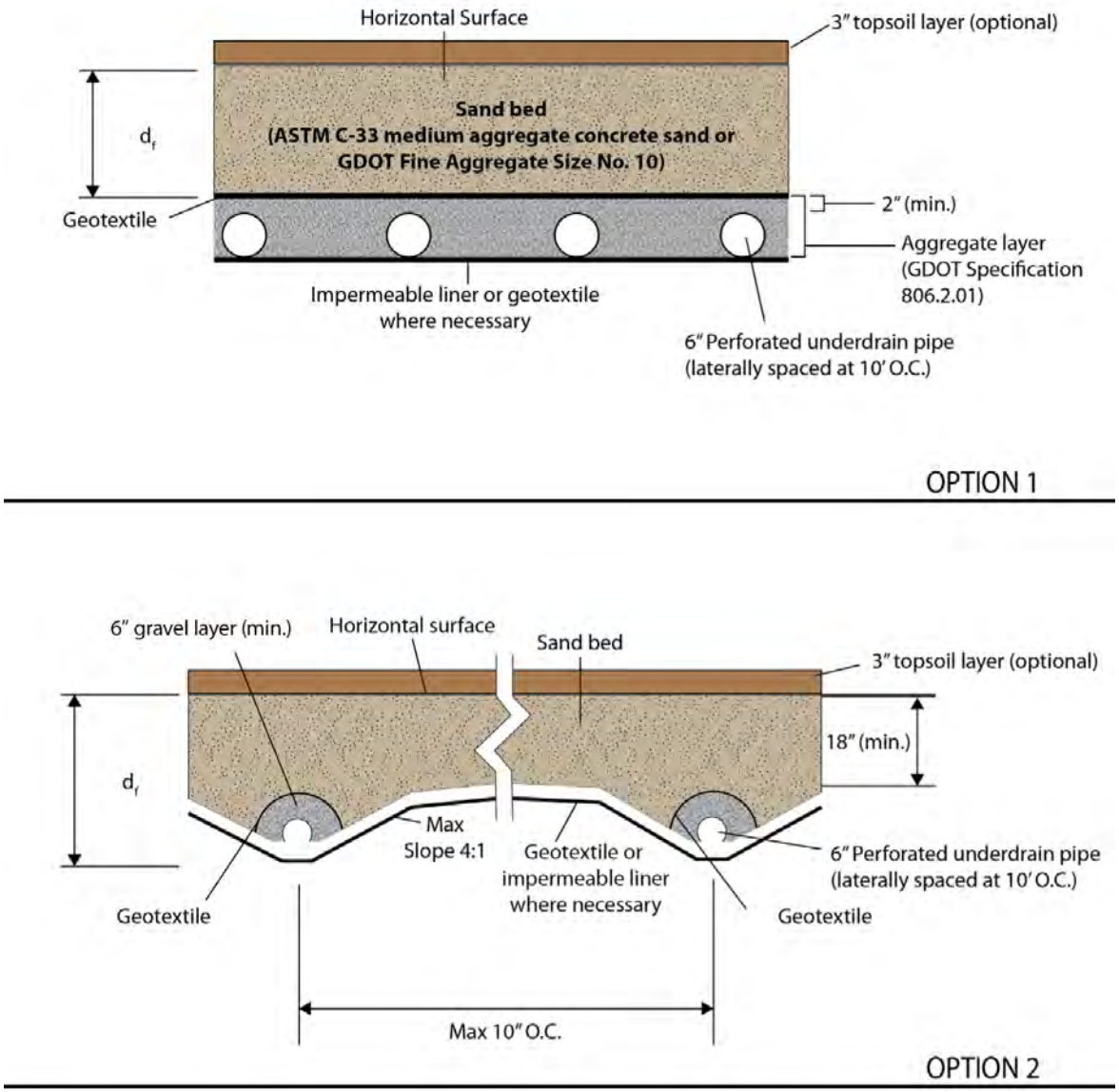


Figure 4.21-2 Typical Sand Filter Media Cross Sections
(Source: GDOT Drainage Manual, 2014)

4.21.5 Planning and Design Criteria

*The following criteria are to be considered **minimum** standards for the design of a sand filter facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be followed.*

4.21.5.1 LOCATION AND LAYOUT

- Surface sand filters should have a contributing drainage area of 10 acres or less. The maximum drainage area for a perimeter sand filter is 2 acres.
- Sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or high clay/silt sediment loads must not use a sand filter without adequate pretreatment due to potential clogging and failure of the filter bed. Any disturbed areas within the sand filter facility drainage area shall be identified and stabilized. Filtration controls shall only be constructed after the construction site is stabilized. Inlet structure shall be designed to spread the flow uniformly across the surface of the filter media.
- Surface sand filters are generally used in an off-line configuration where the water quality volume (WQ_v) is diverted to the filter facility through the use of a flow diversion structure and flow splitter. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.

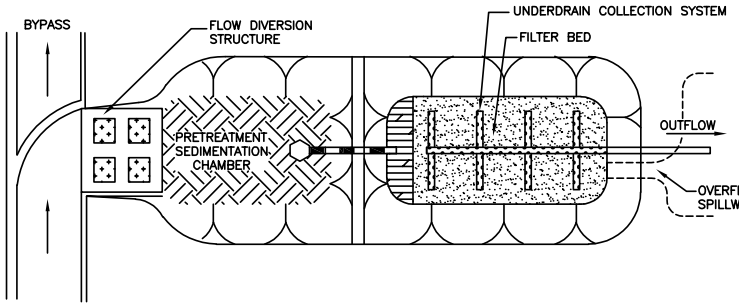
- Perimeter sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.
- Sand filter systems are designed for intermittent flow and must be designed to completely drain within 40 hours. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.
- The maximum ponding depth for any sand filter should not exceed 12".

4.21.5.2 GENERAL DESIGN

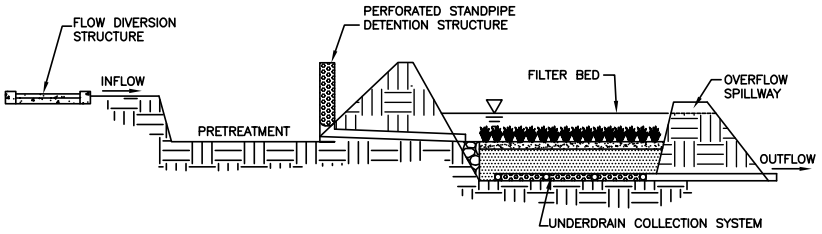
- **Surface Sand Filter**
  A surface sand filter facility consists of a two-chamber open-air structure, which is located at ground-level. The first chamber is the sediment forebay (a.k.a sedimentation chamber) while the second chamber houses the sand filter bed. Flow enters the sedimentation chamber where settling of larger sediment particles occurs. Runoff is then discharged from the sedimentation chamber through a perforated standpipe into the filtration chamber. After passing though the filter bed, stormwater runoff is collected by a perforated pipe and gravel underdrain system. **Figure 4.21-3** provides plan view and profile schematics of a surface sand filter.
- **Perimeter Sand Filter**
  A perimeter sand filter facility is a vault structure located just below grade level. Runoff enters the device through inlet grates along the top of the structure into the sedimentation chamber. Runoff is discharged from the sedimentation chamber through a weir into the filtration chamber. After passing though the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. **Figure 4.21-4** provides plan view and profile schematics of a perimeter sand filter.
- **Underground Sand Filter**
  An underground sand filter is in an underground vault structure designed for high-density land use or ultra-urban applications where there is not enough space for a surface sand filter or other BMP. Due to its location below the surface, underground sand filters have a high maintenance burden and should only be used where adequate inspection and maintenance can be ensured. **Figure 4.21-5** provides plan view and profile schematics of an underground sand filter.

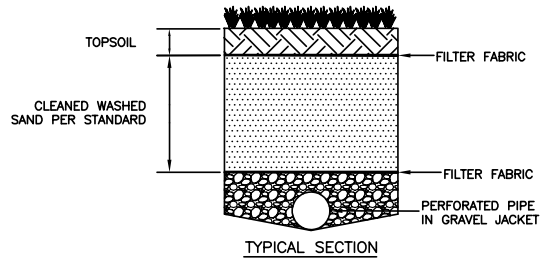
4.21.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

- **Surface Sand Filter**
  - » The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQ_v prior to filtration. **Figure 4.21-6** illustrates the distribution of the treatment volume (0.75 WQv) among the various components of the surface sand filter, including
    - Vs – volume within the sedimentation basin
    - V_f – volume within the voids in the filter bed
    - $V_{f\text{-}temp}$ – temporary volume stored above the filter bed
    - A_s – the surface area of the sedimentation basin
    - A_f – surface area of the filter media
    - h_s – height of water in the sedimentation basin
    - h_f – average height of water above the filter media
    - d_f – depth of filter media
  - » The sedimentation chamber must be sized to at least 25% of the computed WQ_v and have a length-to-width ratio of at least 2:1. Inlet and outlet structures should be located at opposite ends of the chamber.
  - » The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.
  - » The filter media consists of an 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand or GDOT Fine Aggregate Size No. 10) on top of the underdrain system. Three inches of topsoil are placed over the sand bed. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. **Figure 4.21-2** illustrates a typical media cross section.



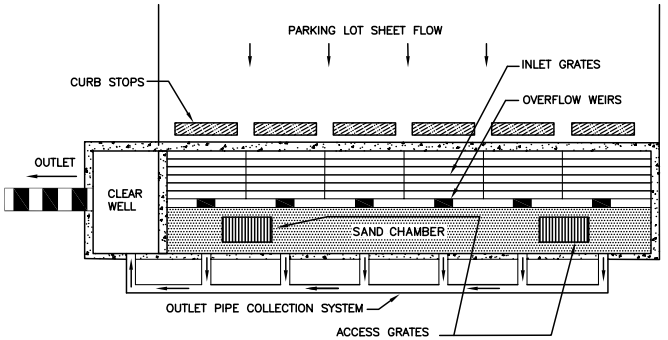
PLAN VIEW



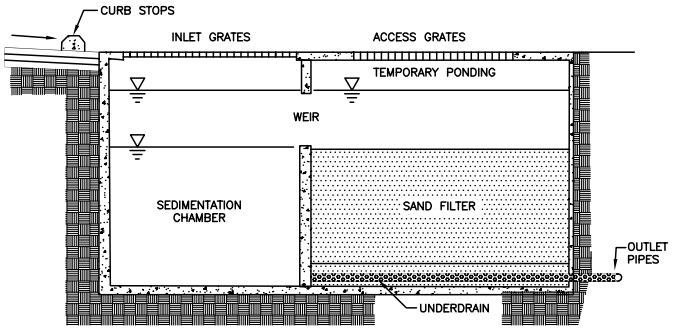


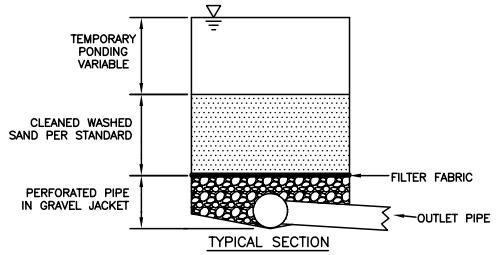
PROFILE

Figure 4.21-3 Schematic of Surface Sand Filter
(Source: Center for Watershed Protection)



PLAN VIEW





PROFILE

Figure 4.21-4 Schematic of Perimeter Sand Filter
(Source: Center for Watershed Protection)

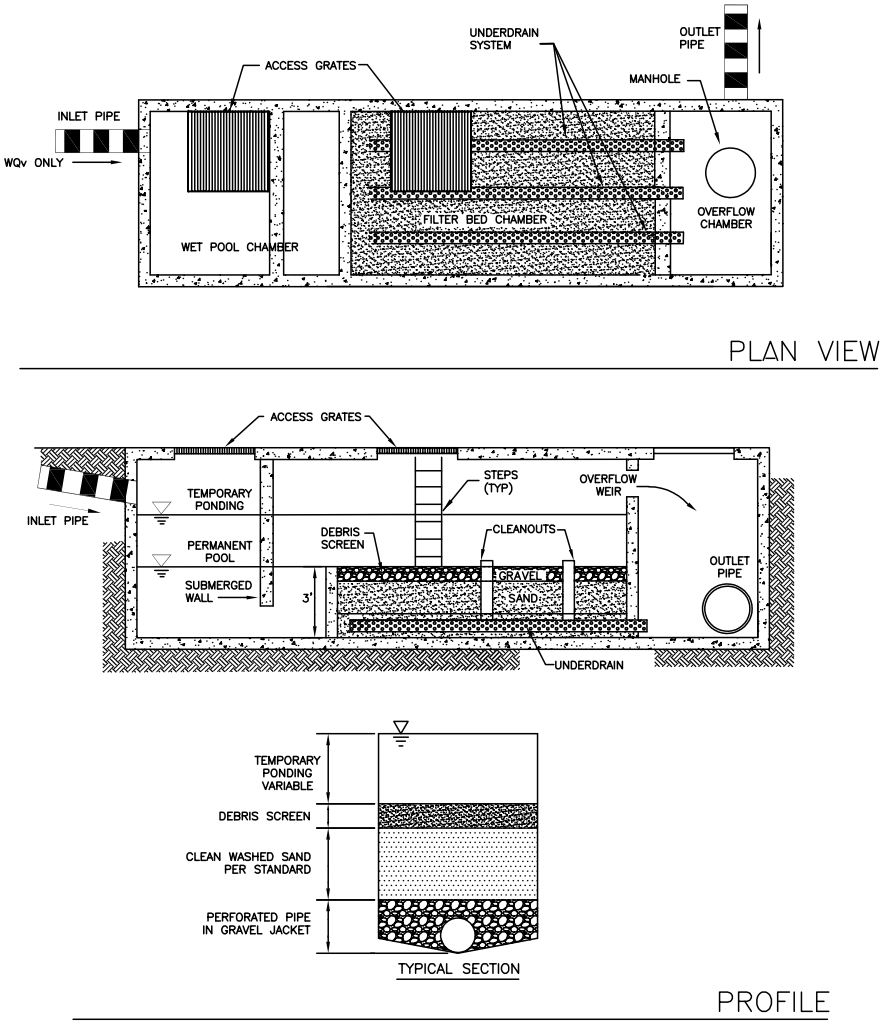


Figure 4.21-5 Schematic of Underground Sand Filter
(Source: Center for Watershed Protection

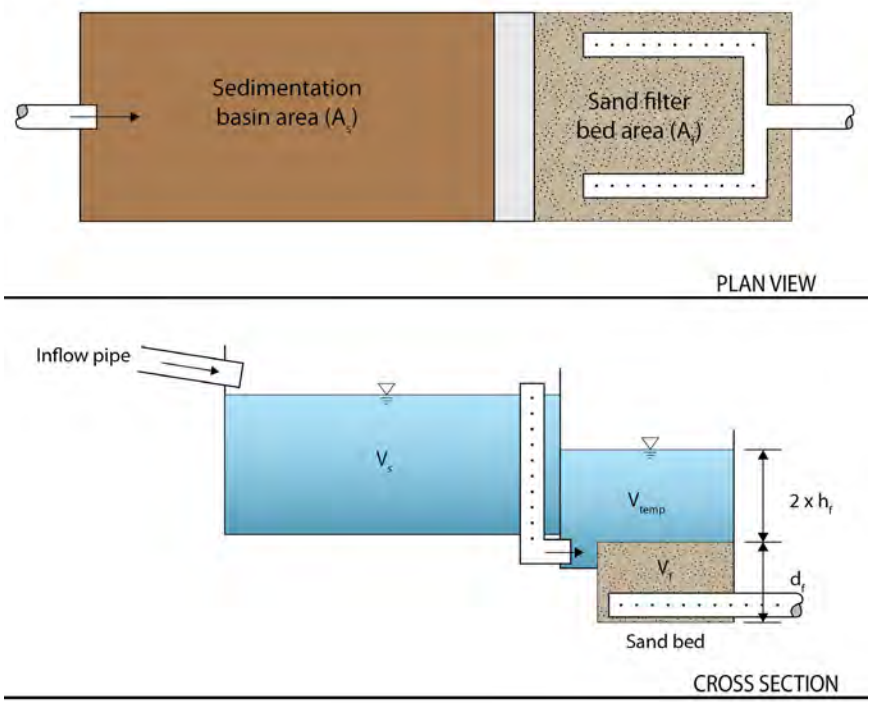


Figure 4.21-6 Surface Sand Filter Volumes
Source: GDOT Drainage Manual, 2014

» The filter bed is typically equipped with a minimum 6-inch perforated Schedule 40 PVC pipe (ASTM D1785) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8-inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40% (GDOT No.3 Stone). Aggregate contaminated with soil shall not be used.

» The structure of the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/ embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media.

- **Perimeter Sand Filter**

» The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQv prior to filtration. **Figure 4.21-7** illustrates the distribution of the treatment volume (0.75 WQ_v) among the various components of the perimeter sand filter, including:

- V_w – wet pool volume within the sedimentation basin
- V_f – volume within the voids in the filter bed
- V_{temp} – temporary volume stored above the filter bed
- A_s – the surface area of the sedimentation basin
- A_f – surface area of the filter media
- h_f – average height of water above the filter media (1/2 h_{temp})
- d_f – depth of filter media

» The sedimentation chamber must be sized to at least 50% of the computed WQ_v.

» The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.

» The filter media should consist of a 12- to 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand or GDOT Fine Aggregate Size No. 10) on top of the underdrain system. **Figure 4.21-2** illustrates a typical media cross section.

» The perimeter sand filter is typically equipped with a minimum 4 inch perforated Schedule 40 PVC pipe (ASTM D1785) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8 inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. A permeable filter fabric should be placed between the gravel layer and the filter media. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40% (GDOT No.3 Stone). Aggregate contaminated with soil shall not be used.

4.21.5.4 PRETREATMENT/INLETS

- Pretreatment of runoff in a sand filter system is provided by the sedimentation chamber.
- Inlets to surface sand filters are to be provided with energy dissipators. Exit velocities from the sedimentation chamber must be nonerosive.
- **Figure 4.21-8** shows a typical inlet pipe from the sedimentation basin to the filter media basin for the surface sand filter.

4.21.5.5 OUTLET STRUCTURES

Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways).

4.21.5.6 EMERGENCY SPILLWAY

An emergency or bypass spillway must be included in the surface sand filter to safely pass flows that exceed the design storm flows. The spillway prevents filter water levels from overtopping the embankment and causing structural damage. The emergency spillway should be located so that downstream buildings and structures will not be impacted by spillway discharges.

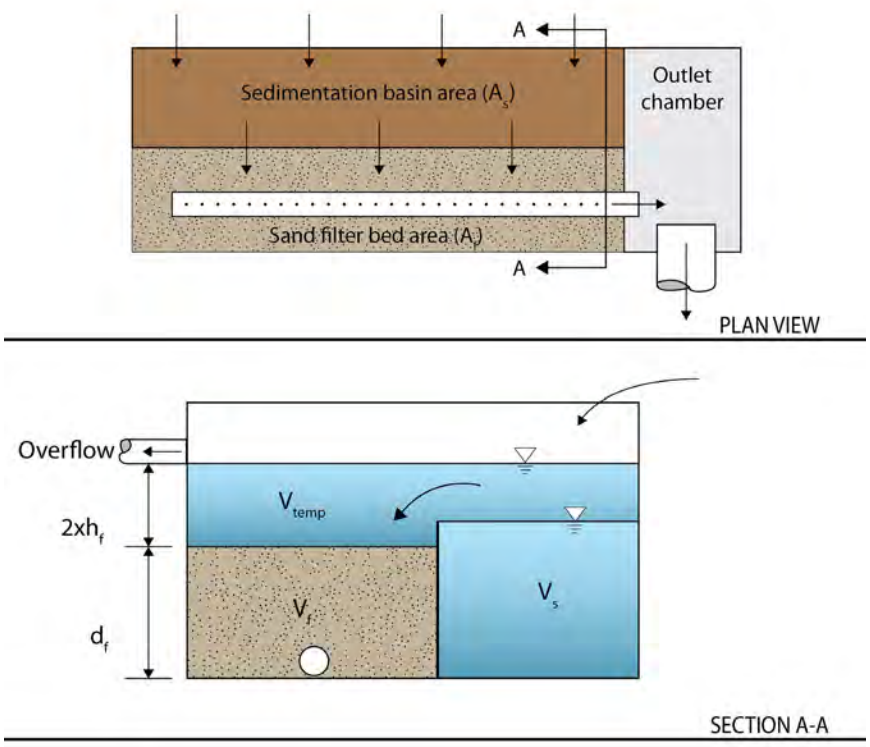


Figure 4.21-7 Perimeter Sand Filter Volumes
(Source: GDOT Drainage Manual, 2014)

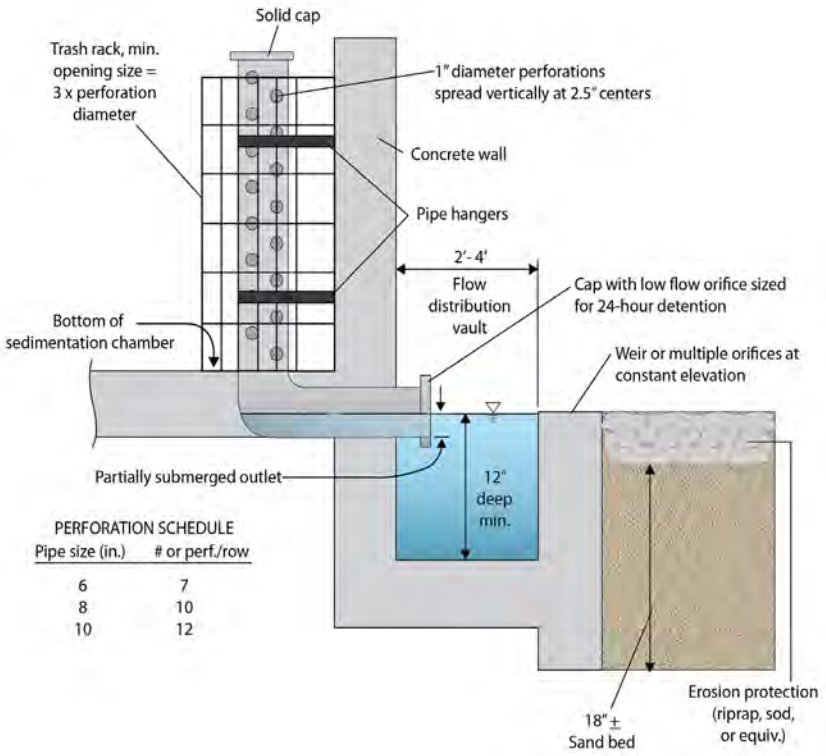


Figure 4.21-8 Surface Sand Filter Perforated Stand-Pipe
(Source: GDOT Drainage Manual, 2014)

4.21.5.7 MAINTENANCE ACCESS

Adequate access must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. Access grates to the filter bed need to be included in a perimeter sand filter design. Facility designs must enable maintenance personnel to easily replace upper layers of the filter media. An observation well is required to provide access for cleaning all underdrain piping.

4.21.5.8 SAFETY FEATURES

Surface sand filter facilities can be fenced to prevent access. Inlet and access grates to perimeter sand filters may be locked.

4.21.5.9 LANDSCAPING

Surface sand filters can be designed with a grass cover to aid in pollutant removal and prevent clogging. he grass should be capable of withstanding frequent periods of inundation and drought. The sand filter is covered with permeable topsoil and planted with grass in a landscaped area. Properly planted, these facilities can be designed to blend into natural surroundings. Vegetated filter strips and buffers should fit into and blend with surrounding area. Native grasses are preferable, if compatible.

4.21.5.10 ADDITIONAL SITE-SPECIFIC DESIGN CRITERIA AND ISSUES

Physiographic Factors - Local terrain design constraints

- Low Relief – Use of surface sand filter may be limited by low head
- High Relief – Filter bed surface must be level
- Karst – Use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure

Soils

No restrictions

Special Downstream Watershed Considerations

- Trout Stream – Evaluate for stream warming; use shorter drain time (24 hours) or consider increasing media filter depth
- Aquifer Protection – Use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure; no exfiltration of filter runoff into groundwater

4.21.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a sand filter.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a sand filter. Create a rough layout of the sand filter dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the sand filter.**

Consider whether the sand filter is intended to:

- Meet a water quality (treatment) target. See Step 3 to size the BMP utilizing the water quality treatment approach.
- Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- Provide a possible solution to a drainage problem

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design. The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3) **Calculate the Target Water Quality Volume**

Calculate the Runoff Reduction Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches))
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to the practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) **Compute WQ_v peak discharge (Q_{wq})**

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d) below:

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v

(Step 5) **Size flow diversion structure, if needed.**

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the sand filter facility. Size low flow orifice, weir, or other device to pass Q_{wq}.

(Step 6) **Size filtration basin chamber.**

The filter area is sized using the following equation (based on Darcy's Law):

$$A_f = (WQ_v)(d_f) / [(k)(h_f + d_f)(t_f)]$$

Where:

A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (typically 18 in, no more than 24 in)
k = coefficient of permeability of filter media (ft/day) use 3.5 ft/day for sand)
h_f = average height of water above filter bed (ft) (1/2 h_{max}, which varies based on site but h_{max} is typically ≤ 6 feet)
t_f = design filter bed drain time (days), (1.67 days or 40 hours is recommended maximum)

Set preliminary dimensions of filtration basin chamber. See Subsection 4.21.5.3 (*Physical Specifications/Geometry*) for filter media specifications.

(Step 7) **Size sedimentation chamber.**

Surface sand filter: The sedimentation chamber should be sized to at least 25% of the computed WQ_v and have a length-to-width ratio of 2:1. The Camp-Hazen equation is used to compute the required surface area:

$$A_s = -(Q_o/w) * Ln(1-E)$$

Where:

A_s = sedimentation basin surface area (ft^2)
Q_o = rate of outflow = the WQ_v over a 24-hour period (ft^3/s)
w = particle settling velocity (ft/sec)
E = trap efficiency

Assuming:

- 90% sediment trap efficiency (0.9)
- Particle settling velocity (ft/sec) = 0.0033 ft/sec for imperviousness ≥ 75%
- Particle settling velocity (ft/sec) = 0.0004 ft/sec for imperviousness < 75%
- Average of 24 hour holding period

Then:

$A_s = (0.066)(WQ_v)\ ft^2$ for I < 75%
$A_s = (0.0081)(WQ_v)\ ft^2$ for I > 75%

Set preliminary dimensions of sedimentation chamber.

Perimeter sand filter: The sedimentation chamber should be sized to at least 50% of the computed WQ_v. Use same approach as for surface sand filter.

(Step 8) Compute V_{min}

$$V_{min} = 0.75 * WQ_v$$

(Step 9) Compute storage volumes within entire facility and sedimentation chamber orifice size.

Surface sand filter:

$$V_{min} = 0.75\ WQ_v = V_s + V_f + V_{f\text{-}temp}$$

1. Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$, where: n = porosity = 0.4 for most applications
2. Compute $V_{f\text{-}temp}$ = temporary storage volume above the filter bed = $2 * h_f * A_f$
3. Compute V_s = volume within sediment chamber = $V_{min} - V_f - V_{f\text{-}temp}$
4. Compute h_s = height in sedimentation chamber = V_s/A_s
5. Ensure h_s and h_f fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.
6. Size orifice from sediment chamber to filter chamber to release V_s within 24-hours at average release rate with 0.5 h_s as average head.
7. Design outlet structure with perforations allowing for a safety factor of 10.
8. Size distribution chamber to spread flow over filtration media – level spreader weir or orifices.

Perimeter sand filter:

1. Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$
2. Where: n = porosity = 0.4 for most applications
3. Compute V_w = wet pool storage volume $A_s * 2$ feet minimum
4. Compute V_{temp} = temporary storage volume = $V_{min} - (V_f + V_w)$
5. Compute h_{temp} = temporary storage height = $V_{temp} / (A_f + A_s)$
6. Ensure $h_{temp} \geq 2 * h_f$, otherwise decrease h_f and re-compute. Ensure dimensions fit available head and area – change as necessary in design iterations until all site dimensions fit.
7. Size distribution slots from sediment chamber to filter chamber.

(Step 10) Design inlets, pretreatment facilities, underdrain system, and outlet structures

See Subsection 4.21.5.4 through 4.21.5.8 for more details.

(Step 11) Compute overflow weir sizes.

Surface sand filter:

1. Size overflow weir at elevation h_s in sedimentation chamber (above perforated stand pipe) to handle surcharge of flow through filter system from 25-year storm (see example).
2. Plan inlet protection for overflow from sedimentation chamber and size overflow weir at elevation hf in filtration chamber (above perforated stand pipe) to handle surcharge of flow through filter system from 25-year storm (see example).

Perimeter sand filter: Size overflow weir at end of sedimentation chamber to handle excess inflow, set at WQ_v elevation.

See Appendix B-3 for a Sand Filter Design Example

4.21.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.22 Site Reforestation/ Revegetation



Description: Site reforestation/revegetation refers to the process of planting trees, shrubs and other native vegetation in disturbed pervious areas to restore them to their pre-development conditions. The process can be used to help establish mature native plant communities (e.g., forests) in pervious areas that have been disturbed by clearing, grading and other land disturbing activities.

LID/GI Consideration: Restoring sites back to their pre-developed conditions improves their ability to reduce post-construction stormwater runoff rates, volumes and pollutant loads. The process can also be used to provide restored habitat for high priority plant and animal species.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Ideal for use in pervious areas that have been disturbed by clearing, grading and other land disturbing activities
- Methods used for site reforestation/revegetation should achieve at least 75% vegetative cover one year after installation
- Reforested/revegetated areas should be protected in perpetuity as secondary conservation areas

ADVANTAGES / BENEFITS

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads.
- Helps restore habitat for priority plant and animal species.

DISADVANTAGES / LIMITATIONS

- Should have a minimum contiguous area of 10,000 square feet.
- Should be managed in a natural state and protected from future land disturbing activities.
- Soil must be adequate or amended to support plant material desired.

MAINTENANCE REQUIREMENTS

- Inspect reforested/revegetated area for erosion. Plant replacement vegetation in any eroded areas.
- Inspect reforested/revegetated area for dead or dying vegetation. Plant replacement vegetation as needed.
- Prune and care for individual trees and shrubs as needed.

STORMWATER MANAGEMENT SUITABILITY

●	[1]Runoff Reduction
●	[1]Water Quality
●	[1]Channel Protection
●	[1]Overbank Flood Protection
●	[1]Extreme Flood Protection

✓ suitable for this practice

★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

M	Land Requirement
L	Capital Cost
L	Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided (see note 1)

1 = helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates, volumes and pollutant loads. Runoff reduction credit is given to other BMPs that use soil restoration to improve hydrologic soil groups. See guidance below for calculating RR_v and other reductions.

4.22.1 General Description

Site reforestation/revegetation refers to the process of planting trees, shrubs and other native vegetation in disturbed pervious areas to restore them to their pre-development conditions (**Figure 4.22-1**). The process can be used to help establish mature native plant communities (e.g., forests) in pervious areas that have been disturbed by clearing, grading and other land disturbing activities. Mature plant communities intercept rainfall, increase evaporation and transpiration rates, slow and filter stormwater runoff and help improve soil porosity and infiltration rates (Cappiella et al., 2006a), which leads to reduced post-construction stormwater runoff rates, volumes and pollutant loads. The site reforestation/revegetation process can also be used to provide restored habitat for high priority plant and animal species.

Areas that have been reforested or revegetated should be maintained in an undisturbed, natural state over time. These areas should be designated as conservation areas and protected in perpetuity through a legally enforceable conservation instrument (e.g., conservation easement, deed restriction). If properly maintained over time, these areas can help improve aesthetics on development sites, provide passive recreational opportunities and create valuable habitat for high priority plant and animal species.

To help create contiguous, interconnected green infrastructure corridors on development sites, site planning and design teams should strive to connect reforested or revegetated areas with one another and with other primary and secondary conservation areas through the use of nature trails, bike trails and other "greenway" areas.

4.22.2 Stormwater Management Suitability

The Center for Watershed Protection (Hirschman et al., 2008) documented the ability of the site reforestation/revegetation process to reduce annual stormwater runoff volumes and pollutant loads on development sites. Consequently, this low impact development practice can be used to help satisfy the reduce runoff volume and provide water quality improvements:

- Runoff Reduction
  Site reforestation/revegetation is an effective low impact development (LID) practice that can reduce post-construction stormwater runoff and improve water quality. When used to improve site areas and create conservation amenities; runoff reduction, lower post-developed flow rates, and lower discharge velocities are all benefits of reforestation or revegetation. Subtract 50% of any reforested/revegetated areas from the total site area and re-calculate the runoff reduction volume (RR_v) that applies to the development site.

- Water Quality Protection
  Site reforestation and/or revegetation helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates in addition to runoff volumes and pollutant loads. Subtract 50% of any reforested/revegetated areas from the total site area and re-calculate the water quality volume (WQ_v) that applies to the development site.



Figure 4.22-1: Active Replanting of Native Trees in a Disturbed Pervious Area
(Source: Center for Watershed Protection)

- Channel Protection
  Assume that the post-development hydrologic conditions of any reforested/revegetated areas are equivalent to those of a similar cover type (e.g., meadow, brush, woods) in fair condition.

- Overbank Flood Protection
  Assume that the post-development hydrologic conditions of any reforested/revegetated areas are equivalent to those of a similar cover type (e.g., meadow, brush, woods) in fair condition.
- Extreme Flood Protection
  Assume that the post-development hydrologic conditions of any reforested/revegetated areas are equivalent to those of a similar cover type (e.g., meadow, brush, woods) in fair condition. Reforested/revegetated areas can only be assumed to be in "fair" hydrologic condition due to the fact that it will take many years for them to mature and provide full stormwater management benefits.

Stormwater Management Suitability when combined with Soil Restoration

If site reforestation/revegetation can be combined with soil restoration (Section 4.23) on a development site, the following stormwater management benefits and incentives are available to help satisfy the requirements presented in this manual:

- Stormwater Runoff Reduction
  Subtract 100% of any restored and reforested/revegetated areas from the total site area *and* re-calculate the runoff reduction volume (RR_v) that applies to the development site.
- Water Quality Protection
  Subtract 100% of any restored and reforested/revegetated areas from the total site area *and* re-calculate the water quality volume (WQ_v) that applies to the development site.
- Channel Protection
  Assume that the post-development hydrologic conditions of any restored and reforested/revegetated areas are equivalent to those of a similar cover type (e.g., meadow, brush, woods) in good condition.
- Overbank Flood Protection
  Assume that the post-development hydrologic conditions of any restored and reforested/revegetated areas are equivalent to those of a similar cover type (e.g., meadow, brush, woods) in good condition.
- Extreme Flood Protection
  Assume that the post-development hydrologic conditions of any restored and reforested/revegetated areas are equivalent to those of a similar cover type (e.g., meadow, brush, woods) in good condition.

4.22.3 Applications and Site Feasibility Criteria

The criteria listed in **Table 4.22-1** should be evaluated to determine whether or not site reforestation/revegetation is appropriate for use on a development site.

General Feasibility

- Suitable for Residential Subdivision Usage – YES
- Suitable for High Density/Ultra Urban Areas – YES
- Regional Stormwater Control – NO

Site Applicability

Although it may be difficult to apply in urban areas, due to space constraints, site reforestation/revegetation can be used on a wide variety of development sites, including residential, commercial, industrial and institutional development sites in rural and suburban areas. When compared with other low impact development practices, it has a moderate construction cost, a relatively low maintenance burden and requires no additional surface area beyond that which will undergo the reforestation/revegetation process. It is ideal for use in pervious areas that have been disturbed by clearing, grading and other land disturbing activities.

Table 4.22-1: Factors to Consider When Evaluating the Overall Feasibility of Using Site Reforestation/ Revegetation on a Development Site

Site Characteristic	Criteria
Drainage Area	N/A
Area Required	Reforested/revegetated areas should at least be 10,000 square feet in size in order to be eligible for the stormwater management "credits" assigned to this low impact development practice (2008, Center for Watershed Protection – Runoff Reduction Technical Memo).
Slope	Maximum 25% in the disturbed pervious area to be reforested/ revegetated.
Minimum Head	N/A
Minimum Depth to Water Table	No restrictions
Soils	Soils need to be capable of sustaining the vegetation proposed which will require significant amendments in most cases.

4.22.4 Planning and Design Criteria

It is *recommended* that the reforestation/re-vegetation process used on a development site meet all of the following criteria to be eligible for the stormwater management "credits" described above:

General Planning and Design

- Reforested/revegetated areas should have a contiguous area of 10,000 square feet or more.
- Reforested/revegetated areas should not be disturbed after construction (except for disturbances associated with landscaping or removal of invasive vegetation).
- Reforested/revegetated areas should be protected, in perpetuity, from the direct impacts of the land development process by a legally enforceable conservation instrument (e.g., conservation easement, deed restriction).

Landscaping

- A soil test should be performed to determine what type of vegetation can be supported by the soils in the area to be reforested/ revegetated and/or what soil amendments will be required.
- A landscaping plan should be prepared by a qualified licensed professional for all reforested/revegetated areas. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- Landscaping commonly used in site reforestation/revegetation efforts includes native trees, shrubs and other herbaceous vegetation. Because the goal of the site reforestation/revegetation process is to establish a mature native plant community (e.g., forest), managed turf cannot be used to landscape reforested/revegetated areas.
- Methods used for site reforestation/ revegetation should achieve at least 75 percent vegetative cover one year after installation.
- A long-term vegetation management plan should be developed for all reforested/ revegetated areas. The plan should clearly specify how the area will be maintained in an undisturbed, natural state over time. Plan should include method for watering during plant establishment period of one to two years. Turf management is not considered to be an acceptable form of vegetation management. Consequently, only reforested/revegetated areas that remain in an undisturbed, natural state are eligible for this "credit" (i.e., pervious areas consisting of managed turf are not eligible for this "credit").

4.22.5 Construction Considerations

To help ensure that the site reforestation/revegetation process is successfully completed on a development site, site planning and design teams should consider the following recommendations: Document the condition of the reforested/revegetated area before, during and after the completion of the site reforestation/revegetation process.

- Document the condition of the reforested/revegetated area before, during and after the completion of the site reforestation/revegetation process.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of all reforested/revegetated areas before, during and after construction. This can typically be accomplished by clearly delineating reforested/revegetated areas on all development plans and, if necessary, protecting them with temporary construction fencing.
- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used on reforested/revegetated areas. If the reforested/revegetated areas will "receive" any stormwater runoff from other portions of the development site, measures should be taken (e.g., silt fence, temporary diversion berm) to prevent it from compromising the reforestation/ revegetation effort.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted on the reforested/revegetated area.

4.22.6 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.23 Soil Restoration



(Source: http://www.towncountryltd.com)

Description: Soil restoration refers to the process of tilling and adding compost and other amendments to soils to restore them to their pre-development conditions, which improves their ability to reduce post-construction stormwater runoff rates, volumes and pollutant loads. The soil restoration process can be used to improve the hydrologic conditions of pervious areas that have been disturbed by clearing, grading and other land disturbing activities.

LID/GI Consideration: Increases the reduction in stormwater runoff rates, volumes and pollutant loads provided by other low impact development practices.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Ideal for use in pervious areas that have been disturbed by clearing, grading and other land disturbing activities
- To properly restore disturbed pervious areas, soil amendments should be added to existing soils to a minimum depth of 18 inches until an organic matter content of 8% to 12% is obtained. Depths greater than 18" should be amended when shrubs or trees are being installed.
- Restored pervious areas should be protected from future land disturbing activities

ADVANTAGES / BENEFITS

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes and pollutant loads
- Promotes plant growth and improves plant health, which helps reduce stormwater runoff rates, volumes and pollutant loads

DISADVANTAGES / LIMITATIONS

- Should not be used on areas that have slopes of greater than 10%
- To help prevent soil erosion, landscaping should be installed immediately after the soil restoration process is complete

STORMWATER MANAGEMENT SUITABILITY

- ● [1]Runoff Reduction
- ● [1]Water Quality
- ● [1]Channel Protection
- ● [1]Overbank Flood Protection
- ● [1]Extreme Flood Protection

✓ suitable for this practice

★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- (M) Land Requirement
- (L) Capital Cost
- (L) Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Yes*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided (see note 1)

1 = helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates, volumes and pollutant loads. See guidance below for calculating RR_V and other reductions.

4.23.1 General Description

Soil restoration refers to the process of tilling and adding compost and other amendments to soils to restore them to their pre-development conditions. It is ideal for use on lawns and other pervious areas that have been disturbed by clearing, grading and other land disturbing activities. Organic compost (**Figure 4.23-1**) and other amendments can be tilled into soils in these areas to help create healthier, uncompacted soil matrices that have enough organic matter to support a diverse community of native trees, shrubs and other herbaceous plants.

Soil restoration can also be used to increase the stormwater management benefits provided by other low impact development practices, such as site reforestation/revegetation (Section 4.22), vegetated filter strips (Section 4.29), grass channels (Section 4.9) and simple downspout disconnection (Section 4.4), on sites that have soils with low permeabilities (i.e., hydrologic soil group C or D soils). The soil restoration process can be used to help increase soil porosity and improve soil infiltration rates on these sites, which improves the ability of these and other low impact development practices to reduce post-construction stormwater runoff rates, volumes and pollutant loads.



Figure 4.23-1: Organic Compost
(Source: http://www.organicgardeninfo.com)

4.23.2 Stormwater Management Suitability

The Center for Watershed Protection (Hirschman et al., 2008) documented the ability of the soil restoration process to reduce annual stormwater runoff volumes and pollutant loads on development sites. Consequently, this low impact development practice can be used to help satisfy the stormwater requirements presented in this manual. Consider including soil restoration in all other stormwater management BMPs where applicable.

- Runoff Reduction
  Soil restoration is one of the most effective low impact development (LID) practices that can be combined with other BMPs to reduce post-construction stormwater runoff and improve runoff quality. Like other LID practices, soil restoration becomes more effective the higher the infiltration rate increases. When used to improve native soils when paired with another BMP, runoff reduction percentages can increase from 15 to 25 percent. Subtract 50% of any restored pervious areas from the total site area and re-calculate the runoff reduction volume (RR_v) that applies to the development site.

- **Water Quality Protection**
  Due to the soil amendments themselves, in addition to the runoff reduction benefits, soil restoration inherently improves water quality. Depending on the organic compounds and other amendments added, nutrient uptake and other pollutant removal processes can be achieved. Subtract 50% of any restored pervious areas from the total site area and re-calculate the water quality volume (WQ_v) that applies to the development site.
- **Channel Protection**
  Soil restoration helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates in addition to runoff volumes and pollutant loads. Assume that the post-development hydrologic conditions of any restored pervious areas are equivalent to those of open space (e.g., lawns, parks, golf courses) in good condition
- **Overbank Flood Protection**
  Soil restoration helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates in addition to runoff volumes and pollutant loads. Assume that the post-development hydrologic conditions of any restored pervious areas are equivalent to those of open space (e.g., lawns, parks, golf courses) in good condition.
- **Extreme Flood Protection**
  Soil restoration helps restore pre-development hydrology, which implicitly reduces post-construction stormwater runoff rates in addition to runoff volumes and pollutant loads. Assume that the post-development hydrologic conditions of any restored pervious areas are equivalent to those of open space (e.g., lawns, parks, golf courses) in good condition.

In order to be eligible for these "credits," it is recommended that restored pervious areas satisfy the planning and design criteria outlined below.

If any type of vegetation other than managed turf can be planted on a restored pervious area, site planning and design teams are encouraged to combine soil restoration with site reforestation/revegetation (Section 4.22) to further reduce post-construction stormwater runoff rates, volumes and pollutant loads.

When soil restoration is used to enhance the performance of other low impact development practices (e.g., site reforestation/revegetation, vegetated filter strips, grass channels), it may be "credited" by improving the soils characterization for purposes of determining the runoff reduction percentage.

4.23.3 Applications and Site Feasibility Criteria

The criteria listed in **Table 4.23-1** should be evaluated to determine whether or not soil restoration is appropriate for use on a development site.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Site Applicability

Soil restoration can be used on a wide variety of development sites, including residential, commercial, industrial and institutional development sites in rural, suburban and urban areas. When compared with other low impact development practices, it has a moderate construction cost, a relatively low maintenance burden and requires no additional surface area beyond that which will undergo the soil restoration process. It is ideal for use in pervious areas that have been disturbed by clearing, grading and other land disturbing activities.

Table 4.23-1: Factors to Consider When Evaluating the Overall Feasibility of Using Soil Restoration on a Development Site

Site Characteristic	Criteria
Drainage Area	N/A
Area Required	No restrictions
Slope	Maximum 10% in the disturbed pervious area to be restored.
Minimum Head	N/A
Minimum Depth to Water Table	A minimum separation distance of 18 inches is recommended between the surface of a restored pervious area and the top of the water table. Depths greater than 18" should be amended when shrubs or trees are installed.
Soils	Pervious areas that have soils with low permeabilities (i.e. hydrologic soil group C or D soils) or that have been disturbed by land disturbing activities are good candidates for soil restoration. Areas that have permeable soils (i.e. hydrologic soil group A or B soils) and that have not been disturbed by land disturbing activities do not need to be restored.

4.23.4 Planning and Design Criteria

It is recommended that the soil restoration process used on a development site meet all of the following criteria to be eligible for the stormwater management "credits" described above:

General Planning and Design

- To avoid damaging existing root systems, soil restoration should not be performed in areas that fall within the drip line of existing trees.
- Compost should be incorporated into existing soils, using a rototiller or similar equipment, to a depth of 18 inches and at an application rate necessary to obtain a final average organic matter content of 8%-12%. Required application rates can be determined using a compost calculator, such as the one provided on the following website: http://www.soilsforsalmon.org/resources.htm. Other calculations are available online.
- Only well-aged composts that have been composted for a period of at least one year should be used to amend existing soils. Composts should be stable and show no signs of further decomposition.
- Composts used to amend existing soils should meet the following specifications (most compost suppliers will be able to provide this information):
  - **Organic Content Matter**: Composts should contain 35%-65% organic matter.
  - **Moisture Content**: Composts should have a moisture content of 40%-60%.
  - **Bulk Density**: Composts should have an "as-is" bulk density of 40-50 pounds per cubic foot (lb/cf). In composts that have a moisture content of 40%-60%, this equates to a bulk density range of 450-800 pounds per cubic yard (lb/cy), by dry weight.
  - **Carbon to Nitrogen (C:N) Ratio**: Composts should have a C:N Ratio of less than 25:1.
  - **pH**: Composts should have a pH of 6-8.
  - **Cation Exchange Capacity (CEC)**: Composts should have a CEC that exceeds 50 milliequivalents (meq) per 100 grams of dry weight.
  - **Foreign Material Content:** Composts should contain less than 0.5% foreign materials (e.g., glass, plastic), by weight.
  - **Pesticide Content:** Composts should be pesticide free.
- The use of biosolids (except Class A biosolids) and composted animal manure to amend existing soils is not recommended.
- It is recommended that composts used to amend existing soils be provided by a member of the U.S. Composting Seal of Testing Assurance program. Additional information on the Seal of Testing Assurance program is available on the following website: http://www.compostingcouncil.org.

Landscaping

- Vegetation commonly planted on restored pervious areas includes turf, shrubs, trees and other herbaceous vegetation. Although managed turf is most commonly used, site planning and design teams are encouraged to use trees, shrubs and/or other native vegetation to help establish mature native plant communities (e.g., forests) in restored pervious areas.
- Methods used to establish vegetative cover within a restored pervious area should achieve at least 75 percent vegetative cover one year after installation.
- To help prevent soil erosion and sediment loss, landscaping should be installed immediately after the soil restoration process is complete. Temporary irrigation may be needed to quickly establish vegetative cover on a restored pervious area.

4.23.5 Construction Considerations

To help ensure that the soil restoration process is successfully completed on a development site, site planning and design teams should consider the following recommendations:

- To help minimize compaction, heavy vehicular and foot traffic should be kept out of all restored pervious areas during and after construction. This can typically be accomplished by clearly delineating soil restoration areas on all development plans and, if necessary, protecting them with temporary construction fencing.
- Simple erosion and sediment control measures, such as temporary seeding and erosion control mats, should be used on restored pervious areas that exceed 2,500 square feet in size. If the restored pervious areas will "receive" any stormwater runoff from other portions of the development site, measures should be taken (e.g., silt fence, temporary diversion berm) to prevent it from compromising the soil restoration effort.
- Test pits or a rod penetrometer can be used to verify that soil amendments have reached a depth of 18 inches.
- Construction contracts should contain a replacement warranty that covers at least three growing seasons to help ensure adequate growth and survival of the vegetation planted on a restored pervious area.

4.23.6 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

Additional Resources

Stenn, H. 2007. *Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13 in Washington Department of Ecology (WDOE) Stormwater Management Manual for Western Washington*. Public Works Department. Snohomish County, WA. Available Online: http://www.soilsforsalmon.org/resources.htm.

Washington Department of Ecology (WDOE). 2005. "BMP T5.13: Post-Construction Soil Quality and Depth." *Stormwater Management Manual for Western Washington*. Volume 5: Runoff Treatment BMPs. Washington Department of Ecology. Water Quality Program. Available Online: http://www.ecy.wa.gov/programs/wq/stormwater/manual.html.

Pennsylvania Department of Environmental Protection (PA DEP). 2006. "BMP 6.7.3: Soil Amendment and Restoration." *Pennsylvania Stormwater Best Management Practices Manual*. Pennsylvania Department of Environmental Protection. Bureau of Watershed Management. Available Online: http://www.depweb.state.pa.us/watershedmgmt/site/default.asp.

4.24 Stormwater Planters/Tree Boxes



(Source: Center for Watershed Protection)

Description: Stormwater planters are landscape planter boxes that are specially designed to receive post-construction stormwater runoff. They consist of planter boxes that are equipped with water-proof liners, filled with an engineered soil mix, and planted with trees, shrubs, and other herbaceous vegetation. Stormwater planters are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where runoff is subject to the hydrologic processes of evaporation and transpiration before being conveyed back into the storm drain system through an underdrain.

LID/GI Considerations: Use of a stormwater planter provides measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites. Stormwater planters and/or tree boxes can take the place of traditional landscaped areas, thus minimizing development space required to treat stormwater runoff.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Stormwater planters should be designed to completely drain within 24 hours of the end of a rainfall event.
- A maximum ponding depth of 6 inches is recommended within stormwater planters to help prevent nuisance ponding conditions.
- Unless a shallow water table is found on the development site, stormwater planter planting beds should be at least 2 feet deep.

ADVANTAGES / BENEFITS

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates, volumes, and pollutant loads
- Can be integrated into development plans as attractive landscaping features
- Particularly well-suited for urban development sites

DISADVANTAGES / LIMITATIONS

- Can only be used to "receive" runoff from small drainage areas of 2,500 square feet or less

ROUTINE MAINTENANCE REQUIREMENTS

- Water to promote plant growth and survival.
- Inspect stormwater planters following rainfall events. Plant replacement vegetation in any eroded areas.
- Prune and weed stormwater planter.
- Remove accumulated trash and debris.

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- N/A **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 60/60% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 80% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ✓ Runoff Reduction
- ✓ Water Quality
- Channel Protection
- Overbank Flood Protection
- Extreme Flood Protection

✓ suitable for this practice

★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- M Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *In urban areas, check clear and safety zones for guidance*

Soils: *The soils used within stormwater planter planting beds should be an engineered soil mix.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 50% of the runoff reduction volume provided

4.24.1 General Description

Stormwater planters are small, underdrained bio-retention areas (Section 4.2) that are designed to fit within landscape planter boxes (**Figure 4.24-1**); they consist of landscape planter boxes equipped with waterproof liners, filled with an engineered soil mix and planted with trees, shrubs, and other herbaceous vegetation. Stormwater planters are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where runoff is subject to the hydrologic processes of evaporation and transpiration before being conveyed back into the storm drain system through an underdrain. This allows stormwater planters to provide measurable reductions in post-construction stormwater runoff rates, volumes, and pollutant loads.

A primary concern associated with the design of a stormwater planter (**Figure 4.24-2**) is its storage capacity, which directly influences its ability to reduce stormwater runoff rates, volumes, and pollutant loads. Site planning and design teams should strive to design stormwater planters that can accommodate the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event). If this cannot be accomplished, due to site characteristics or constraints, site planning and design teams should consider using stormwater planters in combination with other runoff reducing low impact development practices, such as dry wells (Section 4.7) and rainwater harvesting (Section 4.19), to supplement the stormwater management benefits provided by the planters.



Figure 4.24-1: Various Stormwater Planters

(Sources: Center for Watershed Protection, City of Portland, OR, 2008)

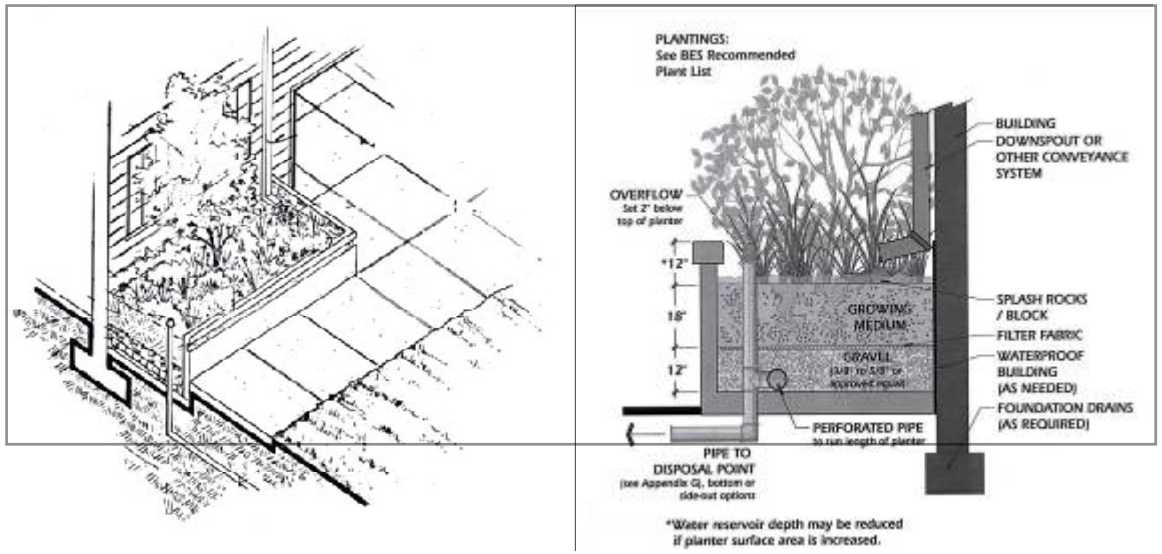


Figure 4.24-2: Stormwater Planters

(Source: City of Portland, OR, 2004)

4.24.2 Stormwater Management Suitability

The Center for Watershed Protection (Hirschman et al., 2008) recently documented the ability of stormwater planters to reduce annual stormwater runoff volumes and pollutant loads on development sites.

- Stormwater Runoff Reduction
  Subtract 50% of the storage volume provided by a stormwater planter from the runoff reduction volume (RR_V) conveyed through the stormwater planter.
- Water Quality Protection
  If installed as per the recommended design criteria and properly maintained, 80% total suspended solids removal will be applied to the water quality volume (WQ_V) flowing to the stormwater planter.
- Channel Protection
  Proportionally adjust the post-development runoff curve number (CN) to account for the runoff reduction provided by a stormwater planter when calculating the channel protection volume (CP_V) on a development site (see Subsection 3.1.7.5).
- Overbank Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a stormwater planter when calculating the overbank peak discharge (Q_{p25}) on a development site (see Subsection 3.1.7.5).
- Extreme Flood Protection
  Proportionally adjust the post-development runoff CN to account for the runoff reduction provided by a stormwater planter when calculating the extreme peak discharge (Q_f) on a development site (see Subsection 3.1.7.5).

4.24.3 Pollutant Removal Capabilities

Stormwater planters are presumed to remove 80% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Stormwater planters also remove 60% of the Phosphorus and Nitrogen, and 80% of fecal coliform. Stormwater planters are not presumed to remove metals such as Cadmium, Copper, Lead, and Zinc in contributing runoff.

4.24.4 Application and Site Feasibility Criteria

Stormwater planters are typically used on commercial, institutional, and industrial development sites. Because they can be constructed immediately adjacent to buildings and other structures, they are ideal for use in urban areas. Although they are well-suited to receive rooftop runoff, they can also be used to treat stormwater runoff from other small impervious and pervious drainage areas, such as sidewalks, plazas, and small parking lots (**Figure 4.24-1**). When compared with other low impact development practices, stormwater planters have a moderate construction cost and maintenance burden, while requiring a relatively small amount of surface area.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – The size of the contributing drainage area should be 2,500 square feet or less.
- **Flow path** – The length of flow path in contributing drainage areas should be 150 feet or less in pervious drainage areas and 75 feet or less in impervious drainage areas.
- **Space Required** – Stormwater planter surface area requirements vary according to the size of the contributing drainage area. In general, stormwater planters require about 5% of the size of their contributing drainage areas.
- **Site Slope** – Although stormwater planters may be used on development sites with slopes of up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the planting bed.
- **Minimum Depth to Water Table** – 2 feet
- **Minimum Head** – 2 feet

- **Soils** – Stormwater planters should be designed to completely drain within 24 hours of the end of a rainfall event.

Other Constraints/Considerations

- **Hot spots** – Because they are constructed with waterproof liners and under/overdrains, stormwater planters may be used to treat hot spot runoff.
- **Damage to existing structures and facilities** – Stormwater planters should not be used in areas where their operation may create a risk for basement flooding, interfere with subsurface sewage disposal systems, or negatively affect other underground structures. Stormwater planters should be designed so that overflow drains away from buildings to prevent damage to building foundations.
- **Proximity** – Stormwater planters may be used without restriction in areas that are:
  - » 10 feet from property lines
  - » 100 feet from private water supply wells
  - » 1,200 feet from public water supply wells
  - » 100 feet from septic systems
  - » 100 feet from surface waters
  - » 400 feet from public water supply surface waters
- **Trout Stream** – Use of a stormwater planter reduces a site's runoff pollutant load, as well as the volume and velocity of stormwater runoff, without significantly warming the water. Therefore, stormwater planters are an effective BMP for use where trout streams or other protected waters may receive stormwater runoff.
- **Poorly Draining Soils** – Since stormwater planters are equipped with waterproof liners and underdrains, the presence of poorly draining soils does not influence their use.
- **Well-Draining Soils** – Since stormwater planters are equipped with waterproof liners and underdrains, the presence of well-draining soils does not influence their use.
- **Flat Terrain** – It may be difficult to provide adequate drainage on flat terrain, which may cause stormwater runoff to pond in the stormwater planter for extended periods of time. Ensure that the underdrain will allow the stormwater planter to drain completely within 24 hours of the end of a rainfall event to prevent nuisance ponding conditions.
- **Shallow Water Table** – It may be difficult to provide 2 feet of clearance between the bottom of the stormwater planter and the top of the water table, which may cause stormwater runoff to pond in the stormwater planter. Designers can address this issue by reducing the depth of the planting bed to 18 inches or reducing the distance between the bottom of the stormwater planter and top of the water table to 12 inches and providing an adequately sized underdrain.

4.24.5 Planning and Design Criteria

Before designing a stormwater planter, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- Proposed site design, including buildings, parking lots, sidewalks, stairs, handicapped ramps, and landscaped areas
- Architectural roof plan for rooftop pitches and downspout locations
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Information about downstream BMPs and receiving waters
- Design data from nearby storm sewer structures
- Water surface elevation of nearby water systems and depth to seasonally high groundwater table

*The following criteria are to be considered **minimum** standards for the design of a stormwater planter. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.*

4.24.5.1 LOCATION AND LAYOUT

- Stormwater planters should be used to receive stormwater runoff from small drainage areas of 2,500 square feet or less. The stormwater runoff rates and volumes from larger contributing drainage areas typically become too large to be properly treated by stormwater planters.
- The length of the flow path within the contributing drainage area should be 150 feet or less for pervious drainage areas and 75 feet or less for impervious drainage areas. In contributing drainage areas with longer flow paths bioretention areas (Section 4.2) should be used to receive post-construction stormwater runoff.
- Stormwater planters should be designed to provide enough storage for the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85th percentile rainfall event).
- A minimum width, measured from inside wall to inside wall, of 18 inches is recommended for all stormwater planters.
- Although stormwater planters may be used on development sites with slopes up to 6%, they should be designed with slopes that are as close to flat as possible to help ensure that stormwater runoff is evenly distributed over the planting bed. Multiple planters can be constructed at varying elevations.
- Unless a shallow water table is found on the development site, the distance from the bottom of a stormwater planter to the top of the water table should be at least 2 feet. If a shallow water table is found on the development site, the distance from the bottom of a stormwater planter to the top of the water table may be reduced to 12 inches.

4.24.5.2 GENERAL DESIGN

- Stormwater planters should be designed to completely drain within 24 hours of the end of a rainfall event. Where site characteristics allow, it is preferable to design stormwater planters to drain within 12 hours of the end of a rainfall event to help prevent nuisance ponding conditions.
- Stormwater planters may be designed with a maximum ponding depth of 12 inches, although a ponding depth of 6 inches is recommended to help prevent nuisance ponding conditions.
- A minimum of 2 inches of freeboard should be provided between the elevation of the maximum ponding depth and the top of the planter box.
- Unless a shallow water table is found on the development site, all stormwater planter planting beds should be at least 24 inches deep. If a shallow water table is found on the development site, the depth of the planting bed may be reduced to 18 inches.
- The soils used within stormwater planter beds should be an engineered soil mix that meets the following specifications:
  - *Texture*: Sandy loam or loamy sand should be used.
  - **Sand Content**: Soils should contain 85-88% clean, washed sand.
  - **Topsoil Content**: Soils should contain 8-12% topsoil.
  - **Organic Matter Content**: Soils should contain 3-5% organic matter.
  - **Infiltration Rate**: Soils should have an infiltration rate of at least 0.25 inches per hour (in/hr), although an infiltration rate of between 1-2 in/hr is preferred.
  - **Phosphorus Index (P-Index)**: Soils should have a P-Index of less than 30.
  - **Exchange Capacity (CEC)**: Soils should have a CEC that exceeds 10 milliequivalents (meq) per 100 grams of dry weight.
  - **pH**: Soils should have a pH of 6-8.
- The organic matter used within a stormwater planter bed should be a well-aged compost that meets the specifications outlined in Appendix D.
- All stormwater planters should be equipped with a waterproof liner to prevent damage to building foundations and other adjacent impervious surfaces. Waterproof liners should be 30 mil (0.030 inch) polyvinylchloride (PVC) or equivalent.
- Stormwater planters should be constructed of stone, concrete, brick, or another durable material. Chemically treated wood that can leach toxic chemicals and contaminate stormwater runoff should not be used to construct a stormwater planter.

- Stormwater planters should be equipped with an underdrain consisting of a 4-inch perforated PVC (AASHTO M 252) pipe bedded in a 6-inch layer of clean, washed stone. The pipe should have 3/8-inch perforations, spaced 6 inches on center, and a minimum slope of 0.5%. The clean, washed stone should be ASTM D448 size No. 57 stone (i.e., 1-1/2 to 1/2 inches in diameter) and should be separated from the planting bed by a layer of permeable filter fabric or a thin, 2-4-inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8" to 1/8" or ASTM D 448 size No. 89, 3/8" to 1/16").
- If permeable filter fabric is used, the filter fabric should be a non-woven geotextile with a permeability that is greater than or equal to the hydraulic conductivity of the overlying planting bed.
- Consideration should be given to the stormwater runoff rates and volumes generated by larger storm events (e.g., 25-year, 24-hour storm event) to help ensure that these larger storm events are able to safely bypass stormwater planters. An overflow system, such as an overdrain with an invert set slightly above the elevation of maximum ponding depth, should be designed to convey the stormwater runoff generated by these larger storm events safely out of the stormwater planter.

4.24.5.3 PRETREATMENT/INLETS

- If used to receive non-rooftop runoff, consider preceding the stormwater planters with a pea gravel diaphragm or equivalent level spreader device (e.g., concrete sills, curb stops, curbs with "sawteeth" cut into them) to intercept stormwater runoff and distribute it evenly, as overland sheet flow, across the stormwater planter.

4.24.5.4 OUTLET STRUCTURES

- An overflow system, such as an overdrain with an invert set slightly above the elevation of maximum ponding depth, should be designed to convey the stormwater runoff generated by larger storm events safely out of the stormwater planter.
- If designed to receive rooftop runoff, stormwater planters should be constructed with bypass structures and/or piping to ensure that stormwater runoff from larger storm events can be safely passed without damaging the practice or nearby property.

4.24.7.5 SAFETY FEATURES

Except for stable outlet and bypass structures, stormwater planters generally do not require any special safety features. Fencing of stormwater planters is not generally desirable.

4.24.5.6 LANDSCAPING

- A landscaping plan should be prepared for all stormwater planters. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- Vegetation commonly planted in stormwater planters includes native trees, shrubs, and other herbaceous vegetation. When developing a landscaping plan, site planning and design teams should choose vegetation that will be able to stabilize soils and tolerate the stormwater runoff rates and volumes that will pass through the stormwater planter. Vegetation used in stormwater planters should also be able to tolerate both wet and dry conditions. See Appendix D for a list of grasses and other plants that are appropriate for use in stormwater planters in the State of Georgia.
- A mulch layer, consisting of 2-4 inches of fine shredded hardwood mulch or hardwood chips, should be included on the surface of the stormwater planter.
- Methods used to establish vegetative cover within a stormwater planter should achieve at least 75% vegetative cover one year after installation.
- To help prevent soil erosion and sediment loss, landscaping should be provided immediately after the stormwater planter has been installed. Temporary irrigation may be needed to quickly establish vegetative cover within a stormwater planter.

4.24.5.7 CONSTRUCTION CONSIDERATIONS

To help ensure that stormwater planters are successfully installed, site planning and design teams should consider the following recommendations:

- If stormwater planters will be used to receive non-rooftop runoff, they should only be installed after their contributing drainage areas have been completely stabilized. To help prevent stormwater planter failure, stormwater runoff may be diverted around the stormwater planter until the contributing drainage area has been stabilized.
- To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of stormwater planters before, during, and immediately after construction. This can typically be accomplished by clearly delineating stormwater planters on all development plans and, if necessary, protecting them with temporary construction fencing.
- Excavation for stormwater planters should be limited to the width and depth specified in the development plans. Excavated material should be placed away from the excavation so as not to jeopardize the stability of the side walls.
- Native soils along the bottom of the stormwater planter should be scarified or tilled to a depth of 3-4 inches prior to the placement of the choker stone and stormwater planter stone.
- The sides of all excavations should be trimmed of large roots that will hamper the installation of the permeable filter fabric used to line the sides and top of the stormwater planter.

4.24.5.8 CONSTRUCTION AND MAINTENANCE COSTS

- The initial cost of a stormwater planter averages around $8 per square foot; however, the overall cost will vary depending on the type and size of vegetation and planters used.
- Maintenance costs average around $400-$500 per year for a 500-square-foot planter. These also vary depending on size and plant choice.

4.24.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a stormwater planter or tree box.**
Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a stormwater planter or tree box. Create a rough layout of the stormwater planters or tree box dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the stormwater planters or tree box.**
Consider whether the stormwater planters or tree box is intended to:

- Meet a runoff reduction* target or water quality (treatment) target. For information on the sizing of a BMP utilizing the runoff reduction approach, see Step 3A. For information on the sizing of the BMP utilizing the water quality treatment approach, see Step 4A.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- Provide a possible solution to a drainage problem
- Enhance landscape and provide aesthetic qualities

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3A, 3B, and 3C for a runoff reduction approach, or skip Step 3 and complete Steps 4A and 4B for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3A) **Calculate the Stormwater Runoff Reduction Target Volume**
Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (R_V)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, look up the appropriate runoff reduction percentage (or credit) provided by the practice:

Using the RR_V calculated above, determine the minimum Volume of the Practice (VP)

$$(VP_{MIN}) \geq RR_v \text{ (target)} / (RR\%)$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice
VP_{MIN} = Minimum storage volume required to provide Runoff Reduction Target Volume (ft^3)
RR_v (target) = Runoff Reduction Target Volume (ft^3)

(Step 3B) Determine the storage volume of the practice and the Pretreatment Volume

To determine the actual volume provided in the stormwater planter or tree box, use the following equation:

$$VP = (PV + VES\ (N))$$

Where:

VP = Volume provided (temporary storage)
PV = Ponding Volume
VES = Volume of Engineered Soils
N = Porosity

To determine the porosity, a qualified licensed professional should be consulted to determine the proper porosity based on the engineered soils used. Most soil media has a porosity of 0.25 and gravel a value of 0.40.

Provide pretreatment by using a grass filter strip or pea gravel diaphragm, as needed, (sheet flow), or a grass channel or forebay (concentrated flow). Where filter strips are used, 100% of the runoff should flow across the filter strip. Pretreatment may also be desired to reduce flow velocities or assist in sediment removal and maintenance. Pretreatment can include a forebay, weir, or check dam. Splash blocks or level spreaders should be considered to dissipate concentrated stormwater runoff at the inlet and prevent scour. Forebays should be sized to contain 0.1 inches per impervious acre of contributing drainage. Refer to Section 4.9 for design criteria for a grass channel and Section 4.29 for vegetated filter strips.

(Step 3C) Determine whether the minimum storage volume was met

When the VP ≥ VP_{MIN}, then the Runoff Reduction requirements are met for this practice. Proceed to Step 5.

When the VP < VP_{MIN}, then the BMP must be sized according to the WQ_V treatment method (See Step 4).

(Step 4A) Calculate the Target Water Quality Volume

Calculate the Water Quality Volume using the following formula:

$$WQ_V = (1.2)\ (R_V)\ (A) / 12$$

Where:

WQ_V = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)
A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4B) **If using the practice for Water Quality treatment, determine the footprint of the stormwater planter practice**

The peak rate of discharge for the water quality design storm is needed for sizing of off-line diversion structures (see Subsection 3.1.7). If designing off-line, follow steps (a) through (d) below:

(a) Using WQ_v, compute CN
(b) Compute time of concentration using TR-55 method
(c) Determine appropriate unit peak discharge from time of concentration
(d) Compute Q_{wq} from unit peak discharge, drainage area, and WQ_v.

To determine the minimum surface area of the stormwater planter, use the following formula:

$$A_f = (WQ_v)\ (d_f) \ / \ [\ (k)\ (h_f + d_f)(t_f)]$$

Where:

A_f = surface area of ponding area (ft^2)
WQ_v = water quality volume (ft^3)
d_f = media depth (ft)
k = coefficient of permeability of planting media (ft/day) (use 1 ft/day for silt-loam if engineered soils is being used)
h_f = average height of water above stormwater planter bed (ft)
t_f = design planting media drain time (days) (1 day is recommended maximum)

(Step 5) **Calculate the adjusted curve numbers for CP_V (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information**

(Step 6) **Size flow diversion structure, if needed**

If the contributing drainage area to stormwater planter exceeds the water quality treatment and/or storage capacity, a flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v (or RR_v) to the stormwater planter.

(Step 7) **Design emergency overflow system**

An overflow system, such as an overdrain with an invert set slightly above the elevation of maximum ponding depth, must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year, 24-hour storm event.

(Step 8) **Prepare site Vegetation and Landscaping Plan**

A landscaping plan for the stormwater planter should be prepared to indicate how it will be established with vegetation.

See Subsection 4.24.5.6 (*Landscaping*) and Appendix D for more details.

4.24.7 Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.25 Stormwater Ponds



Description: Constructed stormwater retention basins that have a permanent pool (or micropool). Runoff from each rain event is detained and treated in the pool primarily through settling and biological uptake mechanisms.

LID/GI Considerations: Stormwater ponds are not generally considered low impact development or green infrastructure best management practices (BMPs).

KEY CONSIDERATIONS

DESIGN CRITERIA

- Minimum contributing drainage area of 25 acres; 10 acres for micropool extended detention pond
- A sediment forebay or equivalent upstream pretreatment facility should be provided.
- Minimum length-to-width ratio for the pond is 1.5:1
- Depth of the permanent pool should not exceed 8 feet.
- Side slopes to the pond should not exceed 3:1 (h:v) without safety precautions or if mowing is anticipated and should terminate on a safety bench

ADVANTAGES / BENEFITS

- Moderate to high removal rate of urban pollutants
- High community acceptance
- Opportunities for wildlife habitat

DISADVANTAGES / LIMITATIONS

- Potential for thermal impacts/downstream warming
- Dam height restrictions for high-relief areas
- Pond drainage can be problematic for low-relief terrain
- Cost of dredging and disposal
- Dredging operations may require a stream buffer variance

MAINTENANCE REQUIREMENTS

- Remove debris from inlet and outlet structures.
- Maintain side slopes and remove invasive vegetation.
- Monitor sediment accumulation and remove it periodically.

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- 50% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/30% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 70% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- H Land Requirement
- L Capital Cost
- L Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Not recommended*
Roadway Projects: *Yes*

Soils: *Underlying soils of hydrologic group "C" or "D" should be adequate to maintain a permanent pool. Hydrologic group "A" soils generally require a pond liner; group "B" soils may require infiltration testing.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% of the runoff reduction volume provided by this practice.

4.25.1 General Description

Stormwater ponds (also referred to as retention ponds, wet ponds, or wet extended detention ponds) are constructed stormwater retention basins that have a permanent (dead storage) pool of water throughout the year. They can be created by excavating an existing natural depression or through the construction of embankments.

In a stormwater pond, runoff from each rain event is detained and treated in the pool through gravitational settling and biological uptake until it is displaced by runoff from the next storm. The permanent pool also serves to protect deposited sediments from resuspension. Above the permanent pool level, additional temporary storage (live storage) is provided for runoff quantity control. The upper stages of a stormwater pond are designed to provide extended detention of the 1-year, 24-hour rainfall event for downstream channel protection, as well as normal detention of larger storm events (25-year, 24-hour and, optionally, the 100-year, 24-hour storm event).

Stormwater ponds are among the most cost-effective and widely used stormwater practices. A well-designed and landscaped pond can be an aesthetic feature on a development site when planned, located, implemented, and maintained properly. However, ponds only work as designed until the deign sediment volume is reached. At that point, the sediment must be removed to maintain treatment performance and aquatic resource, channel and extreme flood protection.

There are several variants of stormwater pond design, the most common of which include the wet pond, the wet extended detention pond, and the micropool extended detention pond. In addition, multiple stormwater ponds can be placed in series or parallel to increase performance or meet site design constraints. Below are descriptions of each design variant:

- **Wet Pond** – Wet ponds are stormwater basins constructed with a permanent (dead storage) pool of water equal to the water quality volume. Stormwater runoff displaces the water already present in the pool. Temporary storage (live storage) can be provided above the permanent pool elevation for larger flows.
- **Wet Extended Detention (ED) Pond** – A wet extended detention pond is a wet pond where the water quality volume is split evenly between the permanent pool and extended detention (ED) storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 24 hours. This design has similar pollutant removal to a traditional wet pond, but consumes less space.
- **Micropool Extended Detention (ED) Pond** – The micropool extended detention pond is a variation of the wet ED pond where only a small "micropool" is maintained at the outlet to the pond. The outlet structure is sized to detain the water quality volume for 24 hours. The micropool prevents resuspension of previously settled sediments and also prevents clogging of the low flow orifice.
- **Multiple Pond Systems** – Multiple pond systems consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The additional cells can create longer pollutant removal pathways and improved downstream protection.

Figure 4.25-1 on the next page shows several examples of stormwater pond variants.

Wet Pool



Wet ED Pond



Micropool ED Pond

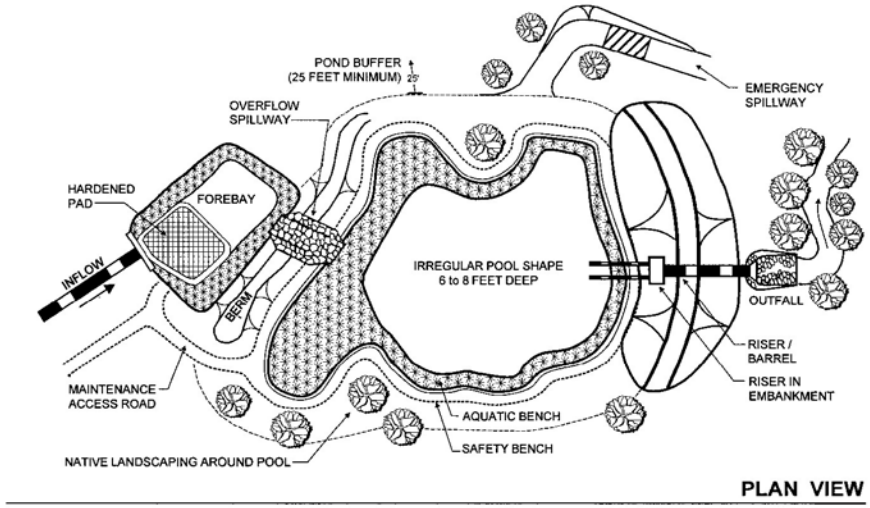


Wet ED Pond



Figure 4.25-1 Stormwater Pond Examples

Figures 4.25-2 through **4.25-5** provide plan view and profile view schematics for the design of a wet pond, wet extended detention pond, micropool extended detention pond, and multiple pond system.



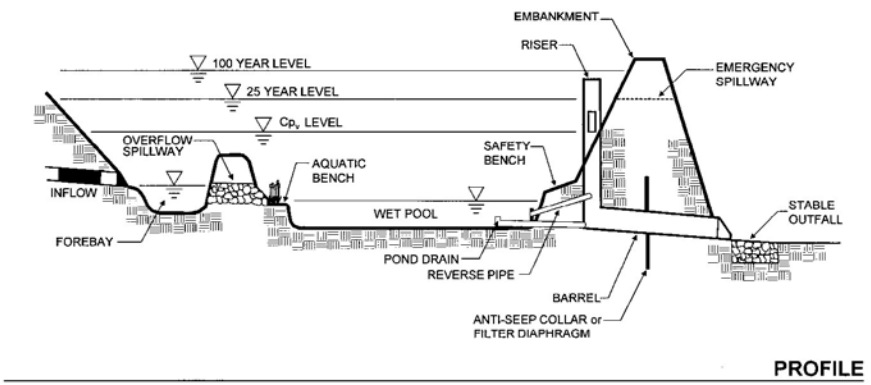
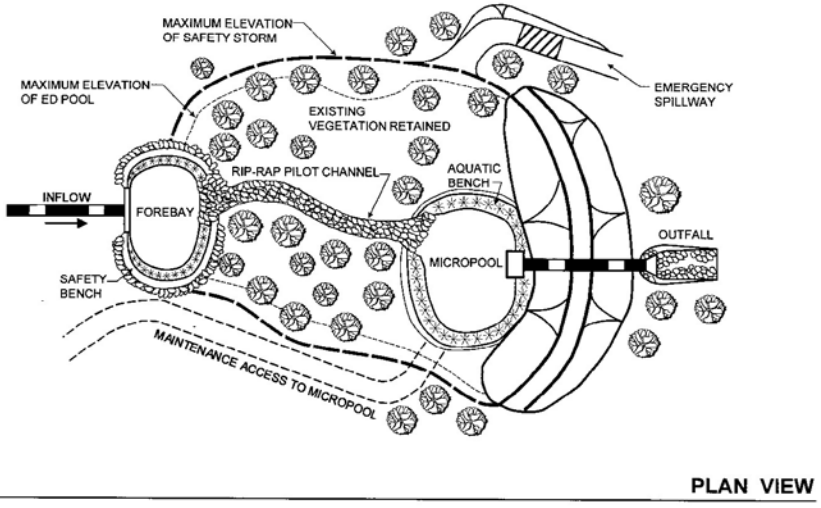


Figure 4.25-2 Schematic of Wet Pond

(Source: Center for Watershed Protection)



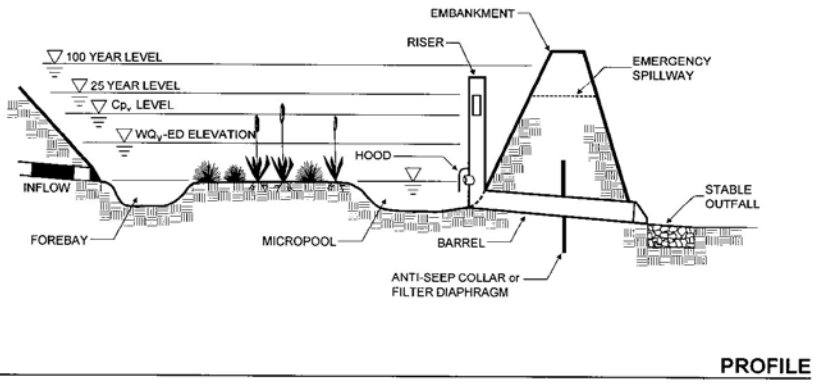
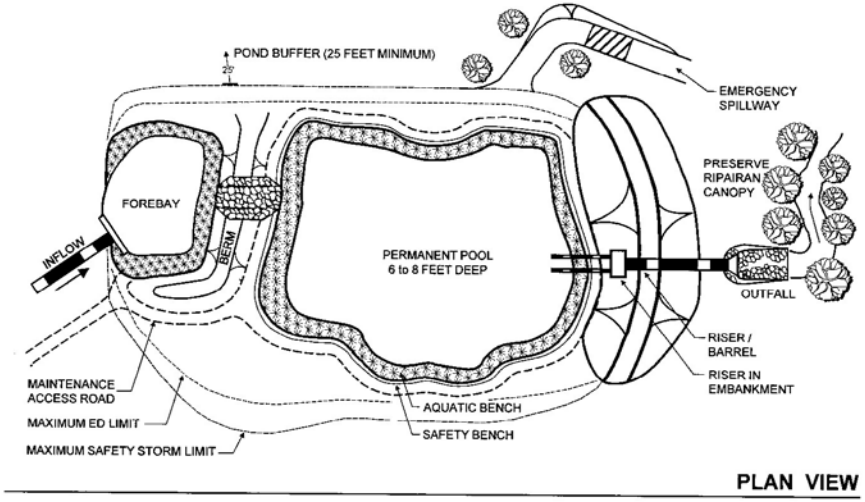


Figure 4.25-3 Schematic of Wet Extended Detention Pond

(Source: Center for Watershed Protection)



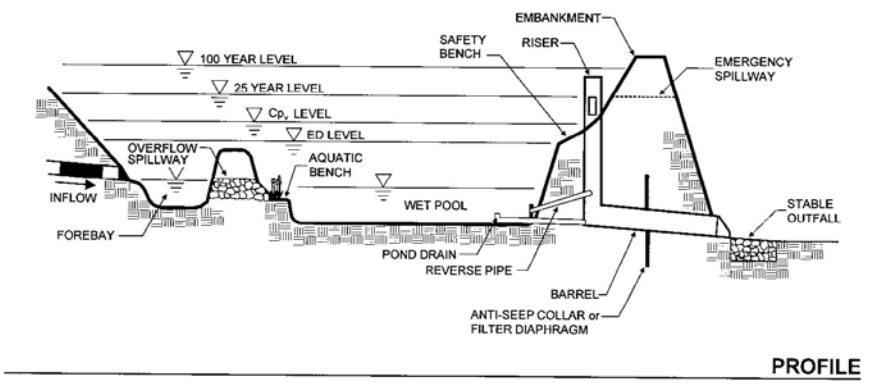
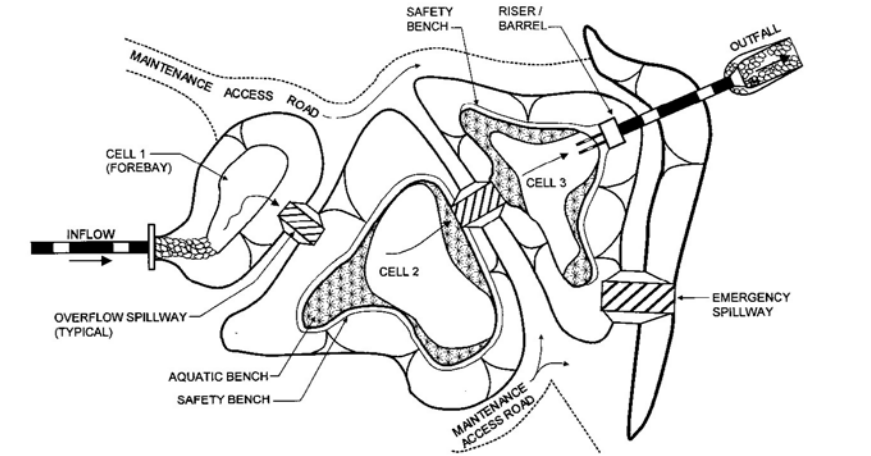


Figure 4.25-4 Schematic of Micropool Extended Detention Pond

(Source: Center for Watershed Protection)



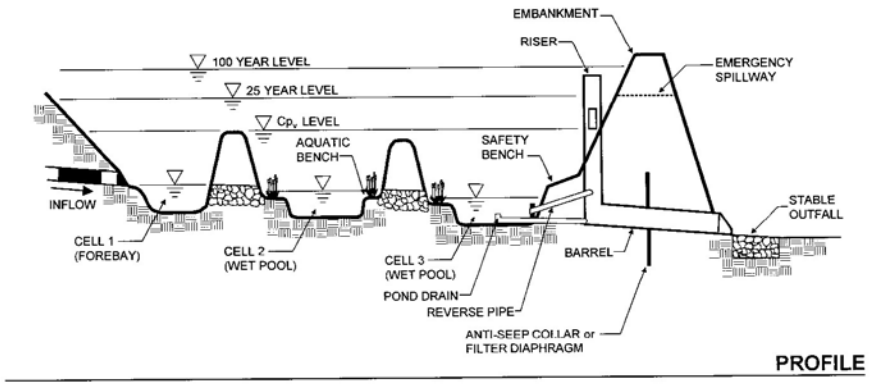


Figure 4.25-5 Schematic of Multiple Pond System

(Source: Center for Watershed Protection)

4.25.2 Stormwater Management Suitability

Stormwater ponds are designed to control both stormwater quantity and quality. Thus, a stormwater pond can be used to address most of the *unified stormwater sizing criteria* for a given drainage area.

- Runoff Reduction
  Stormwater ponds provide negligible stormwater volume runoff reduction. Another BMP should be used in a treatment train with stormwater ponds to provide runoff reduction.
- Water Quality
  Ponds treat incoming stormwater runoff by physical, biological, and chemical processes. The primary removal mechanism is gravitational settling of particulates, organic matter, metals, bacteria, and organics as stormwater runoff resides in the pond. Another mechanism for pollutant removal is uptake by algae and wetland plants in the permanent pool—particularly of nutrients. Volatilization and chemical activity also work to break down and eliminate a number of other stormwater contaminants, such as hydrocarbons.
- Channel Protection
  A portion of the storage volume above the permanent pool in a stormwater pond can be used to provide control of the channel protection volume (CP_v). This is accomplished by releasing the 1-year, 24-hour storm runoff volume over 24 hours (extended detention).
- Overbank Flood Protection
  A stormwater pond can also provide storage above the permanent pool to reduce the post-development peak flow of the 2-25-year, 24-hour storms (Q_{p2-25}) to pre-development levels (detention).
- Extreme Flood Protection
  In situations where it is required, stormwater ponds can also be used to provide detention to control the 100-year, 24-hour storm peak flow (Q_f). Where this is not required, the pond structure is designed to safely pass extreme storm flows.

4.25.3 Pollutant Removal Capabilities

All of the stormwater pond design variants are presumed to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed ponds can reduce TSS removal performance, as can excess sediment.

The following pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- *Total Suspended Solids – 80%*
- *Total Phosphorus – 50%*
- *Total Nitrogen – 30%*
- *Fecal Coliform – 70% (if no resident waterfowl population present)*
- *Heavy Metals – 50%*

For additional information and data on pollutant removal capabilities for stormwater ponds, see the National Pollutant Removal Performance Database (Version 3) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.25.4 Application and Site Feasibility Criteria

Stormwater ponds are generally applicable to most types of new development and redevelopment, and can be used in both residential and nonresidential areas. Ponds can also be used in retrofit situations.

The following criteria should be evaluated to ensure the suitability of a stormwater pond for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **YES**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – A minimum of 25 acres is needed for a wet pond or wet ED pond to maintain a permanent pool, or 10 acres minimum for a micropool ED pond. A smaller drainage area may be acceptable with an adequate water balance and anti-clogging device.
- The maximum drainage area should be 100 to 300 acres. The maximum drainage area of highly impervious drainage areas should be restricted to the lower end of the range (100 acres) and low density residential watersheds should be restricted to a maximum of 300 acres.
- **Space Required** – Approximately 2-3% of the tributary drainage area
- **Site Slope** – There should not be more than 15% slope across the drainage area to the pond.
- **Minimum Head** – 6-8 feet of elevation difference needed on-site from the inflow to the outflow
- **Minimum Depth to Water Table** – If used on a site with an underlying water supply aquifer, or when treating a hot spot, a separation distance of 2 feet is required between the bottom of the pond and the elevation of the seasonally high water table.
- **Soils** – Underlying soils of hydrologic group C or D should be adequate to maintain a permanent pool. Most group A soils and some group B soils will require a pond liner. *Evaluation of soils should be based upon an actual subsurface analysis and permeability tests.*

Other Constraints/Considerations

- **Hot spots** – Stormwater ponds can accept runoff from stormwater hot spots. Reduce potential groundwater contamination by preventing infiltration of hot spot runoff. Pretreatment should be provided for hot spot runoff, as well as a 2-4-foot separation distance from the water table.
- **Damage to existing structures and facilities** – Stormwater ponds should be designed to safely store and/or bypass the overbank flood (Q_{p25}) and extreme flood (Q_f) storms to prevent overflow or failure, which may cause damage to site structures and facilities.
- Minimum setback requirements for stormwater pond facilities (when not specified by local ordinance or criteria):
  - » *Property line* – 10 feet
  - » *Private well* – 100 feet; if a well is down-gradient from a hot spot land use then the minimum setback is 250 feet
  - » *Septic system tank/leach field* – 50 feet
- **Trout Streams** – Consideration should be given to the thermal influence of stormwater pond outflows on downstream trout waters. A micropool ED pond is the best pond alternative, but wet ponds and wet ED ponds can be designed off-line and under shade to minimize their thermal impact. Limit $WQ_{v\text{-}ED}$ to 12 hours.
- **Low-relief** – Maximum normal pool depth is limited, so providing a pond drain can be problematic.
- **High-relief** – Embankment heights are restricted.
- **Karst** – Requires clay or polyliner to sustain a permanent pool of water and protect aquifers. Ponding depth is limited. Geotechnical tests may be required.
- **Swimming Area / Shellfish** – Design for geese prevention. Provide 48-hour ED for maximum coliform die-off.
- **Aquifer Protection** – Reduce potential groundwater contamination by preventing infiltration of hot spot runoff. A liner may be required for type A and B soils. Pretreat hot spots and provide 2-4-foot separation distance from the groundwater table.
- **Poorly Draining Soils** – Poorly draining soils do not inhibit a stormwater pond's ability to temporarily store and treat stormwater runoff.
- **Flat Terrain** – Consider stormwater wetlands as an alternative stormwater management (Section 4.26) practice in areas with flat terrains and a shallow water table.

- Shallow Water Table – If used on a site with an underlying water supply aquifer or when treating a hot spot, a separation distance of 2 feet is required between the bottom of the pond and the elevation of the seasonally high water table. Otherwise, the elevation of the stormwater pond bottom can be below the seasonally high water table, as this will help to maintain a permanent pool within the BMP.

4.25.5 Planning and Design Criteria

Before designing the stormwater pond, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- Impervious and pervious areas and other means to determine the land use data as needed
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Design data for nearby storm sewer structures
- Water surface elevation of nearby water systems and the depth to the seasonally high groundwater table
- Desired sediment storage volume and cleanout frequency

The following criteria are to be considered minimum standards for the design of a stormwater pond facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.25.5.1 LOCATION AND LAYOUT

- Stormwater ponds should have a minimum contributing drainage area of 25 acres for a wet pond or wet ED pond to maintain a permanent pool. For a micropool ED pond, the minimum drainage area is 10 acres. A smaller drainage area can be considered when water availability can be confirmed (such as from a groundwater source or in areas with a high water table). In these cases a water balance may be performed. Ensure that an appropriate anti-clogging device is provided for the pond outlet.
- A stormwater pond should be sited such that the site topography allows for maximum runoff storage at minimum excavation or construction costs. Pond siting should also take into account the location and use of other site features, such as buffers and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape. Bedrock close to the surface may prevent excavation.
- Stormwater ponds should not be located on steep (>15%) or unstable slopes.
- Stormwater ponds cannot be located within a stream or any other navigable waters of the U.S., including wetlands, without obtaining a Section 404 permit under the Clean Water Act, and any other applicable state permit.
- All utilities should be located outside of the pond/basin site.

4.25.5.2 GENERAL DESIGN

- A well-designed stormwater pond consists of the following components.
  1. One or more permanent pools of water
  2. An overlying zone in which runoff control volumes are stored
  3. Shallow littoral zone (aquatic bench) along the edge of the permanent pool that acts as a biological filter
- In addition, all stormwater pond designs should include a sediment forebay at their inflow to allow heavier sediments to drop out of suspension before runoff enters the permanent pool.
- Additional pond design features include an emergency spillway, maintenance access, safety bench, pond buffer, and appropriate native landscaping.
- No more than 50% of the basin perimeter may be a wall of any type unless a drive is provided to the bottom of the pond. The drive shall be a minimum of 15 feet wide with a maximum slope of 20%.
- If the developer desires to install a fence around a detention facility, it shall be a minimum 4-foot high fence of durable material, with a 12-foot wide access gate. The fence shall be contained within an easement and outside the detention facility's slopes and/or walls. This easement is for inspection purposes, more width may be necessary for maintenance purposes.
- The side slope in graded areas is required to be 3H: 1V or flatter.

4.25.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

In general, pond designs are unique for each site and application. However, there are a number of geometric ratios and limiting depths for ponds that must be observed for adequate pollutant removal, ease of maintenance, and improved safety.

- Permanent pool volume is typically sized as follows:
  - » **Standard wet ponds:** 100% of the water quality treatment volume (1.0 WQ_v)
  - » **Wet ED ponds:** 50% of the water quality treatment volume (0.5 WQ_v)
  - » **Micropool ED ponds:** Volume should be approximately 0.1 inch per impervious acre draining to the pond.
- Dam heights greater than 25 feet or a storage volume greater than 100 acre-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated to this depth.
- Proper geometric design is essential to prevent hydraulic short-circuiting (unequal distribution of inflow), which results in failure of the pond to achieve adequate levels of pollutant removal. The minimum length-to-width ratio for the permanent pool shape is 1.5:1, and should ideally be greater than 3:1 to avoid short-circuiting. In addition, ponds should be wedge-shaped when possible so that flow enters the pond and gradually spreads out, improving the sedimentation process. Baffles, pond shaping, and/or islands can be added within the permanent pool to increase the flow path.
- Maximum depth of the permanent pool generally should not exceed 8 feet to avoid stratification and anoxic conditions. Minimum depth for the pond bottom should be 3-4 feet. Deeper depths near the outlet will yield cooler bottom water discharges that may help to mitigate downstream thermal effects.
- Side slopes to the pond shall not exceed 3:1 (h:v) and should terminate on a safety bench (see **Figure 4.25-6**). The safety bench requirement may be waived if slopes are 4:1 or flatter.
- The perimeter of all deep pool areas (4 feet or deeper) should be surrounded by two benches: safety and aquatic. For larger ponds, a safety bench extends approximately 15 feet outward from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench should be 6%. An aquatic bench extends inward from the normal pool edge (15 feet on average) and has a maximum depth of 18 inches below the normal pool water surface elevation (see **Figure 4.25-6**).
- The contours and shape of the permanent pool should be irregular to provide a more natural landscaping effect.

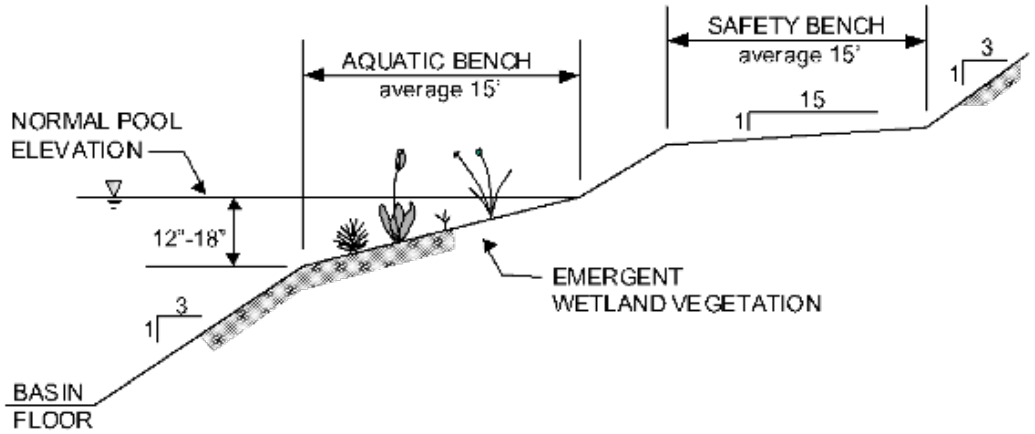


Figure 4.25-6 Typical Stormwater Pond Geometry Criteria

4.25.5.4 PRETREATMENT/INLETS

- Each pond should have a sediment forebay or equivalent upstream pretreatment. A sediment forebay is designed to remove incoming sediment from the stormwater flow prior to dispersal in a larger permanent pool. The forebay should consist of a separate cell, formed by an acceptable barrier. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. In some design configurations, the pretreatment volume may be located within the permanent pool.
- The forebay is sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4-6 feet deep. The pretreatment storage volume is part of the total WQ_v requirement and may be subtracted from WQ_v for permanent pool sizing.
- Forebays should contain a fixed vertical sediment depth marker to measure sediment deposition over time. The bottom of the forebay may be hardened (using concrete, paver blocks, etc.) to make sediment removal easier.
- Inflow channels are to be stabilized with flared aprons, or the equivalent. Inlet pipes to the pond can be partially submerged. Exit velocities from the forebay must be non-erosive.

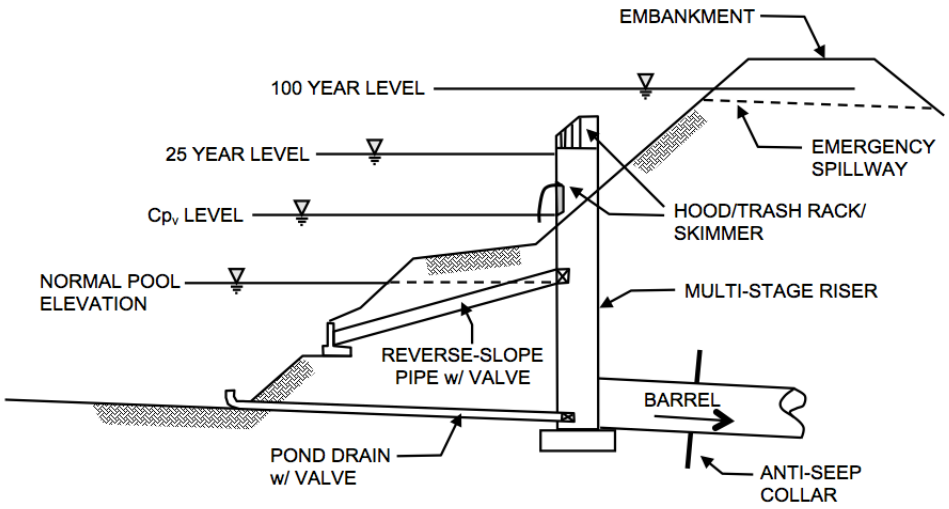


Figure 4.25-7 Typical Pond Outlet Structure

4.25.5.5 OUTLET STRUCTURES

- Flow control from a stormwater pond is typically accomplished with the use of a concrete riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the base of the pond with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see **Figure 4.25-7**). The riser should be located within the embankment for maintenance access, safety, and aesthetics.
- A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality, channel protection, and overbank flood protection runoff volumes. The number of orifices can vary and is usually a function of pond design.
  - » For example, a wet pond riser configuration is typically comprised of a channel protection outlet (usually an orifice) and overbank flood protection outlet (often a slot or weir). The channel protection orifice is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water stream basins). Since the water quality volume is fully contained in the permanent pool, no orifice sizing is necessary for this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the channel protection orifice. Thus an off-line wet pond providing only water quality treatment can use a simple overflow weir as the outlet structure.

» Flow control from a stormwater pond is typically accomplished with the use of a concrete riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the base of the pond with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see **Figure 4.25-7**). The riser should be located within the embankment for maintenance access, safety, and aesthetics.

- If either the Water Quality (WQ) or the Channel Protection (CP) Orifice is less than 4.0 inches, use table below to set orifice diameter:

WQ/CP Orifice Diameter from Design (inches)	WQ/CP Orifice Diameter to use (inches)
0.50 < X < 0.75	0.50
0.75 < X < 1.00	0.75
1.00 < X <1.25	1.00
1.25 < X < 1.50	1.25
1.50 < X < 1.75	1.50
1.75 < X < 2.00	1.75
2.00 < X < 2.50	2.00
2.50 < X < 3.00	2.50
3.00 < X < 3.50	3.00
3.50 < X < 4.00	3.50

- Orifices smaller than 3 inches in diameter shall have internal orifice protection such as a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket. An orifice smaller than 15 inches in diameter shall be protected by a trash rack.
- Unless the 100-year maximum flow velocity in a conduit through a dam forming a pond or a lake is less than 10 feet per second, and the hydraulic grade line for the 100-year condition is at or below the crown of the conduit for at least 90 percent of its length, the conduit must be equal or superior to Class V reinforced concrete pipe in its structural characteristics.
- The water quality outlet (for a wet ED or micropool ED pond) and channel protection outlet should be fitted with adjustable gate valves or other mechanism(s) that can be used to adjust detention time.
- Higher flows (overbank and extreme flood protection) pass through openings or slots protected by trash racks further up on the riser.
- After entering the riser, flow is conveyed through the barrel and discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.
- Riprap, plunge pools or pads, or other energy dissipators should be placed at the outlet of the barrel to prevent scouring and erosion. If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.
- Each pond must have a bottom drain pipe with an adjustable valve that can completely or partially drain the pond within 24 hours. This requirement may be waived where positive drainage is difficult to achieve due to very low relief.
- The pond drain should be sized one pipe size larger than the calculated design diameter. The drain valve is typically a hand-wheel activated knife or gate valve. Valve controls should be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner.

See the design procedures in Subsection 4.25.6 as well as Section 3.3 (*Storage Design*) and Section 3.4 (*Outlet Structures*) for additional information and specifications on pond routing and outlet works.

4.25.5.6 EMERGENCY SPILLWAYS

- An emergency spillway should be included in the stormwater pond design to safely pass the extreme flood flow. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1.5 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood to the lowest point of the dam embankment, not counting the emergency spillway.

4.25.5.7 MAINTENANCE ACCESS

- A maintenance right-of-way or easement must be provided to a pond from a public or private road. Maintenance access shall be at least 15 feet wide, have a maximum slope of no more than 20%, and be appropriately stabilized to support maintenance equipment and vehicles. This maintenance access easement shall be kept cleared and graded for maintenance access by the owner of the property.
- The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser should be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls.

4.25.5.8 SAFETY FEATURES

- Based on pond embankment height and pond storage volume, it may have to be designed to State of Georgia rules for dam safety. Check the latest rules and corresponding laws.
- Dam heights greater than 25 feet or a storage volume greater than 100 acre-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated to this depth.
- Designs of non-earthen dams shall not include planned structure overtopping for emergency overflows.
- Non earthen pond dam structures shall be constructed of monolithic wall materials. Walls shall extend from the toe of exterior fill slope into the pond's earthen embankment a distance 4 times the depth of the 100 year ponding limits.
- Fencing of ponds is not generally desirable, but may be required by the local review authority. A preferred method is to manage the contours of the pond through the inclusion of a safety bench (see above) to eliminate drop-offs and reduce the potential for accidental drowning. In addition, the safety bench may be landscaped to deter access to the pool.
- The principal spillway opening should not permit access by small children. Ponds with endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent access. Warning signs should be posted near the pond to prohibit swimming and fishing in the facility.

4.25.5.9 LANDSCAPING

- Aquatic vegetation can play an important role in pollutant removal in a stormwater pond, including enhancing the appearance of the pond, stabilizing side slopes, serving as wildlife habitat, and temporarily concealing unsightly trash and debris. Therefore, wetland plants should be encouraged in a pond design, along the aquatic bench (fringe wetlands), safety bench, and side slopes (ED ponds), and within shallow areas of the pool itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within 6 inches (plus or minus) of the normal pool elevation. Additional information on establishing wetland vegetation and appropriate wetland species for Georgia can be found in Appendix D (*Planting and Soil Guidance*).
- Trees or other woody vegetation may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment or 25 feet from the principal spillway structure.
- Trees may **not** be planted on the side slopes of the stormwater pond.
- Plantings should be designed not to conflict with the current drainage of the basin.
- All trees should be kept away from any drainage structures to allow for maintenance access and repairs as needed. There are to be no trees or woody vegetation on the dam, the downward slope of the dam, within 15 feet of the toe of the embankment, or within 25 feet of the principal spillway structure.
- Within a detention basin, all stumps are to be removed, and all debris is to be removed. Shrubs may be allowed to remain below this ponding elevation only upon certification of the survivability of the vegetation, under both wet and dry conditions. There are to be no trees or woody vegetation on the side slopes of the detention basin.
- Detention slopes that are disturbed are to be grassed. The ground cover within the basin shall be well established with all exposed areas covered prior to the end of the maintenance period.

- A pond buffer shall be provided that extends 25 feet outward from the maximum water surface elevation of the pond. The pond buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall stormwater management concept plan. No structures should be located within the buffer, and an additional setback to permanent structures may be provided.
- Existing trees should be preserved in the buffer area during construction, except for those not allowed by regulatory requirements. It is desirable to locate forest conservation areas adjacent to ponds. To discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.
- The soils of a pond buffer are often severely compacted during construction to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large, deep holes around the proposed planting sites and backfill these with uncompacted topsoil.
- Fish such as Gambusia can be stocked in a pond to aid in mosquito prevention.
- A fountain or solar-powered aerator may be used for oxygenation of water in the permanent pool.
- Compatible multi-objective use of stormwater ponds is strongly encouraged to leverage additional benefits.
- The use of native plants in stormwater management facilities is encouraged since they are best suited to thrive and can provide benefits to pollinators and other native fauna. Unfortunately native plants may not always be available in quantity from local nurseries. Therefore, non-invasive naturalized plants that can survive under difficult conditions may be a useful alternative. Great care should be taken, however, when introducing plant species so as not to create a situation where they may become invasive and take over adjacent natural plant communities. The Georgia Exotic Pest Plant Council keeps a list of species that are invasive or could become invasive: http://www.gaeppc.org/list/.

4.25.5.10 CONSTRUCTION CONSIDERATIONS

- Construction equipment should be restricted from the stormwater pond area to prevent compaction of the native soils.
- Contributing drainage areas should be properly stabilized with the appropriate erosion and sediment controls or permanent seeding before allowing stormwater runoff to drain to the stormwater pond.

4.25.5.11 CONSTRUCTION AND MAINTENANCE COSTS

A recent study (Brown and Schueler, 1997) estimated that construction costs for stormwater ponds could be calculated with the following equation:

$$C = 24.5V^{0.705}$$

Where:

C = Construction cost and
V = Volume in the pond to include the 10-year storm (ft^3).

Using this equation, typical construction costs are:

- $45,700 for a 1 acre-foot facility
- $232,000 for a 10 acre-foot facility
- $1,170,000 for a 100 acre-foot facility

4.25.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a stormwater pond.**

Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a stormwater pond. Create a rough layout of the stormwater pond dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the stormwater pond.**

Consider whether the stormwater pond is intended to:

- » Meet a water quality (treatment) target. See Step 3 to size the BMP utilizing the water quality treatment approach.
- » Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- » Provide a possible solution to a drainage problem

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3) **Calculate the Target Water Quality Volume**

Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) **Determine the pretreatment volume.**

A sediment forebay should be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond. The forebay should be sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4-6 feet deep. The forebay storage volume counts toward the total WQ_v requirement and may be subtracted from the WQ_v for subsequent calculations.

(Step 5) **Determine permanent pool volume (and water quality ED volume).**

- » *Wet Pond*: Size permanent pool volume to 1.0 WQ_v
- » *Wet ED Pond*: Size permanent pool volume to 0.5 WQ_v and extended detention volume to 0.5 WQ_v
- » *Micropool ED Pond*: Size permanent pool volume to 25-30% of WQ_v and e extended detention volume to remainder of WQ_v

(Step 6) **Determine the pond location and preliminary geometry. Conduct pond grading and determine storage volume available for the permanent pool (and water quality extended detention volume as appropriate).**

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond.

- » Include safety and aquatic benches
- » Set WQ_v permanent pool elevation (and $WQ_{v\text{-}ED}$ elevation for wet ED and micropool ED ponds)

(Step 7) **Compute extended detention orifice release rate(s) and size(s), and establish the CP_v elevation.**

Wet Pond: The CP_v elevation is determined from the stage-storage relationship and the orifice is then sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water stream basins). The channel protection orifice should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an over-perforated vertical stand pipe with ½-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve this equivalent diameter.

Wet ED Pond and Micropool ED Pond: Based on the elevations established in Step 6 for the extended detention portion of the water quality volume, the water quality orifice is sized to release this extended detention volume in 24 hours. The water quality orifice should have a minimum diameter of 3 inches and be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter. The CP_v elevation is then determined from the stage-storage relationship. The invert of the channel protection orifice is located at the water quality extended detention elevation, and the orifice is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams).

(Step 8) **Calculate the Q_{p25} release rate and water surface elevation.**

Set up a stage-storage-discharge relationship for the control structure for the extended detention orifice(s) and the 25-year, 24-hour rainfall event.

(Step 9) **Design embankment(s) and spillway(s).**

To size the emergency spillway, calculate the 100-year, 24-hour storm water surface elevation. Set the top of the embankment elevation at least one foot higher, and analyze safe passage of the Extreme Flood Volume (Q_f).

At final design, provide safe passage for the 100-year, 24-hour rainfall event.

(Step 10) **Investigate potential pond hazard classification.**
The design and construction of stormwater management ponds are required to follow the latest version of the State of Georgia dam safety rules.

(Step 11) **Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features.**
See Subsection 4.25.5.4 to 4.25.5.8 for more details.

(Step 12) **Prepare site Vegetation and Landscaping Plan.**
A landscaping plan for a stormwater pond and its buffer should be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation.

See Subsection 4.25.5.9 (*Landscaping*) and Appendix D for more details.

See Appendix B-1 for a Stormwater Pond Design Example

4.25.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

Additional Resources

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

4.26 Stormwater Wetlands



Description: Constructed wetland systems used for stormwater management. Runoff volume is both stored and treated in the wetland facility which consists of a shallow impoundment with a permanent pool designed to mimic natural wetlands.

LID/GI Considerations: Wetlands should not be designed close to the source of runoff as LID dictates because it is not practical or cost effective. However wetlands employ several LID/GI characteristics, for example mimicking natural systems and providing infiltration and evapotranspiration.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Minimum contributing drainage area of 25 acres; 5 acres for pocket wetland
- Two design variations (level 1 and level 2) to achieve different pollutant removal rates
- Outflow hydrograph should mimic the existing conditions hydrograph, where applicable
- Design should include water balance analysis and landscaping

ADVANTAGES / BENEFITS

- Good nutrient removal for level 2
- Provides natural wildlife habitat
- Relatively low maintenance costs
- Provides moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff
- Ideal for use in flat terrain and in areas with high groundwater

DISADVANTAGES / LIMITATIONS

- Requires large land area
- Needs continuous baseflow for viable wetland
- Sediment regulation is critical to sustain wetlands
- Provides minimal reduction of post-construction stormwater runoff volumes
- More costly than some BMPs
- Difficulties in maintaining the permanent pool may arise

MAINTENANCE REQUIREMENTS

- Plant replacement vegetation in any eroded areas.
- Remove invasive vegetation
- Monitor sediment accumulation and remove periodically
- A valve will be required to dewater the wetland

POLLUTANT REMOVAL

Level 1

- 80% **Total Suspended Solids**
- 50% **Metals** – Cadmium, Copper, Lead, and Zinc removal
- 40/30% **Nutrients** – Total Phosphorus / Total Nitrogen removal
- 70% **Pathogens** – Fecal Coliform

Level 2

- 85% **Total Suspended Solids**
- 60% **Metals** – Cadmium, Copper, Lead, and Zinc removal
- 75/55% **Nutrients** – Total Phosphorus / Total Nitrogen removal
- 85% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ✓ Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- M/H **Land Requirement**
- M **Capital Cost**

Maintenance Burden:

- M Shallow Wetland
- M ED Shallow Wetland
- M/H Pocket Wetland
- M Pond/Wetland

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *No*
Drainage Area: *Minimum contributing drainage area of 25 acres; 5 acres for pocket wetland*
Roadway Projects: *Not applicable*

Soils: *Hydrologic group 'A' and 'B' soils may require a liner (not relevant for pocket wetland)*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- Level 1: 0% - Runoff Reduction Credit
- Level 2: 0% - Runoff Reduction Credit
- Accepts Hotspot Runoff: *Yes, 2 feet of separation distance required to water table*

4.26.1 General Description

Stormwater wetlands (also referred to as constructed wetlands) are constructed shallow marsh systems that are designed to both treat urban stormwater and control runoff volumes (see Figure 4.26-1 for examples). As stormwater runoff flows through the wetland facility, pollutant removal is achieved through settling and uptake by marsh vegetation.

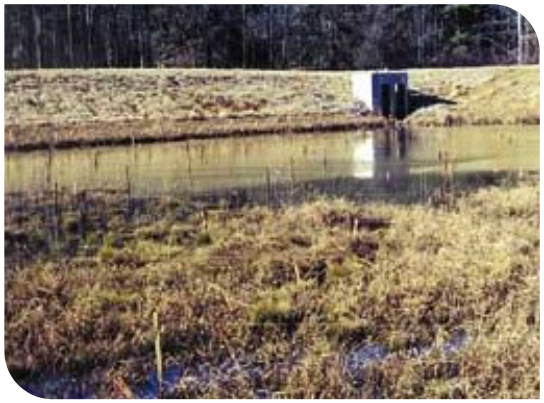
Wetlands are among the most effective stormwater practices in terms of pollutant removal and also offer aesthetic value and wildlife habitat. Constructed stormwater wetlands differ from natural wetland systems in that they are engineered facilities designed specifically for the purpose of treating stormwater runoff and typically have less biodiversity than natural wetlands both in terms of plant and animal life. However, as with natural wetlands, stormwater wetlands require a continuous base flow or a high water table to support aquatic vegetation.

Wetlands are divided into two levels. Level 1 stormwater wetlands can be used to meet water quality volume, channel protection volume, and the 25-year, 24-hour storm event. A riser is used to create the pool and a small orifice is placed in the riser above the bottom of the wetland to create a shallow permanent pool. This allows the wetland to store additional runoff for a short period of time. Storm events that are greater than the design volume can be released through the top of the riser and /or through an emergency spill way channel.

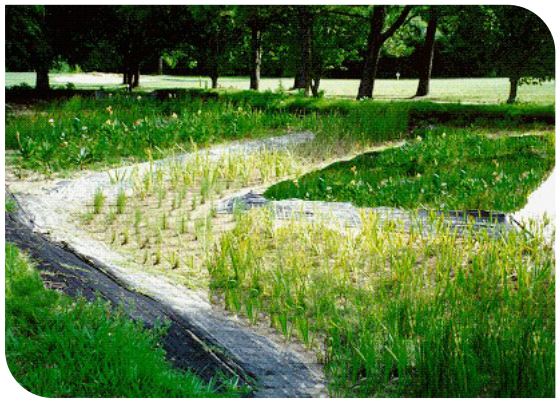
Shallow Wetland



Shallow ED Wetland



Newly Constructed Shallow Wetland



Pocket Wetland



Figure 4.26-1 Stormwater Wetland Examples

Level 2 stormwater wetlands are mainly used to meet water quality requirements. They cannot be used for extended detention, so the outlet structure should be simplified. Level 2 wetlands can be installed parallel to wet detention ponds to meet detention requirements and help maintain the wetland permanent pool level.

There are several design variations of the stormwater wetland, each differing in the relative amounts of shallow and deep water, and dry storage above the wetland. These include shallow wetland, extended detention shallow wetlands, pond/wetland systems, and pocket wetlands. Below are descriptions of each design variant:

- **Shallow Wetland (Level 2)** – In the shallow wetland design, most of the water quality treatment volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland, and the micropool at the outlet. One disadvantage of this design is that, since the pool is very shallow, a relatively large amount of land is typically needed to store the water quality volume.
- **Extended Detention (ED) Shallow Wetland (Level 1)**– The extended detention (ED) shallow wetland design is the same as the shallow wetland; however, part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate both wet and dry periods need to be used in the ED zone.
- **Pond/Wetland Systems (Level 1)** – The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediment and reduces runoff velocities prior to entry into the wetland, where stormwater flows receive additional treatment. Less land is required for a pond/wetland system than for the shallow wetland or the ED shallow wetland systems.
- **Pocket Wetland (Level 2)** – A pocket wetland is intended for drainage areas of 5-10 acres and typically requires excavation down to the water table for a reliable water source to support the wetland system.

Certain types of wetlands, such as submerged gravel wetland systems are not recommended for general use to meet stormwater management goals due to limited performance data. They may be applicable in special or retrofit situations where there are severe limitations on what can be implemented. Please see a further discussion in Section 4..27.

4.26.2 Stormwater Management Suitability

Similar to stormwater ponds, stormwater wetlands are designed to control both stormwater quantity and quality. Thus, a stormwater wetland can be used to address all of the unified stormwater sizing criteria for a given drainage area.

- **Runoff Reduction**
  None. Although stormwater wetlands provide moderate to high removal of many of the pollutants of concern typically contained in post-construction stormwater runoff, recent research shows that they provide little, if any, reduction of post-construction stormwater runoff volumes (Hirschman et al., 2008, Strecker et al., 2004).
- **Water Quality**
  Pollutants are removed from stormwater runoff in a wetland through uptake by vegetation and algae, filtering, and gravitational settling in the slow moving marsh flow. Other pollutant removal mechanisms are also at work in a stormwater wetland, including chemical and biological decomposition, and volatilization. Subsection 4.26.3 provides median pollutant removal efficiencies that can be used for planning and design purposes.
- **Channel Protection**
  The storage volume above the permanent pool/water surface level in a stormwater wetland is used to provide control of the channel protection volume (CP_v) by releasing the 1-year, 24-hour storm runoff volume over 24 hours (extended detention). It is best to do this with minimum vertical water level fluctuation, as extreme fluctuation may stress vegetation.

- Overbank Flood Protection
  A stormwater wetland can also provide storage above the permanent pool/water surface level to reduce the post-development peak flow of the 2-25-year storms (Q_{p2-25}) to pre-development levels (detention). If a wetland facility is not used for overbank flood protection, it should be designed as an off-line system to pass higher flows around rather than through the wetland system.

- Extreme Flood Protection
  In situations where it is required, stormwater wetlands can also be used to provide detention to control the 100-year, 24-hour storm peak flow (Q_f). Where Q_f peak control is not required, a stormwater wetland must be designed to safely pass extreme storm flows.

4.26.3 Pollutant Removal Capabilities

The pollution removal rates below may be used for design purposes. It should be noted that for this BMP there are two different types of Stormwater Wetlands that can be constructed. Level 1 wetlands are a more traditional design and can be used to meet WQ_v, CP_v, Q_{P25}, and Q_f requirements. Level 2, on the other hand, has a different design configuration that includes modifications after nearly 20 years of research. Both of these levels will be explained in greater detail in this section.

For additional information and data on pollutant removal capabilities for stormwater wetlands, see the National Pollutant Removal Performance Database (3rd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.26.4 Application and Site Feasibility Criteria

Stormwater wetlands are generally applicable to most types of new development and redevelopment, and can be utilized in both residential and nonresidential areas. However, due to the large land requirements, wetlands may not be practical in higher density areas.

The following criteria must be evaluated to ensure the suitability of a stormwater wetland for meeting stormwater management objectives on a site or development.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **Land requirements may preclude use**
- Regional Stormwater Control – **YES**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – A minimum of 25 acres and a positive water balance are needed to maintain wetland conditions; 5 acres for pocket wetlands
- **Space Required** – Approximately 3 to 5% of the tributary drainage area
- **Site Slope** – There must be no more than 8% slope across the wetland site for level 1 wetlands. Level 2 wetlands shall be generally flat.
- **Minimum Head** – Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet; 2 to 3 feet for pocket wetland
- **Minimum Depth to Water Table** – If used on a site with an underlying water supply aquifer or when treating a hotspot, a separation distance of 2 feet is recommended between the bottom of the wetland and the elevation of the seasonally high water table; pocket wetlands are typically below the water table.
- **Soils** – Permeable soils are not well-suited for a constructed stormwater wetland without a high water table. Underlying soils of hydrologic group "C" or "D" should be adequate to maintain wetland conditions. Most group "A" soils and some group "B" soils will require a liner. *Evaluation of soils shall be based upon a subsurface analysis and permeability tests.*
- **Setback requirements:**
  - » *Property lines* - 10 feet (this is for site development projects only)
  - » *Private wells* - 100 feet; if well is downgradient from a hotspot land use then the minimum setback is 250 feet
  - » *Septic system tank/leach field* - 50 feet
  - » *Airports* - 5 miles

Other Constraints/Considerations

- **Trout Streams** – Consideration should be given to the thermal influence of stormwater wetland outflows on downstream trout waters.

4.26.5 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a stormwater wetland facility. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.26.5.1 LOCATION AND LAYOUT

- A continuous base flow or high water table is required to support wetland vegetation. A water balance must be performed to demonstrate that a stormwater wetland can withstand a 30-day drought at summer evaporation rates without completely drawing down.
- Wetland siting should also take into account the location and use of other site features such as natural depressions, buffers, and undisturbed natural areas, and should attempt to aesthetically "fit" the facility into the landscape. Bedrock close to the surface may prevent excavation.
- Stormwater wetlands cannot be located within navigable waters of the U.S., including wetlands, without obtaining a Section 404 permit under the Clean Water Act, and any other applicable State permit. In some isolated cases, a wetlands permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts.
- If a wetland facility is not used for overbank flood protection, it should be designed as an off-line system to bypass higher flows rather than passing them through the wetland system.
- All utilities shall be located outside of the wetland site.

4.26.5.2 GENERAL DESIGN

- A well-designed stormwater wetland consists of:
  1. Shallow marsh areas of varying depths with wetland vegetation,
  2. Permanent micropool(s)
  3. An overlying zone where runoff control volumes are stored.
- Pond/wetland systems also include a stormwater pond facility (see Section 4.25, *Stormwater Ponds*, for pond design information).
- In addition, *all wetland designs must include a sediment forebay at the inflow* to the facility to allow heavier sediments to drop out of suspension before the runoff enters the wetland marsh.
- Additional pond design features include an *emergency spillway, maintenance access, safety bench, wetland buffer, and appropriate wetland vegetation and native landscaping.*

Figures 4.26-2 through **4.26-5** in Subsection 4.26.8 provide plan view and profile schematics for the design of a shallow wetland, ED shallow wetland, pond/wetland system, and pocket wetland.

Table 4.26-1 Approximate Level 1 and 2 Dimensional Information for Various Wetland Zones

Wetland Zone	Criteria	Level 1 Design	Level 2 Design
Deep Pools	Depth	-18" to -72"	-18" to -48"
	% of Total Volume	20%	25%
Low Marsh	Depth	-6" to -18"	N/A
	% of Total Volume	20%	N/A
High Marsh	Depth	-6" to 0"	-6" to +6"
	% of Total Volume	10%	75%
Low Land	Depth	0"+	N/A
	% of Total Volume	50%	N/A

4.26.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

In general, wetland designs are unique for each site and application. However, there are a number of geometric ratios and limiting depths for the design of a stormwater wetland that must be observed for adequate pollutant removal, ease of maintenance, and improved safety.

The stormwater wetland shall be designed with the following proportion of "depth zones." Each of the four wetland design variants has depth zone allocations that are given as a percentage of the stormwater wetland surface area. Target allocations are found in **Table 4.26-2**. The four basic depth zones are:

- Deepwater zone
  Includes the outlet micropool and deepwater channels through the wetland facility. This zone supports little emergent wetland vegetation, but may support submerged or floating vegetation.
- Low marsh zone
  This zone is suitable for the growth of several emergent wetland plant species.
- High marsh zone
  This zone will support a greater density and diversity of wetland species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.

Table 4.26-2 Design Criteria for Level 1 and 2 Stormwater Wetlands

Criteria	Level 1	Level 2
WQ_v	Use rainfall depth of 1.2	Use rainfall depth of 1.2
Deep pools	2 (forebay and outlet)	3 (forebay, middle, outlet)
Wetland side slopes (max)	3:1	5:1
Slope profile	8% across the site	Should be generally flat, use several cells if needed; use a maximum drop of 1' between cells
Normal flow path (distance from inlet to oulet)	1:1	1.5:1
Normal flow path (distance from inlet to outlet)	1:1	1.5:1
Dry weather flow path	Not required	5:1
Vegetation	Can use herbaceous only	Include woody vegetation (trees and shrubs)
Average wetland depth	Can be >1	Should be < 1
Extended detention	Limit to 1' vertically	Not allowed

- Semi-wet zone
  This zone includes areas above the permanent pool that are inundated during larger storm events; it supports a number of species that can survive flooding.
- Micro-topology is important to Level 2 wetland designs. Planting peninsulas are the preferred method, but the following list can be used to enhance micro-topology:
  - » Snags
  - » Inverted root wads
  - » Tree peninsulas
  - » Coir fiber islands
  - » Internal pools
  - » Cobble sand weirs

It is recommended that a stream restoration specialist be consulted for additional guidance on these items.

4.26.5.4 PRETREATMENT/INLETS

- Sediment regulation is critical to sustain stormwater wetlands. A wetland facility shall have a sediment forebay or equivalent upstream pretreatment. A sediment forebay is designed to remove incoming sediment from the stormwater flow prior to dispersal into the wetland. The forebay should consist of a separate cell, formed by an acceptable barrier. A forebay is to be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the wetland facility.
- The forebay is sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. The pretreatment storage volume is part of the total WQv requirement and may be subtracted from WQv for wetland storage sizing.
- A fixed vertical sediment depth marker shall be installed in the forebay to measure sediment deposition over time. The bottom of the forebay may be hardened (e.g., using concrete, paver blocks, etc.) to make sediment removal easier.
- Inflow channels are to be stabilized with flared riprap aprons, or the equivalent. Inlet pipes to the pond can be partially submerged. Exit velocities from the forebay must be non-erosive.

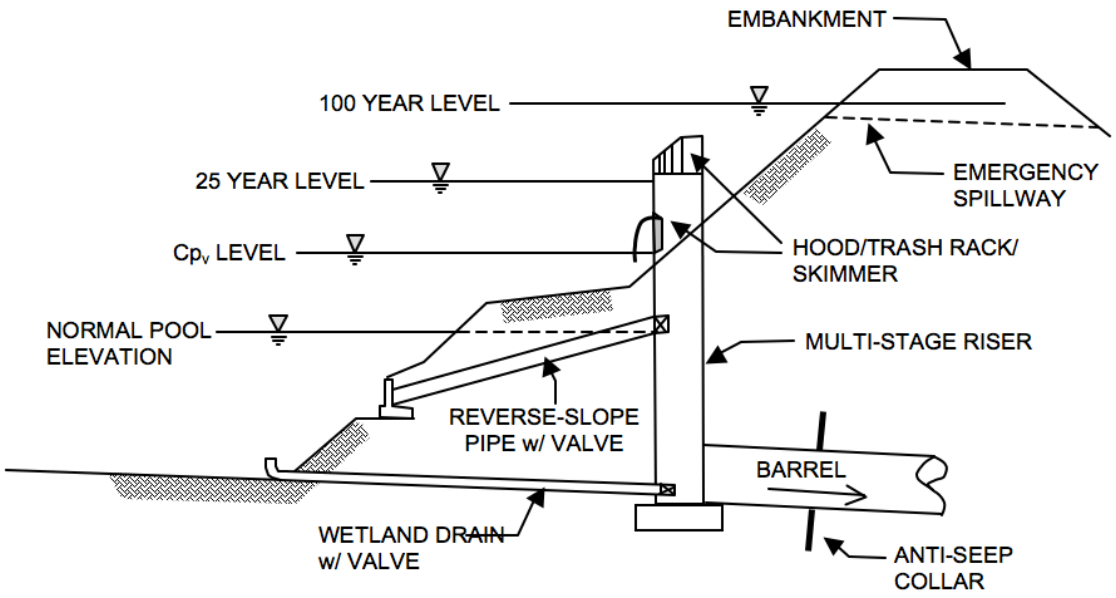


Figure 4.26-6 Typical Wetland Facility Outlet Structure

4.26.5.5 OUTLET STRUCTURES

- Flow control from a stormwater wetland is typically accomplished with the use of a concrete riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the base of the micropool with a watertight connection. The outlet barrel is a horizontal pipe attached to the riser that conveys flow under the embankment (see Figure 4.26-6) The riser should be located within the embankment for maintenance access, safety and aesthetics.
- A number of outlets at varying depths in the riser provide internal flow control for routing of the water quality, channel protection, and overbank flood protection runoff volumes. The number of orifices can vary and is usually a function of the pond design.

For shallow and pocket wetlands, the riser configuration is typically comprised of a channel protection outlet (usually an orifice) and overbank flood protection outlet (often a slot or weir). The channel protection orifice is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams). Since the water quality volume is fully contained in the permanent pool, no orifice sizing is necessary for this volume. As runoff from a water quality event enters the wet pond, it simply displaces that same volume through the channel protection orifice. Thus an off-line shallow or pocket wetland providing only water quality treatment can use a simple overflow weir as the outlet structure.

In the case of an extended detention (ED) shallow wetland, there is generally a need for an additional outlet (usually an orifice) that is sized to pass the extended detention water quality volume that is surcharged on top of the permanent pool. Flow will first pass through this orifice, which is sized to release the water quality ED volume in 24 hours. The preferred design is a reverse slope pipe attached to the riser, with its inlet submerged 1 foot below the elevation of the permanent pool to prevent floatables from clogging the pipe and to avoid discharging warmer water at the surface of the pond. The next outlet is sized for the release of the channel protection storage volume. The outlet (often an orifice) invert is located at the maximum elevation associated with the extended detention water quality volume and is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams).

Alternative hydraulic control methods to an orifice can be used and include the use of a broad-crested rectangular, V-notch, proportional weir, or an outlet pipe protected by a hood that extends at least 12 inches below the normal pool.

- Higher flows (overbank and extreme flood protection) flows pass through openings or slots protected by trash racks further up on the riser.
- After entering the riser, flow is conveyed through the barrel and is discharged downstream. Anti-seep collars should be installed on the outlet barrel to reduce the potential for pipe failure.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the outlet of the barrel to prevent scouring and erosion. If a wetland facility daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. See Section 5.5 (Energy Dissipation Design) for more guidance.
- The wetland facility must have a bottom drain pipe located in the micropool with an adjustable valve that can completely or partially dewater the wetland within 24 hours. (This requirement may be waived where positive drainage is difficult to achieve due to very low relief).
- The wetland drain should be sized one pipe size greater than the calculated design diameter. The drain valve is typically a handwheel activated knife or gate valve. Valve controls shall be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner.

See the design procedures in Subsection 4.26.6 as well as Section 3.3 (*Storage Design*) and Section 3.4 (*Outlet Structures*) for additional information and specifications on pond routing and outlet works.

4.26.5.6 EMERGENCY SPILLWAY

- An emergency spillway shall be included in the stormwater wetland design to safely pass flows that exceed the design storm flows. The spillway prevents the wetland's water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- A minimum of 1 foot of freeboard must be provided, measured from the top of the water surface elevation for the extreme flood to the lowest point of the dam embankment, not counting the emergency spillway.

4.26.5.7 MAINTENANCE ACCESS

- A maintenance right of way or easement must be provided to the wetland facility from a public or private road. Maintenance access should be at least 15 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.
- Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls.

4.26.5.8 SAFETY FEATURES

- All embankments and spillways must be designed to State of Georgia guidelines for dam safety.
- Fencing of wetlands is not generally desirable, but may be required by the local review authority. A preferred method is to manage the contours of deep pool areas through the inclusion of a safety bench (see above) to eliminate dropoffs and reduce the potential for accidental drowning.
- The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

4.26.5.9 LANDSCAPING

- As much vegetation as possible and as much distance as possible shall separate the basin inlet from the outlet.
- A landscaping plan shall be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of landscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed) and sources of plant material.
- Landscaping zones include low marsh, high marsh, and semi-wet zones. The low marsh zone ranges from 6 to 18 inches below the normal pool. This zone is suitable for the growth of several emergent plant species. The high marsh zone ranges from 6 inches below the pool up to the normal pool. This zone will support greater density and diversity of emergent wetland plant species. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone. The semi-wet zone refers to those areas above the permanent pool that are inundated on an irregular basis and can be expected to support wetland plants.
- The landscaping plan should provide elements that promote greater wildlife use within the wetland and buffers.
- Woody vegetation may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.
- A wetland buffer shall extend 25 feet outward from the maximum water surface elevation, with an additional 15-foot setback to structures. The wetland buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers) or that are part of the overall stormwater management concept plan. No structures should be located within the buffer, and an additional setback to permanent structures may be provided.
- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.
- The soils of a wetland buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration and therefore may lead to premature mortality or loss of vigor. Consequently, large and deep holes should be excavated around the proposed planting sites and backfill these with uncompacted topsoil.

Guidance on establishing wetland vegetation can be found in Appendix D (*Planting and Soil Guidance*).

4.26.5.10 ADDITIONAL SITE SPECIFIC DESIGN CRITERIA AND ISSUES

- **Physiographic Factors -** Local terrain design constraints
  - » **Low Relief** – Providing wetland drain can be problematic
  - » **High Relief** – Embankment heights restricted
  - » **Karst** – Requires poly or clay liner to sustain a permanent pool of water and protect aquifers; limits on ponding depth; geotechnical tests may be required
- **Soils**
  - » Hydrologic group "A" soils and some group "B" soils may require liner (not relevant for pocket wetland)
- **Special Downstream Watershed Considerations**
  - » **Trout Stream** – Design wetland offline and provide shading to reduce thermal impact; limit $WQ_{v\text{-}ED}$ to 12 hours
  - » **Aquifer Protection** – Prevent possible groundwater contamination by preventing infiltration of hotspot runoff. May require liner for type "A" soils; pretreat hotspots; 2 to 4 foot separation distance from water table.
  - » **Swimming Area/Shellfish** – Design for geese prevention (see Appendix D); provide 48-hour ED for maximum coliform die-off.

4.26.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a stormwater wetland.**
Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a stormwater wetland. Create a rough layout of the stormwater wetland dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the stormwater wetland.**
Consider whether the stormwater wetland is intended to:

- » Meet a water quality (treatment) target. See Step 3 to size the BMP utilizing the water quality treatment approach.
- » Be "oversized" to include partial credit for storage capacity for other stormwater requirements (Channel Protection Volume (CP_v)
- » Provide a possible solution to a drainage problem

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3) **Calculate the Target Water Quality Volume**
Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) **Determine the pretreatment (forebay volume)**
Size the forebay. The forebay storage volume counts toward the total runoff reduction volume and may be subtracted for the following calculation. Note that the forebay volume should be at least 10% of the total water quality volume.

(Step 5) **Determine the inlet/outlet design and emergency overflow**
Check water surface elevations for all design storm events to ensure the stormwater wetland can pass these flows safely. An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year storm event.

(Step 6) **Prepare Site Vegetation and Landscaping Plan**
A landscaping plan for the submerged gravel wetland should be prepared to indicate how it will be established with vegetation. See Subsection 4.26.5 (*Landscaping*) and Appendix D for more details.

4.26.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.26.8 Example Schematics

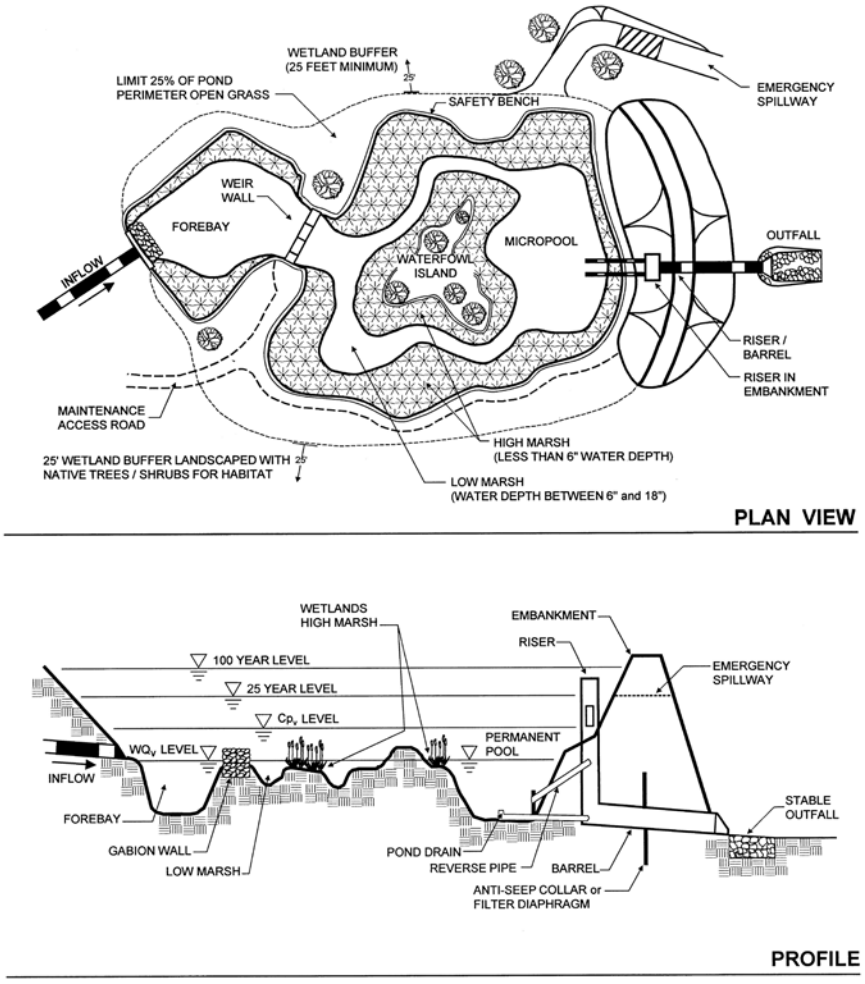


Figure 4.26-2 Schematic of Shallow Wetland

(Source: Center for Watershed Protection)

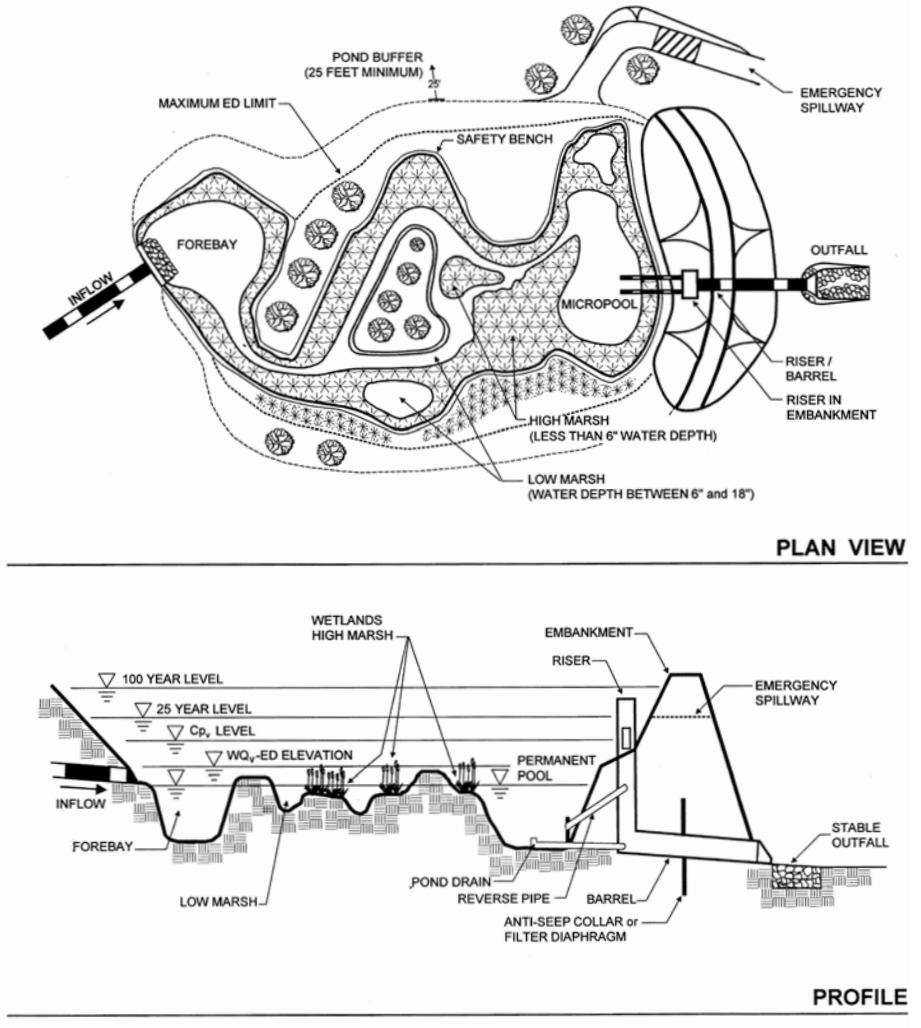


Figure 4.26-3 Schematic of Extended Detention Shallow Wetland

(Source: Center for Watershed Protection)

4.26.8-2 Example Schematics

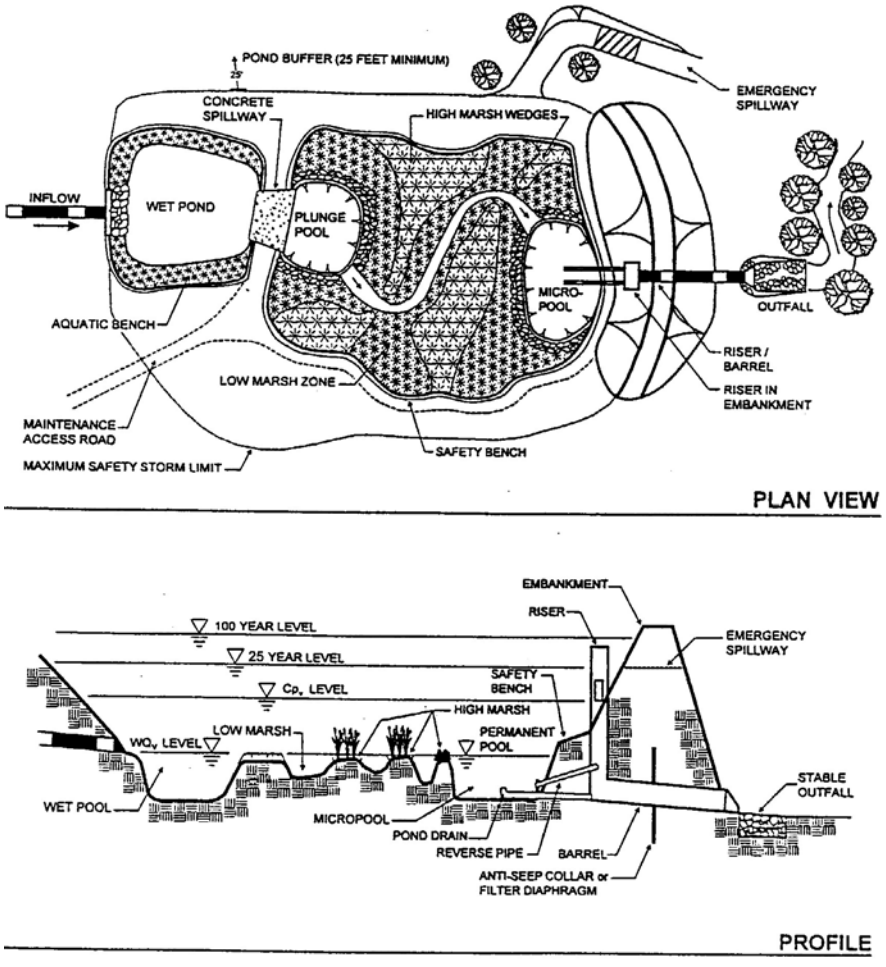


Figure 4.26-4 Schematic of Pond/Wetland System

(Source: Center for Watershed Protection)

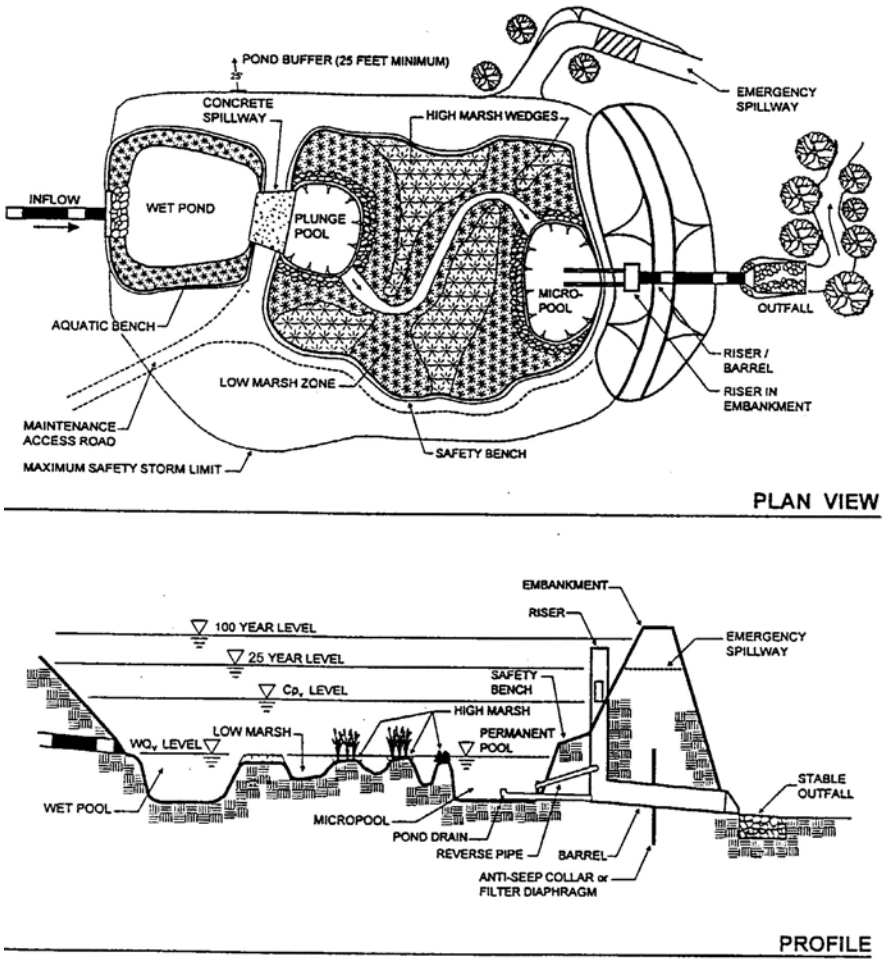


Figure 4.26-5 Schematic of Pocket Wetland

(Source: Center for Watershed Protection)

4.27 Submerged Gravel Wetlands



Description: One or more cells filled with crushed rock designed to support wetland plants. Stormwater flows subsurface through the root zone of the constructed wetland, where pollutant removal takes place.

LID/GI Considerations: Submerged gravel wetlands are designed with a small footprint area and provide high total suspended solids and pollutant removal rates for highly impervious areas.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Submerged gravel wetlands should be designed as off-line systems sized to handle only water quality volume.
- Submerged gravel wetland systems need sufficient drainage area to maintain vegetation.
- The local slope should be relatively flat (<4%).
- Elevation drop from the inlet to the outlet is required to ensure that hydraulic conveyance by gravity is feasible (generally about 2-5 feet).
- All submerged gravel wetland designs should include a sediment forebay or equivalent pretreatment measures to prevent sediment and debris from entering and clogging the gravel bed.
- Unless they receive hot spot runoff, submerged gravel wetland systems can be allowed to intersect the groundwater table.

ADVANTAGES / BENEFITS

- High total suspended solids removal
- High removal rate of urban pollutants
- Useful in space-limited applications
- Can be located in low-permeability soils with a high groundwater table

DISADVANTAGES / LIMITATIONS

- High maintenance requirements
- Drainage through the wetland can be problematic for low-relief terrain.

ROUTINE MAINTENANCE REQUIREMENTS

- Ensure that inlets and outlets for each submerged gravel wetland cell are free from debris and not clogged.
- Check for sediment buildup in the gravel bed.
- If sediment buildup is preventing flow through the wetland, remove gravel and sediment from the cell, replace it with clean gravel, and replant vegetation.

POLLUTANT REMOVAL

- 80% **Total Suspended Solids**
- 50% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 50/20% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 70% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ✓ Water Quality
- ● Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable or this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- H Maintenance Burden

Residential Subdivision Use: *Yes*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *No*

Soils: *Submerged gravel wetlands can be used in almost all soils and geology, but HSG C or D soils are preferred to maintain submerged flow.*

Other Considerations: *Extra space is recommended for pretreatment and to keep the practice from clogging due to sediment and debris.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% Runoff Reduction Credit is provided by this practice.

4.27.1 General Description

The submerged gravel wetland system consists of one or more treatment cells that are filled with crushed rock or gravel and designed to allow stormwater to flow subsurface through the root zone of the constructed wetland. The outlet from each cell is set at an elevation to keep the rock or gravel submerged. Wetland plants are rooted in the media, where they can directly take up pollutants. In addition, algae and microbes thrive on the surface area of the rocks. In particular, the anaerobic conditions on the bottom of the filter can foster the denitrification process. Although widely used for wastewater treatment in recent years, only a handful of submerged gravel wetland systems have been designed to treat stormwater. Mimicking the pollutant removal ability of nature, this BMP relies on the pollutant-stripping ability of plants and soils to remove pollutants from runoff. Typical schematics for a submerged gravel wetland are shown in **Figure 4.27-1** and **Figure 4.27-2.**

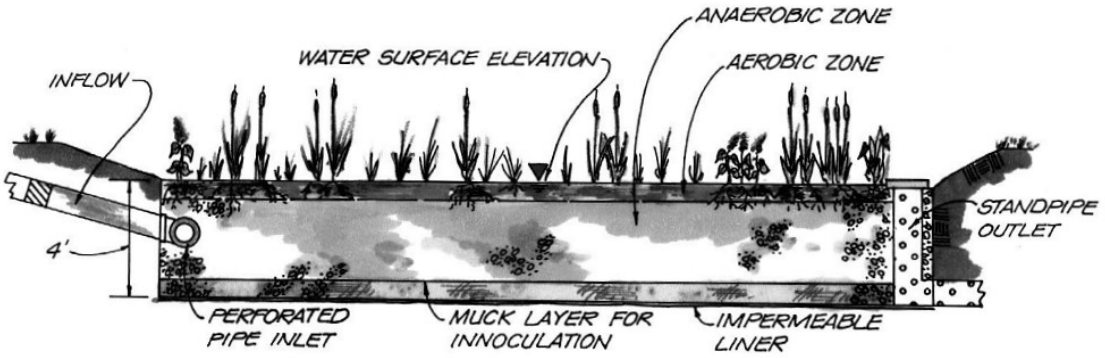


Figure 4.27-1 Schematic of Submerged Gravel Wetland System

(Source: Center for Watershed Protection; Roux Associates Inc.)

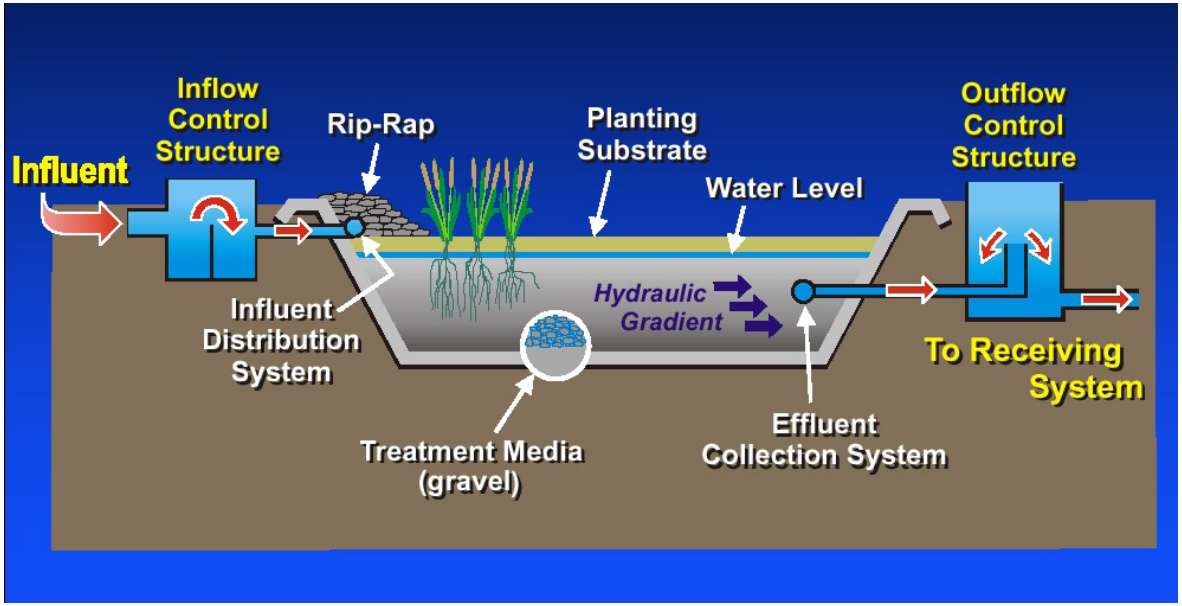


Figure 4.27-2 Schematic of Submerged Gravel Wetland System

(Sources: Center for Watershed Protection; Roux Associates Inc.)

4.27.2 Stormwater Management Suitability

- Runoff Reduction
  Submerged gravel wetlands provide minimal stormwater volume runoff reduction. Another BMP should be used in a treatment train with submerged gravel wetlands to provide runoff reduction.
- Water Quality
  If installed as per the recommended design criteria and properly maintained, 80% total suspended solids removal will be applied to the water quality volume (WQ_v) flowing to the submerged gravel wetland.
- Channel Protection
  Submerged gravel wetlands do not provide channel protection. Another BMP should be used in a treatment train with submerged gravel wetlands to provide channel protection or runoff reduction. (See Subsection 4.1.6.) Additionally, the submerged gravel wetlands should be designed off-line or with a bypass for higher flows.
- Overbank Flood Protection
  Submerged gravel wetlands do not provide overbank flood protection. Another BMP should be used in a treatment train with submerged gravel wetlands to provide overbank flood protection or runoff reduction. Additionally, the submerged gravel wetlands should be designed off-line or with a bypass for higher flows. (See Subsection 3.1.5.)
- Extreme Flood Protection
  Submerged gravel wetlands do not provide extreme flood protection. Another BMP should be used in a treatment train with submerged gravel wetlands to provide extreme flood protection or runoff reduction. Additionally, the submerged gravel wetlands should be designed off-line or with a bypass for higher flows. (See Subsection 3.1.5.)

4.27.3 Pollutant Removal Capabilities

The pollution removal efficiency of the submerged gravel wetland is similar to a typical wetland. Recent data show a TSS removal rate in excess of the 80% goal. This reflects the settling environment of the gravel media. These systems also exhibit removals of about 50% TP, 20% TN, and 50% Zn. The growth of algae and microbes among the gravel media has been determined to be the primary removal mechanism of the submerged gravel wetland.

The following pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling, and professional judgment.

- *Total Suspended Solids* – 80%
- *Total Phosphorus* – 50%
- *Total Nitrogen* – 20%
- *Fecal Coliform* – 70%
- *Heavy Metals* – 50%

4.27.4 Application and Site Feasibility Criteria

The submerged gravel wetland system is similar to a regular stormwater wetland; however, it is filled with crushed rock or gravel and designed to allow stormwater to flow through the root zone of the constructed wetland. The outlet from each cell is set at an elevation to keep the rock or gravel submerged. Wetland plants are rooted in the rock media, where they can directly take up pollutants. In addition, algae and bacteria grow in the rock media and provide an additional avenue for pollutant removal through biological uptake. Mimicking the pollutant removal ability of nature, this structural control relies on the pollutant-stripping ability of plants and bacteria to remove pollutants from runoff.

The following criteria should be evaluated to ensure the suitability of submerged gravel wetlands for meeting stormwater management objectives on a site.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – In general, submerged gravel wetlands should be used on sites with a minimum drainage area of 1 acre to ensure submerged flow conditions. The maximum drainage area for a submerged gravel wetland is 5 acres.
- **Space Required** – Additional space is recommended for pretreatment measures to prevent sediment and debris from entering and clogging the gravel bed.
- **Site Slope** – The local slope should be relatively flat (<4%). While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 2-5 feet).
- **Minimum Depth to Water Table** – Unless they receive hot spot runoff, submerged gravel wetland systems can be allowed to intersect the groundwater table. If a submerged gravel wetland receives hot spot runoff and has an underlying water supply aquifer, a liner and a separation distance of 2 feet is required between the bottom of the gravel and the elevation of the seasonally high water table to prevent groundwater contamination.
- **Soils** – Submerged gravel wetlands can be used in almost all soils and geology, with minor design adjustments for regions of karst (i.e., limestone) topography or in rapidly percolating soils such as sand. In these areas, submerged gravel wetlands should be designed with an impermeable liner to prevent groundwater contamination and sinkhole formation.

Other Constraints/Considerations

- **Hot spots** – Submerged gravel wetlands without a liner should not be used to treat hot spots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff, which could contaminate groundwater.
- **Proximity** – The following is a list of specific setback requirements for the location of a submerged gravel wetland:
  - » 10 feet from building foundations
  - » 10 feet from property lines
  - » 100 feet from private water supply wells
  - » 100 feet from open water (measured from edge of water)
  - » 200 feet from public water supply reservoirs (measured from edge of water)
  - » 1,200 feet from public water supply wells
- **Trout Stream** – In cold water streams, submerged gravel wetlands should be designed to detain stormwater for a relatively short time (i.e., less than twelve hours) to minimize the potential amount of stream warming that occurs in the practice.
- **Poorly Draining Soils, such as hydrologic soil groups C and D** — Since they would normally be equipped with waterproof liners, the presence of poorly draining soils does not influence the use of submerged gravel wetlands on development sites.
- **Well-draining soils, such as hydrologic soil group A and B** – Since they are equipped with waterproof liners, the presence of well-draining soils does not influence the use of submerged gravel wetlands on development sites.
- **Flat Terrain** – The presence of flat terrain does not preclude the use of a submerged gravel wetland.
- **Shallow Water Table** – Except in the case of hot spot runoff, the base of the submerged gravel wetland can intersect the groundwater table.

4.27.5 Planning and Design Criteria

- Existing and proposed site, topographic, and location maps, as well as field reviews
- Impervious and pervious areas and other means used to determine the land use data
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Design data from nearby storm sewer structures
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater

The following criteria are to be considered minimum standards for the design of a submerged gravel wetland. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.27.5.1 LOCATION AND LAYOUT

Submerged gravel wetlands are generally applied to land uses with a high percentage of impervious surfaces. Submerged gravel wetlands should be located upstream or downstream of other BMPs providing runoff reduction, channel protection volume (CP_v), overbank flood protection (Q_{p25}) and extreme flood protection (Q_f). See Subsection 4.1.6 for more information on the use of multiple BMPs in a treatment train.

4.27.5.2 GENERAL DESIGN

Pretreated stormwater enters via piped or overland flow and discharges into the gravel-filled chamber. A perforated pipe (4-6-inch diameter preferred) at the base of the gravel layer allows for flow-through conditions and maintains a constant water surface elevation. Discharges that exceed the WQ_v exit to a stable outfall at non-erosive velocities.

4.27.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

- Gravel layer should be 18-48 inches thick of clean washed uniformly graded material with a porosity of 40%.
- Provide storage for 75% of the submerged gravel wetland drainage area WQ_v. Maximum ponding depth should not be higher than the level of wetland vegetation.
- Use the porosity of the gravel media when calculating submerged gravel wetland storage volumes.
- The gravel layer should be 4 feet or less.
- A flow splitter may be required to redirect the WQ_v to the submerged gravel wetland.
- Optional earth berms may separate multiple treatment cells.
- Observation wells should consist of 6-inch diameter perforated pipe and be at least 6 inches above grade.
- Maintenance right-of-way or drainage easement should be at least 20 feet wide. Maximum slope of access easement should be 15%, and the driveway path should be at least 12 feet wide. This driveway path should be able to support maintenance vehicles and equipment.

4.27.5.4 PRETREATMENT/INLETS

- A sediment forebay or pretreatment is important for controlling and the amount of sediment entering a submerged gravel wetland.
- Forebays should be designed to remove sediment from stormwater runoff prior to entering the submerged gravel wetland.
- The forebay should be a separated from the wetland by a barrier and located at each inlet to the gravel wetland, except if the inlet supplies 10% or less of the inflow to the gravel wetland.
- The forebay should be sized to contain 0.1 inches of impervious area of the WQ_v. This volume may be subtracted from the WQ_v for wetland storage sizing. A device to measure vertical sediment depth shall be installed to measure sediment accumulation over time.

4.27.5.5 OUTLET STRUCTURES

- For a submerged gravel wetland, the outlet structure can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure.
- Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.

4.27.5.6 SAFETY FEATURES

- A minimum of 6 inches of freeboard must be provided, measured from the top of the water surface elevation for the water quality volume, to the lowest point of the ground surface elevation, not counting the outlet weir.
- Stormwater should be conveyed to and from submerged gravel wetlands safely and to minimize erosion potential.

4.27.5.7 LANDSCAPING

- It is recommended that native (local) wetland plant stock is used for establishing vegetation.
- A minimum of three types of wetland species should be provided.
- Mulch or topsoil may be placed on top of the rock media to establish vegetation. Note that using rock media to establish the wetland may require specific planting stock.
- Regular inspection and maintenance may be necessary until vegetation within the wetland is established. It may be necessary to replace some of the plants.

4.27.5.8 CONSTRUCTION CONSIDERATIONS

- Construction equipment should be restricted from the submerged gravel wetland to prevent compaction of the native soils.
- Stabilize disturbed areas prior to runoff entering the constructed wetland.
- Protect the location of a submerged gravel wetland during construction. Divert surface runoff from the practice during grading. Any conveyance infrastructure should be blocked.
- Use wide-tracked equipment to minimize disturbance and compaction. If it is necessary to pump water during construction, discharge filtered water to a stable outlet.

4.27.5.9 CONSTRUCTION AND MAINTENANCE COSTS

- An estimate for submerged gravel wetland construction costs is $5-6 per square foot. This includes sediment forebays.

4.27.6 Design Procedures

(Step 1) **Determine if the development site and conditions are appropriate for the use of a submerged gravel wetland.**
Consider the application and site feasibility criteria in this chapter. In addition, determine if site conditions are suitable for a submerged gravel wetland. Create a rough layout of the submerged gravel wetland dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 2) **Determine the goals and primary function of the submerged gravel wetland.**
Consider whether the submerged gravel wetland is intended to:

- » Meet a water quality (treatment) target. See Step 3 to size the BMP utilizing the water quality treatment approach.
- » Provide a possible solution to a drainage problem

Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply. In addition, consider if the best management practice has any special site-specific design conditions or criteria. List any restrictions or other requirements that may apply or affect the design.

The design of the BMP should be centered on the restrictions/requirements, goals, targets, and primary function(s) of the BMP, described in this section. By considering the primary function, as well as, topographic and soil conditions, the design elements of the practice can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.)

Complete Step 3 for a water quality (treatment) approach. Refer to your local community's guidelines for any additional information or specific requirements regarding the use of either method.

(Step 3) **Calculate the Target Water Quality Volume**
Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A) / 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) **Size flow diversion structure, if needed**
If the contributing drainage area to the submerged gravel wetland exceeds the water quality treatment and/or storage capacity, a flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the submerged gravel wetland.

(Step 5) Design stable outfall(s).

An overflow, such as an overdrain with an invert set slightly above the elevation of maximum ponding depth, must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities need to be ensured at the outlet point. The overflow should be sized to safely pass the peak flows anticipated to reach the practice.

(Step 6) Prepare Site Vegetation and Landscaping Plan

A landscaping plan for the submerged gravel wetland should be prepared to indicate how it will be established with vegetation. See Subsection 4.27.5.7 (*Landscaping*) and Appendix D for more details.

4.27.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.28 Underground Detention



Description: Detention storage located in underground tanks or vaults designed to provide water quantity control through detention and/or extended detention of stormwater runoff.

LID/GI Considerations: Underground detention facilities do not provide runoff reduction or water quality treatment and are not generally considered to be low impact development or green infrastructure

KEY CONSIDERATIONS

DESIGN CRITERIA

- The maximum contributing drainage area to be served by a single underground detention vault or tank is 25 acres.
- Detention vaults should be constructed with a minimum 3,000 psi structural reinforced concrete.
- All construction joints must be provided with water stops.
- Cast-in-place wall sections must be designed as retaining walls.
- The maximum depth from finished grade to the vault invert should be 20 feet.
- The minimum pipe diameter for underground detention tanks is 36 inches.
- Underground detention vaults and tanks must meet structural requirements for overburden support and traffic loading, if appropriate.
- Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion.
- A high flow bypass should be included in the underground detention system design to safely pass the extreme flood flow.

ADVANTAGES / BENEFITS

- Ideal for highly urbanized areas where land is limited
- Can be used for stormwater quantity control downstream of other runoff reducing or water quality treating BMPs
- Some designs require minimal drop between inlet and outlet

DISADVANTAGES / LIMITATIONS

- Not designed to provide storm water quality benefits
- Underground installation may make these systems difficult to maintain.
- Performance dependent on design and frequency of inspection and cleanout of unit
- Some designs may require a confined space entry for maintenance and repairs.

ROUTINE MAINTENANCE REQUIREMENTS

- Adequate maintenance access must be provided for all underground detention systems.
- Remove any trash, debris, and sediment buildup in the underground vaults or tanks.
- Perform structural repairs to inlet and outlets, as needed.

POLLUTANT REMOVAL

- 0% **Total Suspended Solids**
- 0% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 0/0% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- 0% **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ● Runoff Reduction
- ● Water Quality
- ✓ Channel Protection
- ✓ Overbank Flood Protection
- ✓ Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- (L) Land Requirement
- (H) Capital Cost
- (M) Maintenance Burden

Residential Subdivision Use: *No*
High Density/Ultra-Urban: *Yes*
Roadway Projects: *Not recommended*

Soils: *Geotechnical testing for the structural load bearing capacity of subsurface soils may be required prior to underground detention installation.*

Other Considerations: *Install a manhole on the downstream side to provide easy access for sampling of effluent.*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 0% Runoff Reduction Credit is provided by this practice.

4.28.1 General Description

Detention vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Detention tanks are underground storage facilities typically constructed with large diameter metal or plastic pipe. Both serve as an alternative to surface detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area.

Both underground vaults and tanks can provide channel protection through extended detention of the channel protection volume (CP_v) and overbank flood Q_{p25} (and in some cases protection for the extreme flood Q_f). Basic storage design and routing methods are the same as for detention basins except that a bypass for high flows is typically included.

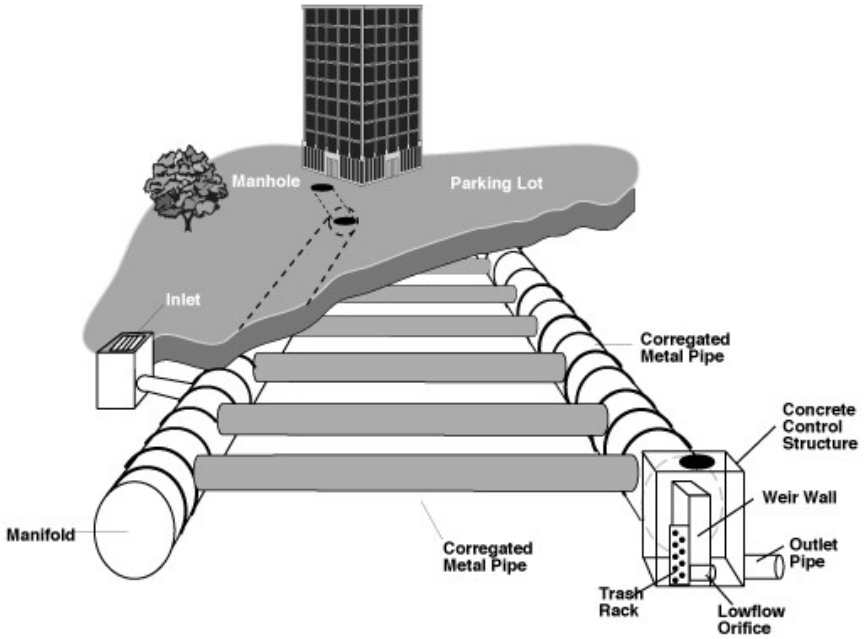


Figure 4.28-1 Example Underground Detention Tank System

(Source: WDE, 2000)

Underground detention vaults and tanks are not intended for water quality treatment and must be used in a treatment train approach with other BMPs that provide treatment of the WQ_v (see Subsection 4.1.6). This will prevent the underground vault or tank from becoming clogged with trash or sediment and significantly reduces the maintenance requirements for an underground detention system.

Prefabricated concrete vaults are available for commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems. **Figures 4.28-1** and **Figure 4.28-2** show example design schematics for underground detention systems.

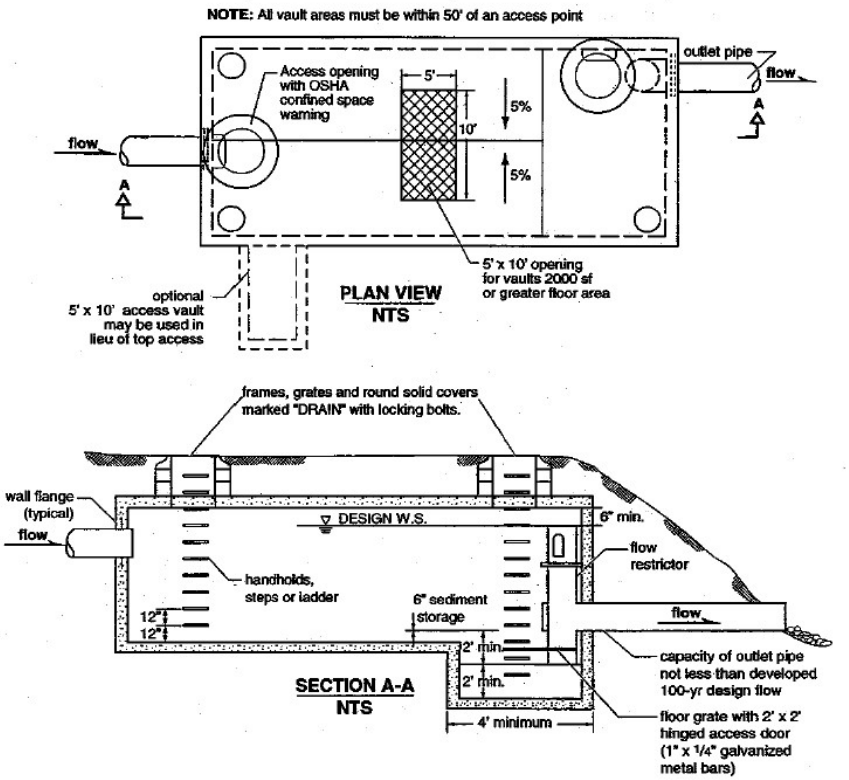


Figure 4.28-2 Example Underground Detention Tank System

(Source: WDE, 2000)

4.28.2 Stormwater Management Suitability

- Runoff Reduction
  Underground detention provides negligible stormwater volume runoff reduction unless modified to include an infiltration component. Another BMP should be used in a treatment train with underground detention to provide runoff reduction. See Subsection 4.1.6 for more information about using BMPs in series.
- Water Quality
  Underground detention provides minimal water quality volume (WQ_v) treatment. Another BMP should be used in a treatment train with underground detention to provide WQ_v treatment. See Subsection 4.1.6 for more information about using BMPs in series.
- Channel Protection
  Underground detention can be sized to store the channel protection volume (CP_v) and to completely drain over 24-72 hours, meeting the requirement of extended detention of the 1-year, 24-hour storm runoff volume.
- Overbank Flood Protection
  Underground detention is intended to provide overbank flood protection (peak flow reduction of the 2-25-year, 24-hour storms, Q_{p2-25}).
- Extreme Flood Protection
  Underground detention can be designed to control the extreme flood (100-year, 24-hour rainfall event peak flow, Q_f).

4.28.3 Pollutant Removal Capabilities

Underground detention does not provide measurable removal of total suspended solids, nutrient, metals, or organic matter. For additional information and data on pollutant removal capabilities for bioretention areas, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.28.4 Application and Site Feasibility Criteria

Underground detention systems are sized to provide extended detention of the channel protection volume over 24 hours and temporary storage of the runoff volume required to provide overbank flood (Q_{p25}) protection (i.e., reduce the post-development peak flow of the 25-year, 24-hour storm event to the pre-development rate). Due to the storage volume required, underground detention vaults and tanks are typically not used to control the 100-year storm (Q_f) except for very small drainage areas (<1 acre).

General Feasibility

- Suitable for Residential Subdivision Usage – NO
- Suitable for High Density/Ultra Urban Areas – **YES**
- Regional Stormwater Control – **YES**
- Roadway Project – **NO**

Physical Feasibility – Physical Constraints at Project Site

- **Drainage Area** – The maximum contributing drainage area to be served by a single underground detention vault or tank is 25 acres.
- **Space Required** – Underground detention is installed underground; therefore, minimal surface area is required for the facility.
- Adequate maintenance access to each chamber must be provided for inspection and cleanout of underground detention units.
- **Site Slope** – Underground detention may be installed on sites with slopes up to 15%.
- **Minimum Depth to Water Table** – 2 feet
- **Minimum Head** – 4-8 feet
- **Soils** – Structural load bearing capacity of subsurface soils must be adequate to support the detention device and stormwater runoff.
- Check with manufacturer recommendations for additional site design constraints.

Other Constraints / Considerations

- **Hot spots** – Underground detention is well-suited for hot spot runoff.
- **Damage to existing structures and facilities:**
  - » Underground detention should not be used in areas where their operation may create a risk for basement flooding, interfere with subsurface sewage disposal systems, or affect other underground structures.
  - » Underground detention should be designed so that overflow drains away from buildings to prevent damage to building foundations.
- **Trout Stream** – Underground detention will not reduce thermal impacts of stormwater runoff, suspended solids, or soluble pollutants impacts. Therefore, they are not considered an effective means of protecting trout streams.
- **Poorly Draining Soils** — Poorly draining soils do not inhibit an underground detention facility's ability to temporarily store and treat stormwater runoff.
- **Flat Terrain** — Flat terrain and low site slopes do not interfere with the operation of underground detention.

4.28.5 Planning and Design Criteria

Before designing the underground detention system, the following data is necessary:

- Existing and proposed site, topographic, and location maps, as well as field reviews
- Impervious and pervious areas and other means used to determine the land use data
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site
- Design data from nearby storm sewer structures
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater table

The following criteria are to be considered minimum standards for the design of an underground detention system. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.28.5.1 LOCATION AND LAYOUT

Underground detention systems should be located downstream of other BMPs providing runoff reduction and/or treatment of the water quality volume (WQ_v). See Subsection 4.1.6 for more information on the use of multiple BMPs in a treatment train.

4.28.5.2 GENERAL DESIGN

- The maximum contributing drainage area to be served by a single underground detention vault or tank is 25 acres.
- Routing calculations must be used to demonstrate that the storage volume is adequate. See Section 3.3 (*Storage Design*) for procedures on the design of detention storage.
- Detention Vaults: Minimum 3,000 psi structural reinforced concrete may be used for underground detention vaults. All construction joints must be provided with water stops. Cast-in-place wall sections must be designed as retaining walls.
- Underground detention vaults and tanks must meet structural requirements for overburden support and traffic loading, if appropriate.
- Adequate maintenance access must be provided for all underground detention systems. Access must be provided over the inlet pipe and outflow structure. Access openings can consist of a standard frame, grate, and solid cover, or a removable panel.
- Vaults with widths of 10 feet or less should have removable lids.

4.28.5.3 PHYSICAL SPECIFICATIONS/ GEOMETRY

- Detention Tanks: The minimum pipe diameter for underground detention tanks is 36 inches.
- The maximum depth from finished grade to the vault invert should be 20 feet.

4.28.5.4 PRETREATMENT/INLETS

- A separate sediment sump or vault chamber sized to 0.1 inches times the impervious acres of contributing drainage should be provided at the inlet for underground detention systems that are in a treatment train with off-line water quality treatment BMPs.
- For CP_v control, a low-flow orifice capable of releasing the channel protection volume over
- 24 hours must be provided. The channel protection orifice should have a minimum diameter of 3 inches and be adequately protected from clogging by an acceptable external trash rack. The orifice diameter may be reduced to 1 inch if internal orifice protection is used (i.e., an overperforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves can also be used to achieve an equivalent diameter.

4.28.5.5 OUTLET STRUCTURES

- For overbank flood protection, additional outlets are sized for Q_{p25} control (based upon hydrologic routing calculations) and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure. See Section 3.4 (*Outlet Structures*) for more information on the design of outlet works.
- Riprap, plunge pools or pads, or other energy dissipators should be placed at the end of the outlet to prevent scouring and erosion.
- A high-flow bypass should be included in the underground detention system design to safely pass the extreme flood flow (Q_f).
- Outlet control structures for underground detention must be constructed of concrete.

4.28.5.6 SAFETY FEATURES

- Maintenance activities for an underground detention device may require a confined space entry.
- Vaults that are greater than 4 feet deep should be equipped with a safety ladder.

4.28.5.7 CONSTRUCTION CONSIDERATIONS

- Newly installed underground detention should be inspected prior to being placed in service. Remove sediment and debris that may have collected in the system during delivery and installation.
- A minimum 20-foot wide maintenance right-of-way or drainage easement should be provided for the underground detention.

4.28.5.8 CONSTRUCTION AND MAINTENANCE COSTS

- Material and installation costs for underground detention systems and vaults can vary based on the size, location, treatment requirements, and manufacturer.
- Typically, underground detention systems can range from approximately $12,000 for a small pipe and manifold system to over $60,000 for a multiple-chamber, high-volume, high-flow device.

4.28.6 Design Procedures

In general, site designers should perform the following design procedures when designing underground detention.

(Step 1) **Determine the goals and primary functions of the underground detention.**

- » Underground detention can be designed to provide 24-hour detention of the channel protection volume (CP_v), and provide Overbank Flood (Q_{p25}) and Extreme Flood (Q_f) protection.
- » Check with local officials and other agencies to determine if there are any additional watershed restrictions that may apply. In addition, consider if the underground detention has any special site-specific design conditions or criteria. List any other requirements that may apply to or affect the design.

(Step 2) **Determine if the development site and conditions are appropriate for the use of underground detention.**
Consider the application and site feasibility criteria in this chapter to determine if site conditions are suitable for underground detention. Create a rough layout of the proposed underground detention facility taking into consideration existing trees, utility lines, and other obstructions.

(Step 3) **Determine underground detention location and preliminary geometry.**
Ensure that there is adequate site area for installation of the underground detention facility, including maintenance access to the vault.

(Step 4) **Compute runoff control volumes and rates.**
Calculate CP_v, Q_{p25}, and Q_f, in accordance with the guidance presented in Subsection 3.1.5.

(Step 5) **Determine pretreatment volume..**
A separate sediment sump or vault chamber sized to 0.1 inches times the impervious acres of contributing drainage area should be provided at the inlet for underground detention systems that are in a treatment train with off-line water quality treatment BMPs.

(Step 6) **Calculate CP_v release rates and water surface elevations.**
Set up a stage-storage-discharge relationship for the control structure for the 1-year, 24-hour rainfall event orifice. Size and determine the invert elevation of the CP_v orifice to ensure that the channel protection volume is stored for at least 24 hours within the underground detention facility.

(Step 7) **Calculate Q_{p2-25} and Q_f release rates and water surface elevations.**
Set up a stage-storage-discharge relationship for the control structure for the 2-25- and 100-year, 24-hour storm orifices.

4.28.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

4.29 Vegetated Filter Strip



Description: Vegetated filter strips are uniformly graded and densely vegetated sections of land, engineered and designed to treat runoff from and remove pollutants through vegetative filtering and infiltration.

LID/GI Considerations: The main means for filtration through vegetated filter strip is where there is permeable soil. These practices work well as a pretreatment and when used with other types of structural stormwater BMPs.

KEY CONSIDERATIONS

DESIGN CRITERIA

- Runoff from an adjacent impervious area must be evenly distributed across the filter strip as sheet flow
- Can be used as part of the runoff conveyance system to provide pretreatment
- Slopes shall be between 2-6%
- Both the top and toe of the slope shall be as flat as possible to encourage sheet flow and prevent erosion
- Uniform grading across filter strip to encourage sheet flow and prevent concentrated flows

ADVANTAGES / BENEFITS

- Can provide groundwater recharge
- Reasonably low construction cost, effort, and changes to existing landscaping
- Works well for mitigating highway runoff pollution
- Works well alone or in series
- Adaptable to a variety of site conditions
- Flexible in design and layout
- Lower cost alternative

DISADVANTAGES / LIMITATIONS

- Cannot alone achieve the 80% TSS removal target
- Large land requirement
- Requires periodic repair, regrading, and sediment removal to prevent channelization
- Vulnerable to erosion and concentrated flow
- Provides less runoff reduction than most BMPs

ROUTINE MAINTENANCE REQUIREMENTS

- Mow grass to a height to maintain a dense vegetative cover
- Inspect for invasive species and remove as needed
- Inspect pea gravel diaphragm for clogging and remove sediment buildup
- Inspect vegetation for rills and gullies. Seed or sod bare areas.
- Sheet flow onto filter strips can be difficult to maintain, resulting in reconcentration of flow.
- Remove trash, debris, sediment, and dead grass.
- Reseed or resod as needed.

POLLUTANT REMOVAL

- 60% **Total Suspended Solids**
- 40% **Metals** - Cadmium, Copper, Lead, and Zinc removal
- 20/20% **Nutrients** - Total Phosphorus / Total Nitrogen removal
- N/A **Pathogens** – Fecal Coliform

STORMWATER MANAGEMENT SUITABILITY

- ★ Runoff Reduction
- ★ Water Quality
- ★ Channel Protection
- ● Overbank Flood Protection
- ● Extreme Flood Protection

✓ suitable for this practice
★ may provide partial benefits

IMPLEMENTATION CONSIDERATIONS

- L Land Requirement
- H Capital Cost
- L Maintenance Burden

Residential Subdivision Use: *Yes, only if without berms*

High Density/Ultra-Urban: *No*
Roadway Projects: *Yes*

Other Considerations: *Use in a buffer system and to treat runoff from pervious areas*

L=Low M=Moderate H=High

RUNOFF REDUCTION CREDIT

- 50% of the RRv conveyed to the practice (A & B hydrologic soils)
- 25% of the RRv conveyed to the practice (C & D hydrologic soils)

4.29.1 General Description

Filter strips are uniformly graded and densely vegetated sections of land, engineered and designed to treat runoff and remove pollutants through vegetative filtering and infiltration. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer, or as pretreatment for another structural stormwater practice. Filter strips can serve as a buffer between incompatible land uses, be landscaped in an aesthetically pleasing way, and provide groundwater recharge in areas with pervious soils. Filter strips are often used as a stormwater site design credit (see Subsection 2.2.4 for more information).

Filter strips rely on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from urban stormwater. There can also be a significant reduction in runoff volume for smaller flows that infiltrate pervious soils beneath the filter strip. To be effective, sheet flow must be maintained across the entire filter strip. Once runoff flow concentrates, it effectively short-circuits the filter strip and reduces any water quality benefits. Therefore, a flow spreader must normally be included in the filter strip design.

There are two different filter strip designs: a simple filter strip and a design that includes a permeable berm at the bottom. The presence of the berm increases contact time with the runoff, thus reducing the overall width of filter strip required to treat stormwater runoff. Filter strips must be designed to withstand the full range of storm events without eroding.

4.29.2 Stormwater Management Suitability

Filter strips are typically built for flowing moving perpendicular to and away from a roadway or parking lot. They must be designed to withstand a full range of storm events without eroding.

- Runoff Reduction
  Vegetated filter strips are an effective low impact development (LID) practice that can be used in Georgia to reduce post-construction stormwater runoff and improve stormwater runoff quality. Like other LID practices, they become even more effective the higher the infiltration rate of the native soils. A vegetated filter strip can be designed to provide 50% of the runoff reduction volume for type A and B hydrologic soils or 25% of the runoff reduction volume for type C and D hydrologic soils. Performance is dependent on vegetation density and contact time for settling, filtration, and infiltration.

- Water Quality
  Use of vegetated filter strip is a stormwater treatment practice that can remove a variety of pollutants through several removal mechanisms. Vegetated filter strips are typically used as a pre-treatment component to reduce incoming runoff velocity, filter particulates, and uptake pollutants from the runoff.

- Channel Protection
  For smaller sites, a vegetated filter strip may be designed to capture the entire channel protection volume (CP_v). Given that a vegetated filter strip is typically designed to completely drain over 48-72 hours, the requirement of extended detention of the 1-year, 24-hour rainfall event runoff volume will be met. For larger sites, or where only the WQ_v is diverted to the vegetated filter strip, another practice must be used to provide CP_v extended detention.

- Overbank Flood Protection
  Another practice in conjunction with a vegetated filter strip will likely be required to reduce the post-development peak flow of the 25-year storm (Q_p) to pre-development levels (detention).

- Extreme Flood Protection
  Vegetated filter strips must provide flow diversion and/or be designed to safely pass extreme storm flows (Q_f) and protect the vegetation.

Credit for the volume of runoff reduced in the vegetated filter strip may be taken in the overbank flood protection and extreme flood protection calculations. If the practice is designed to provide runoff reduction for water quality compliance, then the practice is given credit for channel protection and flood control requirements by allowing the designer to compute an Adjusted CN (see Subsection 3.1.7.5 for more information).

4.29.3 Pollutant Removal Capabilities

Pollutant removal from filter strips is highly variable and depends primarily on density of vegetation and contact time for filtration and infiltration. These, in turn, depend on soil and vegetation type, slope, and presence of sheet flow. Research on fecal coliform removal has been inconclusive, but suggests that filter strips are generally not effective BMPs for treating bacterial loads.

For additional information and data on pollutant removal capabilities for vegetated filter strips, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the National Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.29.4 Application and Site Feasibility Criteria

Vegetated filter strips are best suited to treat smaller drainage areas. Flow must enter the filter strip as sheet flow spread out over the width (long dimension normal to flow) of the strip, generally no deeper than 1 to 2 inches. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (CWP, 1996). For longer flow paths, special provision must be made to ensure design flows spread evenly across the filter strip.

Because of design constraints, vegetated filter strips generally have a maximum drainage area of 5 acres, but 2 acres are preferred. Filter strips shall be designed for slopes between 2-6%. Greater slopes than this would encourage the formation of concentrated flow. Flatter slopes would encourage standing water. The sheet flow depth through the filter strip shall be no more than 2 inches.

General Feasibility

- Suitable for Residential Subdivision Usage – **YES**
- Suitable for High Density/Ultra Urban Areas – **NO**
- Regional Stormwater Control – **NO**
- Roadway Projects – **YES**

Physical Feasibility - Physical Constraints at Project Site

- **Drainage Area** – 5 acres or less, 2 acres preferred.
- **Space Required** – Rough rule of thumb ratio of drainage area to filter strip surface area required is 10:1.
- **Site Slope** – Slopes shall be between 2-6% (perpendicular to the roadway).
- **Minimum Depth to Water Table** – A separation distance of at least 2 feet is required between the bottom of the vegetated filter strip and the elevation of the seasonally high water table.

Other Constraints/Considerations

- **Location requirements** – The following is a list of specific setback requirements for the location of a vegetated filter strip:
  - » Filter strips shall be constructed outside the undisturbed Gwinnett County stream buffer area to maintain a more natural buffer along the streambank.
  - » Filter strips shall not be used on soils that cannot sustain a dense grass cover with high retardance. Designers shall choose a grass that can withstand relatively high velocity flows at the entrances, and both wet and dry periods. See Appendix D for a list of appropriate grasses for use in Georgia.
  - » Pedestrian traffic across the filter strip shall be limited through channeling onto sidewalks.
  - » The filter strip shall be at least 15 feet long (25 feet preferred) to provide filtration and contact time for water quality treatment. 100 feet the recommended maximum strip length.

4.29.5 Planning and Design Criteria

Before designing the vegetated filter strip, the following data is necessary:

- Existing and proposed site, topographic and location maps, and field reviews
- Field measured topography or digital terrain model (DTM)
- Aerial site photographs
- Drainage basin characteristics (slope, shape, size, soils, and land use)
- Preliminary plans including plan view, roadway and drainage profiles, cross sections, utility plans, and soil report
- Environmental constraints
- Design data of nearby structures (storm sewer as-built information)
- Additional survey information

The following criteria are considered to be minimum standards for the design of a vegetated filter strip. Consult with the local review authority to determine if there are any variations to these criteria or additional standards that must be met.

4.29.5.1 LOCATION AND LAYOUT

Vegetated filter strips location and layout areas based on site constraints such as proposed and existing infrastructure, soils, existing vegetation, contributing drainage area, and utilities. Vegetated filter strips systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources. Vegetated filter strip locations should be integrated into the site planning process and aesthetic and maintenance considerations should be taken into account in their siting and design. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility as sheet flow with no more than the maximum design depth and velocity.

4.29.5.2 GENERAL DESIGN

- Filter strips shall be integrated within site designs.
- An effective flow spreader may use a pea gravel diaphragm at the top of the slope (ASTM D 448 size no. 6, 1/8" to 3/8"). The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip. Other types of flow spreaders include a concrete sill, curb stops, or curb and gutter with "sawteeth" cut into it.
- Ensure that flows in excess of the design flow move across or around the strip without damaging it. Often a bypass channel or overflow spillway with protected channel section is designed to handle higher flows.
- Maximum discharge loading per foot of filter strip width (perpendicular to flow path) is found using the Manning's equation:

$$q = \frac{0.00236}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}}$$

(Equation 4.29.1)

Where:

q = discharge per foot of width of filter strip (cfs/ft)
Y = allowable depth of flow (inches; maximum flow depth of 2 inches)
S = slope of filter strip (percent)
n = Manning's "n" roughness coefficient *(n=0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)*

- The minimum length of a filter strip is:

$$W_{fMIN} = \frac{Q_{WQ}}{q}$$

(Equation 4.29.2)

Where:

W_{fMIN} = minimum filter strip width perpendicular to flow (feet)
Q_{WQ} = water quality volume peak flow (ft^3/s)
q = discharge per foot of width of filter strip (cfs/ft)

Filter without Berm

- Size filter strip (parallel to flow path) for a contact time of 5 minutes minimum
- The equation for filter length is based on the SCS TR55 travel time equation (SCS, 1986):

$$L_f = \frac{(T_t)^{1.25}(P_{2-24})^{0.625}(S)^{0.5}}{0.338n}$$

(Equation 4.29.3)

Where:

L_f = length of filter strip parallel to flow path (ft)
T_t = travel time through filter strip (minutes)
P_{2-24} = 2-year, 24-hour rainfall depth (inches)
S = slope of filter strip (percent)
n = Manning's "n" roughness coefficient *(n=0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)*

Table 4.29-1 Vegetated Filter Strip Sizing Guidance
(Source: Claytor and Schueler, 1996)

Parameter	Impervious Areas		Pervious Areas (lawns, etc)	
Maximum inflow approach length (feet)	35	75	75	100
Filter strip minimum length (feet)	15	25	12	18

Filter Strips with Berm

- Size outlet pipes to ensure that the bermed area drains within 24 hours.
- Specify grasses resistant to frequent inundation within the shallow ponding limits.
- Berm material shall be composed of sand, gravel, and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02"-0.04", Gravel: AASHTO M-43 ½" to 1").
- Size filter strip to contain the WQv within the wedge of water backed up behind the berm.
- Maximum berm height is 12 inches.

Filter Strips for Pretreatment

- A number of other structural controls, including vegetated filter strips and infiltration trenches, may utilize a filter strip as a pretreatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. **Table 4.29-1** provides sizing guidance for bioretention filter strips for pretreatment.

4.29.5.3 PHYSICAL SPECIFICATIONS/GEOMETRY

- Both the top and toe of the slope shall be as flat as possible to encourage sheet flow and prevent erosion.
- A minimum strip length of 15 feet shall be used (25 feet is preferred).
- A maximum strip length of 100 feet is recommended.
- Slopes shall be between 2-6% (perpendicular to the roadway).
- Acceptable velocities for filter strips shall be less than 4 feet per second for grass and less than 1 foot per second for native herbaceous vegetation.
- Filter strips shall not be located in areas designated as stream buffers.
- Filter strips with berms shall not be used in residential areas.

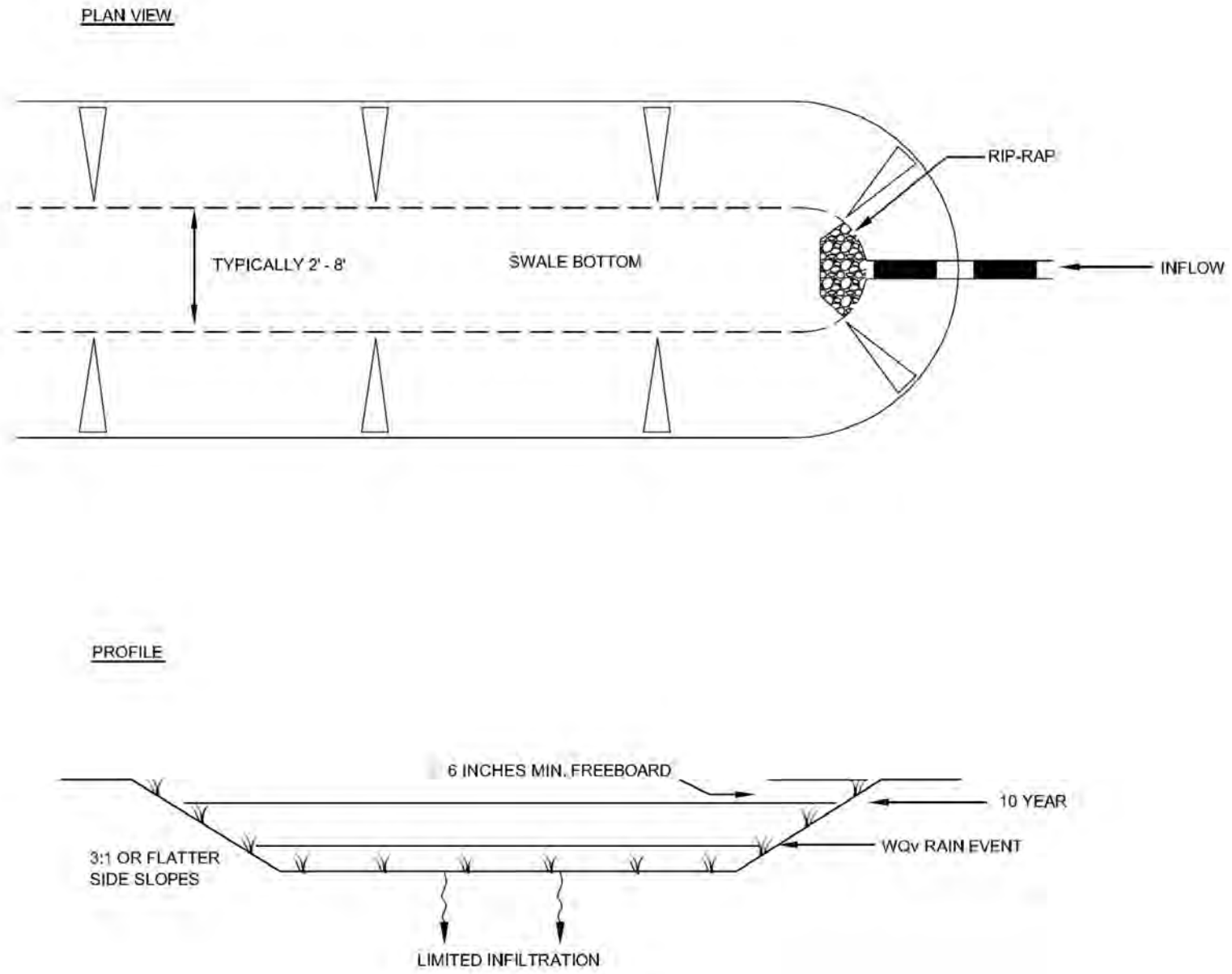


Figure 4.29-1 Typical Vegetated Filter Strip

4.29.6 Design Procedures

(Step 1) **Determine the goals and primary function of the vegetated filter strips.**

Consider whether vegetated filter strip is intended to:

- » Meet a runoff reduction* target or water quality (treatment) target.
  **Note that minimum infiltration rates of the surrounding native soils must be acceptable and suitable when used in runoff reduction applications.*
- » Be "oversized" to include partial credit for storage capacity for Channel Protection Volume (CP_v).
- » Provide a possible solution to a drainage problem.
- » Enhance landscape and provide aesthetic qualities.

Check with local officials and other agencies to determine if there are any additional watershed restrictions that may apply. In addition, consider if the vegetated filter strip has any special site-specific design conditions or criteria. List any other requirements that may apply to or affect the design.

The design of the vegetated filter strip should be centered on the restrictions/requirements, goals, targets, and primary function(s) of a vegetated filter strip. By considering the primary function, as well as, topographic and soil conditions, the design elements of the vegetated filter strip can be determined (i.e. planting media, underdrain, inlet/outlet, overflow, etc.).

(Step 2) **Determine if the development site and conditions are appropriate for the use of a vegetated filter strip**

Consider the application and site feasibility criteria in this chapter to determine if site conditions are suitable for a vegetated filter strip. Create a rough layout of the vegetated filter strip dimensions taking into consideration existing trees, utility lines, and other obstructions.

(Step 3) **Calculate the Target Water Quality Volume**

Calculate the Water Quality Volume using the following formula:

$$WQ_v = (1.2)\ (R_v)\ (A)\ /\ 12$$

Where:

WQ_v = Water Quality Volume (ft^3)
1.2 = Target rainfall amount to be treated (inches)
R_v = Volumetric runoff coefficient which can be found by:

$$R_v = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 4) **Determine the maximum discharge loading per foot of filter strip.**

$$q = \frac{0.0237}{n} S^{\frac{1}{2}}$$

Where:

q = discharge per foot of width of filter strip (cfs/ft) based on WQ_v storm event
S = slope of filter strip (percent)
n = Manning's "n" roughness coefficient
(n=0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

(Step 5) Determine the minimum width (perpendicular to flow) of a filter strip.

$$W_{fMIN} = \frac{Q_{WQ}}{q}$$

(Equation 4.29.5)

Where:

W_{fMIN} = min. filter strip width perpendicular to flow (ft)
Q_{WQ}=water quality volume peak flow (ft^3/s)
q=discharge per foot of width of filter strip (cfs/ft)

(Step 6) Calculate the depth of flow of the stormwater runoff across the buffer to be sure it is <1 inch.

$$D = (1.04*q^{0.6}*n^{0.6})/S^{0.3}$$

Where:

D = depth of flow (ft)

(Step 7) Calculate the velocity of the stormwater runoff across the buffer to be sure it is < 2.0 fps.

$$V = Q_{WQ}/(D* W_{fMIN})$$

(Step 8) Size filter strip (parallel to flow path) for a contact time of at least 5 minutes.

$$L_f = \frac{(T_t)^{1.25}(P_{2-24})^{0.625}(S)^{0.5}}{0.338 * n}$$

(Equation 4.29.4)

Where:

L_f = length of filter strip parallel to flow path (ft)
T_t = travel time through filter strip (minutes)
P_{2-24} = 2-year, 24-hour rainfall depth (feet)
S = slope of filter strip (percent)
n = Manning's "n" roughness coefficient
(n=0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

(Step 9) To calculate the RR_V credited for the practice (sized for WQ_V), Steps 5, 6, 7 and 8 have to be met, then proceed to Step 10. Otherwise proceed to Step 13.

(Step 10) Calculate the Stormwater Runoff Reduction Volume conveyed to the practice.
Calculate the Runoff Reduction Volume using the following formula:

$$RR_V = (P)\ (RV)\ (A) / 12$$

Where:

RR_V = Runoff Reduction Target Volume (ft^3)
P = Target runoff reduction rainfall (inches)
R_V = Volumetric runoff coefficient which can be found by:

$$R_V = 0.05+0.009(I)$$

Where:

I = new impervious area of the contributing drainage area (%)

A = Area draining to this practice (ft^2)
12 = Unit conversion factor (in/ft)

(Step 11) Calculate RR_v credited.

Using **Table 4.1.3-2** - *BMP Runoff Reduction Credits*, lookup the appropriate runoff reduction percentage (or credit) provided by the practice:

$$\mathbf{RR_v\ (credited) = RR_v(RR\%)}$$

Where:

RR% = Runoff Reduction percentage, or credit, assigned to the specific practice

RR_v (credited) = Runoff Reduction Volume provided by this practice (ft^3)

RR_v = RR_v conveyed to the practice

(Step 12) Calculate the adjusted curve numbers for CP_v (1-yr, 24-hour storm), Q_{P25} (25-yr, 24-hour storm), and Q_f (100-yr, 24-hour storm). See Subsection 3.1.7.5 for more information

(Step 13) Prepare site Vegetation and Landscaping Plan

A landscaping plan for the vegetated filter strip shall be prepared to indicate how it will be established with vegetation. See section Appendix D for more details.

4.29.7 Inspection and Maintenance Requirements

All best management practices require proper maintenance. Without proper maintenance, BMPs will not function as originally designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. For additional information on inspection and maintenance requirements, see Appendix E.

References

Anne Arundel County. 2012. *Step Pool Storm Conveyance (SPSC) Systems.* Anne Arundel County, Maryland.

ASTM International. 2005. *Standard Practice for Determination of Deadloads and Live Loads Associated with Green Roof Systems.* Standard E2397.05. ASTM International. West Conshohocken, PA.

ASTM International. 2006. *Standard Guide for Selection, Installation and Maintenance of Plants for Green Roof Systems.* Standard E2400-06. ASTM International. West Conshohocken, PA.

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual, Volume 2.* Atlanta Regional Commission, Atlanta, GA.

Bureau of Environmental Services. 2008. *Portland Stormwater Management Manual.* City of Portland, OR.

Cappiella, K., T. Schueler and T. Wright. 2006. *Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites.* NA-TP-01-06. US Department of Agriculture. Forest Service. Northeastern Area. State and Private Forestry. Newtown Square, PA.

Cappiella, K., T. Schueler, J. Tomlinson and T. Wright. 2006. *Urban Watershed Forestry Manual. Part 3: Urban Tree Planting Guide.* NA-TP-01-06. US Department of Agriculture. Forest Service. Northeastern Area. State and Private Forestry. Newtown Square, PA.

Chesapeake Stormwater Network. 2015. About. Chesapeake Stormwater Network, Ellicott City, MD.

Green Building Alliance. 2013. *Stormwater Planters.* Green Building Alliance. Pittsburgh, PA.

Georgia Department of Transportation. 2014. *Manual on Drainage Design for Highways.* Atlanta, GA.

Knox County, Tennessee. 2008. Knox County *Tennessee Stormwater Management Manual.* Knox County, Tennessee.

Maryland Department of the Environment (MDE). 2009. *Environmental Site Design, Chapter 5.* Baltimore, Maryland.

Minnesota Pollution Control Agency (MPCA). 2006. *Minnesota Stormwater Manual.* Minnesota Pollution Control Agency.

NCHRP. 2013. *Synthesis 444: Pollutant Load Reductions for Total Maximum Daily Loads for Highways.* National Cooperative Highway Research Program, Transportation Research Board, National Research Council.

Novotney, M., P. Sturm, C. Swann, and J. Tasillo. 2008. *Downspout Disconnection in the City of Baltimore, Maryland.* City of Baltimore, Maryland. Center for Watershed Protection, Ellicott City, MD.

Oregon Department of Transportation. Appendix E – Bioslopes. GDOT, Salem, Oregon.

Pennsylvania Department of Environmental Protection. 2006. *Pennsylvania Stormwater Best Management Practices Manual.* Pennsylvania DEP.

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices. Manual 3: Urban Subwatershed Restoration Manual Series.* Center for Watershed Protection (CWP). Ellicott City, MD.

United States Environmental Protection Agency. 2014. *National Menu of Stormwater Best Management Practices.* United States Environmental Protection Agency. Washington, D.C.

Washington State Department of Transportation. 2006. *Technology Evaluation and Engineering Report.* Washington State Department of Transportation (WSDOT).

West Virginia Department of Environmental Protection. 2015. *West Virginia Stormwater Management and Design Guidance Manual.* West Virginia Department of Environmental Protection.

5. Stormwater Drainage System Design

5.1 Stormwater Drainage Design Overview

5.1.1 Stormwater Drainage System Design

5.1.1.1 INTRODUCTION

Stormwater drainage design is an integral component of both site and overall stormwater management design. Good drainage design must strive to maintain compatibility and minimize interference with existing drainage patterns; control flooding of property, structures and roadways for design flood events; and minimize potential environmental impacts on stormwater runoff.

Stormwater collection systems must be designed to provide adequate surface drainage while at the same time meeting other stormwater management goals such as runoff reduction, water quality, streambank channel protection, habitat protection and groundwater recharge.

5.1.1.2 DRAINAGE SYSTEM COMPONENTS

In every location there are two stormwater drainage systems, the minor system and the major system. Three considerations largely shape the design of these systems: flooding, public safety and water quality.

The minor drainage system is designed to remove stormwater from areas such as streets and sidewalks for public safety reasons. The minor drainage system consists of inlets, street and roadway gutters, roadside ditches, small channels and swales, and small underground pipe systems which collect stormwater runoff and transport it to structural control facilities, pervious areas and/or the major drainage system (i.e., natural waterways, large man-made conduits, and large water impoundments).

Paths taken by runoff from very large storms are called major systems. The major system (designed for the less frequent storm up to the 100-yr level) consists of natural waterways, large man-made conduits, and large water impoundments. In addition, the major system includes some less obvious drainageways such as overload relief swales and infrequent temporary ponding areas. The major system includes not only the trunk line system that receives the water from the minor system, but also the natural backup system which functions in case of overflow from or failure of the minor system. Overland relief must not flood or damage houses, buildings or other property.

The major/minor concept may be described as a 'system within a system' for it comprises two distinct but conjunctive drainage networks. The major and minor systems are closely interrelated, and their design needs to be done in tandem and in conjunction with the design of structural stormwater controls and the overall stormwater management concept and plan.

This chapter is intended to provide design criteria and guidance on several drainage system components, including street and roadway gutters, inlets and storm drain pipe systems (Section 5.2); culverts (Section 5.3); vegetated and lined open channels (Section 5.4); and energy dissipation devices for outlet protection (Section 5.5). The rest of this section covers important considerations to keep in mind in the planning and design of stormwater drainage facilities.

5.1.1.3 CHECKLIST FOR DRAINAGE PLANNING AND DESIGN

The following is a general procedure for drainage system design on a development site.

1. Analyze topography
   a. Check off-site drainage pattern. Where is water coming onto the site? Where is water leaving the site?
   b. Check on-site topography for surface runoff and storage, and infiltration
      1. Determine runoff pattern; high points, ridges, valleys, streams, and swales. Where is the water going?
      2. Overlay the grading plan and indicate watershed areas; calculate square footage (acreage), points of concentration, low points, etc.
   c. Check potential drainage outlets and methods
      1. On-site (structural control, receiving water)
      2. Off-site (highway, storm drain, receiving water, regional control)
      3. Natural drainage system (swales)
      4. Existing drainage system (drain pipe)

2. Analyze other site conditions.
   a. Land use and physical obstructions such as walks, drives, parking, patios, landscape edging, fencing, grassed area, landscaped area, tree roots, etc.
   b. Soil type determines the amount of water that can be absorbed by the soil.
   c. Vegetative cover will determine the amount of slope possible without erosion.
3. Analyze areas for probable location of drainage structures and facilities.
4. Identify the type and size of drainage system components that are required. Design the drainage system and integrate with the overall stormwater management system and plan.

5.1.2 Key Issues in Stormwater Drainage Design

5.1.2.1 INTRODUCTION

The traditional design of stormwater drainage systems has been to collect and convey stormwater runoff as rapidly as possible to a suitable location where it can be discharged. This Manual takes a different approach wherein the design methodologies and concepts of drainage design are to be integrated with the objectives for water quantity and quality control in the stormwater management minimum standards. This means that:

- Stormwater conveyance systems are to remove water efficiently enough to meet flood protection criteria and level of service requirements, and
- These systems are to complement the ability of the site design and structural stormwater controls to mitigate the major impacts of urban development.

The following are some of the key issues in integrating water quantity and quality control consideration in stormwater drainage design.

5.1.2.2 GENERAL DRAINAGE DESIGN CONSIDERATIONS

- Stormwater systems should be planned and designed so as to generally conform to natural drainage patterns and discharge to natural drainage paths within a drainage basin. These natural drainage paths should be modified as necessary to contain and safely convey the peak flows generated by the development.
- Runoff must be discharged in a manner that will not cause adverse impacts on downstream properties or stormwater systems. In general, runoff from development sites within a drainage basin should be discharged at the existing natural drainage outlet or outlets. If the developer wishes to change discharge points he or she must demonstrate that the change will not have any adverse impacts on downstream properties or stormwater systems.
- It is important to ensure that the combined minor and major system can handle blockages and flows in excess of the design capacity to minimize the likelihood of nuisance flooding or damage to private properties. If failure of minor systems and/or major structures occurs during these periods, the risk to life and property could be significantly increased.
- In establishing the layout of stormwater networks, it is essential to ensure that flows will not discharge onto private property during flows up to the major system design capacity.

5.1.2.3 STREET AND ROADWAY GUTTERS

- Gutters are efficient flow conveyance structures. This is not always an advantage if removal of pollutants and reduction of runoff is an objective. Therefore, impervious surfaces should be disconnected hydrologically where possible and runoff should be allowed to flow across pervious surfaces or through grass channels. Gutters should be used only after other options have been investigated and only after runoff has had as much chance as possible to infiltrate and filter through vegetated areas.
- It may be possible not to use gutters at all, or to modify them to channel runoff to off-road pervious areas or open channels. For example, curb opening type designs take roadway runoff to smaller feeder grass channels. Care should be taken not to create erosion problems in off-road areas. Protection during construction, establishment of strong stands of grass, and active maintenance may be necessary in some areas.

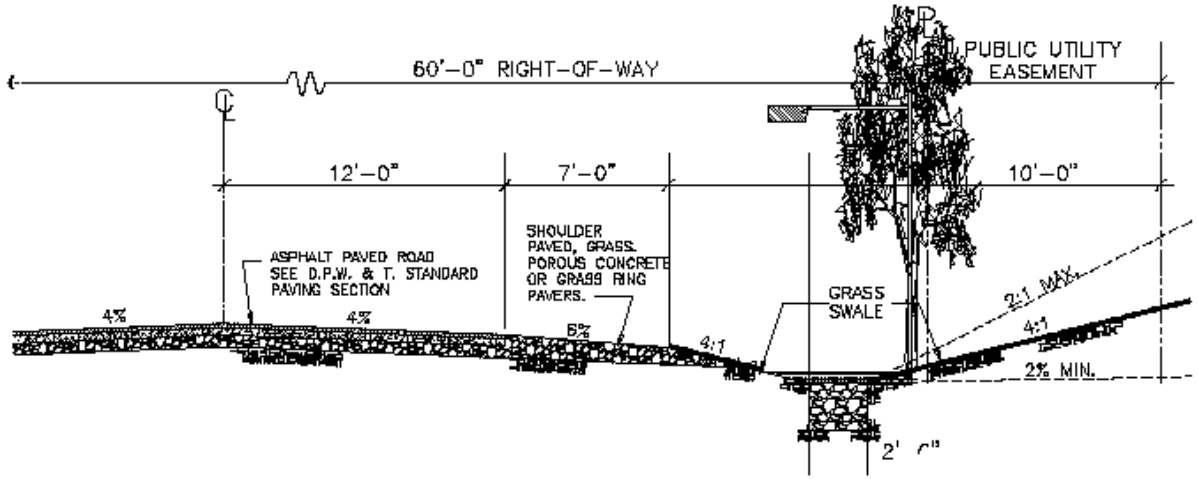


Figure 5.1-1 Alternate Roadway Section without Gutters
(Source: Prince George's County, MD, 1999)

- Use road cross sections that include grass channels or swales instead of gutters to provide for pollution reduction and reduce the impervious area required. **Figure 5.1-1** illustrates a roadway cross section that eliminates gutters for residential neighborhoods. Flow can also be directed to center median strips in divided roadway designs. To protect the edge of pavement, ribbons of concrete can be used along the outer edges of asphalt roads.

5.1.2.4 INLETS AND DRAINS

- Inlets should be located to maximize overland flow path, take advantage of pervious areas, and seek to maximize vegetative filtering and infiltration. For example, it might be possible to design a parking lot so that water flows into vegetated areas prior to entering the nearest inlet.
- Inlet location should not compromise safety or aesthetics. It should not allow for standing water in areas of vehicular or pedestrian traffic, but should take advantage of natural depression storage where possible.
- Inlets should be located to serve as overflows for structural stormwater controls. For example, a bioretention device in a commercial area could be designed to overflow to a catch basin for larger storm events.
- The choice of inlet type should match its intended use. A sumped inlet may be more effective supporting water quality objectives.
- Use several smaller inlets instead of one large inlet in order to:
  1. Prevent erosion on steep landscapes by intercepting water before it accumulates too much volume and velocity.
  2. Provide a safety factor. If a drain inlet clogs, the other surface drains may pick up the water.
  3. Improve aesthetics. Several smaller drains will be less obvious than one large drain.
  4. Spacing smaller drain inlets will give surface runoff a better chance of reaching the drain. Water will have farther to travel to reach one large drain inlet.

5.1.2.5 STORM DRAIN PIPE SYSTEMS (STORM SEWERS)

- The use of better site design practices (and corresponding site design credits) should be considered to reduce the overall length of a piped stormwater conveyance system.
- Shorter and smaller conveyances can be designed to carry runoff to nearby holding areas, natural conservation areas, or filter strips (with spreaders at the end of the pipe).
- Ensure that storms in excess of pipe design flows can be safely conveyed through a development without damaging structures or flooding major roadways. This is often done through design of both a major and minor drainage system. The minor (piped) system carries the mid-frequency design flows while larger runoff events may flow across lots and along streets as long as it will not cause property damage or impact public safety.

5.1.2.6 CULVERTS

- Culverts can serve double duty as flow retarding structures in grass channel design. Care should be taken to design them as storage control structures if depths exceed several feet, and to ensure safety during flows.
- Improved inlet designs can absorb considerable slope and energy for steeper sloped designs, thus helping to protect channels.

5.1.2.7 OPEN CHANNELS

- Open channels provide opportunities for reduction of flow peaks and pollution loads. They may be designed as wet or dry enhanced swales or grass channels.
- Channels can be designed with natural meanders improving both aesthetics and pollution removal through increase of contact time.
- Grass channels generally provide better habitat than hardened channel sections, though studies have shown that riprap interstices provide significant habitat as well. Velocities should be carefully checked at design flows and the outer banks at bends should be specifically designed for increased shear stress.
- Compound sections can be developed that carry the annual flow in the lower section and higher flows above them. **Figure 5.1-2** illustrates a compound section that carries the 2-year and 10-year flows within banks. This reduces channel erosion at lower flows, and meandering, self-forming low flow channels that attack banks. The shelf in the compound section should have a minimum 1:12 slope to ensure drainage.
- Flow control structures can be placed in the channels to increase residence time. Higher flows should be calculated using a channel slope that goes from the top of the cross piece to the next one if it is significantly different from the channel bottom for normal depth calculations. Channel slope stability can also be ensured through the use of grade control structures that can serve as pollution reduction enhancements if they are set above the channel bottom. Regular maintenance is necessary to remove sediment and keep the channels from aggrading and losing capacity for larger flows.

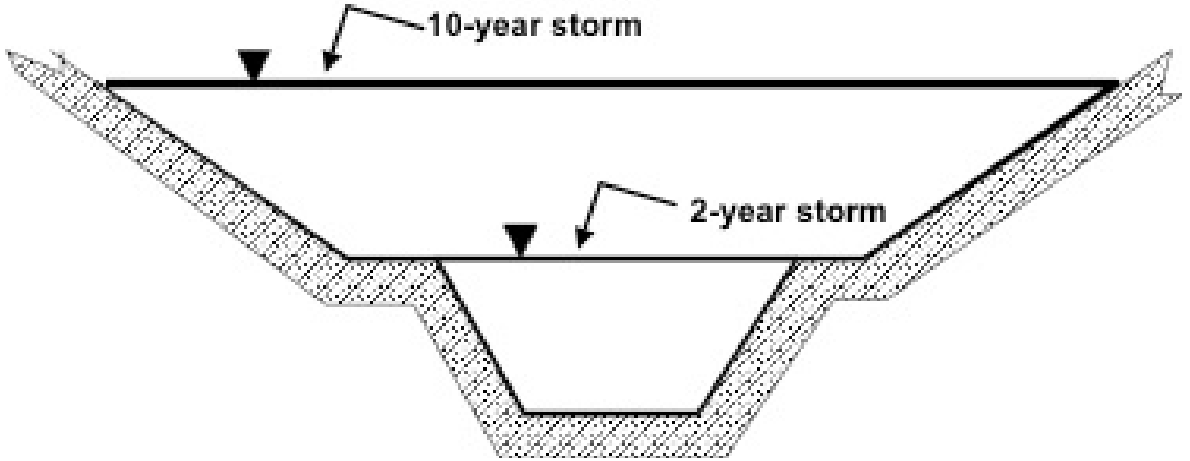


Figure 5.1-2 Compound Channel

5.1.2.8 ENERGY DISSIPATORS

- Energy dissipaters should be designed to return flows to non-eroding velocities to protect downstream channels.
- Care must be taken during construction that design criteria are followed exactly. The designs presented in this Manual have been carefully developed through model and full-scale tests. Each part of the criteria is important to the proper function.

5.1.3 Design Storm Requirements

Listed below are the design storm recommendations for various stormwater drainage system components to be designed and constructed in accordance with the minimum stormwater management standards. Some jurisdictions may require the design of both a minor and major stormwater conveyance system, sized for two different storm frequencies. Please consult your local review authority to determine the local requirements. *It is recommended that the full build-out conditions be used to calculate flows for the design storm frequencies below.*

Storm Drainage Systems

Includes storm drainage systems and pipes that do not convey runoff through roadway embankments, sometimes called lateral closed systems.

- 25-year design storm (for pipe design)
- 10-year design storm (for inlet design)
- 50-year design storm (for sumped inlets, unless overflow facilities are provided)
- 100-year design storm (for culvert design)
- All culverts, pipe systems, and open channel flow systems shall be sized based on all on-site upstream areas being developed in accordance with the development plans and the off-site upstream areas being fully developed in accordance with the Land Use Plan with no detention. Upstream detention may be included when determining flows, provided the following conditions are met:
  - » The engineer calculates the reduced flows by routing the developed flows through any stormwater facility included in the analysis rather than assuming the reduction will occur.
  - » The engineer shall provide the maintenance agreement(s) for all BMPs used in the analysis, and verify that they have been properly maintained.
  - » The engineer shall show that the storage volume and outlet structure is based on current conditions.
  - » All BMPs used in the analysis shall pass a final inspection by Gwinnett County, ensuring that all necessary maintenance is performed.
- BMPs shall be designed using predevelopment flows based on existing conditions for all upstream areas including existing on-site lakes and detention.

Roadway Culvert Design

Single pipe or pipe drainage facilities that transport storm runoff through roadway embankments.

- 100-year design storm

Open Channel Design

Open channels include all channels, swales, etc.

- 25-year design storm

Channels may be designed with multiple stages (e.g., a low flow channel section containing the 2-year to 5-year flows, and a high flow section that contains the design discharge) to improve stability and better mimic natural channel dimensions. Where flow easements can be obtained and structures kept clear, overbank areas may also be designed as part of a conveyance system wherein floodplain areas are designed for storage and/or conveyance of larger storms.

Energy Dissipation Design

Includes all outlet protection facilities.

- 25-year design storm

Check Storm

Used to estimate the runoff that is routed through the drainage system and stormwater management facilities to determine the effects on the facilities, adjacent property, floodplain encroachment and downstream areas.

- 100-year design storm, or as required by the Georgia Safe Dams Act.

5.2 Minor Drainage System Design

5.2.1 Overview

5.2.1.1 INTRODUCTION

Minor stormwater drainage systems, also known as convenience systems, quickly remove runoff from areas such as streets and sidewalks for public safety purposes. The minor drainage system consists of inlets, street and roadway gutters, roadside ditches, small channels and swales, and small underground pipe systems which collect stormwater runoff and transport it to structural control facilities, pervious areas and/or the major drainage system (i.e., natural waterways, large man-made conduits, and large water impoundments).

This section is intended to provide criteria and guidance for the design of minor drainage system components including:

- Street and roadway gutters
- Stormwater inlets
- Storm drain pipe systems

Ditch, channel and swale design criteria and guidance are covered in Section 5.4, *Open Channel Design*.

Procedures for performing gutter flow calculations are based on a modification of Manning's Equation. Inlet capacity calculations for grate, curb and combination inlets are based on information contained in HEC-12 (USDOT, FHWA, 1984). Storm drain system design is based on the use of the Rational Formula.

5.2.1.2 GENERAL CRITERIA

Design Frequency

See Section 5.1 or the local review authority for design storm requirements for the sizing of minor storm drainage system components.

Flow Spread Limits

Catch basins shall be spaced so that the spread in the street for the 25-year design flow shall not exceed the following, as measured from the face of the curb:

- 8 feet if the street is classified as a Collector or Arterial street (for 2-lane streets spread may extend to one-half of the travel lane; for 4-lane streets spread may extend across one travel lane)
- 16 feet at any given section, but in no case greater than 10 feet on one side of the street, if the street is classified as a Local or Sub-Collector street
- Catch basins shall be spaced so that the spread in the street for a 10-year design flow shall not exceed 8 feet as measured from the face of the curb. Gutter spread calculations shall be submitted to Gwinnett County for review and approval prior to issuance of a Development Permit.

5.2.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual, the symbols listed in **Table 5.2-1** will be used. These symbols were selected because of their wide use. In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equations.

Table 5.2-1 Symbols and Definitions

Symbol	Definition	Units
a	Gutter depression	in
A	Area of cross section	ft^2
d or D	Depth of gutter flow at the curb line	ft
D	Diameter of pipe	ft
E_O	Ratio of frontal flow to total gutter flow Q_w/Q	-
g	Acceleration due to gravity (32.2 ft/s^2)	ft/s^2
h	Height of curb opening inlet	ft
H	Head Loss	ft
K	Loss coefficient	-
L or L_T	Length of curb opening inlet	ft
L	Pipe length	ft
n	Roughness coefficient in the modified Manning's formula for triangular gutter flow	-
P	Perimeter of grate opening, neglecting bars and side against curb	ft
Q	Rate of discharge in guttter	cfs
Q_i	Intercepted flow	cfs
Q_s	Gutter capacity above the depressed section	cfs
S or S_X	Cross Slope - Traverse Slope	ft/ft
S or S_L	Longitudinal slope of pavement	ft/ft
S_f	Friction slope	ft/ft
S_W	Depression section slope	ft/ft
T	Top width of water surface (spread on pavement)	ft
T_S	Spread above depressed section	ft
V	Velocity of flow	ft/s
W	Width of depression for curb opening inlets	ft
Z	T/d, reciprocal of the cross slope	-

5.2.3 Street and Roadway Gutters

Effective drainage of street and roadway pavements is essential to the maintenance of the roadway service level and to traffic safety. Water on the pavement can interrupt traffic flow, reduce skid resistance, increase potential for hydroplaning, limit visibility due to splash and spray, and cause difficulty in steering a vehicle when the front wheels encounter puddles. Surface drainage is a function of transverse and longitudinal pavement slope, pavement roughness, inlet spacing, and inlet capacity. The design of these elements is dependent on storm frequency and the allowable spread of stormwater on the pavement surface.

This section presents design guidance for gutter flow hydraulics originally published in HEC-12, Drainage of Highway Pavements and AASHTO's Model Drainage Manual.

5.2.3.1 FORMULA

The following form of Manning's Equation should be used to evaluate gutter flow hydraulics:

$$Q = [0.56 / n]\ S_x^{5/3}\ S^{1/2}\ T^{8/3} \qquad (5.2.1)$$

Where:

Q = gutter flow rate, cfs
$\mathbf{S_x}$ = pavement cross slope, ft/ft
n = Manning's roughness coefficient
S = longitudinal slope, ft/ft
T = width of flow or spread, ft

5.2.3.2 NOMOGRAPH

Figure 5.2-1 is a nomograph for solving **Equation 5.2.1**. Manning's n values for various pavement surfaces are presented in **Table 5.2-2** below.

5.2.3.3 MANNING'S N TABLE

Table 5.2-2 Manning's n Values for Street and Pavement Gutters

Type of Gutter or Pavement	Range of Manning's n
Concrete gutter, trowled finish	0.012
Ashphalt pavement:	
Smooth Texture	0.013
Rough Texture	0.016
Concrete gutter with asphalt pavement:	
Smooth	0.013
Rough	0.015
Concrete pavement:	
Float Finish	0.014
Broom Finish	0.016
For gutters with small slopes, where sediment may accumulate, increase above values of n by	0.002

Note: Estimates are by the Federal Highway Administration
Source: USDOT, FHWA, HDS-3 (1961)

5.2.3.4 UNIFORM CROSS SLOPE

The nomograph in **Figure 5.2-1** is used with the following procedures to find gutter capacity for uniform cross slopes:

Condition 1: Find spread, given gutter flow.

(Step 1) Determine input parameters, including longitudinal slope (S), cross slope (S_x), gutter flow (Q), and Manning's n.

(Step 2) Draw a line between the S and S_x scales and note where it intersects the turning line.

(Step 3) Draw a line between the intersection point from Step 2 and the appropriate gutter flow value on the capacity scale. If Manning's n is 0.016, use Q from Step 1; if not, use the product of Q and n.

(Step 4) Read the value of the spread (T) at the intersection of the line from Step 3 and the spread scale.

Condition 2: Find gutter flow, given spread.

(Step 1) Determine input parameters, including longitudinal slope (S), cross slope (S_x), spread (T), and Manning's n.

(Step 2) Draw a line between the S and S_x scales and note where it intersects the turning line.

(Step 3) Draw a line between the intersection point from Step 2 and the appropriate value on the T scale. Read the value of Q or Q_n from the intersection of that line on the capacity scale.

(Step 4) For Manning's n values of 0.016, the gutter capacity (Q) from Step 3 is selected. For other Manning's n values, the gutter capacity times n (Q_n) is selected from Step 3 and divided by the appropriate n value to give the gutter capacity.

5.2.3.5 COMPOSITE GUTTER SECTIONS

Figure 5.2-2 in combination with **Figure 5.2-1** can be used to find the flow in a gutter with width (W) less than the total spread (T). Such calculations are generally used for evaluating composite gutter sections or frontal flow for grate inlets.

Figure 5.2-3 provides a direct solution of gutter flow in a composite gutter section. The flow rate at a given spread or the spread at a known flow rate can be found from this figure. **Figure 5.2-3** involves a complex graphical solution of the equation for flow in a composite gutter section. Typical of graphical solutions, extreme care in using the figure is necessary to obtain accurate results.

Condition 1: Find spread, given gutter flow.

(Step 1) Determine input parameters, including longitudinal slope (S), cross slope (S_x), depressed section slope (S_w), depressed section width (W), Manning's n, gutter flow (Q), and a trial value of gutter capacity above the depressed section (Q_s).

(Step 2) Calculate the gutter flow in W (Q_w), using the equation:

$$Q_w = Q - Q_s \qquad (5.2.2)$$

(Step 3) Calculate the ratios Q_w/Q or E_o and S_w/S_x and use **Figure 5.2-2** to find an appropriate value of W/T.

(Step 4) Calculate the spread (T) by dividing the depressed section width (W) by the value of W/T from Step 3.

(Step 5) Find the spread above the depressed section (T_s) by subtracting W from the value of T obtained in Step 4.

(Step 6) Use the value of Ts from Step 5 along with Manning's n, S, and S_x to find the actual value of Q_s from **Figure 5.2-1**.

(Step 7) Compare the value of Q_s from Step 6 to the trial value from Step 1. If values are not comparable, select a new value of Qs and return to Step 1.

Condition 2: Find gutter flow, given spread.

(Step 1) Determine input parameters, including spread (T), spread above the depressed section (T_s), cross slope (S_x), longitudinal slope (S), depressed section slope (S_w), depressed section width (W), Manning's n, and depth of gutter flow (d).

(Step 2) Use **Figure 5.2-1** to determine the capacity of the gutter section above the depressed section (Q_s). Use the procedure for uniform cross slopes, substituting T_s for T.

(Step 3) Calculate the ratios W/T and S_w/S_x, and, from **Figure 5.2-2**, find the appropriate value of Eo (the ratio of Q_w/Q).

(Step 4) Calculate the total gutter flow using the equation:

$$Q = Q_s / (1 - E_o) \qquad (5.2.3)$$

Where:

Q = gutter flow rate, cfs

$\mathbf{Q_s}$ = flow capacity of the gutter section above the depressed section, cfs

$\mathbf{E_o}$ = ratio of frontal flow to total gutter flow (Q_w/Q)

(Step 5) Calculate the gutter flow in width (W), using **Equation 5.2.2**.

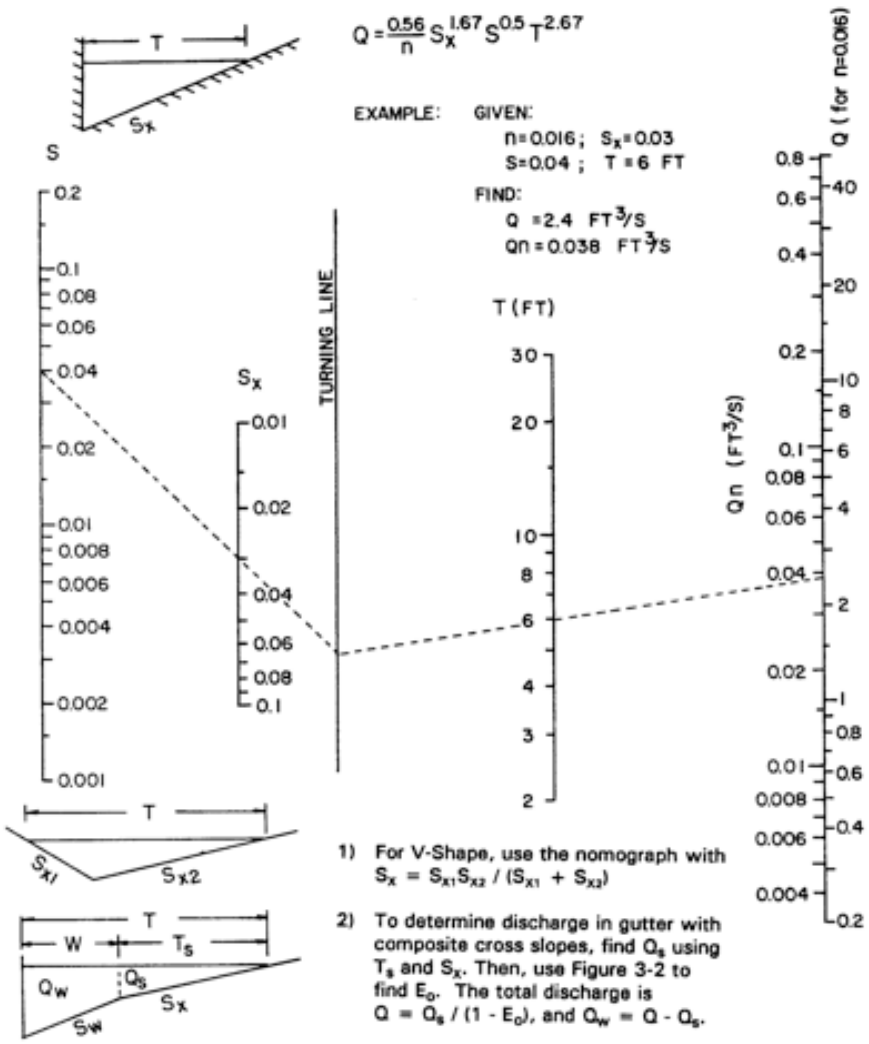


Figure 5.2-1 Flow in Triangular Gutter Sections
(Source: AASHTO Model Drainage Manual, 2005)

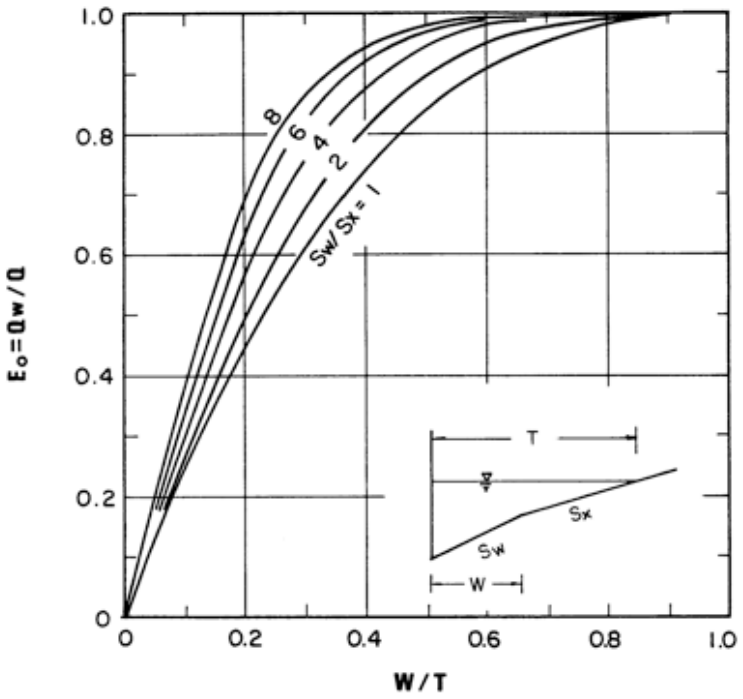


Figure 5.2-2 Ratio of Frontal Flow to Total Gutter Flow
(Source: AASHTO Model Drainage Manual, 2005)

5.2.3.6 EXAMPLES

Example 1

Given: **T** = 8 ft **S**$_x$ = 0.025 ft/ft
n = 0.015 **S** = 0.01 ft/ft

Find: (a) Flow in gutter at design spread
(b) Flow in width (W = 2 ft) adjacent to the curb

Solution:

(a) From **Figure 5.2-1**, Qn = 0.03
Q = Qn/n = 0.03/0.015 = 2.0 cfs

(b) T = 8 - 2 = 6 ft
(Qn)$_2$ = 0.014 (**Figure 5.2-1**)
(flow in 6-foot width outside of width (W))
Q = 0.014/0.015 = 0.9 cfs
Q$_w$ = 2.0 - 0.9 = 1.1 cfs

Flow in the first 2 ft adjacent to the curb is 1.1 cfs and 0.9 cfs in the remainder of the gutter.

Example 2

Given:

T$_s$ = 6 - 1.5 = 4.5 ft **T** = 6 ft
S$_w$ = 0.0833 ft/ft **W** = 1.5 ft
S$_x$ = 0.03 ft/ft **n** = 0.014
S = 0.04 ft/ft

Find: Flow in the composite gutter

Solution:

(1) Use **Figure 5.2-1** to find the gutter section capacity above the depressed section.
Q$_s$n = 0.038
Q$_s$ = 0.038/0.014 = 2.7 cfs

(2) Calculate W/T = 1.5/6 = 0.25 and S$_w$/S$_x$ = 0.0833/0.03 = 2.78
Use **Figure 5.2-2** to find
E$_o$ = 0.64

(3) Calculate the gutter flow using **Equation 5.4.2.3:**
Q = 2.7/(1 - 0.64) = 7.5 cfs

(4) Calculate the gutter flow in width, W, using **Equation 5.2.2:**
Q$_w$ = 7.5 - 2.7 = 4.8 cfs

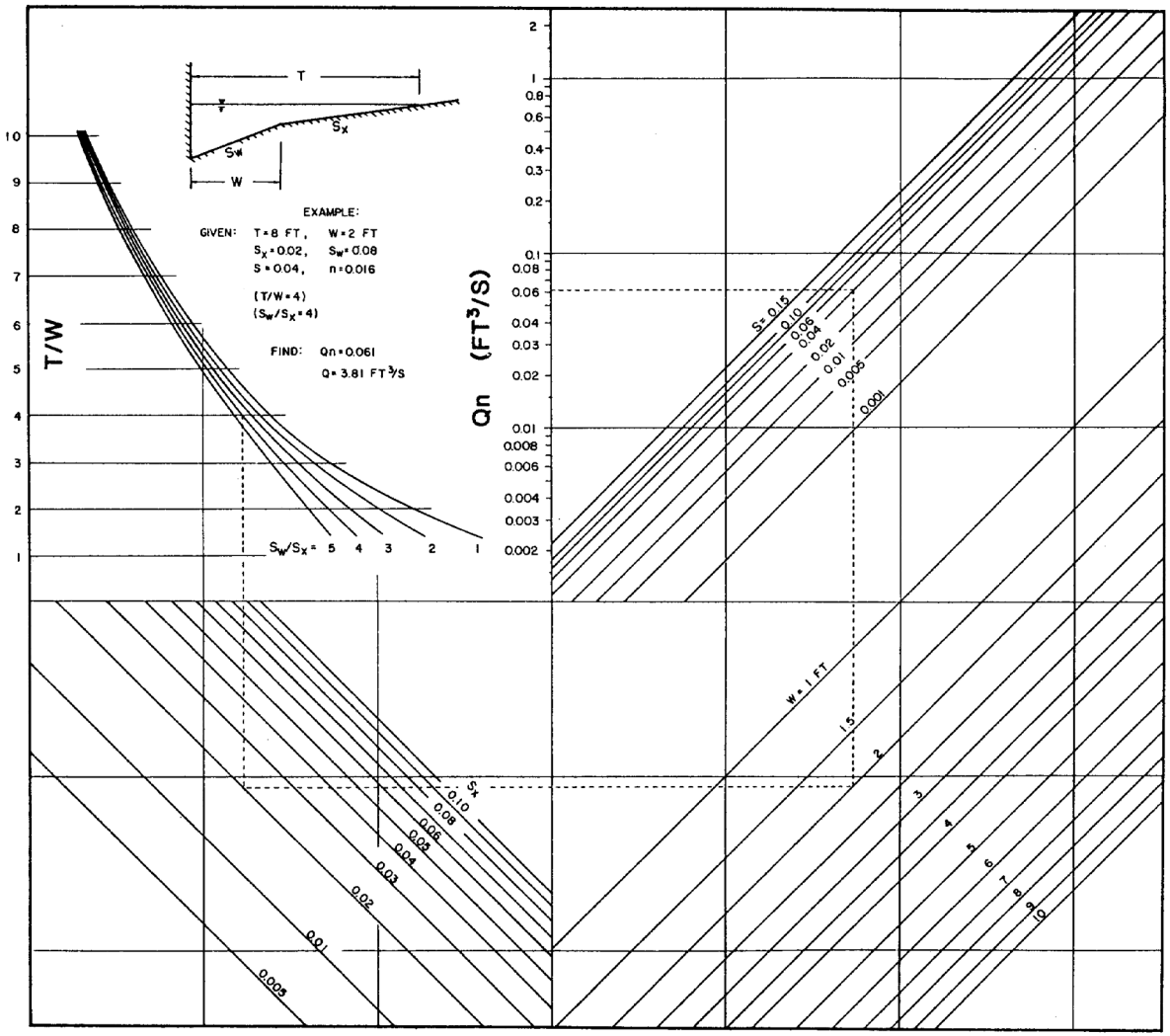


Figure 5.2-3 Flow in Composite Gutter Sections
(Source: AASHTO Model Drainage Manual, 1991)

5.2.4 Stormwater Inlets

Inlets are drainage structures used to collect surface water through grate or curb openings and convey it to storm drains or direct outlet to culverts. Grate inlets subject to traffic should be bicycle safe and be load-bearing adequate. Appropriate frames should be provided.

Inlets used for the drainage of highway surfaces can be divided into three major classes:

1. **Grate Inlets** – These inlets include grate inlets consisting of an opening in the gutter covered by one or more grates, and slotted inlets consisting of a pipe cut along the longitudinal axis with a grate or spacer bars to form slot openings.
2. **Curb-Opening Inlets** – These inlets are vertical openings in the curb covered by a top slab.
3. **Combination Inlets** – These inlets usually consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located in part upstream of the grate.

Inlets may be classified as being on a continuous grade or in a sump. The term "continuous grade" refers to an inlet located on the street with a continuous slope past the inlet with water entering from one direction. The "sump" condition exists when the inlet is located at a low point and water enters from both directions.

Where significant ponding can occur, in locations such as underpasses and in sag vertical curves in depressed sections, it is good engineering practice to place flanking inlets on each side of the inlet at the low point in the sag. The flanking inlets should be placed so that they will limit spread on low gradient approaches to the level point and act in relief of the inlet at the low point if it should become clogged or if the design spread is exceeded.

The design of grate inlets will be discussed in Section 5.2.5, curb inlet design in Section 5.2.6, and combination inlets in Section 5.2.7.

5.2.5 Grate Inlet Design

5.2.5.1 GRATE INLETS ON GRADE

The capacity of an inlet depends upon its geometry and the cross slope, longitudinal slope, total gutter flow, depth of flow and pavement roughness. The depth of water next to the curb is the major factor in the interception capacity of both gutter inlets and curb opening inlets. At low velocities, all of the water flowing in the section of gutter occupied by the grate, called frontal flow, is intercepted by grate inlets, and a small portion of the flow along the length of the grate, termed side flow, is intercepted. On steep slopes, only a portion of the frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. For grates less than 2 feet long, intercepted flow is small.

For inlet efficiency data for various sizes and shapes of grates, refer to the most current edition of Hydraulic Engineering Circular No. 22 Federal Highway Administration.

A parallel bar grate is the most efficient type of gutter inlet; however, when crossbars are added for bicycle safety, the efficiency is greatly reduced.

Table 5.2-3 Grate Debris Handling Efficiencies

Rank	Grate	Longitudinal Slope	
		(0.005)	(0.04)
1	CV - 3-1/4 - 4-1/4	46	61
2	30 - 3-1/4 - 4	44	55
3	45 - 3-1/4 - 4	43	48
4	P - 1-7/8	32	32
5	P - 1-7/8 - 4	18	28
6	45 - 2-1/4 - 4	16	23
7	Recticuline	12	16
8	P - 1-1/8	9	20

Source: "Drainage of Highway Pavements" (HEC-12), Federal Highway Administration, 1984.

Where bicycle traffic is a design consideration, the curved vane grate and the tilt bar grate are recommended for both their hydraulic capacity and bicycle safety features. They also handle debris better than other grate inlets but the vanes of the grate must be turned in the proper direction.
Where debris is a problem, consideration should be given to debris handling efficiency rankings of grate inlets from laboratory tests in which an attempt was made to qualitatively simulate field conditions. **Table 5.2-3** presents the results of debris handling efficiencies of several grates.

The ratio of frontal flow to total gutter flow, E_o, for straight cross slope is expressed by the following equation:

$$E_o = Q_w/Q = 1 - (1 - W/T)^{2.67} \qquad (5.2.4)$$

Where:

Q = total gutter flow, cfs
$\mathbf{Q_w}$ = flow in width W, cfs
W = width of depressed gutter or grate, ft
T = total spread of water in the gutter, ft

Figure 5.2-2 provides a graphical solution of E_o for either depressed gutter sections or straight cross slopes. The ratio of side flow, Q_s, to total gutter flow is:

$$Q_s/Q = 1 - Q_w/Q = 1 - E_o \qquad (5.2.5)$$

The ratio of frontal flow intercepted to total frontal flow, R_f, is expressed by the following equation:

$$R_f = 1 - 0.09\,(V - V_0) \qquad (5.2.6)$$

Where:

V = velocity of flow in the gutter, ft/s
(using Q from **Figure 5.2-1**)
$\mathbf{V_o}$ = gutter velocity where splash-over first occurs, ft/s
(from **Figure 5.2-4**)

This ratio is equivalent to frontal flow interception efficiency. **Figure 5.2-4** provides a solution of **equation 5.2.6**, which takes into account grate length, bar configuration and gutter velocity at which splash-over occurs. The gutter velocity needed to use **Figure 5.2-4** is total gutter flow divided by the area of flow. The ratio of side flow intercepted to total side flow, Rs, or side flow interception efficiency, is expressed by:

$$Rs = 1 / [1 + (0.15V^{1.8}/S_xL^{2.3})] \qquad (5.2.7)$$

Where:

L = length of the grate, ft
$\mathbf{S_x}$ = pavement cross slope, ft/ft

Figure 5.2-5 provides a solution to equation **5.2.7**.

The efficiency, E, of a grate is expressed as:

$$E = R_fE_o + R_s(1 - E_o) \qquad (5.2.8)$$

The interception capacity of a grate inlet on grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i = EQ = Q[R_f E_o + R_s(1 - E_o)] \qquad (5.2.9)$$

The following example illustrates the use of this procedure.

Given:

W = 2 ft
T = 8 ft
S_x = 0.025 ft/ft
S = 0.01 ft/ft
E_o = 0.69
Q = 3.0 cfs
V = 3.1 ft/s
Gutter depression = 2 in

Find:

Interception capacity of:

(1) a curved vane grate, and

(2) a reticuline grate 2-ft long and 2-ft wide

Solution:

From **Figure 5.2-4** for Curved Vane Grate, R_f = 1.0
From **Figure 5.2-4** for Reticuline Grate, R_f = 1.0
From **Figure 5.2-5** R_s = 0.1 for both grates
From **Equation 5.2.9**:

$$Q_i = 3.0[1.0 \text{ X } 0.69 + 0.1(1 - 0.69)] = 2.2 \text{ cfs}$$

For this example, the interception capacity of a curved vane grate is the same as that for a reticuline grate for the sited conditions.

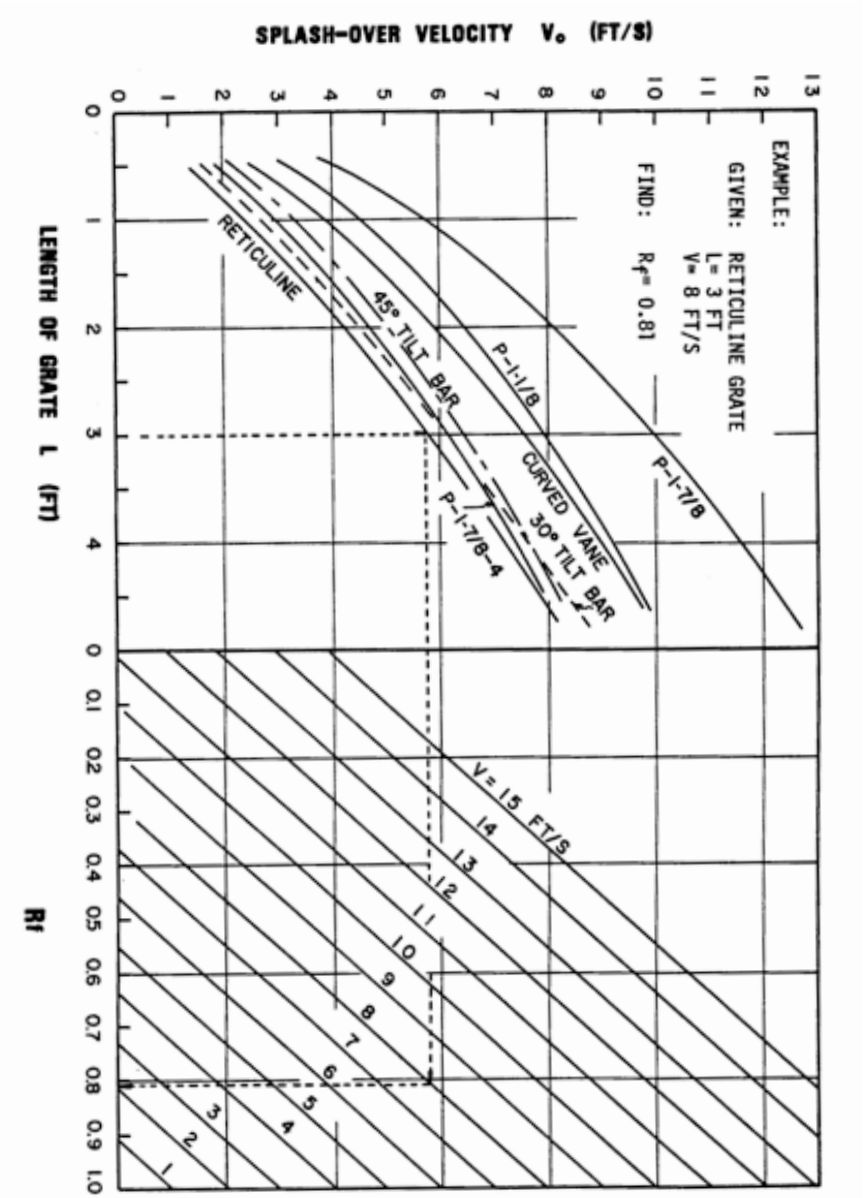


Figure 5.2-4 Grate Inlet Frontal Flow Interception Efficiency
(Source: HEC-12, 1984)

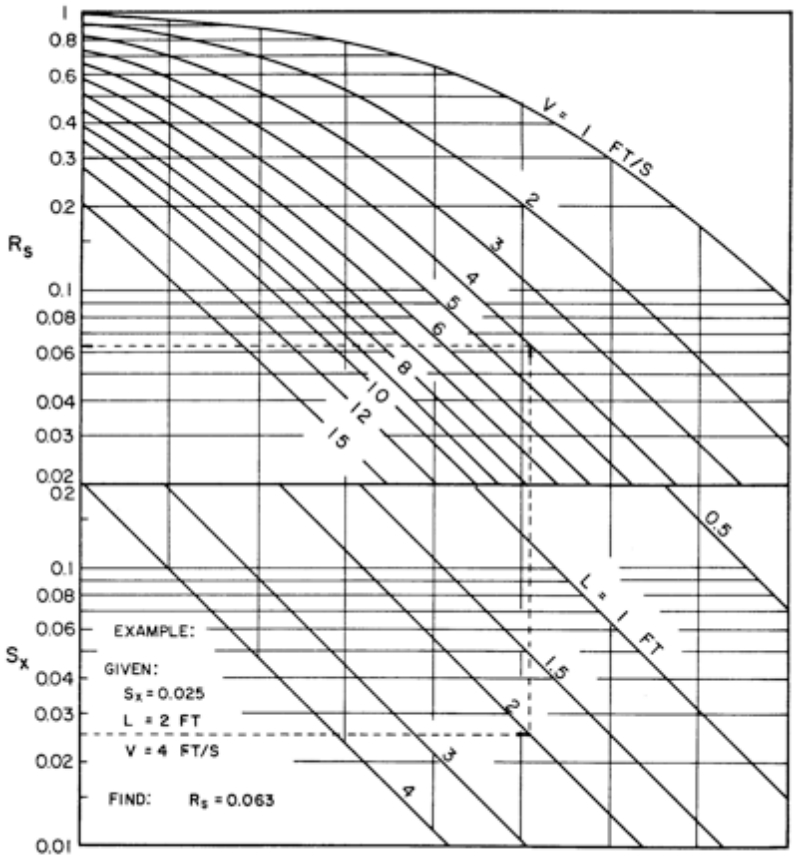


Figure 5.2-5 Grate Inlet Side Flow Interception Efficiency
(Source: HEC-12, 1984)

5.2.5.2 GRATE INLETS IN SAG

A grate inlet in a sag operates as a weir up to a certain depth, depending on the bar configuration and size of the grate, and as an orifice at greater depths. For a standard gutter inlet grate, weir operation continues to a depth of about 0.4 feet above the top of grate and when depth of water exceeds about 1.4 feet, the grate begins to operate as an orifice. Between depths of about 0.4 feet and about 1.4 feet, a transition from weir to orifice flow occurs.

The capacity of grate inlets operating as a weir is:

$$Q_i = CPd^{1.5} \qquad (5.2.10)$$

Where:

P = perimeter of grate excluding bar widths and the side against the curb, ft

C = 3.0

d = depth of water above grate, ft

and as an orifice is:

$$Q_i = CA(2gd)^{0.5} \qquad (5.2.11)$$

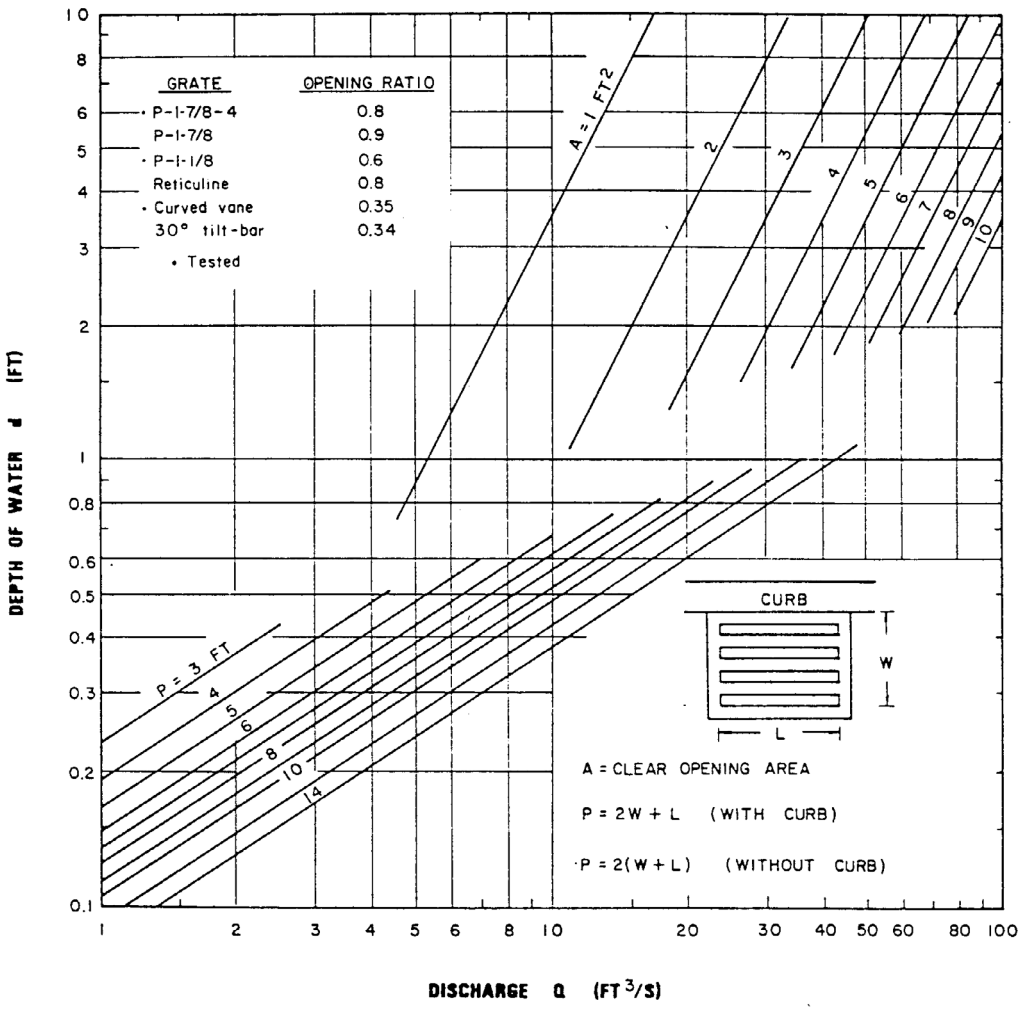
Where:

C = 0.67 orifice coefficient

A = clear opening area of the grate, ft^2

g = 32.2 ft/s^2

Figure 5.2-6 is a plot of **equations 5.2.10** and **5.2.11** for various grate sizes. The effects of grate size on the depth at which a grate operates as an orifice is apparent from the chart. Transition from weir to orifice flow results in interception capacity less than that computed by either weir or the orifice equation. This capacity can be approximated by drawing in a curve between the lines representing the perimeter and net area of the grate to be used. The following example illustrates the use of this figure.



Reference: USDOT, FHWA, HEC-12 (1984).

Figure 5.2-6 Grate Inlet Capacity in Sag Conditions
(Source: HEC-12, 1984)

Example

Given: A symmetrical sag vertical curve with equal bypass from inlets upgrade of the low point; allow for 50% clogging of the grate.

$\mathbf{Q_b}$ = 3.6 cfs
Q = 8 cfs, 25-year storm
T = 10 ft, design
$\mathbf{S_x}$ = 0.05 ft/ft
d = TS_x = 0.5 ft

Find: Grate size for design Q. Check spread at S = 0.003 on approaches to the low point.

Solution: From **Figure 5.2-6**, a grate must have a perimeter of 8 ft to intercept 8 cfs at a depth of 0.5 ft.

Some assumptions must be made regarding the nature of the clogging in order to compute the capacity of a partially clogged grate. If the area of a grate is 50% covered by debris so that the debris-covered portion does not contribute to interception, the effective perimeter will be reduced by a lesser amount than 50%. For example if a 2-ft x 4-ft grate is clogged so that the effective width is 1 ft, then the perimeter, P = 1 + 4 + 1 = 6 ft, rather than 8 ft, the total perimeter, or 4 ft, half of the total perimeter. The area of the opening would be reduced by 50% and the perimeter by 25%.

Therefore, assuming 50% clogging along the length of the grate, a 4 x 4, a 2 x 6, or a 3 x 5 grate would meet requirements of an 8-ft perimeter 50% clogged.

Assuming that the installation chosen to meet design conditions is a double 2 x 3 ft grate, for 50% clogged conditions: P = 1 + 6 + 1 = 8 ft

For 10-year flow: d = 0.5 ft (from **Figure 5.2-6**)

The American Society of State Highway and Transportation Officials (AASHTO) geometric policy recommends a gradient of 0.3% within 50 ft of the level point in a sag vertical curve.

Check T at S = 0.003 for the design and check flow (from **Figure 5.2-1**):

Q = 3.6 cfs,
T = 8.2 ft (10-year storm)

Thus a double 2 x 3-ft grate 50% clogged is adequate to intercept the design flow at a spread that does not exceed design spread, and spread on the approaches to the low point will not exceed design spread. However, the tendency of grate inlets to clog completely warrants consideration of a combination inlet, or curb-opening inlet in a sag where ponding can occur, and flanking inlets on the low gradient approaches.

5.2.6 Curb Inlet Design

5.2.6.1 CURB INLETS ON GRADE

Following is a discussion of the procedures for the design of curb inlets on grade. Curb-opening inlets are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. They are a viable alternative to grates in many locations where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists.

The length of curb-opening inlet required for total interception of gutter flow on a pavement section with a straight cross slope is determined using **Figure 5.2-7**. The efficiency of curb-opening inlets shorter than the length required for total interception is determined using **Figure 5.2-8**.

The length of inlet required for total interception by depressed curb-opening inlets or curb-openings in depressed gutter sections can be found by the use of an equivalent cross slope, S_e, in the following equation:

$$S_e = S_x + S_w E_o \qquad (5.2.12)$$

Where:

S_x = pavement cross slope, ft/ft

S_w = gutter cross slope = (a/12W), ft/ft

a = gutter depression, in

W = gutter width, ft

E_o = ratio of flow in the depressed section to total gutter flow

It is apparent from examination of **Figure 5.2-7** that the length of curb opening required for total interception can be significantly reduced by increasing the cross slope or the equivalent cross slope. The equivalent cross slope can be increased by use of a continuously depressed gutter section or a locally depressed gutter section.

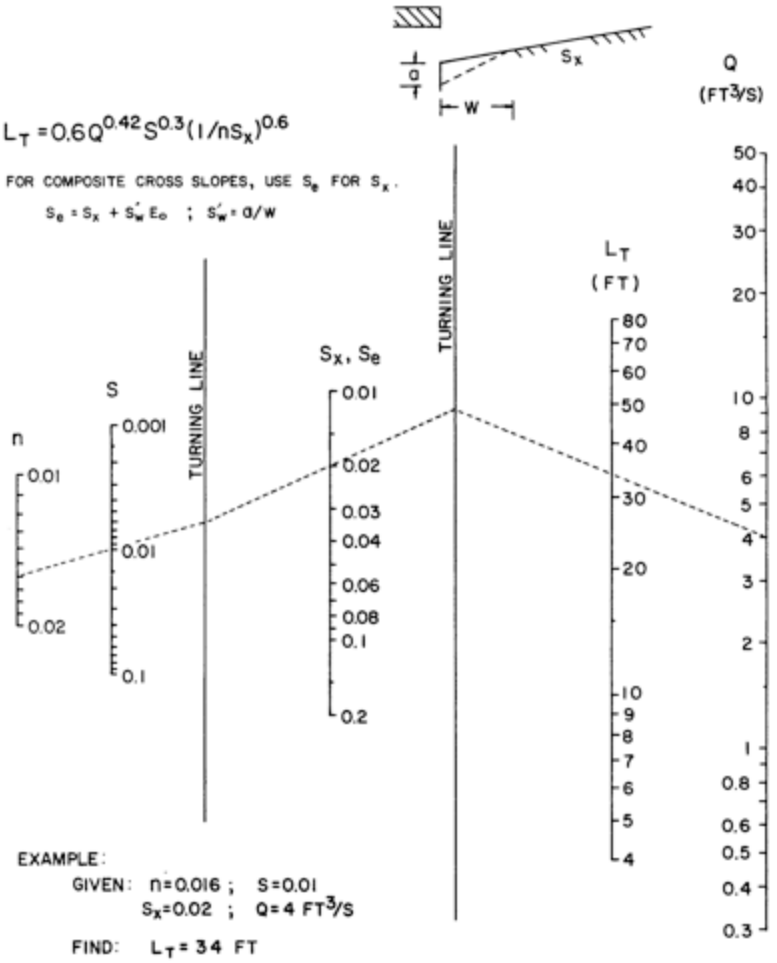


Figure 5.2-7 Curb-Opening and Slotted Drain Inlet Length for Total Interception
(Source: HEC-12, 1984)

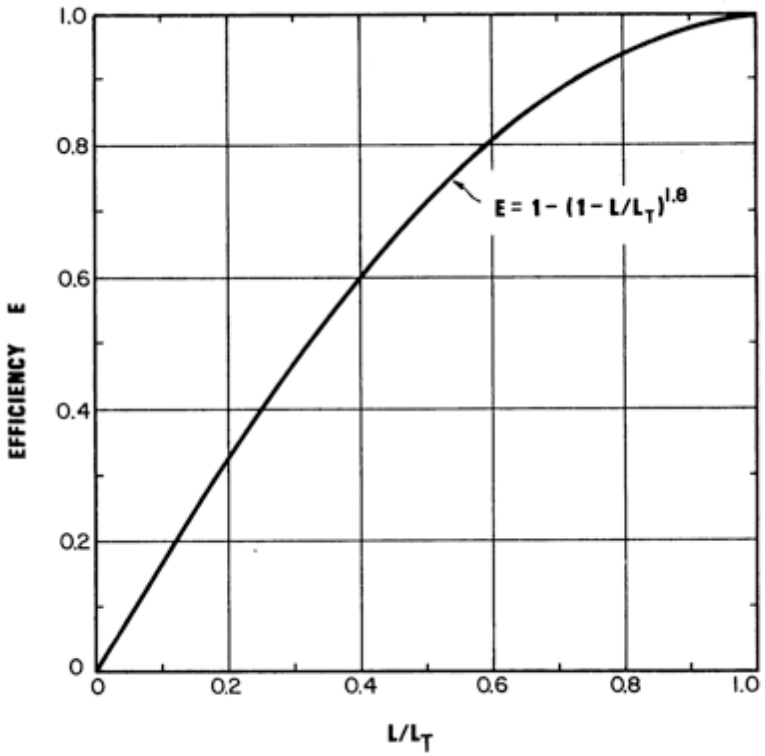


Figure 5.2-8 Curb-Opening and Slotted Drain Inlet Interception Efficiency
(Source: HEC-12, 1984)

Design Steps

Steps for using **Figures 5.2-7** and **5.2-8** in the design of curb inlets on grade are given below.

(Step 1) Determine the following input parameters:
Cross slope = Sx (ft/ft)
Longitudinal slope = S (ft/ft)
Gutter flow rate = Q (cfs)
Manning's n = n
Spread of water on pavement = T (ft) from **Figure 5.2-1**

(Step 2) Enter **Figure 5.2-7** using the two vertical lines on the left side labeled n and S. Locate the value for Manning's n and longitudinal slope and draw a line connecting these points and extend this line to the first turning line.

(Step 3) Locate the value for the cross slope (or equivalent cross slope) and draw a line from the point on the first turning line through the cross slope value and extend this line to the second turning line.

(Step 4) Using the far right vertical line labeled Q locate the gutter flow rate. Draw a line from this value to the point on the second turning line. Read the length re-quired from the vertical line labeled L_T.

(Step 5) If the curb-opening inlet is shorter than the value obtained in Step 4, **Figure 5.2-8** can be used to calculate the efficiency. Enter the x-axis with the L/L_T ratio and draw a vertical line upward to the E curve. From the point of intersection, draw a line horizontally to the intersection with the y-axis and read the efficiency value.

Example

Given:

S_x = 0.03 ft/ft n = 0.016
S = 0.035 ft/ft Q = 5 cfs
S_w = 0.083 (a = 2 in, W = 2 ft)

Find:

(1) Q_i for a 10-ft curb-opening inlet
(2) Q_i for a depressed 10-ft curb-opening inlet with a = 2 in, W = 2 ft, T = 8 ft (**Figure 5.2-1**)

Solution:

(1) From **Figure 5.2-7**, LT = 41 ft, L/LT = 10/41 = 0.24
From Figure 5.2-8, E = 0.39, Qi = EQ = 0.39 x 5 = 2 cfs
(2) Qn = 5.0 x 0.016 = 0.08 cfs

S_w/S_x = (0.03 + 0.083)/0.03 = 3.77
T/W = 3.5 (from **Figure 5.2-3**)
T = 3.5 x 2 = 7 ft
W/T = 2/7 = 0.29 ft
E_o = 0.72 (from **Figure 5.2-2**)

Therefore, $S_e = S_x + S_wE_o$ = 0.03 + 0.083(0.72) = 0.09

From **Figure 5.2-7**, LT = 23 ft, L/LT = 10/23 = 0.4
From **Figure 5.2-8**, E = 0.64, Q_i = 0.64 x 5 = 3.2 cfs

The depressed curb-opening inlet will intercept 1.6 times the flow intercepted by the undepressed curb opening and over 60% of the total flow.

5.2.6.2 CURB INLETS IN SUMP

For the design of a curb-opening inlet in a sump location, the inlet operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The capacity of curb-opening inlets in a sump location can be determined from **Figure 5.2-9**, which accounts for the operation of the inlet as a weir and as an orifice at depths greater than 1.4h. This figure is applicable to depressed curb-opening inlets and the depth at the inlet includes any gutter depression. The height (h) in the figure assumes a vertical orifice opening (see sketch on **Figure 5.2-9**). The weir portion of **Figure 5.2-9** is valid for a depressed curb-opening inlet when $d \leq (h + a/12)$.

The capacity of curb-opening inlets in a sump location with a vertical orifice opening but without any depression can be determined from **Figure 5.2-10**. The capacity of curb-opening inlets in a sump location with other than vertical orifice openings can be determined by using **Figure 5.2-11**.

Design Steps

Steps for using **Figures 5.2-9, 5.2-10**, and **5.2-11** in the design of curb-opening inlets in sump locations are given below.

(Step 1) Determine the following input parameters:
Cross slope = S_x (ft/ft)
Spread of water on pavement = T (ft) from **Figure 5.2-1**
Gutter flow rate = Q (cfs) or dimensions of curb-opening inlet [L (ft) and H (in)]
Dimensions of depression if any [a (in) and W (ft)]

(Step 2) To determine discharge given the other input parameters, select the appropriate figure (**5.2-9, 5.2-10**, or **5.2-11** depending on whether the inlet is in a depression and if the orifice opening is vertical).

(Step 3) To determine the discharge (Q), given the water depth (d), locate the water depth value on the y-axis and draw a horizontal line to the appropriate perimeter (p), height (h), length (L), or width x length (hL) line. At this intersection draw a vertical line down to the x-axis and read the discharge value.

(Step 4) To determine the water depth given the discharge, use the procedure described in Step 3 except enter the figure at the value for the discharge on the x-axis.

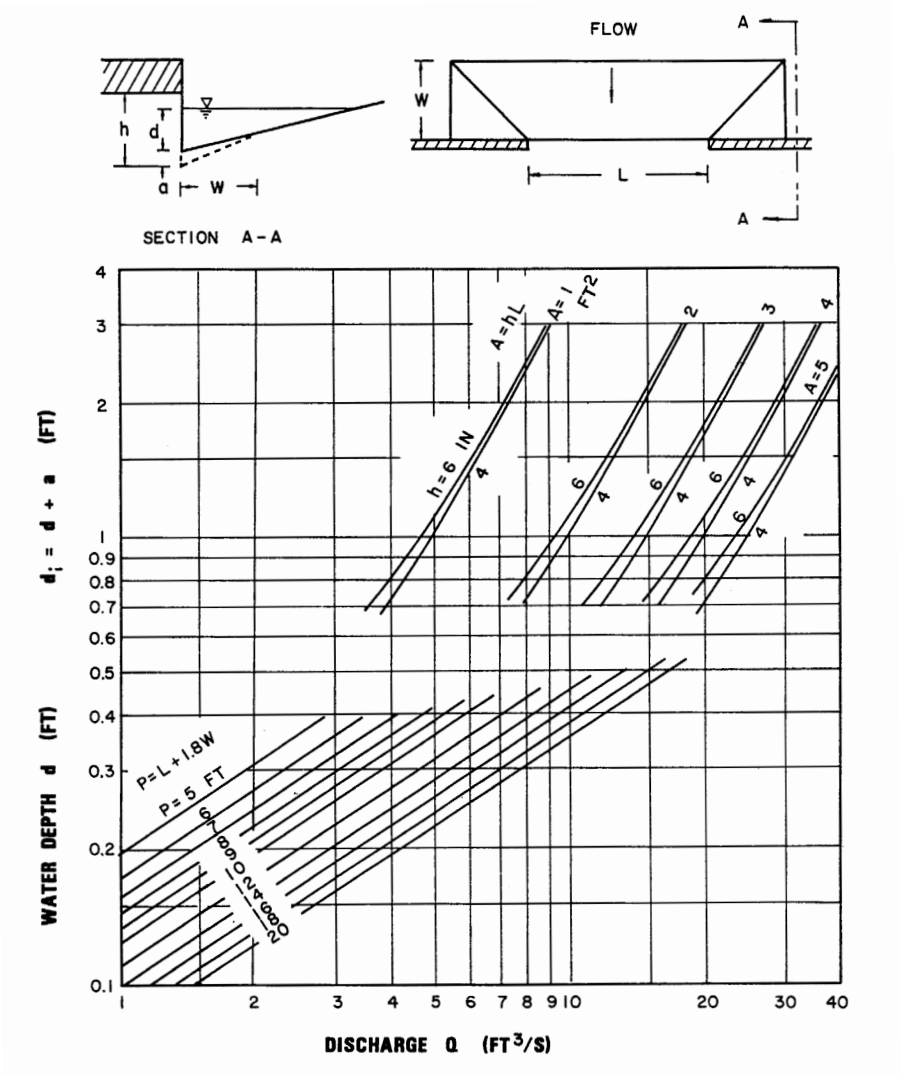


Figure 5.2-9 Depressed Curb-Opening Inlet Capacity in Sump Locations
(Source: AASHTO Model Drainage Manual, 2005)

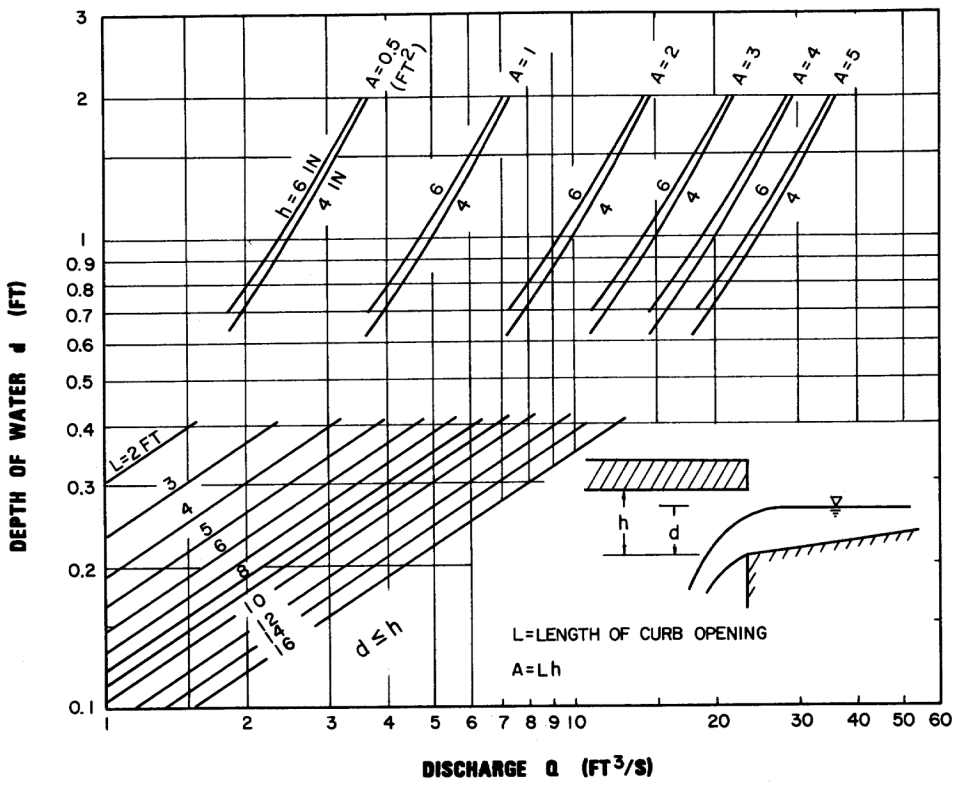


Figure 5.2-10 Curb-Opening Inlet Capacity in Sump Locations
(Source: AASHTO Model Drainage Manual, 2005)

Example

Given: Curb-opening inlet in a sump location

L = 5 ft

h = 5 in

(1) Undepressed curb opening

S_x = 0.05 ft/ft

T = 8 ft

(2) Depressed curb opening

S_x = 0.05 ft/ft

a = 2 in

W = 2 ft

T = 8 ft

Find: Discharge Q_i

Solution:

(1) $d = TS_x = 8 \times 0.05 = 0.4$ ft

d < h

From **Figure 5.2-10**, Q_i = 3.8 cfs

(2) d = 0.4 ft

h + a/12 = (5 + 2/12)/12 = 0.43 ft

Since d < 0.43 the weir portion of **Figure 5.2-9** is applicable (lower portion of the figure).

P = L + 1.8W = 5 + 3.6 = 8.6 ft

From **Figure 5.2-9**, Q_i = 5 cfs

At d = 0.4 ft, the depressed curb-opening inlet has about 30% more capacity than an inlet without depression.

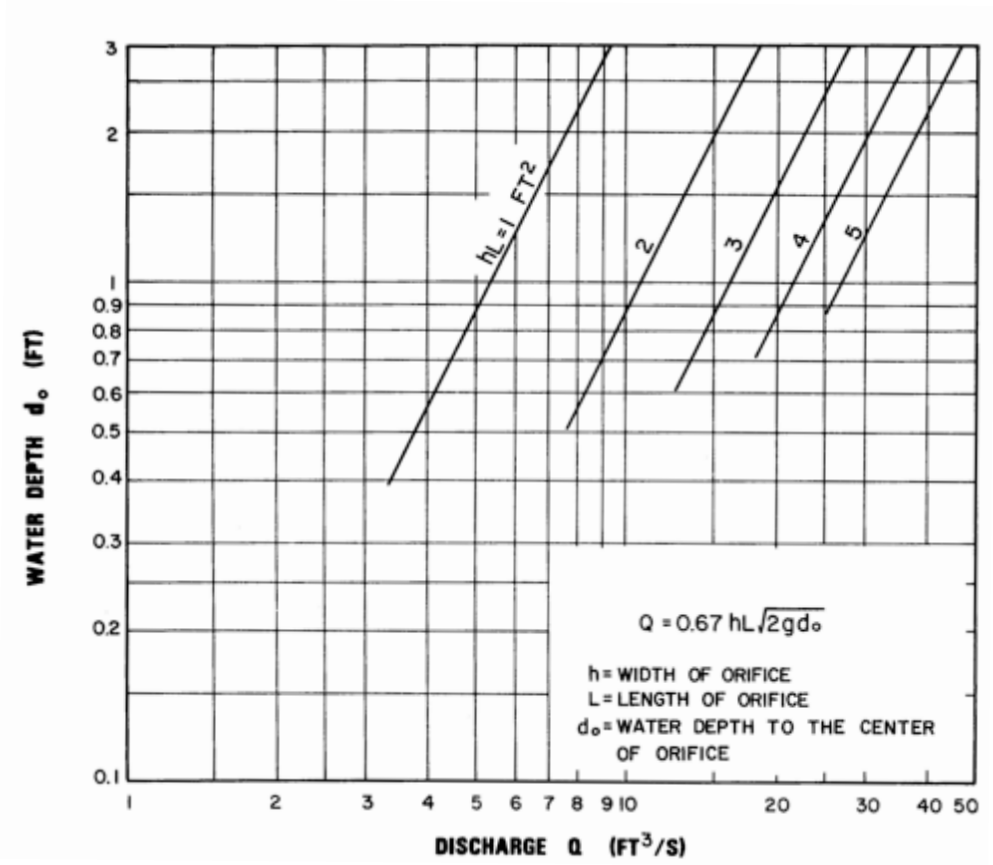


Figure 5.2-11 Curb-Opening Inlet Orifice Capacity for Inclined and Vertical Orifice Throats
(Source: AASHTO Model Drainage Manual, 2005)

5.2.7 Combination Inlets

5.2.7.1 COMBINATION INLETS ON GRADE

On a continuous grade, the capacity of an unclogged combination inlet with the curb opening located adjacent to the grate is approximately equal to the capacity of the grate inlet alone. Thus capacity is computed by neglecting the curb opening inlet and the design procedures should be followed based on the use of **Figures 5.2-4, 5.2-5** and **5.2-6**.

5.2.7.2 COMBINATION INLETS IN SUMP

All debris carried by stormwater runoff that is not intercepted by upstream inlets will be concentrated at the inlet located at the low point, or sump. Because this will increase the probability of clogging for grated inlets, it is generally appropriate to estimate the capacity of a combination inlet at a sump by neglecting the grate inlet capacity. Assuming complete clogging of the grate, Figures **5.2-9**, **5.2-10**, and **5.2-11** for curb-opening inlets should be used for design.

5.2.8 Storm Drain Pipe Systems

5.2.8.1 INTRODUCTION

Storm drain pipe systems, also known as storm sewers, are pipe conveyances used in the minor stormwater drainage system for transporting runoff from roadway and other inlets to outfalls at structural stormwater controls and receiving waters. Pipe drain systems are suitable mainly for medium to high-density residential and commercial/industrial development where the use of natural drainageways and/or vegetated open channels is not feasible.

5.2.8.2 GENERAL DESIGN PROCEDURE

The design of storm drain systems generally follows these steps:

(Step 1) Determine inlet location and spacing as outlined earlier in this section.

(Step 2) Prepare a tentative plan layout of the storm sewer drainage system including:

a. Location of storm drains
b. Direction of flow
c. Location of manholes
d. Location of existing facilities such as water, gas, or underground cables

(Step 3) Determine drainage areas and compute runoff using the Rational Method

(Step 4) After the tentative locations of inlets, drain pipes, and outfalls (including tailwaters) have been determined and the inlets sized, compute of the rate of discharge to be carried by each storm drain pipe and determine the size and gradient of pipe required to care for this discharge. This is done by proceeding in steps from upstream of a line to downstream to the point at which the line connects with other lines or the outfall, whichever is applicable. The discharge for a run is calculated, the pipe serving that discharge is sized, and the process is repeated for the next run downstream. The storm drain system design computation form (**Figure 5.2-12**) can be used to summarize hydrologic, hydraulic and design computations.

(Step 5) Examine assumptions to determine if any adjustments are needed to the final design.

It should be recognized that the rate of discharge to be carried by any particular section of storm drain pipe is not necessarily the sum of the inlet design discharge rates of all inlets above that section of pipe, but as a general rule is somewhat less than this total. It is useful to understand that the time of concentration is most influential and as the time of concentration grows larger, the proper rainfall intensity to be used in the design grows smaller.

5.2.8.3 DESIGN CRITERIA

Storm drain pipe systems should conform to the following criteria:

- For ordinary conditions, storm drain pipes should be sized on the assumption that they will flow full or practically full under the design discharge but will not be placed under pressure head. The Manning Formula is recommended for capacity calculations.
- The maximum hydraulic gradient should not produce a velocity that exceeds those specified in the Gwinnett County Storm Sewer Pipe Standards.
- The minimum desirable physical slope shall be 0.5% or the slope that will produce a velocity of 2.5 feet per second when the storm sewer is flowing full, whichever is greater.
- If the potential water surface elevation exceeds 1 foot below ground elevation for the design flow, the top of the pipe, or the gutter flow line, whichever is lowest, adjustments are needed in the system to reduce the elevation of the hydraulic grade line.

- All culverts carrying a live stream shall be embedded in accordance with USACE and GA EPD requirements.
- Based on the analysis of 100-year conditions, the preliminary design shall be revised where necessary to produce a final design for which the likelihood of dwelling flooding, major property damage, or substantial public access and/or utility interruption shall be less than one chance in 100 years.
- The minimum allowable pipe diameter shall be 18 inches.
- Complete flow, velocity, and hydraulic grade line computations, shall be provided for all portions of a piped collection system. Hydraulic grade lines shall be shown on the storm drainage profiles contained with the Development Plans for the 25-year storm.
- Pipes that do not carry live streams shall extend at least 50 feet beyond the front building setback lines, and may be required to extend farther where necessary to provide an adequately protected building site on the property. In nonresidential subdivisions, these pipes may temporarily end at the right-of-way line, but shall be extended as part of a subsequent development permit approved for the individual site.
- The length requirement, however, shall be subject to requirements for
  - » Maintaining stream buffers in accordance with Georgia law, or County regulations.
  - » Regulations enforced by the U. S. Army Corps of Engineers.
- The maximum velocity in a pipe system for the design flow shall meet the requirements noted in the Gwinnett County Storm Sewer Pipe Standards.
- The maximum allowable slope for a concrete storm drainage pipe shall be 10 percent, for a corrugated metal pipe shall be 14 percent and for a HDPE pipe shall be 14 percent. Greater slopes may be approved if installation is in accordance with manufacturer's recommendations. In cases where the slope is in excess of 10 percent, anchor collars may be required.
- Minimum pipe cover of one (1) foot shall be required, and if drainage pipe is installed prior to the completion of grading, minimum cover must be provided in accordance with the Gwinnett County Storm Sewer Pipe Standards.
- Outlet structures (such as headwalls) shall not be located closer to the project site's property line with an adjoining property than the greater of the distance necessary to construct any velocity protection or a flow distance equal to six (6) pipe diameters. For non-circular conduits, this distance shall be six (6) times the rise dimension of the conduit.
- The invert elevation of a culvert or pipe outlet shall be no more than 2 feet above the elevation of the bottom of the receiving watercourse at the outlet.

The discharge of concentrated flows of storm water into public roadways shall be avoided. In no case shall such concentrated flows, including flows from swales, ditches, draws, driveways, or piped systems, exceed the allowable peak flow rates in **Table 9-G**, below.

Table 9-G Maximum Flows into Streets

Street Classification	Allowable Peak Flow Rate for A 2-Year Storm
Local	2.0 cfs
Minor Collector	1.0 cfs
Other	0.5 cfs

- In residential subdivisions, the drainage area contributing to the peak flow along any property line between lots within 50 feet of the building setback line for either lot shall not exceed 2 acres, unless contained within a piped drainage system or maintained in a natural watercourse. The storm water conveyance shall be in a drainage easement.

STORM DRAIN COMPUTATION SHEET

COMPUTED _____ DATE _____

CHECKED _____ DATE _____

ROUTE _____

SECTION _____

COUNTY _____

STATION		LENGTH FEET	DRAINAGE AREA "A" (ACRES)		RUNOFF COEFFICIENT "C"	"A" • "C"		FLOW TIME MIN.		RAINFALL INTENSITY "I" in/hour	TOTAL RUNOFF C.I.A. = Q (c.f.s.)	DIAMETER PIPE inches	CAPACITY FULL c.f.s.	VELOCITY f.p.s.		INVERT ELEV		MANHOLE INVERT DROP	SLOPE OF DRAIN ft/ft
FROM	TO		INCREMENT	TOTAL		INCREMENT	TOTAL	TO UPPER END	IN SECTION					FLOWING FULL	DESIGN FLOW	UPPER END	LOWER END		

5.2.8.4 CAPACITY CALCULATIONS

Formulas for Gravity and Pressure Flow

The most widely used formula for determining the hydraulic capacity of storm drain pipes for gravity and pressure flows is the Manning's Formula, expressed by the following equation:

$$V = [1.486\ R^{2/3}S^{1/2}]/n \qquad (5.2.13)$$

Where:

V = mean velocity of flow, ft/s
R = the hydraulic radius, ft -defined as the area of flow divided by the wetted flow surface or wetted perimeter (A/WP)
S = the slope of hydraulic grade line, ft/ft
n = Manning's roughness coefficient

In terms of discharge, the above formula becomes:

$$Q = [1.486\ AR^{2/3}S^{1/2}]/n \qquad (5.2.14)$$

Where:

Q = rate of flow, cfs
A = cross sectional area of flow, ft^2

For pipes flowing full, the above equations become:

$$V = [0.590\ D^{2/3}S^{1/2}]/n \qquad (5.2.15)$$

$$Q = [0.463\ D^{8/3}S^{1/2}]/n \qquad (5.2.16)$$

Where:

D = diameter of pipe, ft

The Manning's equation can be written to determine friction losses for storm drain pipes as:

$$H_f = [2.87\ n^2V^2L]/[S^{4/3}] \qquad (5.2.17)$$

$$H_f = [29\ n^2V^2L]/[(R^{4/3})\ (2g)] \qquad (5.2.18)$$

Where:

H_f = total head loss due to friction, ft
n = Manning's roughness coefficient
D = diameter of pipe, ft
L = length of pipe, ft
V = mean velocity, ft/s
R = hydraulic radius, ft
g = acceleration of gravity = 32.2 ft/sec^2

5.2.8.5 NOMOGRAPHS AND TABLE

The nomograph solution of Manning's formula for full flow in circular storm drain pipes is shown in **Figures 5.2-13, 5.2-14**, and **5.2-15**. **Figure 5.2-16** has been provided to solve the Manning's equation for partially full flow in storm drains.

5.2.8.6 HYDRAULIC GRADE LINES

All head losses in a storm sewer system are considered in computing the hydraulic grade line to determine the water surface elevations, under design conditions in the various inlets, catch basins, manholes, junction boxes, etc.

Hydraulic control is a set water surface elevation from which the hydraulic calculations are begun. All hydraulic controls along the alignment are established. If the control is at a main line upstream inlet (inlet control), the hydraulic grade line is the water surface elevation minus the entrance loss minus the difference in velocity head. If the control is at the outlet, the water surface is the outlet pipe hydraulic grade line.

Design Procedure - Outlet Control

The head losses are calculated beginning from the control point upstream to the first junction and the procedure is repeated for the next junction. The computation for an outlet control may be tabulated on **Figure 5.2-17** using the following procedure:

(Step 1) Enter in Column 1 the station for the junction immediately upstream of the outflow pipe. Hydraulic grade line computations begin at the outfall and are worked upstream taking each junction into consideration.

(Step 2) Enter in Column 2 the outlet water surface elevation if the outlet will be sub-merged during the design storm or 0.8 diameter plus invert elevation of the outflow pipe, whichever is greater.

(Step 3) Enter in Column 3 the diameter (D_o) of the outflow pipe.

(Step 4) Enter in Column 4 the design discharge (Q_o) for the outflow pipe.

(Step 5) Enter in Column 5 the length (L_o) of the outflow pipe.

(Step 6) Enter in Column 6 the friction slope (S_f) in ft/ft of the outflow pipe. This can be determined by using the following formula:

$$S_f = (Q^2)/K \qquad (5.2.19)$$

Where:

S_f = friction slope

$K = [1.486\ AR^{2/3}]/n$

(Step 7) Multiply the friction slope (S_f) in Column 6 by the length (L_o) in Column 5 and enter the friction loss (H_f) in Column 7. On curved alignments, calculate curve losses by using the formula $H_c = 0.002\ (\Delta)(V_o^2/2g)$, where Δ = angle of curvature in degrees and add to the friction loss.

(Step 8) Enter in Column 8 the velocity of the flow (V_o) of the outflow pipe.

(Step 9) Enter in Column 9 the contraction loss (H_o) by using the formula:

$$H_o = [0.25\ V_o^2)]/2g, \textit{ where } g = 32.2\ ft/s^2$$

(Step 10) Enter in Column 10 the design discharge (Q_i) for each pipe flowing into the junction. Neglect lateral pipes with inflows of less than 10% of the mainline outflow. Inflow must be adjusted to the mainline outflow duration time before a comparison is made.

(Step 11) Enter in Column 11 the velocity of flow (V_i) for each pipe flowing into the junction (for exception see Step 10).

(Step 12) Enter in Column 12 the product of $Q_i \times V_i$ for each inflowing pipe. When several pipes inflow into a junction, the line producing the greatest $Q_i \times V_i$ product is the one that should be used for expansion loss calculations.

(Step 13) Enter in Column 13 the controlling expansion loss (H_i) using the formula:

$$H_i = [0.35\ (V_1^2)]/2g$$

(Step 14) Enter in Column 14 the angle of skew of each inflowing pipe to the outflow pipe (for exception, see Step 10).

(Step 15) Enter in Column 15 the greatest bend loss (H) calculated by using the formula H = $[KV_i^2)]/2g$ where K = the bend loss coefficient corresponding to the various angles of skew of the inflowing pipes.

(Step 16) Enter in Column 16 the total head loss (H_t) by summing the values in Column 9 (H_o), Column 13 (H_i), and Column 15 (HΔ).

(Step 17) If the junction incorporates adjusted surface inflow of 10% or more of the mainline outflow, i.e., drop inlet, increase H_t by 30% and enter the adjusted H_t in Column 17.

(Step 18) If the junction incorporates full diameter inlet shaping, such as standard man-holes, reduce the value of H_t by 50% and enter the adjusted value in Column 18.

(Step 19) Enter in Column 19 the FINAL H, the sum of H_f and H_t, where H_t is the final adjusted value of the H^t.

(Step 20) Enter in Column 20 the sum of the elevation in Column 2 and the Final H in Column 19. This elevation is the potential water surface elevation for the junction under design conditions.

(Step 21) Enter in Column 21 the rim elevation or the gutter flow line, whichever is lowest, of the junction under consideration in Column 20. If the potential water surface elevation exceeds 1 foot below ground elevation for the design flow, the top of the pipe or the gutter flow line, whichever is lowest, adjustments are needed in the system to reduce the elevation of the Hydraulic Grade Line (H.G.L.).

(Step 22) Repeat the procedure starting with Step 1 for the next junction upstream.

(Step 23) At last upstream entrance, add $V_1^2/2g$ to get upstream water surface elevation.

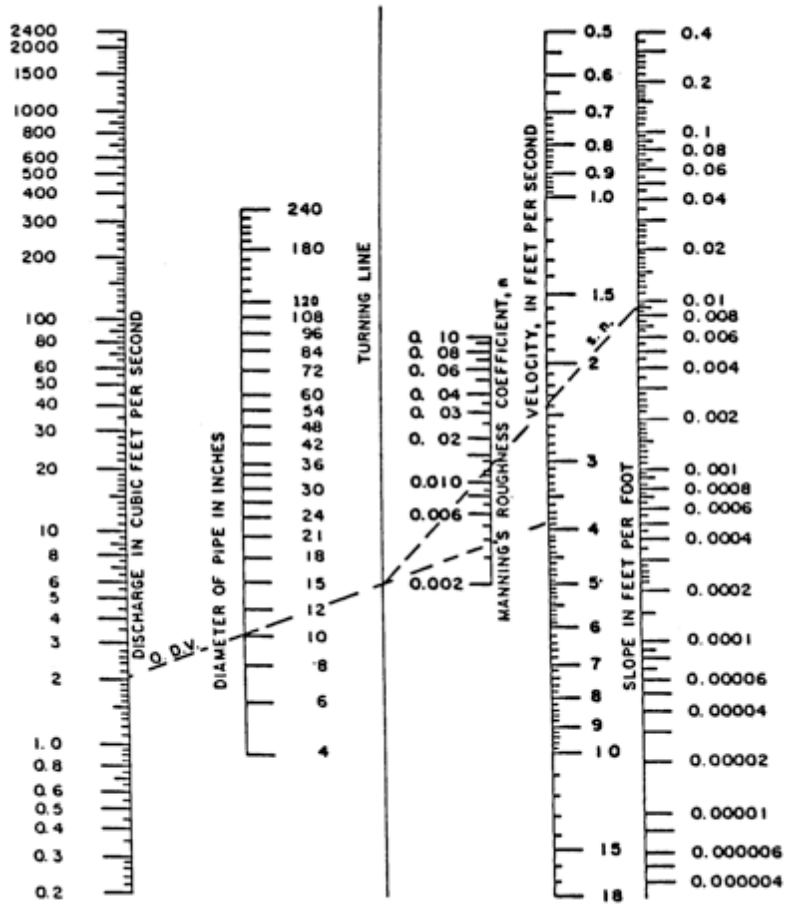


Figure 5.2-13 Nomograph for Solution of Manning's Formula for Flow in Storm Sewers
(Source: AASHTO Model Drainage Manual, 2005)

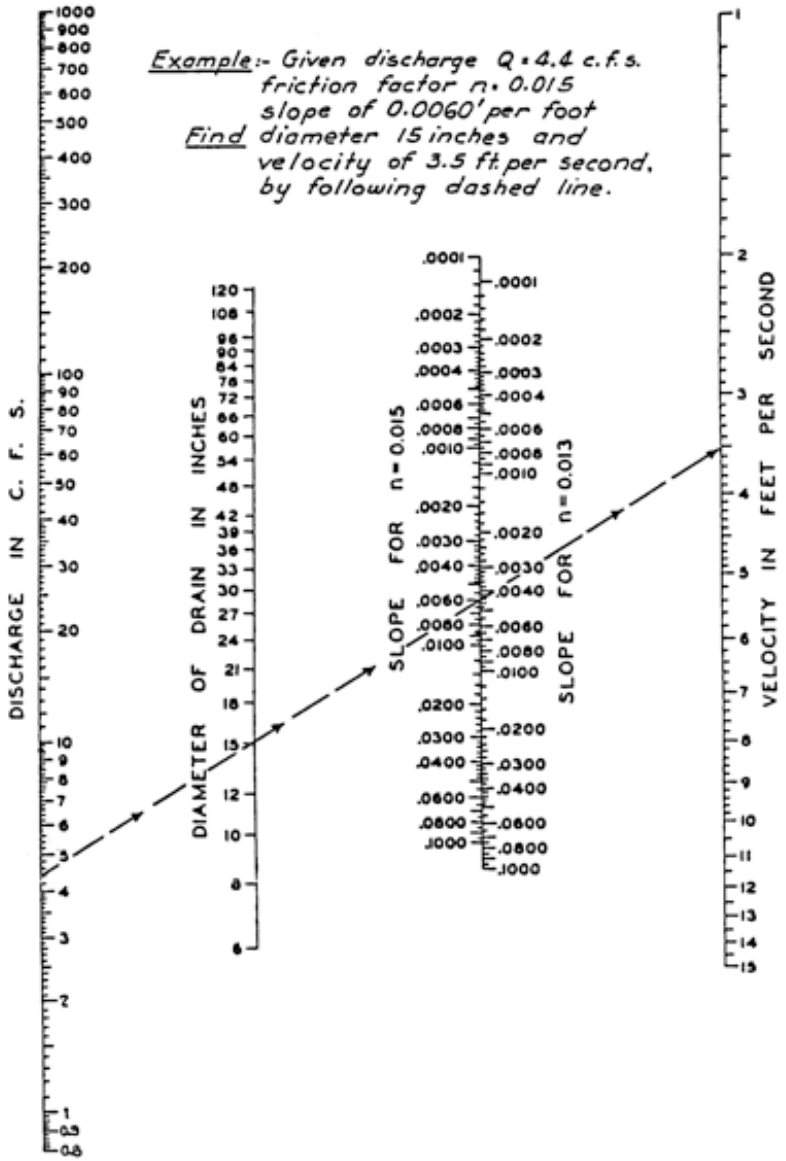


Figure 5.2-14 Nomograph for Computing Required Size of Circular Drain, Flowing Full n = 0.013 or 0.015

(Source: AASHTO Model Drainage Manual, 2005)

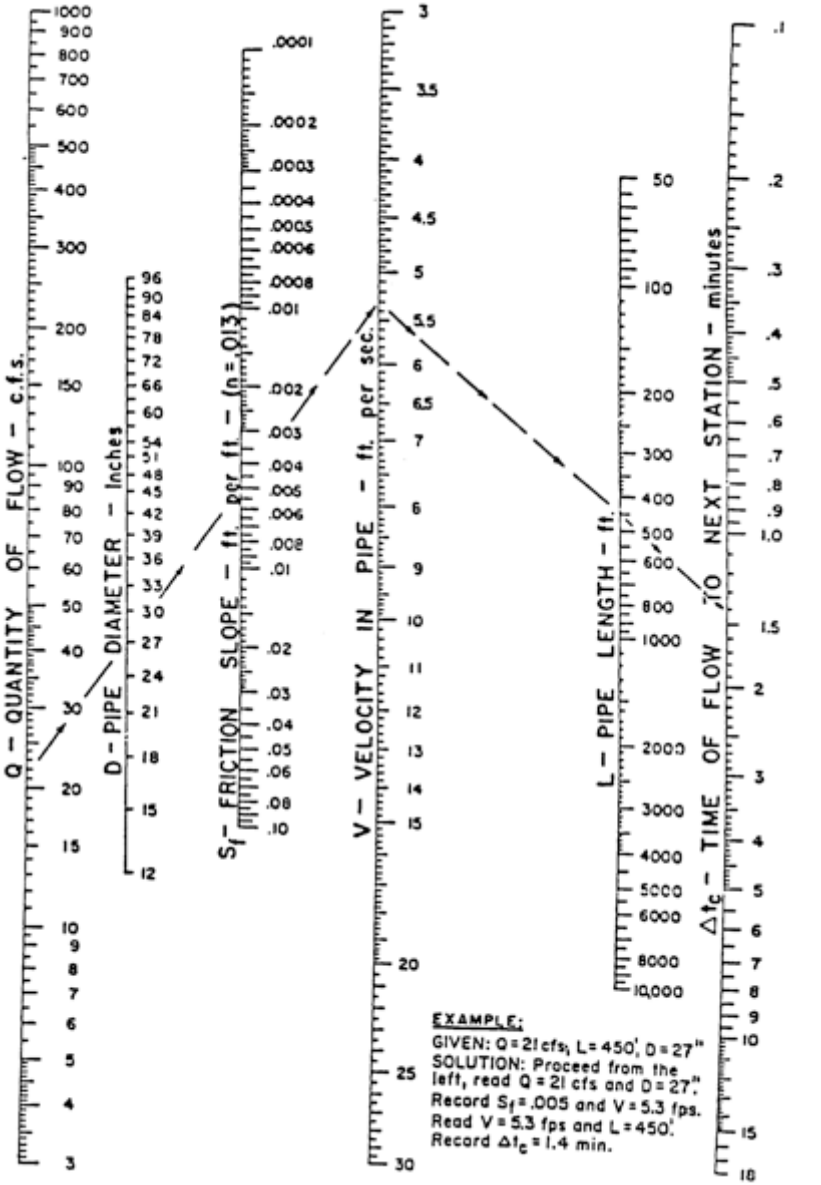
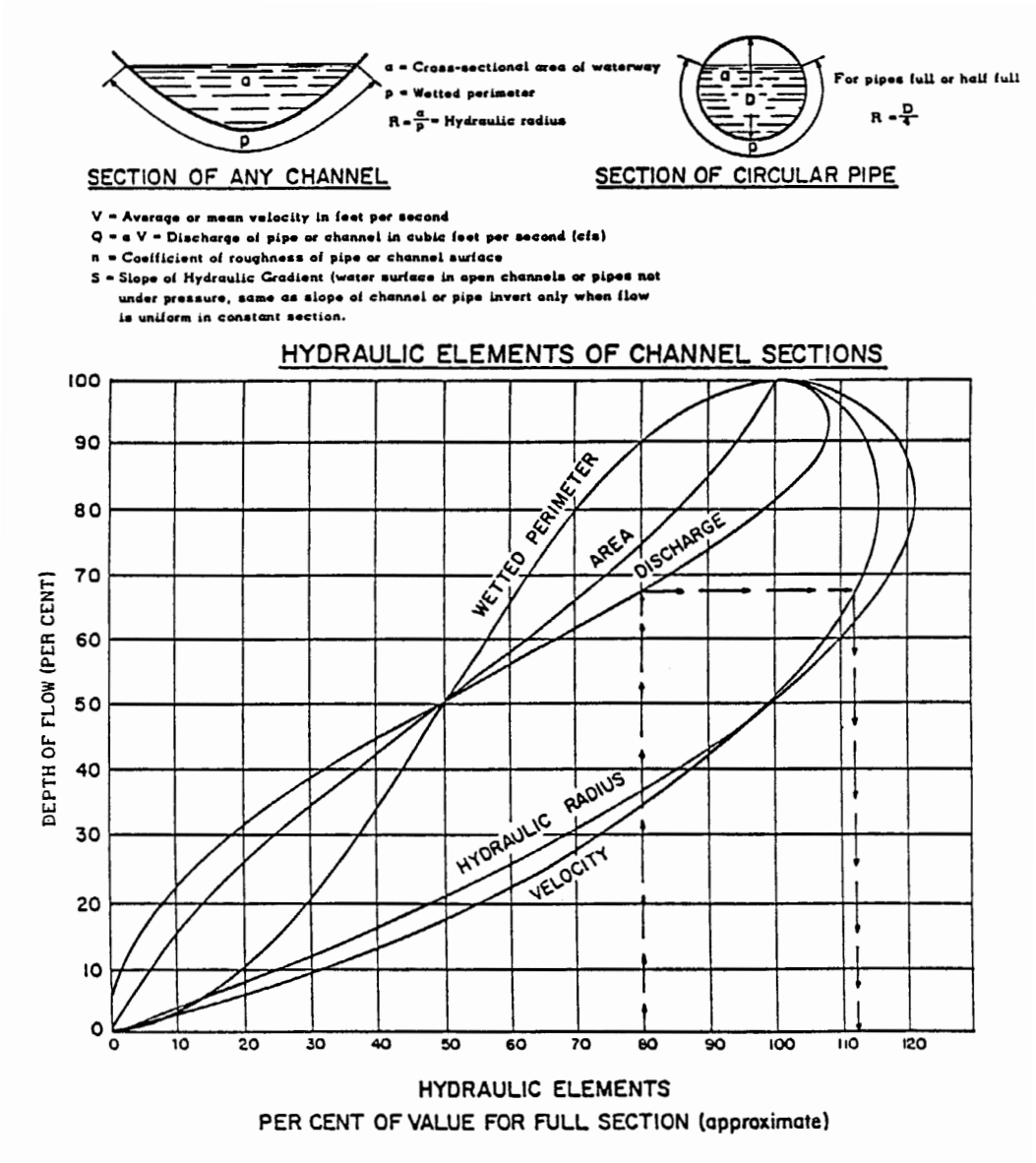


Figure 5.2-15 Concrete Pipe Flow Nomograph

(Source: AASHTO Model Drainage Manual, 2005)



V = Average of mean velocity in feet per second

Q = Discharge of pipe or channel in cubic feet per second

S = Slope of hydraulic grade line

Figure 5.2-16 Values of Various Elements of Circular Section for Various Depths of Flow

(Source: AASHTO Model Drainage Manual, 2005)

HYDRAULIC GRADE LINE PROJECT

STATION	Outlet Water Surface Elev.	D_o	Q_o	L_o	S_{f_o} %	H_f	JUNCTION LOSS												FINAL H	Inlet Water Surface Elev.	Rim Elev.
							V_o	H_o	Q_I	V_I	$Q_I V_I$	$\frac{V_I^2}{2g}$	H_I	ANGLE	H_Δ	H_t	1.3 H_t	0.5 H_t			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)

$H_I = 0.35 \frac{V_I^2}{2g}$ $H_o = 0.25 \frac{V_o^2}{2g}$ $H_\Delta = K \frac{V_I^2}{2g}$

FINAL $H = H_f + H_t$

$H_t = H_o + H_I + H_\Delta$

90° K = 0.70	50° K = 0.47	20° K = 0.16
80° K = 0.66	40° K = 0.38	15° K = 0.10
70° K = 0.61	30° K = 0.28	
60° K = 0.55	25° K = 0.22	

Figure 5.2-17 Hydraulic Grade Line Computation Form

(Source: AASHTO Model Drainage Manual, 2005)

5.2.8.7 MINIMUM GRADE

All storm drains should be designed such that velocities of flow will not be less than 2.5 feet per second at design flow or lower, with a minimum slope of 0.5%.For very flat flow lines the general practice is to design components so that flow velocities will increase progressively throughout the length of the pipe system. Upper reaches of a storm drain system should have flatter slopes than slopes of lower reaches. Progressively increasing slopes keep solids moving toward the outlet and deter settling of particles due to steadily increasing flow streams.

The minimum slopes are calculated by the modified Manning's formula:

$$S = [(nV)^2]/[2.208R^{4/3}] \qquad (5.2.20)$$

Where:

S = the slope of the hydraulic grade line, ft/ft
n = Manning's roughness coefficient
V = mean velocity of flow, ft/s
R = hydraulic radius, ft (area dived by wetted perimeter)

5.2.8.8 STORM DRAIN STORAGE

If downstream drainage facilities are undersized for the design flow, a structural stormwater control may be needed to reduce the possibility of flooding. The required storage volume can also be provided by using larger than needed storm drain pipe sizes and restrictors to control the release rates at manholes and/or junction boxes in the storm drain system. The same design criteria for sizing structural control storage facilities are used to determine the storage volume required in the system (see Section 3.3 for more information).

5.3 Culvert Design

5.3.1 Overview

A *culvert* is a short, closed (covered) conduit that conveys stormwater runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and/or roadway, and protect traffic and adjacent property owners from flood hazards to the extent practicable.

Most culvert design is empirical and relies on nomographs and "cookbook procedures." The purpose of the section is to provide an overview of culvert design criteria and procedures.

5.3.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual the symbols listed in **Table 5.3-1** will be used. These symbols were selected because of their wide use.

5.3.3 Design Criteria

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The following design criteria should be considered for all culvert designs as applicable.

5.3.3.1 FREQUENCY FLOOD

See Section 5.1 or the local review authority for design storm requirements for the sizing of culverts.

Culverts or pipe systems designed to convey water through a roadway embankment shall be designed to pass the fully developed peak flow associated with a 100-year storm with at least 1.5 feet of freeboard between the 100-year ponding elevation and the centerline of the road, without raising the 100-year flood elevation on the upstream properties, and in accordance with the Floodplain Management Ordinance. Fully developed flows shall be based on the Land Use Plan adopted by the Board of Commissioners.

The 100-year frequency storm shall be routed through all culverts to be sure building structures (e.g., houses, commercial buildings) are not flooded or increased damage does not occur to the highway or adjacent property for this design event.

Table 5.3-1 Symbols and Definitions

Symbol	Definition	Units
A	Area of cross section of flow	ft^2
B	Barrel width	ft
C_d	Overtopping discharge coefficient	-
D	Culvert Diameter or barrel depth	in or ft
d	Depth of flow	ft
d_c	Critical depth of flow	ft
d_u	Uniform depth of flow	ft
g	Acceleration of gravity	ft/s^2
H_f	Depth of pool or head, above the faction section of invert	ft
h_O	Height of hydraulic grade line above outlet invert	ft
HW	Headwater depth above invert of culvert (depth from inlet invert to upstream total energy grade line)	ft
K_e	Inlet loss coefficient	-
L	Length of culvert	ft
N	Number of barrels	-
Q	Rate of discharge	cfs
S	Slope of culvert	ft/ft
TW	Tailwater depth above invert of culvert	ft
V	Mean velocity of flow	ft/s
V_C	Critical velocity	ft/s

5.3.3.2 VELOCITY LIMITATIONS

Both minimum and maximum velocities should be considered when designing a culvert. The maximum velocity should be consistent with channel stability requirements at the culvert outlet. Outlet protection shall be provided where discharge velocities will cause erosion problems. To ensure self-cleaning, a minimum velocity of 2.5 feet per second, for the 2-year flow, is required. Velocities over 10 fps in a culvert of any material shall be considered a special design with particular attention required to structure invert protection and to fill slope, stream bed, and stream bank stability.

5.3.3.3 BUOYANCY PROTECTION

Headwalls, endwalls, slope paving or other means of anchoring to provide buoyancy protection should be considered for all flexible culverts.

5.3.3.4 LENGTH AND SLOPE

The culvert length and slope should be chosen to approximate existing topography and, to the degree practicable, the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment. The maximum slope using concrete pipe is 10% and for CMP is 14% before pipe-restraining methods must be taken. Maximum drop in a drainage structure is 10 feet.

When constructing a culvert in a perennial stream, the design must also satisfy current USACOE permit requirements.

Culverts carrying live streams shall extend to where the crown of the pipe intersects the roadway slope.

5.3.3.5 DEBRIS CONTROL

In designing debris control structures it is recommended that the Hydraulic Engineering Circular No. 9 entitled Debris Control Structures be consulted.

5.3.3.6 HEADWATER LIMITATIONS

Headwater is water above the culvert invert at the entrance end of the culvert. The allowable headwater elevation is that elevation above which damage may be caused to adjacent property and/or the roadway and is determined from an evaluation of land use upstream of the culvert and the proposed or existing roadway elevation. It is this allowable headwater depth that is the primary basis for sizing a culvert.

The following criteria related to headwater should be considered:

- The allowable headwater is the depth of water that can be ponded at the upstream end of the culvert during the design flood, which will be limited by one or more of the following constraints or conditions:
  1. Headwater be nondamaging to upstream property
  2. Ponding depth be no greater than the low point in the road grade
  3. Ponding depth be no greater than the elevation where flow diverts around the culvert
  4. Elevations established to delineate floodplain zoning
  5. 18-inch (or applicable) freeboard requirements, below road centerline at lowest point.
- The following HW/D criteria:
  1. For drainage facilities with cross-sectional area equal to or less than 30 ft^2, HW/D should be equal to or less than 1.5
  2. For drainage facilities with cross-sectional area greater than 30 ft^2, HW/D should be equal to or less than 1.2
- The headwater should be checked for the 100-year flood to ensure compliance with flood plain management criteria and for most facilities the culvert should be sized to maintain flood-free conditions on major thoroughfares with 18-inch freeboard at the low-point of the road.
- The maximum acceptable outlet velocity should be identified (see Subsection 5.4.3).
- Either the headwater should be set to produce acceptable velocities, or stabilization or energy dissipation should be provided where these velocities are exceeded.
- In general, the constraint that gives the lowest allowable headwater elevation establishes the criteria for the hydraulic calculations.
- Other site-specific design considerations should be addressed as required.

5.3.3.7 TAILWATER CONSIDERATIONS

The hydraulic conditions downstream of the culvert site must be evaluated to determine a tailwater depth for a range of discharge. At times there may be a need for calculating backwater curves to establish the tailwater conditions. The following conditions must be considered:

- If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line should be determined.
- For culverts that discharge to an open channel, the stage-discharge curve for the channel must be determined. See Section 5.4, *Open Channel Design*.
- If an upstream culvert outlet is located near a downstream culvert inlet, the head-water elevation of the downstream culvert may establish the design tailwater depth for the upstream culvert.
- If the culvert discharges to a lake, pond, or other major water body, the expected high water elevation of the particular water body may establish the culvert tailwater.

5.3.3.8 STORAGE

If storage is being assumed or will occur upstream of the culvert, refer to Subsection 5.3.4.6 regarding storage routing as part of the culvert design.

5.3.3.9 CULVERT INLETS

Hydraulic efficiency and cost can be significantly affected by inlet conditions. The inlet coefficient Ke, is a measure of the hydraulic efficiency of the inlet, with lower values indicating greater efficiency. Recommended inlet coefficients are given in **Table 5.3-2**.

5.3.3.10 INLETS WITH HEADWALLS

Headwalls may be used for a variety of reasons, including increasing the efficiency of the inlet, providing embankment stability, providing embankment protection against erosion, providing protection from buoyancy, and shortening the length of the required structure. Headwalls are required for all metal culverts and where buoyancy protection is necessary. If high headwater depths are to be encountered, or the approach velocity in the channel will cause scour, a short channel apron should be provided at the toe of the headwall.

This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.

5.3.3.11 WINGWALLS AND APRONS

Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable or where the culvert is skewed to the normal channel flow.

5.3.3.12 IMPROVED INLETS

Where inlet conditions control the amount of flow that can pass through the culvert, improved inlets can greatly increase the hydraulic performance of the culvert.

5.3.3.13 MATERIAL SELECTION

Reinforced concrete pipe (RCP) is generally recommended for use (1) under a roadway, (2) when pipe slopes are less than 1%, or (3) for all flowing streams. RCP and any other Georgia Department of Transportation approved pipe material may be used as allowed by the Gwinnett County Storm Sewer Pipe Standards. **Table 5.3-3** gives recommended Manning's n values for different materials.

5.3.3.14 CULVERT SKEWS

Culvert skews shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without approval.

5.3.3.15 CULVERT SIZES

The minimum allowable pipe diameter shall be 18".

5.3.3.16 WEEP HOLES

Weep holes are sometimes used to relieve uplift pressure. Filter materials should be used in conjunction with the weep holes in order to intercept the flow and prevent the formation of piping channels. The filter materials should be designed as an underdrain filter so as not to become clogged and so that piping cannot occur through the pervious material and the weep hole.

5.3.3.17 OUTLET PROTECTION

See Section 5.5 for information on the design of outlet protection. Outlet protection should be provided for the 25-year storm.

5.3.3.18 EROSION AND SEDIMENT CONTROL

Erosion and sediment control shall be in accordance with the latest approved Soil Erosion and Sediment Control Ordinance for the municipality. See also the *Manual for Erosion and Sediment Control in Georgia* for design standards and details related to erosion and sediment control.

5.3.3.19 ENVIRONMENTAL CONSIDERATIONS

Where compatible with good hydraulic engineering, a site should be selected that will permit the culvert to be constructed to cause the least impact on the stream or wetlands. This selection must consider the entire site, including any necessary lead channels.

Table 5.3-2 Inlet Coefficients

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (grove-end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (grove-end)	0.2
Square-edge	0.5
Rounded [radius = 1/12(D)]	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal[1]	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to fill slope, paved or unpaved slope	0.7
*End-section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of [1/12(D)] or beveled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of [1/12(D)] or beveled top edge	0.2
Wingwalls at 10° or 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

[1] Although laboratory tests have not been completed on K_e values for High-Density Polyethylene (HDPE) pipes, the K_e values for corrugated metal pipes are recommended for HDPE pipes

* Note: End Section conforming to fill slope, made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests, they are equivalent in operation to a headwall in both inlet and outlet control.

Source: HDS No. 5, 2012, C.6 (216)

Table 5.3-3 Manning's n Values for Culverts

Type of Conduit	Wall & Joint Description	Manning's n
Concrete Pipe	Good joints, smooth walls	0.012
	Good joints, rough walls	0.016
	Poor joints, rough walls	0.017
Concrete Box	Good joints, smooth finished walls	0.012
	Poor joints, rough, unfinished walls	0.018
Corrugated Metal Pipes and Boxes - Annular and Helical Corrugations	2 2/3 by 1/2 inch corrugations	0.024
	6 by 1 inch corrugations	0.025
	5 by 1 inch corrugations	0.026
	3 by 1 inch corrugations	0.028
	6 by 2 inch structural plate	0.035
	9 by 2 1/2 inch structural plate	0.035
Spiral Rib Metal Pipe	3/4 by 3/4 in recesses at 12 inch spacing, good joints	0.013
High Density Polyethylene (HDPE)	Corrugated Smooth Liner	0.015
	Corrugated	0.020
Polyvinyl Chloride (PVC)		0.011

Note: For further information concerning Manning n values for selected conduits consult Hydraulic Design of Highway Culverts, Federal Highway Administration, HDS No. 5

5.3.4 Design Procedures

5.3.4.1 TYPES OF FLOW CONTROL

There are two types of flow conditions for culverts that are based upon the location of the control section and the critical flow depth:

» **Inlet Control** – Inlet control occurs when the culvert barrel is capable of conveying more flow that the inlet will accept. This typically happens when a culvert is operating on a steep slope. The control section of a culvert is located just inside the entrance. Critical depth occurs at or near this location, and the flow regime immediately downstream is supercritical.

» **Outlet Control** – Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions.

Proper culvert design and analysis requires checking for both inlet and outlet control to determine which will govern particular culvert designs. For more information on inlet and outlet control, see the FHWA Hydraulic Design of Highway Culverts, HDS-5, 2012.

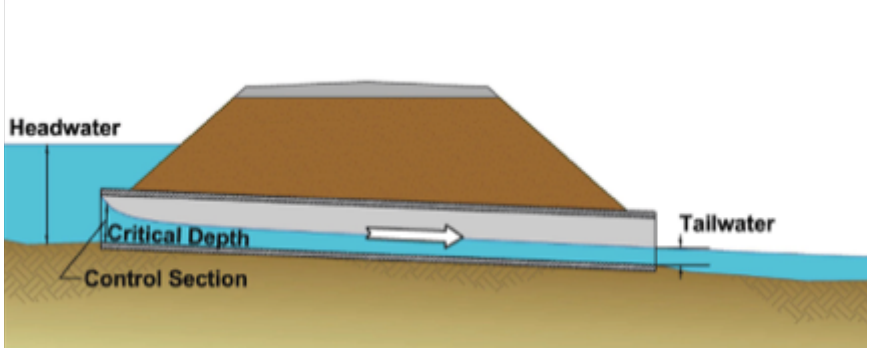


Figure 5.3-1(a) Typical Inlet Control Flow Section
(Adapted from: HDS-5, 2012)

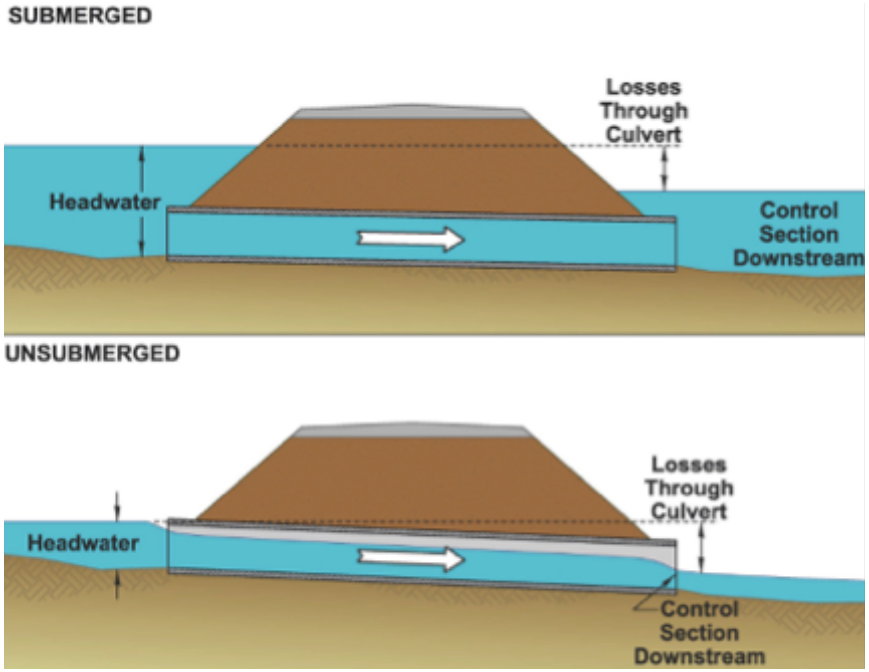


Figure 5.3-1(b) Typical Outlet Control Flow Conditions
(Adapted from: HDS-5, 2012)

5.3.4.2 PROCEDURES

There are two procedures for designing culverts: manual use of inlet and outlet control nomographs, and the use computer programs such as HY8. It is recommended that the HY8 computer model or equivalent be used for culvert design. The computer software package HYDRAIN, which includes HY8, uses the theoretical basis from the nomographs to size culverts. In addition, this software can evaluate improved inlets, route hydrographs, consider road over-topping, and evaluate outlet streambed scour. By using water surface profiles, this procedure is more accurate in predicting backwater effects and outlet scour.

5.3.4.3 NOMOGRAPHS

The use of culvert design nomographs requires a trial and error solution. No-mograph solutions provide reliable designs for many applications. It should be remembered that velocity, hydrograph routing, roadway overtopping, and

outlet scour require additional, separate computations beyond what can be obtained from the nomographs. **Figures 5.3-2(a)** and **(b)** show examples of an inlet control and outlet control nomograph for the design of concrete pipe culverts. For other culvert designs, refer to the complete set of nomographs in Appendix C.

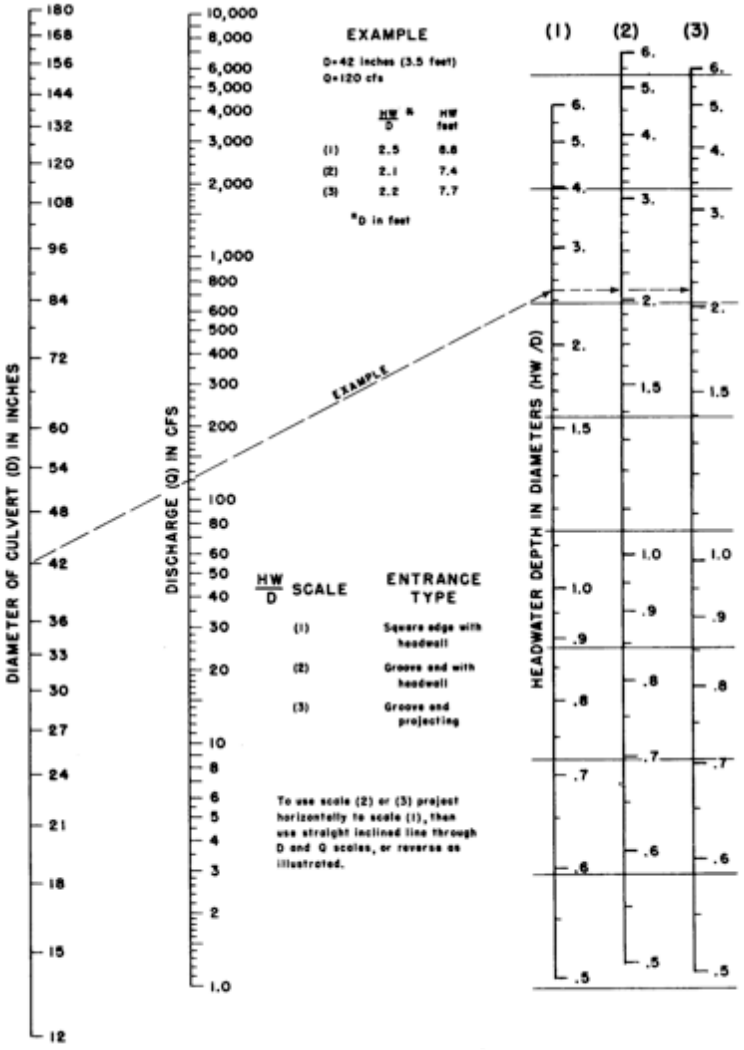


Figure 5.3-2(a) Headwater Depth for Concrete Pipe Culvert with Inlet Control

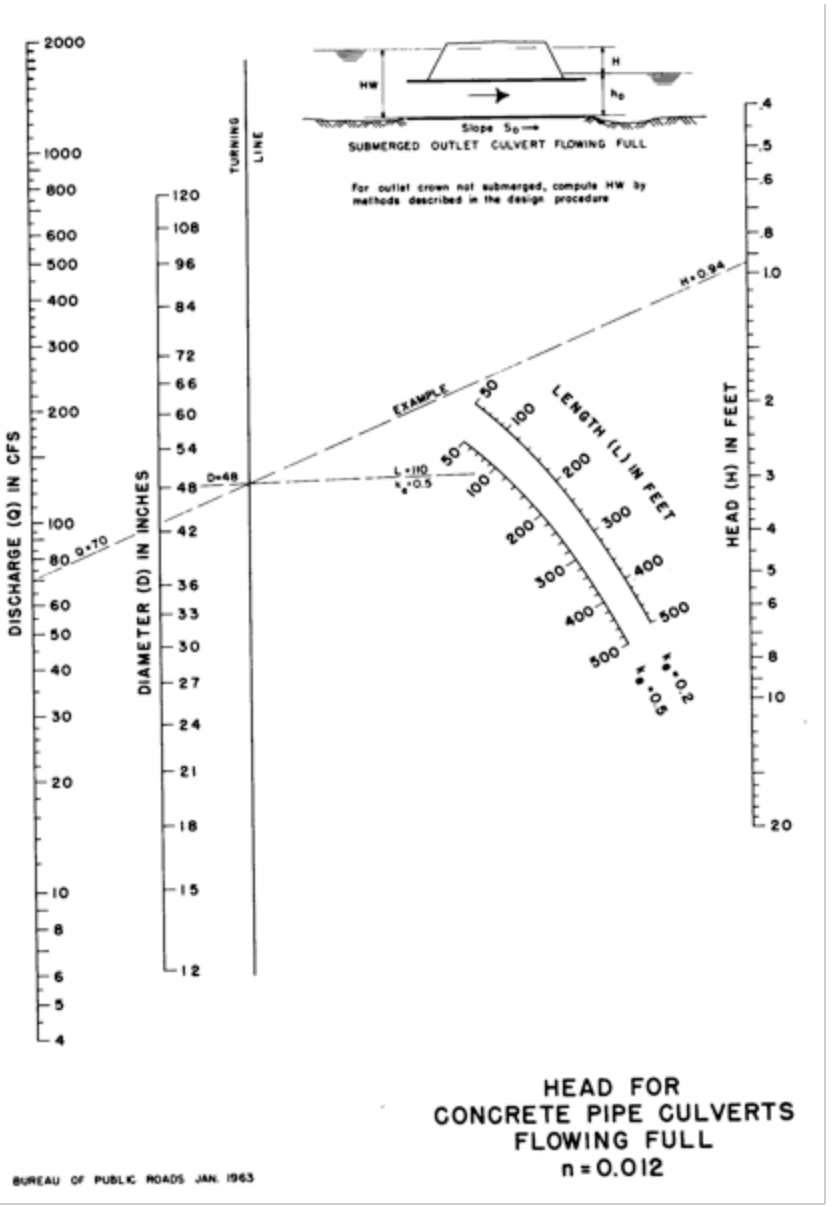


Figure 5.3-2(b) Head for Concrete Pipe Culverts Flowing Full

5.3.4.4 DESIGN PROCEDURE

The following design procedure requires the use of inlet and outlet nomographs.

(Step 1) List design data:

Q = discharge (cfs) **L** = culvert length (ft)
S = culvert slope (ft/ft) **TW**= tailwater depth (ft)
V = velocity for trial diameter (ft/s)
K_e= inlet loss coefficient
HW= allowable headwater depth for the design storm (ft)

(Step 2) Determine trail culvert size by assuming a trial velocity 3 to 5 ft/s and computing the culvert area, A = Q/V. Determine the culvert diameter (inches).

(Step 3) Find the actual HW for the trial size culvert for both inlet and outlet control.

- For **inlet control**, enter inlet control nomograph with D and Q and find HW/D for the proper entrance type.
- Compute HW and, if too large or too small, try another culvert size before computing HW for outlet control.
- For **outlet control** enter the outlet control nomograph with the culvert length, entrance loss coefficient, and trial culvert diameter.
- To compute HW, connect the length scale for the type of entrance condition and culvert diameter scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation HW from the equation:

$$HW = H + h_o \quad LS \qquad (5.3.1)$$

Where:

h_o = ½ (critical depth + D), or tailwater depth, whichever is greater
L = culvert length
S = culvert slope

(Step 4) Compare the computed headwaters and use the higher HW nomograph to determine if the culvert is under inlet or outlet control.

- If **inlet control** governs, then the design is complete and no further analysis is required.
- If **outlet control** governs and the HW is unacceptable, select a larger trial size and find another HW with the outlet control nomographs. Since the smaller size of culvert had been selected for allowable HW by the inlet control nomographs, the inlet control for the larger pipe need not be checked.

(Step 5) Calculate exit velocity and if erosion problems might be expected, refer to Section 5.5 for appropriate energy dissipation designs.

5.3.4.5 PERFORMANCE CURVES - ROADWAY OVERTOPPING

A performance curve for any culvert can be obtained from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for that particular culvert design. A graph is then plotted of headwater versus discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater, velocities, and scour depths versus discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes. Such computations are made much easier by the use of computer programs.

To complete the culvert design, roadway overtopping should be analyzed. A performance curve showing the culvert flow as well as the flow across the roadway is a useful analysis tool. Rather than using a trial and error procedure to determine the flow division between the overtopping flow and the culvert flow, an overall performance curve can be developed.

The overall performance curve can be determined as follows:

(Step 1) Select a range of flow rates and determine the corresponding headwater elevations for the culvert flow alone. The flow rates should fall above and below the design discharge and cover the entire flow range of interest. Both inlet and outlet control headwaters should be calculated.

(Step 2) Combine the inlet and outlet control performance curves to define a single performance curve for the culvert.

(Step 3) When the culvert headwater elevations exceed the roadway crest elevation, overtopping will begin. Calculate the equivalent upstream water surface depth above the roadway (crest of weir) for each selected flow rate. Use these water surface depths and **equation 5.3.2** to calculate flow rates across the roadway.

$$Q = C_d L(HW)^{1.5} \qquad (5.3.2)$$

Where:

Q = overtopping flow rate (ft^3/s)
$\mathbf{C_d}$ = overtopping discharge coefficient
L = length of roadway (ft)
HW = upstream depth, measured from the roadway crest to the water surface upstream of the weir drawdown (ft)

Note: See **Figure 5.3-3** for guidance in determining a value for C_d. For more information on calculating overtopping flow rates see pages 39 - 42 in HDS No. 5.

(Step 4) Add the culvert flow and the roadway overtopping flow at the corresponding headwater elevations to obtain the overall culvert performance curve.

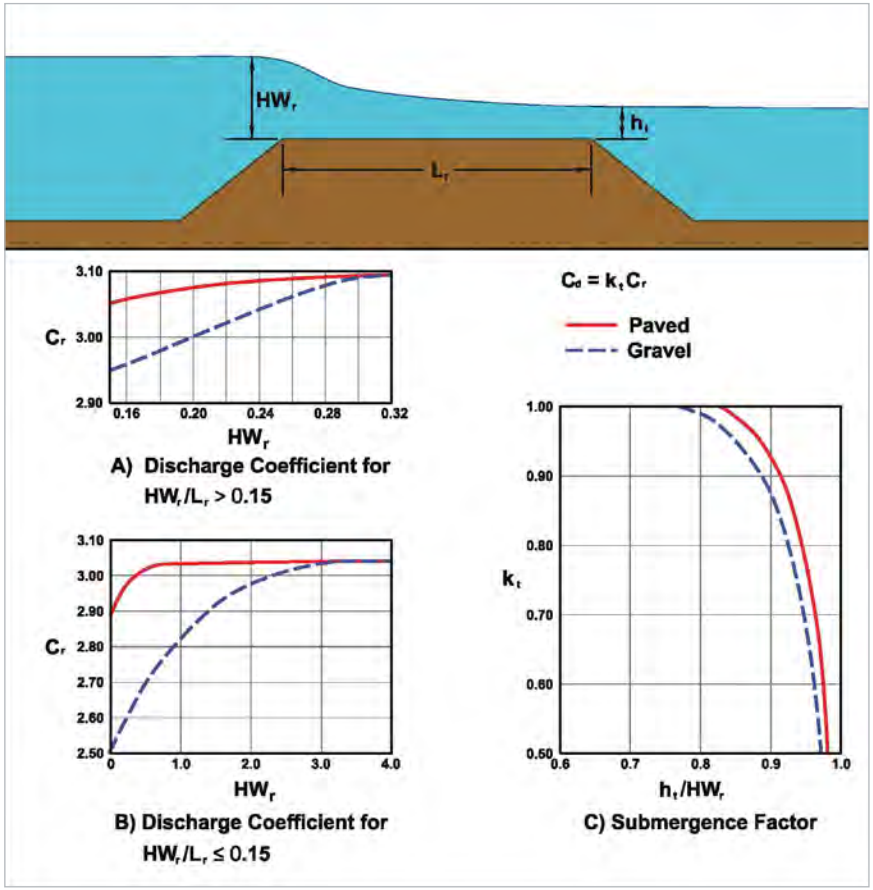


Figure 5.3-3 Discharge Coefficients for Roadway Overtopping
(Source: HDS No. 5, 2012)

5.3.4.6 STORAGE ROUTING

A significant storage capacity behind a highway embankment attenuates a flood hydrograph. Because of the reduction of the peak discharge associated with this attenuation, the required capacity of the culvert, and its size, may be reduced considerably. If significant storage is anticipated behind a culvert, the design should be checked by routing the design hydrographs through the culvert to determine the discharge and stage behind the culvert. See subsection 5.3.7 and Section 3.3 for more information on routing. Additional routing procedures are outlined in Hydraulic Design of Highway Culverts, Section V - Storage Routing, HDS No. 5, Federal Highway Administration.

Note: Storage should be taken into consideration only if the storage area will remain available for the life of the culvert as a result of purchase of ownership or right-of-way or an easement has been acquired.

5.3.5 Culvert Design Example

5.3.5.1 INTRODUCTION

The following example problem illustrates the procedures to be used in designing culverts using the nomographs.

5.3.5.2 EXAMPLE

Size a culvert given the following example data, which were determined by physical limitations at the culvert site and hydraulic procedures described elsewhere in this handbook.

5.3.5.3 EXAMPLE DATA

Input Data

- **Discharge for 2 yr flood** = 35 cfs
- **Discharge for 100 yr flood** = 70 cfs
- **Allowable Hw for 100 yr discharge** = 5.25 ft
- **Length of culvert** = 100 ft
- **Natural channel invert elevations - inlet** = 15.50 ft, **outlet** = 14.30 ft
- **Culvert slope** = 0.012 ft/f
- **Tailwater depth for 100 yr discharge** = 3.5 ft
- **Tailwater depth is the normal depth in downstream channel**
- **Entrance type** = Groove end with headwall

5.3.5.4 COMPUTATIONS

1. Assume a culvert velocity of 5 ft/s. Required flow area = 70 cfs/5 ft/s = 14 ft^2 (for the 100 yr recurrence flood).
2. The corresponding culvert diameter is about 48 in. This can be calculated by using the formula for area of a circle: Area = $(3.14D^2)/4$ or D = (Area times $4/3.14)^{0.5}$. Therefore: D = $((14 \text{ sq ft} \times 4)/3.14)^{0.5} \times 12$ in/ft) = 50.7 in
3. A grooved end culvert with a headwall is selected for the design. Using the inlet control nomograph (Figure 5.3-1), with a pipe diameter of 48 inches and a discharge of 70 cfs; read a HW/D value of 0.93.
4. The depth of headwater (HW) is (0.93) x (4) = 3.72 ft, which is less than the allowable headwater of 5.25 ft. Since 3.72 ft is considerably less than 5.25 try a small culvert.
5. Using the same procedures outlined in steps 4 and 5 the following results were obtained.
   - 42-inch culvert – HW = 4.13 ft
   - 36-inch culvert – HW = 4.98 ft
   - Select a 36-inch culvert to check for outlet control.
6. The culvert is checked for outlet control by using **Figure 5.3-2**.
   - With an entrance loss coefficient Ke of 0.20, a culvert length of 100 ft, and a pipe diameter of 36 in., an H value of 2.8 ft is determined. The headwater for outlet control is computed by the equation: HW = H + h_o LS
   - Compute h_o
     - $h_o = T_w$ or ½ (critical depth in culvert + D), whichever is greater.
     - h_o = 3.5 ft or h_o = ½ (2.7 + 3.0) = 2.85 ft
   - Therefore: h_o = 3.5 ft
   - The headwater depth for outlet control is:

     HW = H + h_o LS = 2.8 + 3.5 (100) x (0.012) = 5.10 ft

7. Since HW for outlet (5.10 ft) is greater than the HW for inlet control (4.98 ft), outlet control governs the culvert design. Thus, the maximum headwater expected for a 100 year recurrence flood is 5.10 ft, which is less than the allowable headwater of 5.25 ft.
8. Estimate outlet exit velocity. Since this culvert is on outlet control and discharges into an open channel downstream with tailwater above culvert, the culvert will be flowing full at the flow depth in the channel. Using the design peak discharge of 70 cfs and the area of a 36-inch or 3.0-foot diameter culvert the exit velocity will be:
   - » Q = VA
   - » Therefore: V = 70 / (3.14(3.0)^2)/4 = 9.9 ft/s
   - » With this high velocity, consideration should be given to provide an energy dissipator at the culvert outlet. See Section 5.5 (*Energy Dissipation Design*).
9. Check for minimum velocity using the 2-year flow of 35 cfs.
   - » Therefore: V = 35 / (3.14(3.0)^2/4 = 5.0 ft/s > minimum of 2.5 - OK

Figure 5.3-4 provides a convenient form to organize culvert design calculations.

PROJECT: _____

STATION: _____

SHEET _____ OF _____

CULVERT DESIGN FORM

DESIGNER / DATE: _____ / _____

REVIEWER / DATE: _____ /

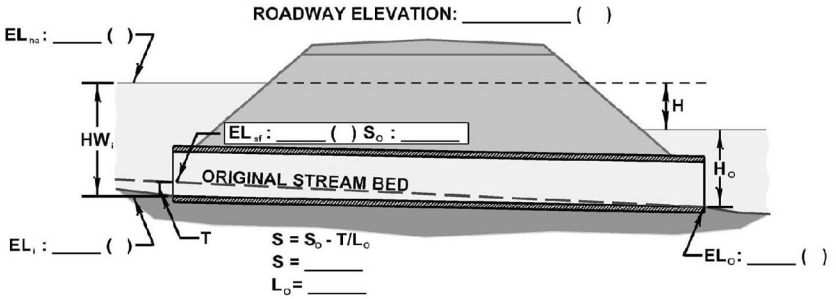
HYDROLOGICAL DATA

See Add'l Shts.

- ☐ METHOD: _____
- ☐ DRAINAGE AREA: _____ ☐ STREAM SLOPE: _____
- ☐ CHANNEL SHAPE: _____
- ☐ ROUTING: _____ ☐ OTHER: _____

DESIGN FLOWS/TAILWATER

R.I. (YEARS)	FLOW (cfs)	TW (ft)



CULVERT DESCRIPTION:

MATERIAL – SHAPE – SIZE – ENTRANCE

Total Flow Q (cfs)	Flow Per Barrel Q / N (1)	HEADWATER CALCULATIONS											Control Headwater Elevation	Outlet Velocity	Comments
		INLET CONTROL				OUTLET CONTROL									
		HW$_i$/D (2)	HW$_i$	T (3)	EL$_{hi}$ (4)	TW (5)	d$_c$	$\frac{d_c+D}{2}$	h$_o$ (6)	k$_e$	H (7)	EL$_{ho}$ (8)			

TECHNICAL FOOTNOTES:

(1) USE Q/NB FOR BOX CULVERTS

(2) HW$_i$ / D = HW / D OR HW$_i$ / D FROM DESIGN CHARTS

(3) T = HW$_i$ – (EL$_{hd}$ – EL$_{sf}$)
T IS ZERO FOR CULVERTS ON GRADE

(4) EL$_{hi}$ = HW$_i$ + EL$_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL

(6) h$_o$ = TW or (d$_c$ + D) /2 (WHICHEVER IS GREATER)

(7) H = [1 + k$_e$ + (K$_u$ n^2 L) / R$^{1.33}$] v^2 / 2g WHERE Ku = 19.63 (29 IN ENGLISH UNITS)

(8) EL$_{ho}$ = EL$_o$ + H + h$_o$

SUBSCRIPT DEFINITIONS:

a. APPROXIMATE
f. CULVERT FACE
ha. ALLOWABLE HEADWATER
hi. HEADWATER IN INLET CONTROL
ho. HEADWATER IN OUTLET CONTROL
i. INLET CONTROL SECTION
o. OUTLET
sf. STREAMBED AT CULVERT FACE
tw. TAILWATER

COMMENTS / DISCUSSION:

CULVERT BARREL SELECTED:

SIZE: _____

SHAPE: _____

MATERIAL: _____ n _____

ENTRANCE: _____

Figure 5.3-4 Culvert Design Calculation Form
(Source: HDS No. 5, 2012)

5.3.6 Design Procedures for Beveled-Edged Inlets

5.3.6.1 INTRODUCTION

Improved inlets include inlet geometry refinements beyond those normally used in conventional culvert design practice. Several degrees of improvements are possible, including bevel-edged, side-tapered, and slope-tapered inlets. Those designers interested in using side and slope tapered inlets should consult the detailed design criteria and example designs outlined in the U. S. Department of Transportation publication Hydraulic Engineering Circular No. 5 entitled, Hydraulic Design of Highway Culverts.

5.3.6.2 DESIGN FIGURES

Four inlet control figures for culverts with beveled edges are included in Appendix C.

Chart	Page	Use for :
3	A-3	circular pipe culverts with beveled rings
10	A-10	90° headwalls (same for 90° wingwalls)
11	A-11	skewed headwalls
12	A-12	wingwalls with flare angles of 18 to 45 degrees

The following symbols are used in these figures:

- B - Width of culvert barrel or diameter of pipe culvert
- D - Height of box culvert or diameter of pipe culvert
- H_f - Depth of pool or head, above the face section of invert
- N - Number of barrels
- Q - Design discharge

5.3.6.3 DESIGN PROCEDURE

The figures for bevel-edged inlets are used for design in the same manner as the conventional inlet design nomographs discussed earlier. *Note* that **Charts 10, 11,** and **12** in Appendix C apply only to bevels having either a 33° angle (1.5:1) or a 45° angle (1:1).

For box culverts the dimensions of the bevels to be used are based on the culvert dimensions. The top bevel dimension is determined by multiplying the height of the culvert by a factor. The side bevel dimensions are determined by multiplying the width of the culvert by a factor. For a 1:1 bevel, the factor is 0.5 inch/ft. For a 1.5:1 bevel the factor is 1 inch/ft. For example, the minimum bevel dimensions for a 8 ft x 6 ft box culvert with 1:1 bevels would be:

- **Top Bevel** = d = 6 ft x 0.5 inch/ft = 3 inches
- **Side Bevel** = b = 8 ft x 0.5 inch/ft = 4 inches

For a 1.5:1 bevel computations would result in d = 6 and b = 8 inches.

5.3.6.4 DESIGN FIGURE LIMITS

The improved inlet design figures are based on research results from culvert models with barrel width, B, to depth, D, ratios of from 0.5:1 to 2:1. For box culverts with more than one barrel, the figures are used in the same manner as for a single barrel, except that the bevels must be sized on the basis of the total clear opening rather than on individual barrel size.

For example, in a double 8 ft by 8 ft box culvert:

- **Top Bevel** is proportioned based on the height of 8 feet which results in a bevel of 4 in. for the 1:1 bevel and 8 in. for the 1.5:1 bevel.
- **Side Bevel** is proportioned based on the clear width of 16 feet, which results in a bevel of 8 in. for the 1:1 bevel and 16 in. for the 1.5:1 bevel.

5.3.6.5 MULTIBARREL INSTALLATIONS

For multibarrel installations exceeding a 3:1 width to depth ratio, the side bevels become excessively large when proportioned on the basis of the total clear width. For these structures, it is recommended that the **side bevel** be sized in proportion to the total clear width, B, or three times the height, whichever is smaller.

The **top bevel** dimension should always be based on the culvert height.

The shape of the upstream edge of the intermediate walls of multibarrel installations is not as important to the hydraulic performance of a culvert as the edge condition of the top and sides. Therefore, the edges of these walls may be square, rounded with a radius of one half their thickness, chamfered, or beveled. The intermediate walls may also project from the face and slope downward to the channel bottom to help direct debris through the culvert.

Multibarrel pipe culverts should be designed as a series of single barrel installations since each pipe requires a separate bevel.

5.3.6.6 SKEWED INLETS

It is recommended that **Chart 11** (see Appendix C) for skewed inlets not be used for multiple barrel installations, as the intermediate wall could cause an extreme contraction in the downstream barrels. This would result in underdesign due to a greatly reduced capacity. Skewed inlets (at an angle with the centerline of the stream) should be avoided whenever possible and should not be used with side or slope tapered inlets. It is important to align culverts with streams in order to avoid erosion problems associated with changing the direction of the natural stream flow.

5.3.7 Flood Routing and Culvert Design

5.3.7.1 INTRODUCTION

Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. By not considering flood routing it is possible that the findings from culvert analyses will be conservative. If the selected allowable headwater is accepted without flood routing, then costly overdesign of both the culvert and outlet protection may result, depending on the amount of temporary storage involved. However, if storage is used in the design of culverts, consideration should be given to:

- The total area of flooding,
- The average time that bankfull stage is exceeded for the design flood up to 48 hours in rural areas or 6 hours in urban areas, and
- Ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

5.3.7.2 DESIGN PROCEDURE

The design procedure for flood routing through a culvert is the same as for reservoir routing. The site data and roadway geometry are obtained and the hydrology analysis completed to include estimating a hydrograph. Once this essential information is available, the culvert can be designed.

Flood routing through a culvert can be time consuming. It is recommended that a computer program be used to perform routing calculations; however, an engineer should be familiar with the culvert flood routing design process.

A multiple trial and error procedure is required for culvert flood routing. In general:

(Step 1) A trial culvert(s) is selected

(Step 2) A trial discharge for a particular hydrograph time increment (selected time increment to estimate discharge from the design hydrograph) is selected

(Step 3) Flood routing computations are made with successive trial discharges until the flood routing equation is satisfied

(Step 4) The hydraulic findings are compared to the selected site criteria

(Step 5) If the selected site criteria are satisfied, then a trial discharge for the next time increment is selected and this procedure is repeated; if not, a new trial culvert is selected and the entire procedure is repeated.

5.4 Open Channel Design

5.4.1 Overview

5.4.1.1 INTRODUCTION

Open channel systems and their design are an integral part of stormwater drainage design, particularly for development sites utilizing better site design practices and open channel structural controls. Open channels include drainage ditches, grass channels, dry and wet enhanced swales, riprap channels and concrete-lined channels.

The purpose of this section is to provide an overview of open channel design criteria and methods, including the use of channel design nomographs.

5.4.1.2 OPEN CHANNEL TYPES

The three main classifications of open channel types according to channel linings are vegetated, flexible and rigid. Vegetated linings include grass with mulch, sod and lapped sod, and wetland channels. Riprap and some forms of flexible man-made linings or gabions are examples of flexible linings, while rigid linings are generally concrete or rigid block.

1. **Vegetative Linings** – Vegetation, where practical, is the most desirable lining for an artificial channel. It stabilizes the channel body, consolidates the soil mass of the bed, checks erosion on the channel surface, provides habitat, provides runoff reduction, and provides water quality benefits (see Chapter 4 for more details on using enhanced swales and grass channels for runoff reduction and water quality purposes).

   » Conditions under which vegetation may not be acceptable include but are not limited to:

   - High velocities
   - Standing or continuously flowing water
   - Lack of regular maintenance necessary to prevent growth of taller or woody vegetation
   - Lack of nutrients and inadequate topsoil
   - Excessive shade

   » Proper seeding, mulching and soil preparation are required during construction to assure establishment of healthy vegetation.

2. **Flexible Linings** – Rock riprap, including rubble, is the most common type of flexible lining for channels. It presents a rough surface that can dissipate energy and mitigate increases in erosive velocity. These linings are usually less expensive than rigid linings and have self-healing qualities that reduce maintenance. However, they may require the use of a filter fabric depending on the underlying soils, and the growth of grass and weeds may present maintenance problems.

3. **Rigid Linings** – Rigid linings are generally constructed of concrete and used where high flow capacity is required. Higher velocities, however, create the potential for scour at channel lining transitions and channel headcutting.

5.4.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual, the symbols listed in **Table 5.4-1** will be used. These symbols were selected because of their wide use. In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equations.

Table 5.4-1 Symbols and Definitions

Symbol	Definition	Units
α	Energy coefficient	-
A	Cross-sectional area	ft^2
b	Bottom width	ft
C_g	Specific weight correction factor	-
D or d	Depth of flow	ft
d	Stone Diameter	ft
delta d	Superelevation of the water surface profile	ft
d_x	Diamter of stone for which x percent, by weight, of the gradation is finer	ft
E	Specific energy	ft
Fr	Froude Number	-
g	Acceleration of gravity	32.2 ft/s^2
h_{loss}	Head loss	ft
K	Channel conveyance	-
k_e	Eddy head loss coefficient	ft
K_T	Trapezoidal open channel conveyance factor	-
L	Length of channel	ft
L_p	Length of downstream protection	ft
n	Manning's roughness coefficient	-
P	Wetted Perimeter	ft
Q	Discharge rate	cfs
R	Hydraulic radius of flow	ft
R_C	Mean radius of the bend	ft
S	Slope	ft/ft
SW_S	Specific weight of stone	lbs/ft^3
T	Top width of water surface	ft
V or v	Velocity of flow	ft/s
w	Stone weight	lbs
y_C	Critical depth	ft
y_n	Normal depth	ft
z	Critical flow section factor	-

5.4.3 Design Criteria

5.4.3.1 GENERAL CRITERIA

The following criteria should be followed for open channel design:

- Channels with bottom widths greater than 10 feet shall be designed with a minimum bottom cross slope of 12 to 1, or with compound cross sections.
- Channel side slopes shall be stable throughout the entire length and side slope shall depend on the channel material. A maximum of 2:1 should be used for channel side slopes, unless otherwise justified by calculations. Roadside ditches should have a maximum side slope of 3:1.
- Superelevation of the water surface at horizontal curves shall be accounted for by increased freeboard.
- Trapezoidal or parabolic cross sections are preferred over triangular shapes. The cross-sectional shape of channels shall be as found in the Standard Drawings. "V" shaped cross sections are not permitted in grassed channels. The channel shall be shaped to the dimensions specified on the approved plans and shall be free of gullies, or other irregularities.
- For vegetative channels, design stability should be determined using low vegetative retardance conditions (Class D) and for design capacity higher vegetative retardance conditions (Class C) should be used. Protective cover in grassed channels shall be installed as soon as the earthwork is completed.
- For vegetative channels, flow velocities within the channel should not exceed the maximum permissible velocities given in **Tables 5.4-2** and **5.4-3**.
- If relocation of a stream channel is unavoidable, the cross-sectional shape, meander, pattern, roughness, sediment transport, and slope should conform to the existing conditions insofar as practicable. Some means of energy dissipation may be necessary when existing conditions cannot be duplicated.
- Streambank stabilization should be provided, when appropriate, as a result of any stream disturbance such as encroachment and should include both upstream and downstream banks as well as the local site.
- All new proposed channels shall be designed to carry at least the fully developed 25-year storm with freeboard equal to 20% of the design flow depth. The 100-year design storm should be routed through the channel system to determine if the 100-year plus applicable building elevation restrictions are exceeded, structures are flooded, or flood damages increased.
- Sediment transport should be considered for conditions of flow below the design frequency. A low flow channel component within a larger channel can reduce maintenance by improving sediment transport in the channel.
- In cases of potential erosion due to irregular channel alignment, extreme velocities, or excessive slopes, a paved ditch may be required. However, if, in the opinion of the County, the expected long-term maintenance of a surface drainage system could prove impractical, a pipe design may be required.
- If the channel will be affected by backwater from culverts, bridges, other structures or floodplains, backwater curves shall be shown in profiles of the channel.
- Transition to channel sections shall be smooth and gradual. A straight line connecting flow lines at both ends of the transition shall not make an angle greater than 12.5 degrees with the axis of the main channel without additional design considerations approved by the County.
- Transition sections should be designed to provide a gradual transition to avoid turbulence and eddies.
- Energy losses in transitions should be accounted for as part of the water surface profile calculations.
- Scour downstream from rigid-to-natural and steep-to-mild slope transition sections should be accounted for through velocity slowing and energy dissipating devices.
- Transition channels shall be provided at the inlet and outlet ends of all culverts and pipe systems, unless otherwise provided herein.

5.4.3.2 VELOCITY LIMITATIONS

The final design of artificial open channels should be consistent with the velocity limitations for the selected channel lining. Maximum velocity values for selected lining categories are presented in **Table 5.4-2**. Seeding and mulch should only be used when the design value does not exceed the allowable value for bare soil. Velocity limitations for vegetative linings are reported in **Table 5.4-3**. Vegetative lining calculations are presented in Section 5.4.7 and riprap procedures are presented in Section 5.4.8. Channels in fills shall be lined.

Table 5.4-2 Maximum Velocities for Comparing Lining Materials

Material	Maximum Velocity (ft/s)
Sand	2.0
Silt	3.5
Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay	5.0
Graded Loam or Silt to Cobbles	5.0
Coarse Gravel	6.0
Shales and Hard Pans	6.0

Source: AASHTO Model Drainage Manual, 2005

Table 5.4-3 Maximum Velocities for Vegetative Channel Linings

Vegetation Type	Slope Range (%)[1]	Maximum Velocity[2] (ft/s)
Bermuda Grass	0->10	5
Bahia		4
Tall fescue grass mixtures[3]	0-10	4
Kentucky bluegrass	0-5	6
Buffalo Grass	5-10	5
	>10	4
Grass Mixture	0-5[1]	4
	5-10	3
Sericea lespedeza, Weeping lovegrass Alfalfa	0-5[4]	3
Annuals[5]	0-5	3
Sod		4
Lapped Sod		5

[1] Do not use on slopes steeper than 10%, except for side-slope in combination channel.
[2] Use velocities exceeding 5 ft/s only where good stands can be maintained.
[3] Mixures of Tall Fescue, Bahia, and/or Bermuda
[4] Do not use on slopes steeper than 5%, except for side-slope in combination channel.
[5] Annuals - used on mild slopes or as temporary protection until permanent covers are established.

Source: Manual for Erosion and Sediment Control in Georgia

5.4.4 Manning's Values

The Manning's n value is an important variable in open channel flow computations. Variation in this variable can significantly affect discharge, depth, and velocity estimates. Since Manning's n values depend on many different physical characteristics of natural and man-made channels, care and good engineering judgment must be exercised in the selection process.

Recommended Manning's n values for artificial channels with rigid, unlined, temporary, and riprap linings are given in **Table 5.4-4**. Recommended values for vegetative linings should be determined using **Figure 5.4-1**, which provides a graphical relationship between Manning's n values and the product of velocity and hydraulic radius for several vegetative retardance classifications (see **Table 5.4-6**). **Figure 5.4-1** is used iteratively as described in Section 5.4.6. Recommended Manning's values for natural channels that are either excavated or dredged and natural are given in **Table 5.4-5.** For natural channels, Manning's n values should be estimated using experienced judgment and information presented in publications such as the *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*, FHWA-TS-84-204, 1984.

5.4.5 Uniform Flow Calculations

5.4.5.1 DESIGN CHARTS

Following is a discussion of the equations that can be used for the design and analysis of open channel flow. The Federal Highway Administration has prepared numerous design charts to aid in the design of rectangular, trapezoidal and triangular open channel cross sections. In addition, design charts for grass-lined channels have been developed. These charts and instructions for their use are given in Appendix C.

5.4.5.2 MANNING'S EQUATION

Manning's Equation, presented in three forms below, is recommended for evaluating uniform flow conditions in open channels:

$$v = (1.49/n)\, R^{2/3}\, S^{1/2} \qquad (5.4.1)$$

$$Q = (1.49/n)\, A\, R^{2/3}\, S^{1/2} \qquad (5.4.2)$$

$$S = [Q_n/(1.49\, A\, R^{2/3})]^2 \qquad (5.4.3)$$

Where:

v = average channel velocity (ft/s)
Q = discharge rate for design conditions (cfs)
n = Manning's roughness coefficient
A = cross-sectional area (ft^2)
R = hydraulic radius A/P (ft)
P = wetted perimeter (ft)
S = slope of the energy grade line (ft/ft)

For prismatic channels, in the absence of backwater conditions, the slope of the energy grade line, water surface and channel bottom are assumed to be equal.

5.4.5.3 GEOMETRIC RELATIONSHIPS

Area, wetted perimeter, hydraulic radius, and channel top width for standard channel cross sections can be calculated from geometric dimensions. Irregular channel cross sections (i.e., those with a narrow deep main channel and a wide shallow overbank channel) must be subdivided into segments so that the flow can be computed separately for the main channel and overbank portions. This same process of subdivision may be used when different parts of the channel cross section have different roughness coefficients. When computing the hydraulic radius of the subsections, the water depth common to the two adjacent subsections is not counted as wetted perimeter.

5.4.5.4 DIRECT SOLUTIONS

When the hydraulic radius, cross-sectional area, and roughness coefficient and slope are known, discharge can be calculated directly from **equation 5.4.2**. The slope can be calculated using **equation 5.4.3** when the discharge, roughness coefficient, area, and hydraulic radius are known.

Nomographs for obtaining direct solutions to Manning's Equation are presented in **Figures 5.4-2** and **5.4-3. Figure 5.4-2** provides a general solution for the velocity form of Manning's Equation, while **Figure 5.4-3** provides a solution of Manning's Equation for trapezoidal channels.

Table 5.4-4 Manning's Roughness Coefficients (n) for Artificial Channels

Category	Lining Type	Depth Ranges		
		0-0.5 ft	0.5-2.0 ft	>2.0 ft
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock Cut	0.045	0.035	0.025
Temporary*	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Fiberglass Roving	0.028	0.022	0.019
	Straw with Net	0.065	0.033	0.025
	Curled Wood Mat	0.066	0.035	0.028
	Synthetic Mat	0.036	0.025	0.021
Gravel Riprap	1-inch D_{50}	0.044	0.033	0.030
	2-inch D_{50}	0.066	0.041	0.034
Rock Riprap	6-inch D_{50}	0.104	0.069	0.035
	12-inch D_{50}	-	0.078	0.040

Note: Values listed are representative values for the respective depth ranges. Manning's roughness coefficients, n, vary with the flow depth.

*Some "temporary" linings become permanent when buried.

Source: HEC-15, 2005.

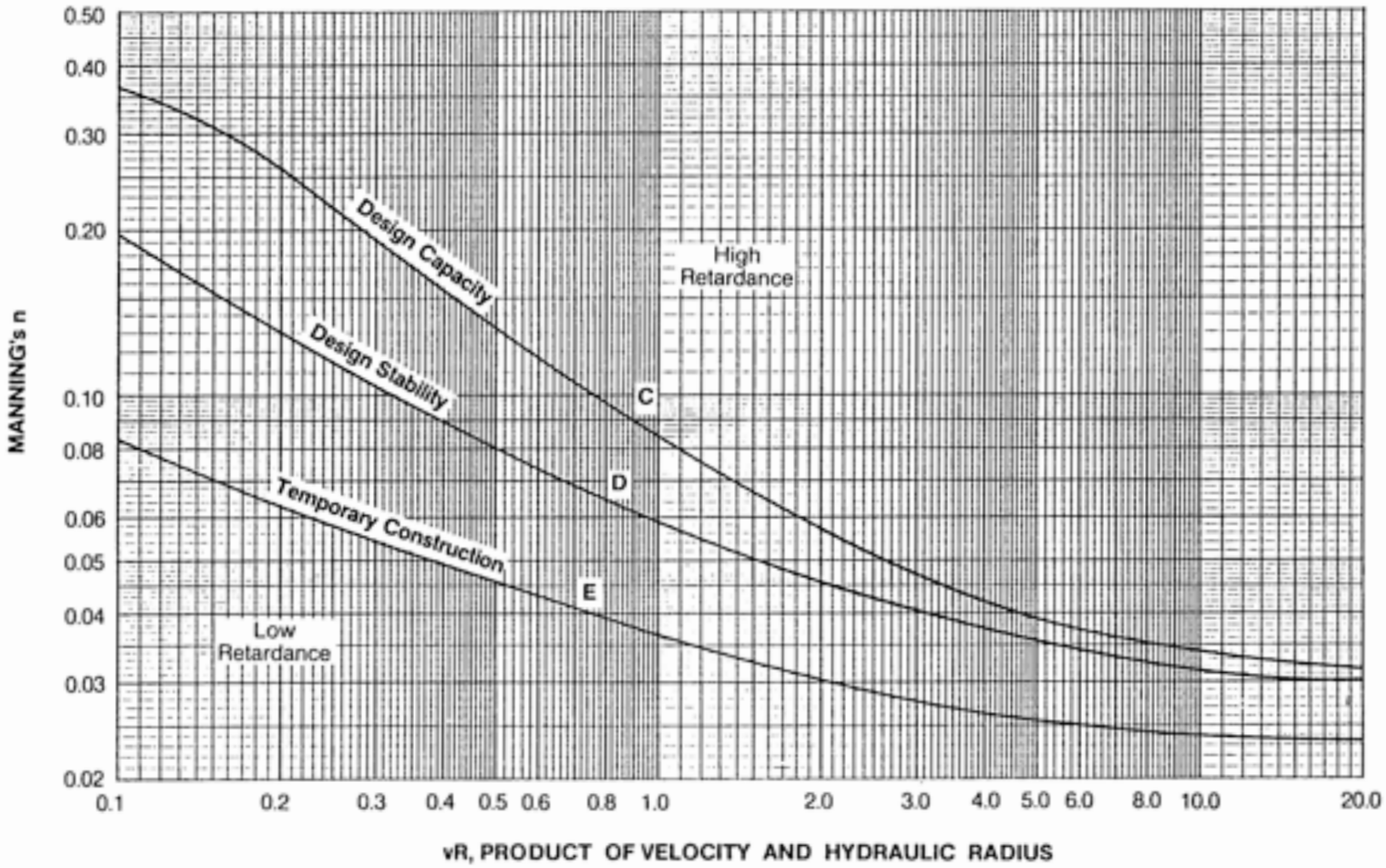


Figure 5.4-1 Manning's n Values for Vegetated Channels

(Source: USDA, TP-61, 1947)

Table 5.4-5 Uniform Flow Values of Roughness Coefficient n

Type of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
a. Earth, straight and uniform	0.016	0.018	0.020
1. Clean, recently completed	0.018	0.022	0.025
2. Clean, after weathering	0.022	0.025	0.030
3. Gravel, uniform sector, clean	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds/plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
NATURAL STREAMS			
Minor Streams (top width at flood stage < 100 ft)			
a. Steams on Plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and some stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
FLOODPLAINS			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated area			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land, tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of spouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
Major streams (top width at flood stage > 100 ft). The n value is less than that for minor streams of similar description, because banks offers less effective resistance.			
a. Regular section with no boulders or brush	0.025	-	0.060
b. Irregular and rough section	0.035	-	0.100

Source: HEC-15, 2005

Table 5.4-6 Classification of Vegetal Covers as to Degrees of Retardance

Retardance	Cover	Condition
A	Weeping Lovegrass Yellow Bluestem Ischaemum	Excellent stand, tall (average 30") Excellent stand, tall (average 36")
B	Kudzu	Very dense growth, uncut
	Bermuda Grass	Good stand, tall (average 12")
	Native grass mixture: little bluestem, bluestem, blue gamma, other short and long stem midwest lovegrass	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (average 24")
	Laspedeza sericea	Good stand, not woody, tall (average 19")
	Alfalfa	Good stand, uncut (average 11")
	Weeping lovegrass	Good stand, unmowed (average 13")
	Kudzu	Dense growth, uncut
	Blue gamma	Good stand, uncut (average 13")
C	Crabgrass Bermuda Grass	Fair stand, uncut (10 - 48") Good stand, mowed (average 6")
	Common lespedeza	Good stand, uncut (average 11")
	Grass-legume mixture: summer (orchard grass redtop, Italian ryegrass, and common lespedeza	Good stand, uncut (6 - 8")
	Centipede Grass	Very dense cover (average 6")
D	Bermuda grass Common lespedeza	Good stand, cut to 2.5" Excellent stand, uncut (average 4.5")
	Buffalo grass	Good stand, uncut (3 - 6")
	Grass-legume mixture: fall, spring (orchard grass, redtop, Italian ryegrass, and common lespedeza	Good stand, uncut (4 - 5")
	Lespedeza serices	After cutting to 2" (very good before cutting)
E	Bermuda grass Bermuda grass	Good stand, cut to 1.5" Burned stubble

Note: Covers classified have been tested in experimental channels. Covers were green and generally uniform.

Source: HEC-15, 2005

General Solution Nomograph

The following steps are used for the general solution nomograph in **Figure 5.4-2**:

(Step 1) Determine open channel data, including slope in ft/ft, hydraulic radius in ft, and Manning's n value.

(Step 2) Connect a line between the Manning's n scale and slope scale and note the point of intersection on the turning line.

(Step 3) Connect a line from the hydraulic radius to the point of intersection obtained in Step 2.

(Step 4) Extend the line from Step 3 to the velocity scale to obtain the velocity in ft/s.

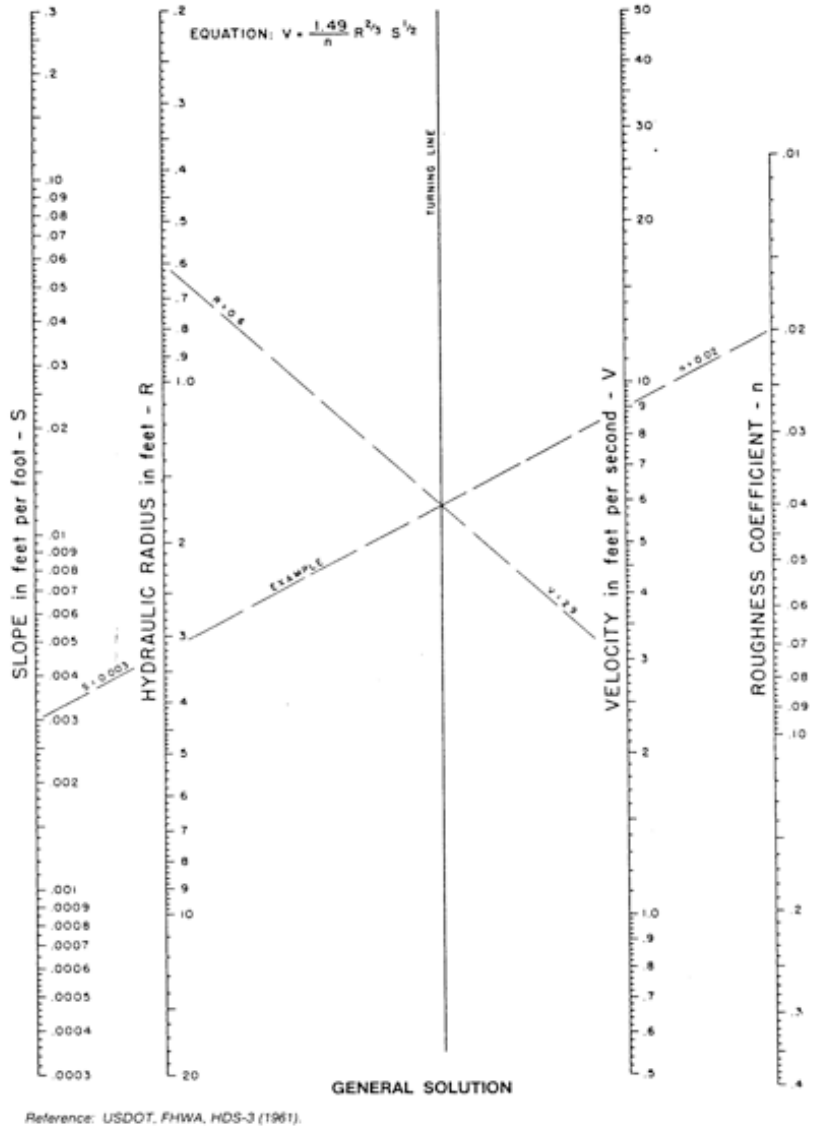
Trapezoidal Solution Nomograph

The trapezoidal channel nomograph solution to Manning's Equation in **Figure 5.4-3** can be used to find the depth of flow if the design discharge is known or the design discharge if the depth of flow is known.

Determine input data, including slope in ft/ft, Manning's n value, bottom width in ft, and side slope in ft/ft.

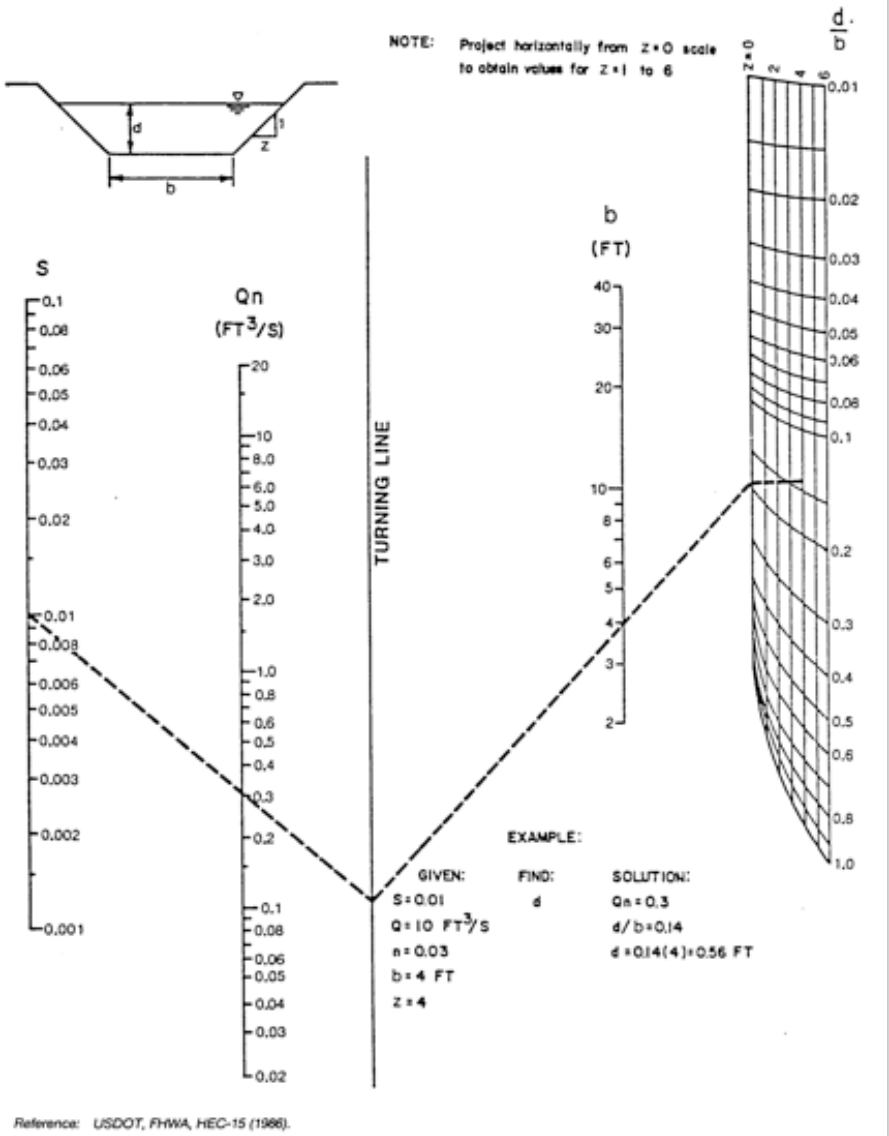
1. Given Q, find d.
   a. Given the design discharge, find the product of Q times n, connect a line from the slope scale to the Qn scale, and find the point of intersection on the turning line.
   b. Connect a line from the turning point from Step 1a to the b scale and find the intersection with the z = 0 scale.
   c. Project horizontally from the point located in Step 1b to the appropriate z value and find the value of d/b.
   d. Multiply the value of d/b obtained in Step 1c by the bottom width b to find the depth of uniform flow, d.

2. Given d, find Q
   a. Given the depth of flow, find the ratio d divided by b and project a horizontal line from the d/b ratio at the appropriate side slope, z, to the z = 0 scale.
   b. Connect a line from the point located in Step 2a to the b scale and find the intersection with the turning line.
   c. Connect a line from the point located in Step 2b to the slope scale and find the intersection with the Qn scale.
   d. Divide the value of Qn obtained in Step 2c by the n value to find the design discharge, Q.



Reference: USDOT, FHWA, HDS-3 (1961).

Figure 5.4-2 Nomograph for the Solution of Manning's Equation



Reference: USDOT, FHWA, HEC-15 (1988).

Figure 5.4-3 Solution of Manning's Equation for Trapezoidal Channels

5.4.5.5 TRIAL AND ERROR SOLUTIONS

A trial and error procedure for solving Manning's Equation is used to compute the normal depth of flow in a uniform channel when the channel shape, slope, roughness, and design discharge are known. For purposes of the trial and error process, Manning's Equation can be arranged as:

$$AR^{2/3} = (Q_n)/(1.49\ S^{1/2}) \qquad (5.4.4)$$

Where:

A = cross-sectional area (ft)
R = hydraulic radius (ft)
Q = discharge rate for design conditions (cfs)
n = Manning's roughness coefficient
S = slope of the energy grade line (ft/ft)

To determine the normal depth of flow in a channel by the trial and error process, trial values of depth are used to determine A, P, and R for the given channel cross section. Trial values of $AR^{2/3}$ are computed until the equality of **equation 5.4.4** is satisfied such that the design flow is conveyed for the slope and selected channel cross section.

Graphical procedures for simplifying trial and error solutions are presented in **Figure 5.4-4** for trapezoidal channels.

(Step 1) Determine input data, including design discharge, Q, Manning's n value, channel bottom width, b, channel slope, S, and channel side slope, z.

(Step 2) Calculate the trapezoidal conveyance factor using the equation:

$$K_T = (Q_n)/(b^{8/3}S^{1/2}) \qquad (5.4.5)$$

Where:

K_T = trapezoidal open channel conveyance factor
Q = discharge rate for design conditions (cfs)
n = Manning's roughness coefficient
b = bottom width (ft)
S = slope of the energy grade line (ft/ft)

(Step 3) Enter the x-axis of **Figure 5.4-4** with the value of KT calculated in Step 2 and draw a line vertically to the curve corresponding to the appropriate z value from Step 1.

(Step 4) From the point of intersection obtained in Step 3, draw a horizontal line to the y-axis and read the value of the normal depth of flow over the bottom width, d/b.

(Step 5) Multiply the d/b value from Step 4 by b to obtain the normal depth of flow.

Note: If bends are considered, refer to **equation 5.4.11**

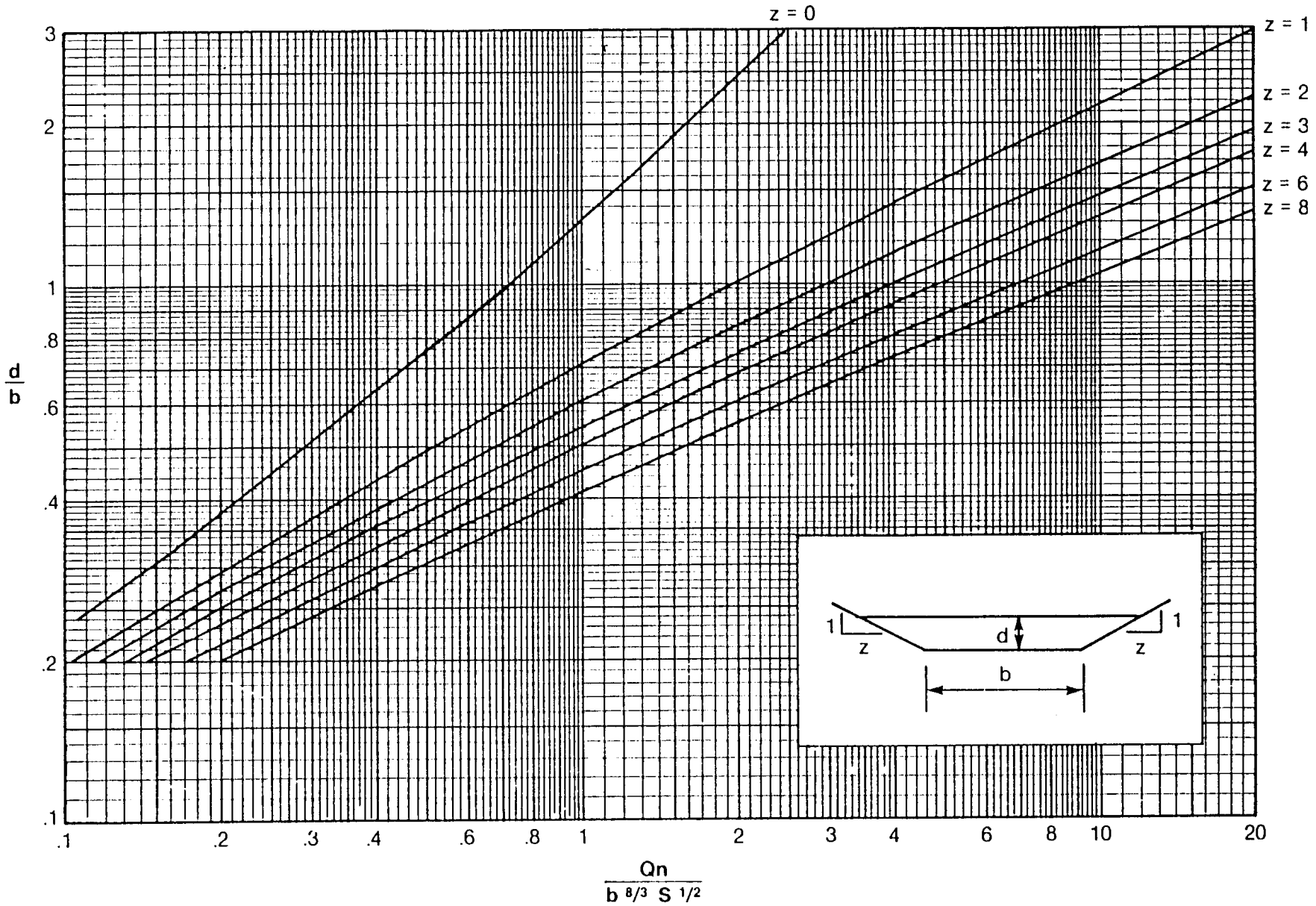


Figure 5.4-4 Trapezoidal Channel Capacity Chart

(Source: Nashville Storm Water Management Manual, 1988)

5.4.6 Critical Flow Calculations

5.4.6.1 BACKGROUND

In the design of open channels, it is important to calculate the critical depth in order to determine if the flow in the channel will be subcritical or supercritical. If the flow is subcritical it is relatively easy to handle the flow through channel transitions because the flows are tranquil and wave action is minimal. In subcritical flow, the depth at any point is influenced by a downstream control, which may be either the critical depth or the water surface elevation in a pond or larger downstream channel. In supercritical flow, the depth of flow at any point is influenced by a control upstream, usually critical depth. In addition, the flows have relatively shallow depths and high velocities.

Critical depth depends only on the discharge rate and channel geometry. The general equation for determining critical depth is expressed as:

$$Q^2/g = A^3/T \qquad (5.4.6)$$

Where:

Q = discharge rate for design conditions (cfs)
g = acceleration due to gravity (32.2 ft/sec^2)
A = cross-sectional area (ft^2)
T = top width of water surface (ft)

Note: A trial and error procedure is needed to solve **equation 5.4-6**.

5.4.6.2 SEMI-EMPIRICAL EQUATIONS

Semi-empirical equations (as presented in **Table 5.4-7**) or section factors (as presented in **Figure 5.4-5**) can be used to simplify trial and error critical depth calculations. The following equation is used to determine critical depth with the critical flow section factor, Z:

$$Z = Q/(g^{0.5}) \qquad (5.4.7)$$

Where:

Z = critical flow section factor
Q = discharge rate for design conditions (cfs)
g = acceleration due to gravity (32.2 ft/sec^2)

The following guidelines are given for evaluating critical flow conditions of open channel flow:

1. A normal depth of uniform flow within about 10% of critical depth is unstable and should be avoided in design, if possible.
2. If the velocity head is less than one-half the mean depth of flow, the flow is subcritical.
3. If the velocity head is equal to one-half the mean depth of flow, the flow is critical.
4. If the velocity head is greater than one-half the mean depth of flow, the flow is supercritical.

Note: The head is the height of water above any point, plane or datum of reference. The velocity head in flowing water is calculated as the velocity squared divided by 2 times the gravitational constant ($V^2/2g$).

The Froude number, Fr, calculated by the following equation, is useful for evaluating the type of flow conditions in an open channel:

$$Fr = v/(gA/T)^{0.5} \qquad (5.4.8)$$

Where:

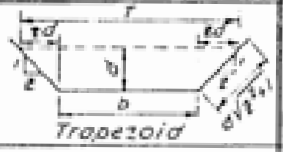
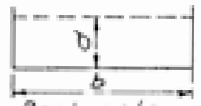
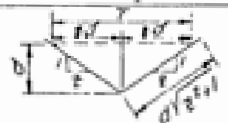
Fr = Froude number (dimensionless)
v = velocity of flow (ft/s)
g = acceleration of gravity (32.2 ft/sec^2)
A = cross-sectional area of flow (ft^2)
T = top width of flow (ft)

If Fr is greater than 1.0, flow is supercritical; if it is under 1.0, flow is subcritical. Fr is 1.0 for critical flow conditions.

Table 5.4-7 Critical Depth Equations for Uniform Flow in Selected Channel Cross Sections

Channel Type[1]	Semi-Empirical Equations[2] for Estimating Critical Depth	Range of Applicability
1. Rectangular[3]	$d_c = [Q^2/(gb^2)]^{1/3}$	N/A
2. Trapezoidal[3]	$d_c = 0.81[Q^2/gz^{0.75}b^{1.25})]^{0.27}$ - b/30z	$0.1 < 0.5522\ Q/b^{2.5} < 0.4$ For $0.5522\ Q/b^{2.5} < 0.1$, use rectangular channel equation
3. Triangular[3]	$d_c = [(2Q^2)/(gz^2)]^{1/5}$	N/A
4. Circular[3]	$d_c = 0.325(Q/D)^{2/3} + 0.083D$	$0.3 < d_c/D < 0.9$
5. General[3]	$(A^3/T) = (Q^2/g)$	N/A
Where:	d_c = critical depth (ft) Q = design discharge (cfs) G = acceleration due to gravity (32.2 ft/s^2) b = bottom width of channel (ft) z = side slopes of a channel (horizontal to vertical) D = diameter of a circular conduit (ft) A = cross-sectional area of flow (ft^2) T = top width of water surface (ft)	

[1]See **Figure 5.4-5** for channel sketches
[2]Assumes uniform flow with the kinetic energy coefficient equal to 1.0
[3]Reference: French (1985)
[4]Reference: USDOT, FHWA, HDS-4 (1965)
[5]Reference: Brater and King (1976)

Section	Area A	Wetted Perimeter P	Hydraulic Radius R	Top Width T	Critical Depth Factor, Z
 Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$	$\frac{\sqrt{(b+zd)d}^{1.5}}{\sqrt{b+2zd}}$
 Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b	$bd^{1.5}$
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$	$\frac{\sqrt{2}}{2}zd^{2.5}$
 Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ [1]	$\frac{2dT^2}{3T^2+8d^2}$ [1]	$\frac{3a}{2d}$	$\frac{2}{9}\sqrt{6}\,Td^{1.5}$
 Circle - <½ full [2]	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$	$a\sqrt{\frac{a}{D\sin\frac{\theta}{2}}}$
 Circle - >½ full [3]	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$	$a\sqrt{\frac{a}{D\sin\frac{\theta}{2}}}$

[1] Satisfactory approximation for the interval $0<\frac{d}{T}\leq 0.25$
When $d/T>0.25$, use $p=\frac{1}{2}\sqrt{16d^2+T^2}+\frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta=4\sin^{-1}\sqrt{d/D}$
[3] $\theta=4\cos^{-1}\sqrt{d/D}$
} Insert θ in degrees in above equations

Note: Small z = Side Slope Horizontal Distance
Large Z = Critical Depth Section Factor

Reference: USDA, SCS, NEH-5 (1956).

Figure 5.4-5 Open Channel Geometric Relationships for Various Cross Sections

5.4.7 Vegetative Design

5.4.7.1 INTRODUCTION

A two-part procedure is recommended for final design of temporary and vegetative channel linings. Part 1, the design stability component, involves determining channel dimensions for low vegetative retardance conditions, using Class D as defined in **Table 5.4-6**. Part 2, the design capacity component, involves determining the depth increase necessary to maintain capacity for higher vegetative retardance conditions, using Class C as defined in **Table 5.4-6**. If temporary lining is to be used during construction, vegetative retardance Class E should be used for the design stability calculations.

If the channel slope exceeds 10%, or a combination of channel linings will be used, additional procedures can be found in HEC-15 (USDOT, FHWA, 2005) and HEC-14 (USDOT, FHWA, 2012).

5.4.7.2 DESIGN STABILITY

The following are the steps for design stability calculations:

(Step 1) Determine appropriate design variables, including discharge, Q, bottom slope, S, cross section parameters, and vegetation type.

(Step 2) Use **Table 5.4-3** to assign a maximum velocity, vm based on vegetation type and slope range.

(Step 3) Assume a value of n and determine the corresponding value of vR from the n versus vR curves in **Figure 5.4-1**. Use retardance Class D for permanent vegetation and E for temporary construction.

(Step 4) Calculate the hydraulic radius using the equation:

$$R = (vR)/v_m \quad (5.4.9)$$

Where:

R = hydraulic radius of flow (ft)
vR = value obtained from **Figure 5.4-1** in Step 3
v_m = maximum velocity from Step 2 (ft/s)

(Step 5) Use the following form of Manning's Equation to calculate the value of vR:

$$vR = (1.49\ R^{5/3}\ S^{1/2})/n \quad (5.4.10)$$

Where:

vR = calculated value of vR product
R = hydraulic radius value from Step 4 (ft)
S = channel bottom slope (ft/ft)
n = Manning's n value assumed in Step 3

(Step 6) Compare the vR product value obtained in Step 5 to the value obtained from **Figure 5.4-1** for the assumed n value in Step 3. If the values are not reasonably close, return to Step 3 and repeat the calculations using a new assumed n value.

(Step 7) For trapezoidal channels, find the flow depth using **Figures 5.4-3** or **5.4-4**, as described in Section 5.4.4. The depth of flow for other channel shapes can be evaluated using the trial and error procedure described in Section 5.4.5.

(Step 8) If bends are considered, calculate the length of downstream protection, L_p, for the bend, using **Figure 5.4-6**. Provide additional protection, such as gravel or riprap in the bend and extending downstream for length, L_p.

5.4.7.3 DESIGN CAPACITY

The following are the steps for design capacity calculations:

(Step 1) Assume a depth of flow greater than the value from Step 7 above and compute the waterway area and hydraulic radius (see **Figure 5.4-5** for equations).

(Step 2) Divide the design flow rate, obtained using appropriate procedures from, Chapter 3 Stormwater Hydrology, by the waterway area from Step 1 to find the velocity.

(Step 3) Multiply the velocity from Step 2 by the hydraulic radius from Step 1 to find the value of vR.

(Step 4) Use **Figure 5.4-1** to find a Manning's n value for retardance Class C based on the vR value from Step 3.

(Step 5) Use Manning's Equation (**equation 5.4.1**) or **Figure 5.4-2** to find the velocity using the hydraulic radius from Step 1, Manning's n value from Step 4, and appropriate bottom slope.

(Step 6) Compare the velocity values from Steps 2 and 5. If the values are not reasonably close, return to Step 1 and repeat the calculations.

(Step 7) Add an appropriate freeboard to the final depth from Step 6. Generally, 20% is adequate.

(Step 8) If bends are considered, calculate superelevation of the water surface profile at the bend using the equation:

$$\Delta d = (v^2T)/(gR_c) \qquad (5.4.11)$$

Where:

Δd = superelevation of the water surface profile due to the bend (ft)

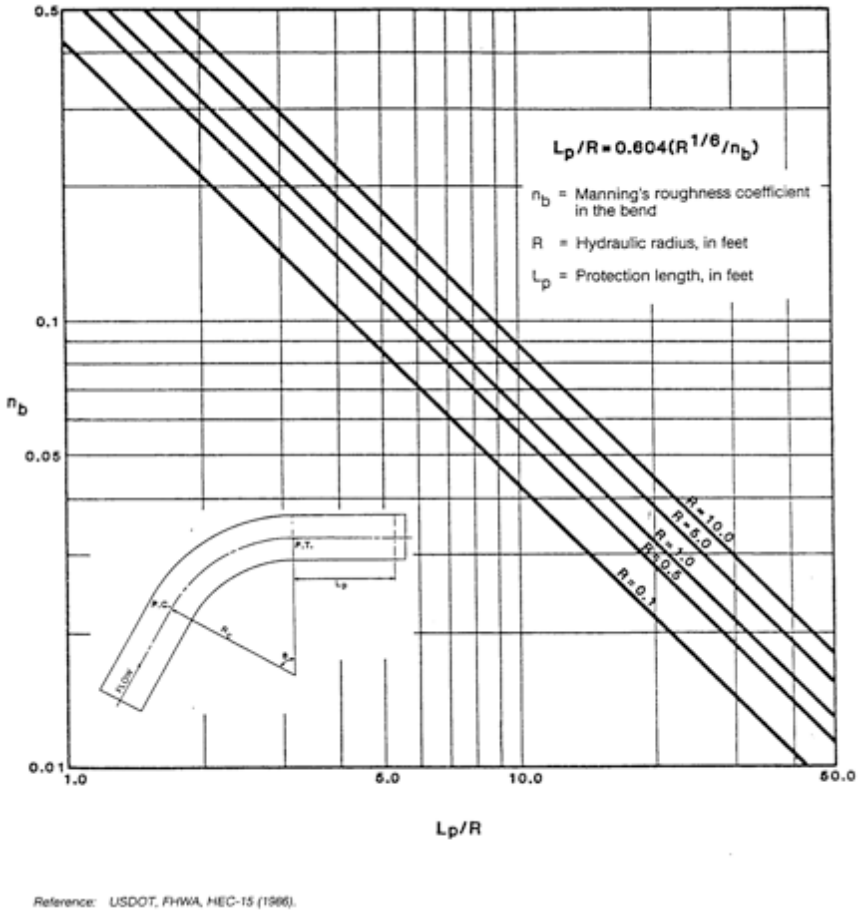
v = average velocity from Step 6 (ft/s)

T = top width of flow (ft)

g = acceleration of gravity (32.2 ft/sec^2)

R_c = mean radius of the bend (ft)

Note: Add freeboard consistent with the calculated Δd.



Reference: USDOT, FHWA, HEC-15 (1988).

Figure 5.4-6 Protection Length, Lp, Downstream of Channel Bend

5.4.8 Riprap Design

5.4.8.1 ASSUMPTIONS

The following procedure is based on results and analysis of laboratory and field data (Maynord, 1987; Reese, 1984; Reese, 1988). This procedure applies to riprap placement in both natural and prismatic channels and has the following assumptions and limitations:

- Minimum riprap thickness equal to d_{100}
- The value of d_{85}/d_{15} less than 4.6
- Froude number less than 1.2
- Side slopes up to 2:1
- A safety factor of 1.2
- Maximum velocity less than 18 feet per second

If significant turbulence is caused by boundary irregularities, such as obstructions or structures, this procedure is not applicable.

5.4.8.2 PROCEDURE

Following are the steps in the procedure for riprap design:

(Step 1) Determine the average velocity in the main channel for the design condition. Manning's n values for riprap can be calculated from the equation:

$$n = 0.0395 (d_{50})^{1/6} \qquad (5.4.12)$$

Where:

n = Manning's roughness coefficient for stone riprap

$\mathbf{d_{50}}$ = diameter of stone for which 50%, by weight, of the gradation is finer (ft)

(Step 2) If rock is to be placed at the outside of a bend, multiply the velocity determined in Step 1 by the bend correction coefficient, C_b, given in **Figure 5.4-7** for either a natural or prismatic channel. This requires determining the channel top width, T, just upstream from the bend and the centerline bend radius, R_b.

(Step 3) If the specific weight of the stone varies significantly from 165 pounds per cubic foot, multiply the velocity from Step 1 or 2 (as appropriate) by the specific weight correction coefficient, C_g, from **Figure 5.4-8**.

(Step 4) Determine the required minimum d_{30} value from **Figure 5.4-9**, or from the equation:

$$\mathbf{d_{30}/D = 0.193\ Fr^{2.5}} \qquad \mathbf{(5.4.13)}$$

Where:

$\mathbf{d_{30}}$ = diameter of stone for which 30%, by weight, of the gradation is finer (ft)

D = depth of flow above stone (ft)

Fr = Froude number (see equation 5.4.8), dimensionless

v = mean velocity above the stone (ft/s)

(Step 5) Determine available riprap gradations. A well graded riprap is preferable to uniform size or gap graded. The diameter of the largest stone, d_{100}, should not be more than 1.5 times the d_{50} size. Blanket thickness should be greater than or equal to d_{100} except as noted below. Sufficient fines (below d_{15}) should be available to fill the voids in the larger rock sizes. The stone weight for a selected stone size can be calculated from the equation:

$$\mathbf{W = 0.5236\ SW_s\ d^3} \qquad \mathbf{(5.4.14)}$$

Where:

W = stone weight (lbs)

d = selected stone diameter (ft)

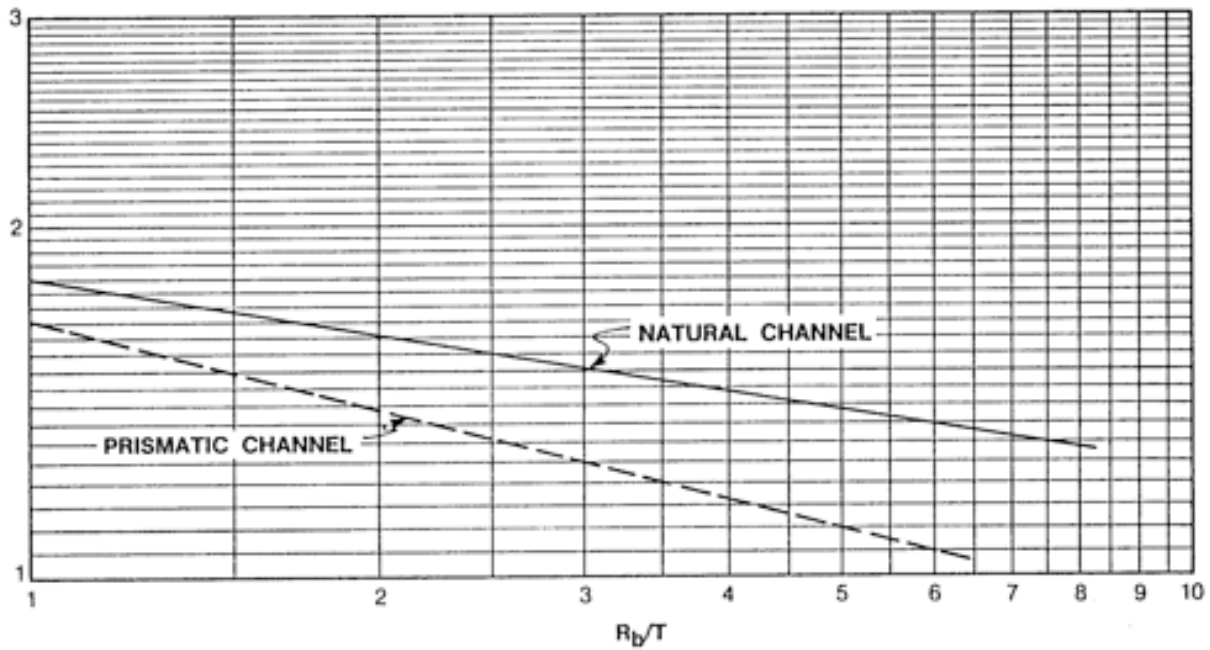
$\mathbf{SW_s}$ = specific weight of stone (lbs/ft^3)

Filter fabric or a filter stone layer should be used to prevent turbulence or groundwater seepage from removing bank material through the stone or to serve as a foundation for unconsolidated material. Layer thickness should be increased by 50% for underwater placement.

(Step 6) If d_{85}/d_{15} is between 2.0 and 2.3 and a smaller d_{30} size is desired, a thickness greater than d_{100} can be used to offset the smaller d_{30} size. **Figure 5.4-10** can be used to make an approximate adjustment using the ratio of d_{30} sizes. Enter the y-axis with the ratio of the desired d_{30} size to the standard d_{30} size and find the thickness ratio increase on the x-axis. Other minor gradation deficiencies may be compensated for by increasing the stone blanket thickness.

(Step 7) Perform preliminary design, ensuring that adequate transition is provided to natural materials both up and downstream to avoid flanking and that toe protection is provided to avoid riprap undermining.

Figure 5.4-7 Riprap Lining Bend Correction Coefficient



To obtain effective velocity, multiply known velocity by C_b.

T = Channel Top Width
R_b = Centerline Bend Radius
C_b = Correction Coefficient

Reference: Maynord (1987).

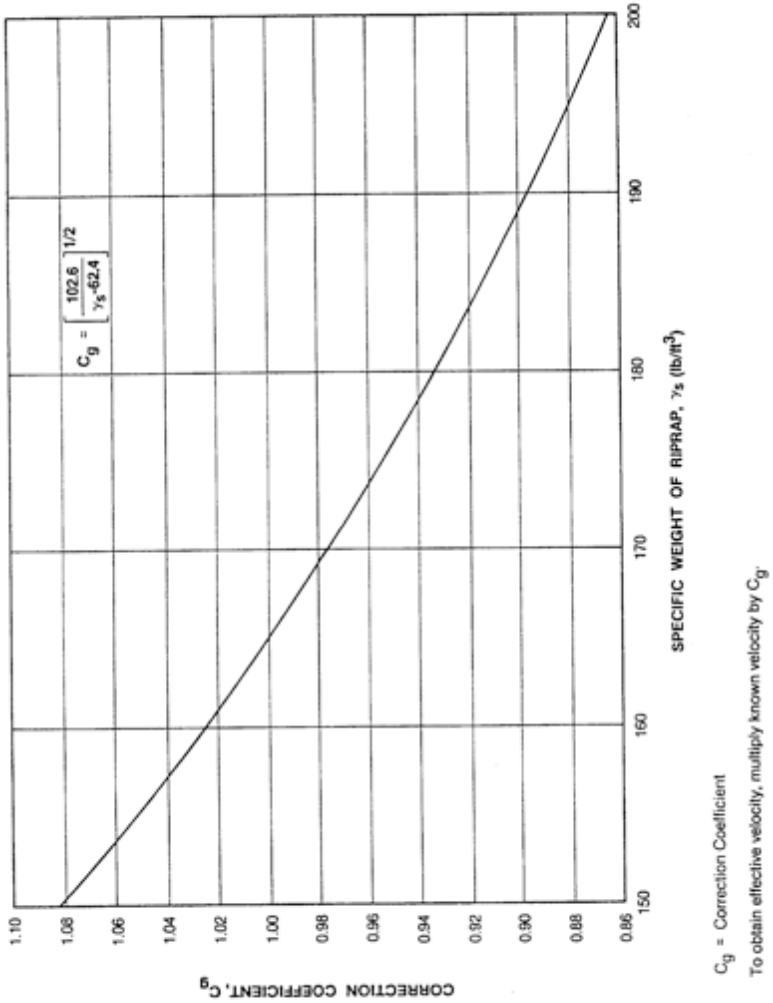


Figure 5.4-8 Riprap Lining Specific Weight Correction Coefficient

(Source: Nashville Storm Water Management Manual, 1988)

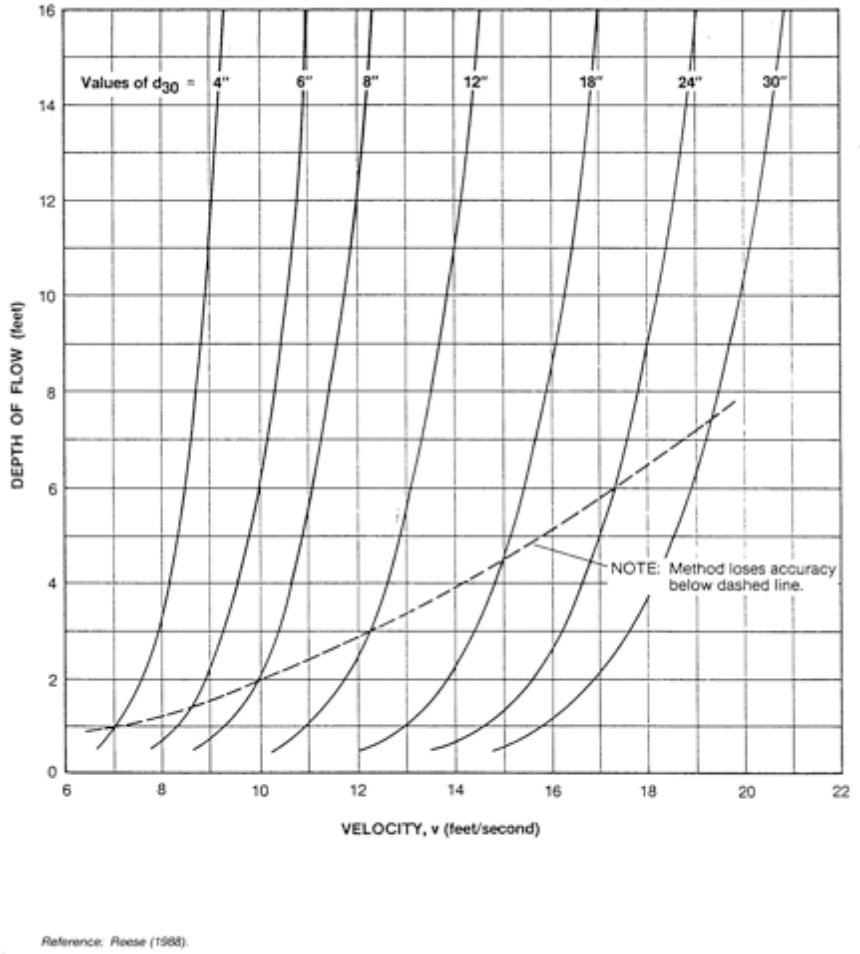


Figure 5.4-9 Riprap Lining d^{30} Stone Size – Function of Mean Velocity and Depth

5.4.9 Uniform Flow - Example Problems

Example 1 -- Direct Solution of Manning's Equation

Use Manning's Equation to find the velocity, v, for an open channel with a hydraulic radius value of 0.6 ft, an n value of 0.020, and slope of 0.003 ft/ft. Solve using **Figure 5.4-2**:

1. Connect a line between the slope scale at 0.003 and the roughness scale at 0.020 and note the intersection point on the turning line.

2. Connect a line between that intersection point and the hydraulic radius scale at 0.6 ft and read the velocity of 2.9 ft/s from the velocity scale.

Example 2 -- Grassed Channel Design Stability

A trapezoidal channel is required to carry 50 cfs at a bottom slope of 0.015 ft/ft. Find the channel dimensions required for design stability criteria (retardance Class D) for a grass mixture.

1. From **Table 5.4-3**, the maximum velocity, vm, for a grass mixture with a bottom slope less than 5% is 4 ft/s.

2. Assume an n value of 0.035 and find the value of vR from **Figure 5.4-1**, vR = 5.4

3. Use **equation 5.4.9** to calculate the value of R: R = 5.4/4 = 1.35 ft

4. Use **equation 5.4.10** to calculate the value of vR:

   $vR = [1.49\ (1.35)^{5/3}\ (0.015)^{1/2}]/0.035 = 8.60$

5. Since the vR value calculated in Step 4 is higher than the value obtained from Step 2, a higher n value is required and calculations are repeated. The results from each trial of calculations are presented below:

Assumed n Value	vR (Fig. 5.4-1)	R (eq. 5.4.9)	vR (eq. 5.4.10)
0.035	5.40	1.35	8.60
0.038	3.8	0.95	4.41
0.039	3.4	0.85	3.57
0.040	3.2	0.80	3.15

Select n = 0.040 for stability criteria.

6. Use **Figure 5.4-3** to select channel dimensions for a trapezoidal shape with 3:1 side slopes.

   - Qn = (50) (0.040) = 2.0 S = 0.015
   - For b = 10 ft, d = (10) (0.098) = 0.98 ft
     b = 8 ft, d = (8) (0.14) = 1.12 ft

Select:

- b = 10 ft, such that R is approximately 0.80 ft
- z = 3
- d = 1 ft
- v = 3.9 ft/s (**equation 5.4.1**)
- Fr = 0.76 (**equation 5.4.8**)
- Flow is subcritical

Design capacity calculations for this channel are presented in Example 3 below.

Example 3 -- Grassed Channel Design Capacity

Use a 10-ft bottom width and 3:1 side-slopes for the trapezoidal channel sized in Example 2 and find the depth of flow for retardance Class C.

1. Assume a depth of 1.0 ft and calculate the following (see Figure 5.4-5):
   - A = (b + zd) d = [10 + (3) (1)] (1) = 13.0 sq ft
   - $R = \{[b + zd]\ d\}/\{b + [2d(1 + z^2)^{0.5}]\} = \{[10+(3)(1)](1)\}/\{10+[(2)(1)(1+3^2)^{0.5}]\}$
   - R = 0.796 ft

2. Find the velocity: v = Q/A = 50/13.0 = 3.85 ft/s

3. Find the value of vR: vR = (3.85) (0.796) = 3.06

4. Using the vR product from Step 3, find Manning's n from **Figure 5.4-1** for retardance Class C (n = 0.047)

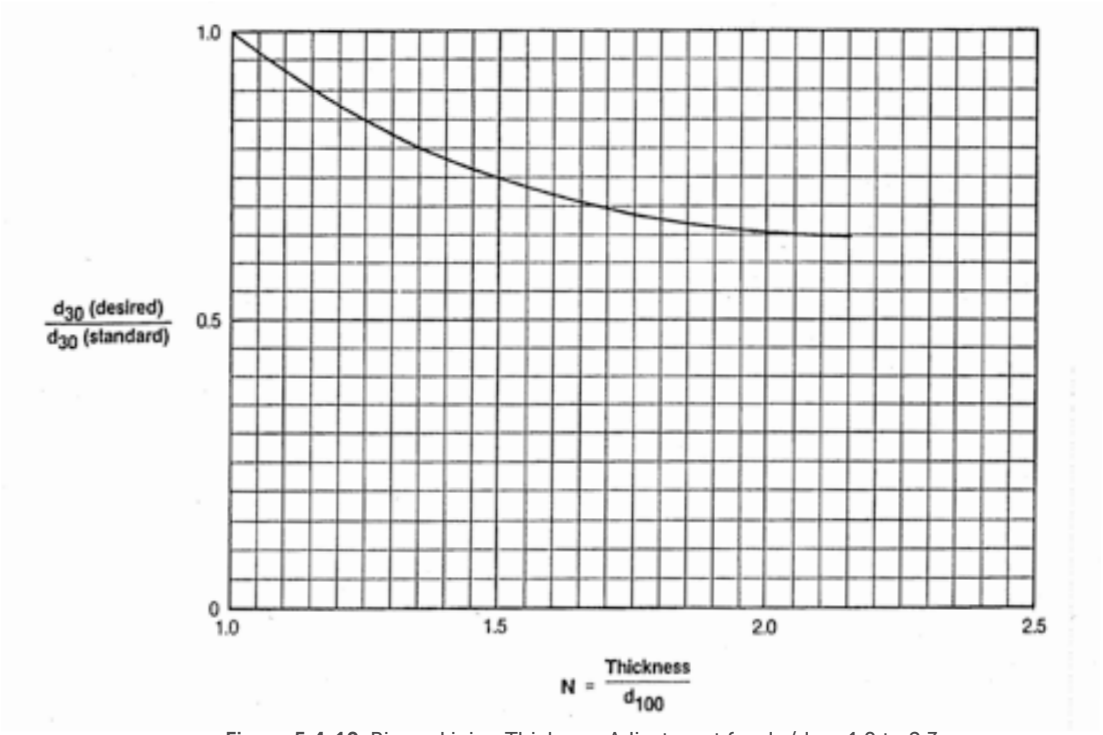


Figure 5.4-10 Riprap Lining Thickness Adjustment for d_{85}/d_{15} = 1.0 to 2.3

(Source: Maynord, 1987)

5. Use **Figure 5.4-2** or **equation 5.4.1** to find the velocity for S = 0.015, R = 0.796, and n = 0.047: v = 3.34 ft/s

6. Since 3.34 ft/s is less than 3.85 ft/s, a higher depth is required and calculations are repeated. Results from each trial of calculations are presented below:

Assumed Depth (ft)	Area (ft^2)	R (ft)	Velocity Q/A (ft/sec)	vR	Manning's n **(Fig. 5.4-3)**	Velocity **(Eq. 5.4.11)**
1.0	13.00	0.796	3.85	3.06	0.047	3.34
1.05	13.81	0.830	3.62	3.00	0.047	3.39
1.1	14.63	0.863	3.42	2.95	0.048	3.45
1.2	16.32	0.928	3.06	2.84	0.049	3.54

7. Select a depth of 1.1 with an n value of 0.048 for design capacity requirements. Add at least 0.2 ft for freeboard to give a design depth of 1.3 ft. Design data for the trapezoidal channel are summarized as follows:

   - Vegetation lining = grass mixture, v_m = 4 ft/s
   - Q = 50 cfs
   - b = 10 ft, d = 1.3 ft, z = 3, S = 0.015
   - Top width = (10) + (2) (3) (1.3) = 17.8 ft
   - n (stability) = 0.040, d = 1.0 ft, v = 3.9 ft/s, Froude number = 0.76 (**equation 5.4.8**)
   - n (capacity) = 0.048, d = 1.1 ft, v = 3.45 ft/s, Froude number = 0.64 (**equation 5.4.8**)

Example 4 -- Riprap Design

A natural channel has an average bankfull channel velocity of 8 ft per second with a top width of 20 ft and a bend radius of 50 ft. The depth over the toe of the outer bank is 5 ft. Available stone weight is 170 lbs/ft^3. Stone placement is on a side slope of 2:1 (horizontal:vertical). Determine riprap size at the outside of the bend.

1. Use 8 ft/s as the design velocity, because the reach is short and the bend is not protected.

2. Determine the bend correction coefficient for the ratio of $R_b/T = 50/20 = 2.5$. From **Figure 5.4-7**, $C_b = 1.55$. The adjusted effective velocity is (8) (1.55) = 12.4 ft/s.

3. Determine the correction coefficient for the specific weight of 170 lbs from **Figure 5.4-8** as 0.98. The adjusted effective velocity is (12.4) (0.98) = 12.15 ft/s.

4. Determine minimum d_{30} from **Figure 5.4-9** or **equation 5.4.13** as about 10 inches.

5. Use a gradation with a minimum d_{30} size of 10 inches.

6. (Optional) Another gradation is available with a d_{30} of 8 inches. The ratio of desired to standard stone size is 8/10 or 0.8. From **Figure 5.4-10**, this gradation would be acceptable if the blanket thickness was increased from the original d_{100} (diameter of the largest stone) thickness by 35% (a ratio of 1.35 on the horizontal axis).

7. Perform preliminary design. Make sure that the stone is carried up and downstream far enough to ensure stability of the channel and that the toe will not be undermined. The downstream length of protection for channel bends can be determined using **Figure 5.4-6**.

5.4.10 Gradually Varied Flow

The most common occurrence of gradually varied flow in storm drainage is the backwater created by culverts, storm sewer inlets, or channel constrictions. For these conditions, the flow depth will be greater than normal depth in the channel and the water surface profile should be computed using backwater techniques.

Many computer programs are available for computation of backwater curves. The most general and widely used programs are, HEC-RAS, developed by the U.S. Army Corps of Engineers and Bridge Waterways Analysis Model (WSPRO) developed for the Federal Highway Administration. These programs can be used to compute water surface profiles for both natural and artificial channels.

For prismatic channels, the backwater calculation can be computed manually using the direct step method. For an irregular nonuniform channel, the standard step method is recommended, although it is a more tedious and iterative process. The use of HEC-RAS is recommended for standard step calculations.

Cross sections for water surface profile calculations should be normal to the direction of flood flow. The number of sections required will depend on the irregularity of the stream and flood plain. In general, a cross section should be obtained at each location where there are significant changes in stream width, shape, or vegetal patterns. Sections should usually be no more than 4 to 5 channel widths apart or 100 feet apart for ditches or streams and 500 feet apart for floodplains, unless the channel is very regular.

5.4.11 Rectangular, Triangular, and Trapezoidal Open Channel Design Figures

5.4.11.1 INTRODUCTION

The Federal Highway Administration has prepared numerous design figures to aid in the design of open channels. Copies of these figures, a brief description of their use, and several example design problems are presented. For design conditions not covered by the figures, a trial and error solution of Manning's Equation must be used.

5.4.11.2 DESCRIPTION OF FIGURES

Figures given in Appendix C are for the direct solution of the Manning's Equation for various sized open channels with rectangular, triangular, and trapezoidal cross sections. Each figure (except for the triangular cross section) is prepared for a channel of given bottom width and a particular value of Manning's n.

The figures for rectangular and trapezoidal cross section channels (Appendix C) are used the same way. The abscissa scale of discharge in cubic feet per second (cfs), and the ordinate scale is velocity in feet per second (ft/s). Both scales are logarithmic. Superimposed on the logarithmic grid are steeply inclined lines representing depth (ft), and slightly inclined lines representing channel slope (ft/ft).

A heavy dashed line on each figure shows critical flow conditions. Auxiliary abscissa and ordinate scales are provided for use with other values of n and are explained in the example problems. In the figures, interpolations may be made not only on the ordinate and abscissa scales but between the inclined lines representing depth and slope.

The chart for a triangular cross section (Appendix C) is in nomograph form. It may be used for street sections with a vertical (or nearly vertical) curb face. The nomograph also may be used for shallow V shaped sections by following the instructions on the chart.

5.4.11.3 INSTRUCTIONS FOR RECTANGULAR AND TRAPEZOIDAL FIGURES

Figures in Appendix C provide a solution of the Manning equation for flow in open channels of uniform slope, cross section, and roughness, provided the flow is not affected by backwater and the channel has a length sufficient to establish uniform flow.

For a given slope and channel cross section, when n is 0.015 for rectangular channels or 0.03 for trapezoidal channels, the depth and velocity of uniform flow may be read directly from the figure for that size channel. The initial step is to locate the intersection of a vertical line through the discharge (abscissa) and the appropriate slope line. At this intersection, the depth of flow is read from the depth lines, and the mean velocity is read on the ordinate scale.

The procedure is reversed to determine the discharge at a given depth of flow. Critical depth, slope, and velocity for a given discharge can be read on the appropriate scale at the intersection of the critical curve and a vertical line through the discharge.

Auxiliary scales, labeled Qn (abscissa) and Vn (ordinate), are provided so the figures can be used for values of n other than those for which the charts were basically prepared. To use these scales, multiply the discharge by the value of n and use the Qn and Vn scales instead of the Q and V scales, except for computation of critical depth or critical velocity. To obtain normal velocity V from a value on the Vn scale, divide the value by n. The following examples will illustrate these points.

Example Design Problem 1

Given:
A rectangular concrete channel 5 ft wide with n = 0.015, .06 percent slope (S = .0006), discharging 60 cfs.

Find:
Depth, velocity, and type of flow

Procedure:

1. From Appendix C select the rectangular figure for a 5-ft width (**Figure 5.4-11**).
2. From 60 cfs on the Q scale, move vertically to intersect the slope line S = .0006, and from the depth lines read dn = 3.7 ft.
3. Move horizontally from the same intersection and read the normal velocity, V = 3.2 ft/s, on the ordinate scale.
4. The intersection lies below the critical curve, and the flow is therefore in the subcritical range.

Example Design Problem 2

Given:
A trapezoidal channel with 2:1 side slopes and a 4 ft bottom width, with n = 0.030, 0.2% slope (S = 0.002), discharging 50 cfs.

Find:
Depth, velocity, type flow.

Procedure:

1. Select the trapezoidal figure for b = 4 ft (see **Figure 5.4-12**).
2. From 50 cfs on the Q scale, move vertically to intersect the slope line S = 0.002 and from the depth lines read dn = 2.2 ft.
3. Move horizontally from the same intersection and read the normal velocity, V = 2.75 ft/s, on the ordinate scale. The intersection lies below the critical curve,\; the flow is therefore subcritical.

Example Design Problem 3

Given:
A rectangular cement rubble masonry channel 5 ft wide, with n = 0.025, 0.5% slope (S = 0.005), discharging 80 cfs.

Find:
Depth velocity and type of flow

Procedure:

1. Select the rectangular figure for a 5 ft width (**Figure 5.4-13**).

2. Multiply Q by n to obtain Qn: 80 x 0.025 = 2.0.

3. From 2.0 on the Qn scale, move vertically to intersect the slope line, S = 0.005, and at the intersection read d_n = 3.1 ft.

4. Move horizontally from the intersection and read Vn = .13, then Vn/n = 0.13/0.025 = 5.2 ft/s.

5. Critical depth and critical velocity are independent of the value of n so their values can be read at the intersection of the critical curve with a vertical line through the discharge. For 80 cfs, on **Figure 5.4-13**, d_c = 2.0 ft and V_c = 7.9 ft/s. The normal velocity, 5.2 ft/s (from step 4), is less than the critical velocity, and the flow is therefore subcritical. It will also be noted that the normal depth, 3.0 ft, is greater than the critical depth, 2.0 ft, which also indicates subcritical flow.

6. To determine the critical slope for Q = 80 cfs and n = 0.025, start at the intersection of the critical curve and a vertical line through the discharge, Q = 80 cfs, finding d_c (2.0 ft) at this point. Follow along this d_c line to its intersection with a vertical line through Qn = 2.0 (step 2), at this intersection read the slope value S_c = 0.015.

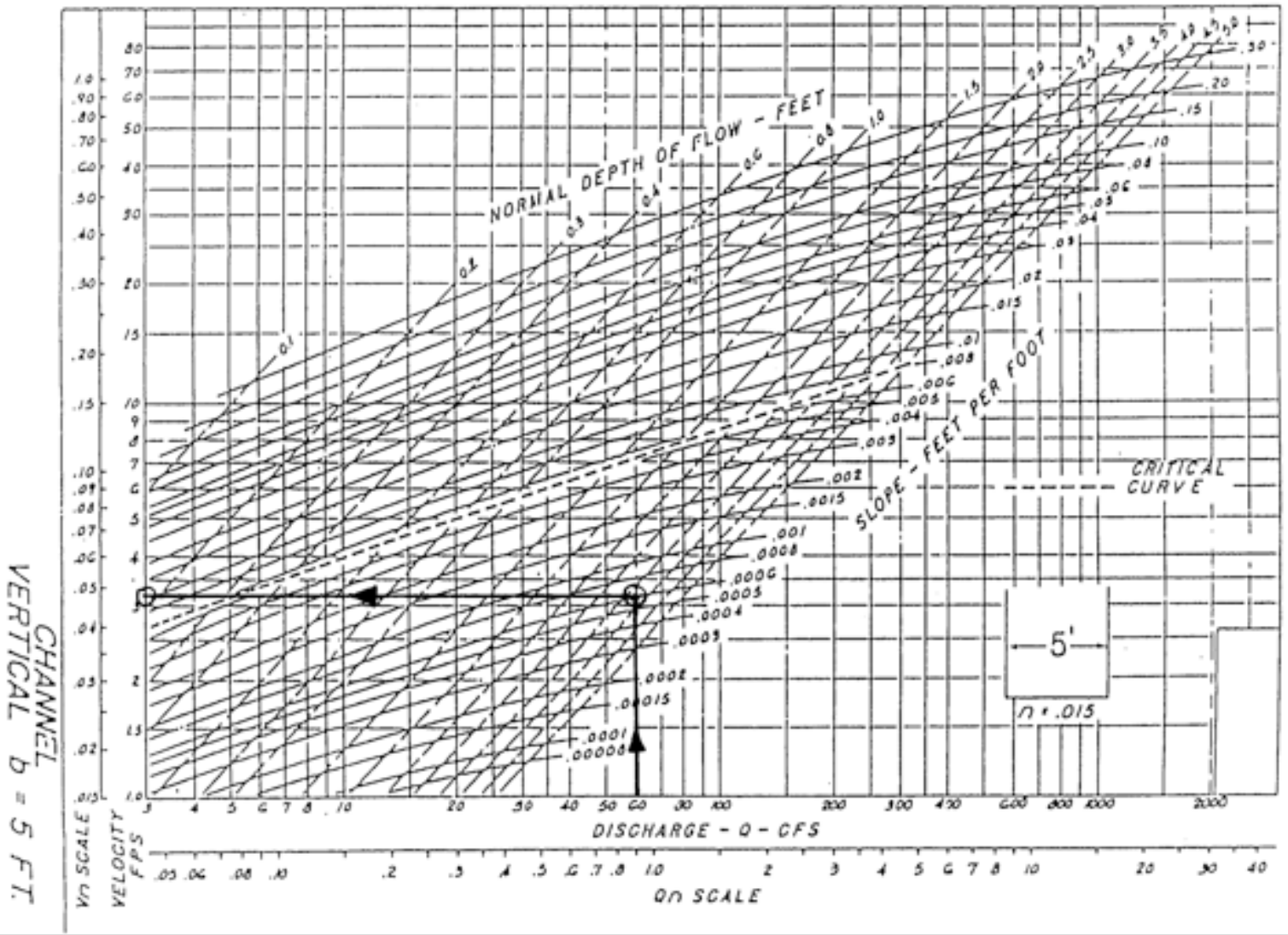


Figure 5.4-11 Example Nomograph #1

(Source: FHWA)

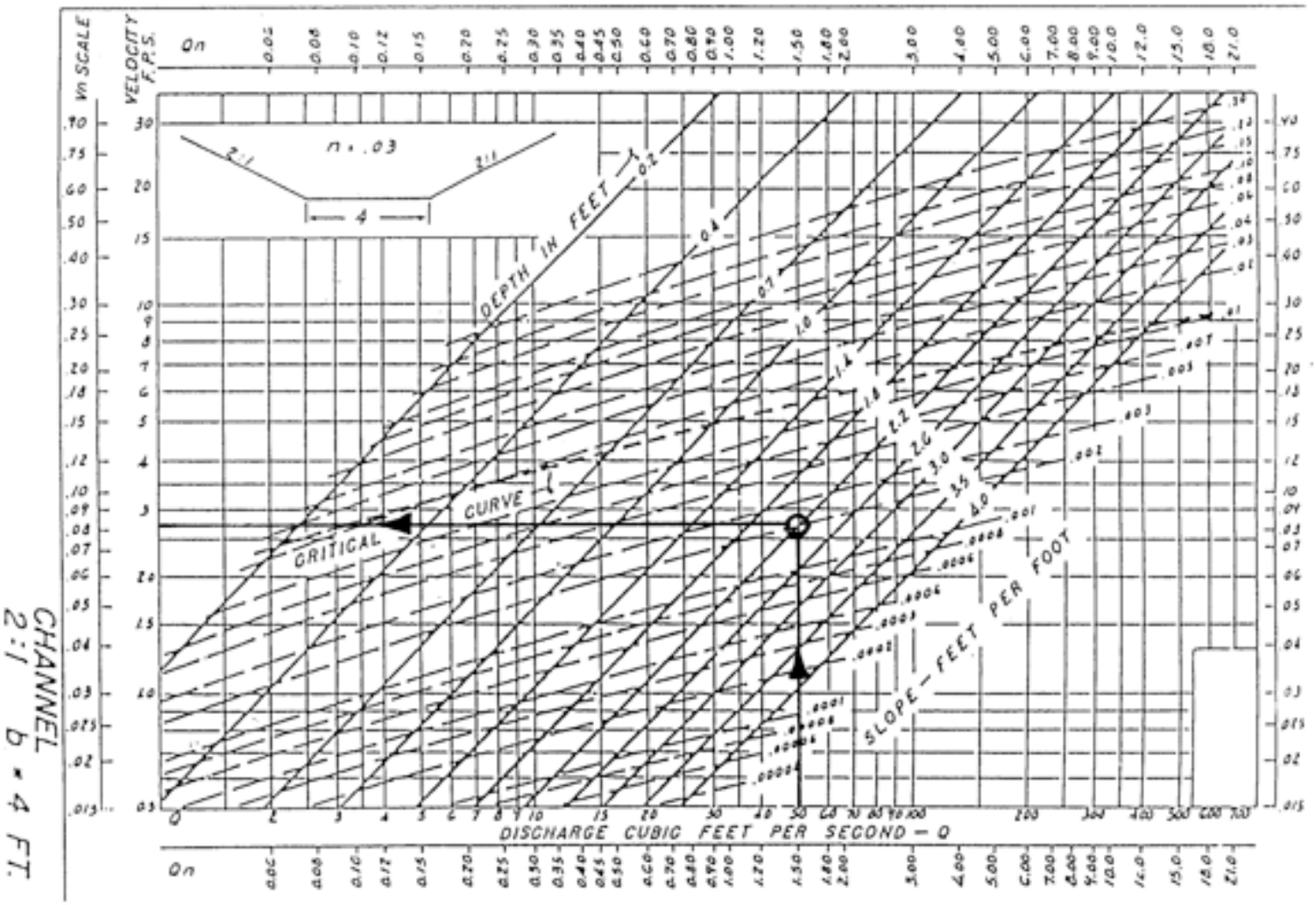


Figure 5.4-12 Example Nomograph #2

(Source: FHWA)

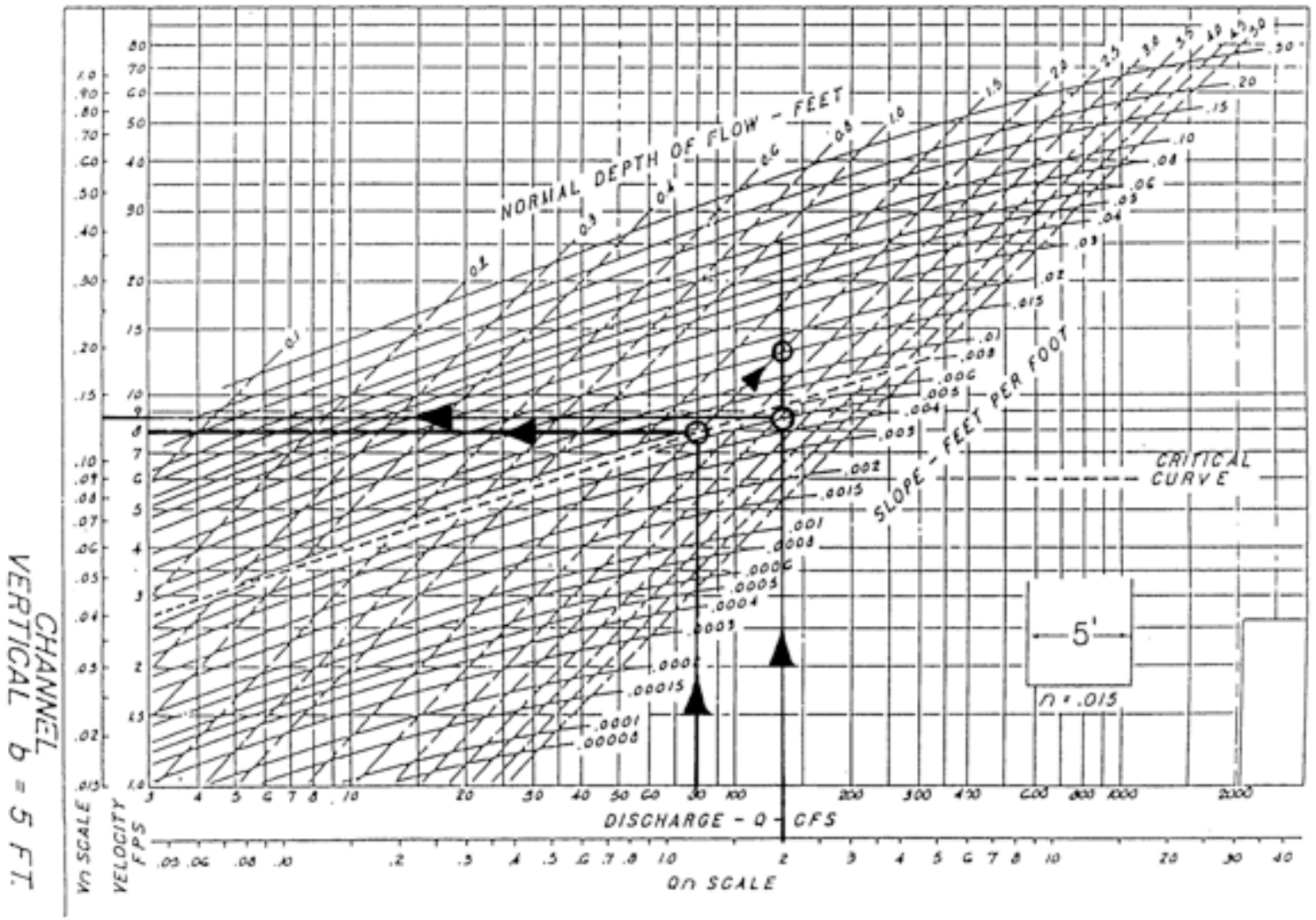


Figure 5.4-13 Example Nomograph #3

(Source: FHWA)

5.4.11.4 GRASSED CHANNEL FIGURES

The Manning equation can be used to determine the capacity of a grass lined channel, but the value of n varies with the type of grass, development of the grass cover, depth, and velocity of flow. The variable value of n complicates the solution of the Manning equation. The depth and velocity of flow must be estimated and the Manning equation solved using the n value that corresponds to the estimated depth and velocity. The trial solution provides better estimates of the depth and velocity for a new value of n and the equation is again solved. The procedure is repeated until a depth is found that carries the design discharge.

To prevent excessive erosion, the velocity of flow in a grass lined channel must be kept below some maximum value (referred to as permissible velocity). The permissible velocity in a grass lined channel depends upon the type of grass, condition of the grass cover, texture of the soil comprising the channel bed, channel slope, and to some extent the size and shape of the drainage channel. To guard against overtopping, the channel capacity should be computed for taller grass than is expected to be maintained, while the velocity used to check the adequacy of the protection should be computed assuming a lower grass height than will likely be maintained.

To aid in the design of grassed channels, the Federal Highway Administration has prepared numerous design figures. Copies of these figures are in Appendix C. Following is a brief description of general design criteria, instructions on how to use the figures, and several example design problems. For design conditions not covered by the figures, a trial and error solution of the Manning equation must be used.

5.4.11.5 DESCRIPTION OF FIGURES

The figures in Appendix C are designed for use in the direct solution of the Manning equation for various channel sections lined with grass. The figures are similar in appearance and use to those for trapezoidal cross sections described earlier. However, their construction is much more difficult because the roughness coefficient (n) changes as higher velocities and/or greater depths change the condition of the grass. The effect of velocity and depth of flow on n is evaluated by the product of velocity and hydraulic radius V times R. The variation of Manning's n with the retardance (**Table 5.4-6**) and the product V times R is shown in **Figure 5.4-1**. As indicated in **Table 5.4-6**, retardance varies with the height of the grass and the condition of the stand. Both of these factors depend upon the type of grass, planting conditions, and maintenance practices. **Table 5.4-6** is used to determine retardance classification.

The grassed channel figures each have two graphs, the upper graph for retardance Class D and the lower graph for retardance Class C. The figures are plotted with discharge in cubic feet per second on the abscissa and slope in feet per foot on the ordinate. Both scales are logarithmic. Superimposed on the logarithmic grid are lines for velocity in feet per second and lines for depth in feet. A dashed line shows the position of critical flow.

5.4.11.6 INSTRUCTIONS FOR GRASSED CHANNEL FIGURES

The grassed channel figures provide a solution of the Manning equation for flow in open grassed channels of uniform slope and cross section. The flow should not be affected by backwater and the channel should have length sufficient to establish uniform flow. The figures are sufficiently accurate for design of drainage channels of fairly uniform cross section and slope, but are not appropriate for irregular natural channels.

The design of grassed channels requires two operations:

1. Selecting a section that has the capacity to carry the design discharge on the available slope
2. Checking the velocity in the channel to ensure that the grass lining will not be eroded.

Because the retardance of the channel is largely beyond the control of the designer, it is good practice to compute the channel capacity using retardance Class C and the velocity using retardance Class D. The calculated velocity should then be checked against the permissible velocities listed in **Tables 5.4-2** and **5.4-3**.

The use of the figures is explained in the following steps:

(Step 1) Select the channel cross section to be used and find the appropriate figure.

(Step 2) Enter the lower graph (for retardance Class C) on the figure with the design discharge value on the abscissa and move vertically to the value of the slope on the ordinate scale. At this intersection, read the normal velocity and normal depth and note the position of the critical curve. If the intersection point is below the critical curve, the flow is subcritical; if it is above, the flow is supercritical.

(Step 3) To check the velocity developed against the permissible velocities (**Tables 5.4-2** and **5.4-3**), enter the upper graph on the same figure and repeat Step 2. Then compare the computed velocity with the velocity permissible for the type of grass, channel slope, and erosion resistance of the soil. If the computed velocity is less, the design is acceptable. If not, a different channel section must be selected and the process repeated.

Example Design Problem 1

Given:
A trapezoidal channel in easily eroded soil, lined with a grass mixture with 4:1 side slopes, and a 4 ft bottom width on slope of 0.02 ft per foot (S=.02), discharging 20 cfs.

Find:
Depth, velocity, type of flow, and adequacy of grass to prevent erosion

Procedure:

4. From Appendix C-4, select the FHWA channel design figure for 4:1 side slopes (see **Figure 5.4-14**).

5. Enter the lower graph with Q = 20 cfs, and move vertically to the line for S=0.02. At this intersection read d_n = 1.0 ft, and normal velocity V_n 2.6 ft/s.

6. The velocity for checking the adequacy of the grass cover should be obtained from the upper graph, for retardance Class D. Using the same procedure as in step 2, the velocity is found to be 3.0 ft/s. This is about three-quarters of that listed as permissible, 4.0 ft/s in **Table 5.4-3**.

Example Design Problem 2

Given:
The channel and discharge of Example 1.

Find:
The maximum grade on which the 20 cfs could safely be carried

Procedure:
With an increase in slope (but still less than 5%), the allowable velocity is estimated to be 4 ft/s (see **Table 5.4-3**). On the upper graph of **Figure 5.4-15** for short grass, the intersection of the 20 cfs line and the 4 ft/s line indicates a slope of 3.7% and a depth of 0.73 ft.

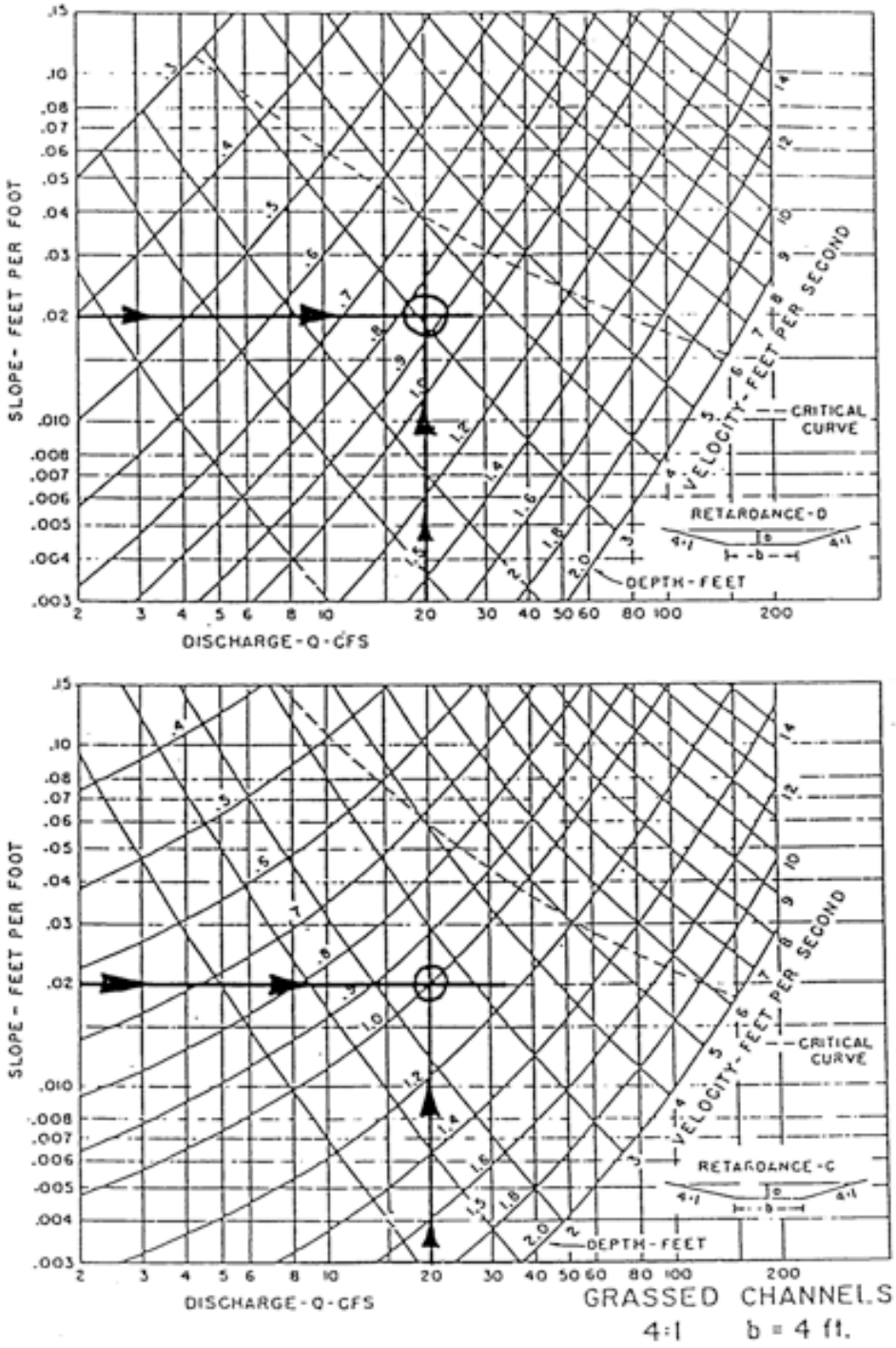


Figure 5.4-14 Example Nomograph #4

(Source: FHWA)

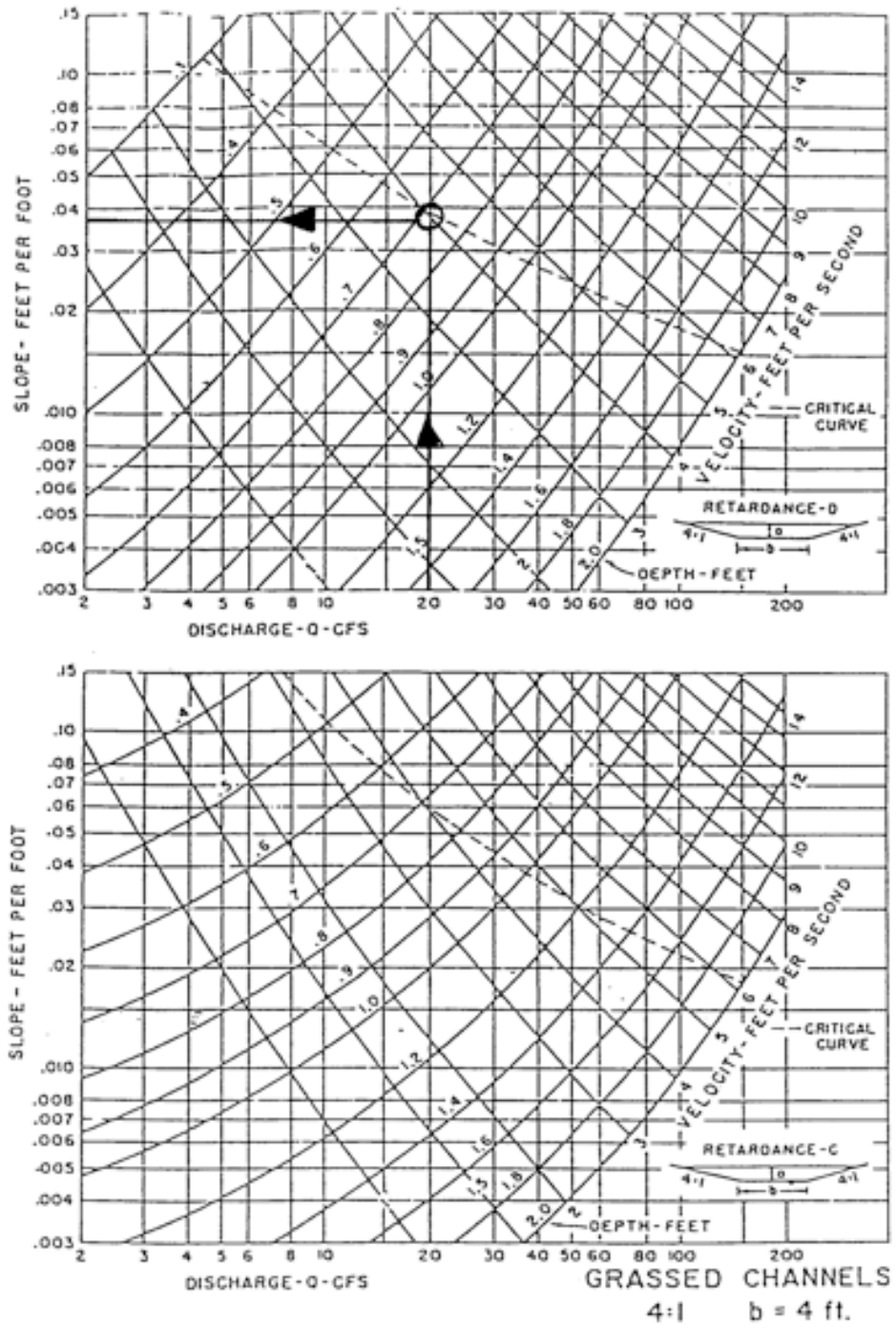


Figure 5.4-15 Example Nomograph #5

(Source: FHWA)

5.5 Energy Dissipation Design

5.5.1 Overview

5.5.1.1 INTRODUCTION

The outlets of pipes and lined channels are points of critical erosion potential. Stormwater that is transported through man-made conveyance systems at design capacity generally reaches a velocity that exceeds the capacity of the receiving channel or area to resist erosion. To prevent scour at stormwater outlets, protect the outlet structure and minimize the potential for downstream erosion, a flow transition structure is needed to absorb the initial impact of flow and reduce the speed of the flow to a non-erosive velocity.

Energy dissipators are engineered devices such as rip-rap aprons or concrete baffles placed at the outlet of stormwater conveyances for the purpose of reducing the velocity, energy and turbulence of the discharged flow.

5.5.1.2 GENERAL CRITERIA

- Erosion problems at culvert, pipe and engineered channel outlets are common; therefore, it is necessary to design on the basis that erosion at a culvert outlet and the downstream channel is to be expected. Determination of the flow conditions, scour potential, and channel erosion resistance shall be standard procedure for all designs.
- Energy dissipation devices, such as splash pads, rip-rap, stilling basins, etc., shall be provided at the outlet of every culvert and piped collection system (refer to the Standard Drawings). Energy dissipation for driveway pipes to be considered on a case by case basis.
- Energy dissipator designs will vary based on discharge specifics and tailwater conditions.
- Outlet structures should provide uniform redistribution or spreading of the flow without excessive separation and turbulence.
- If there is a need to encroach into the stream buffer, for energy dissipation purposes, all state and local stream buffer requirements shall be met.

5.5.1.3 RECOMMENDED ENERGY DISSIPATORS

For many designs, the following outlet protection devices and energy dissipators provide sufficient protection at a reasonable cost:

- Riprap apron
- Riprap outlet basins
- Baffled outlets

This section focuses on the design on these measures. The reader is referred to the Federal Highway Administration Hydraulic Engineering Circular No. 14 entitled, *Hydraulic Design of Energy Dissipators for Culverts and Channels*, for the design procedures of other energy dissipators.

Table 5.5-1 Symbols and Definitions

Symbol	Definition	Units
A	Cross-sectional area	ft^2
D	Height of box culvert	ft
d_{50}	Size of riprap	ft
d_w	Culvert width	ft
Fr	Froude Number	-
g	Acceleration of gravity	ft/s^2
h_s	Depth of dissipator pool	ft
L	Length	ft
L_a	Riprap apron length	ft
L_B	Overall length of basin	ft
L_s	Length of dissipator pool	ft
PI	Plasticity index	-
Q	Rate of discharge	cfs
S_V	Saturated shear strength	lbs/in^2
t	Time of scour	min.
t_c	Critical tractive shear stress	lbs/in^2
TW	Tailwater depth	ft
V_L	Velocity L feet from brink	ft/s
V_O	Normal velocity at brink	ft/s
V_O	Outlet mean velocity	ft/s
V_s	Volume of dissipator pool	ft^3
W_O	Diameter or width of culvert	ft
W_s	Width of dissipator pool	ft
y_e	Hydraulic depth at brink	ft
y_O	Normal flow depth at brink	ft

5.5.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual, the symbols listed in **Table 5.5-1** will be used. These symbols were selected because of their wide use. In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equations.

5.5.3 Design Guidelines

1. If outlet protection is required, choose an appropriate type. Suggested outlet protection facilities and applicable flow conditions (based on Froude number and dissipation velocity) are described below:

    » **Riprap aprons** may be used when the outlet Froude number (Fr) is less than or equal to 2.5. In general, riprap aprons prove economical for transitions from culverts to overland sheet flow at terminal outlets, but may also be used for transitions from culvert sections to stable channel sections. Stability of the surface at the termination of the apron should be considered.

    » **Riprap outlet basins** may also be used when the outlet Fr is less than or equal to 2.5. They are generally used for transitions from culverts to stable channels. Since riprap outlet basins function by creating a hydraulic jump to dissipate energy, performance is impacted by tailwater conditions.

    » **Baffled outlets** have been used with outlet velocities up to 50 feet per second. Practical application typically requires an outlet Fr between 1 and 9. Baffled outlets may be used at both terminal outlet and channel outlet transitions. They function by dissipating energy through impact and turbulence and are not significantly affected by tailwater conditions.

2. When outlet protection facilities are selected, appropriate design flow conditions and site-specific factors affecting erosion and scour potential, construction cost, and long-term durability should be considered.

3. If outlet protection is not provided, energy dissipation will occur through formation of a local scourhole. A cutoff wall will be needed at the discharge outlet to prevent structural undermining. The wall depth should be slightly greater than the computed scourhole depth, h_s. The scourhole should then be stabilized. If the scourhole is of such size that it will present maintenance, safety, or aesthetic problems, other outlet protection will be needed.

4. Evaluate the downstream channel stability and provide appropriate erosion protection if channel degradation is expected to occur. **Figure 5.5-1** provides the riprap size recommended for use downstream of energy dissipators.

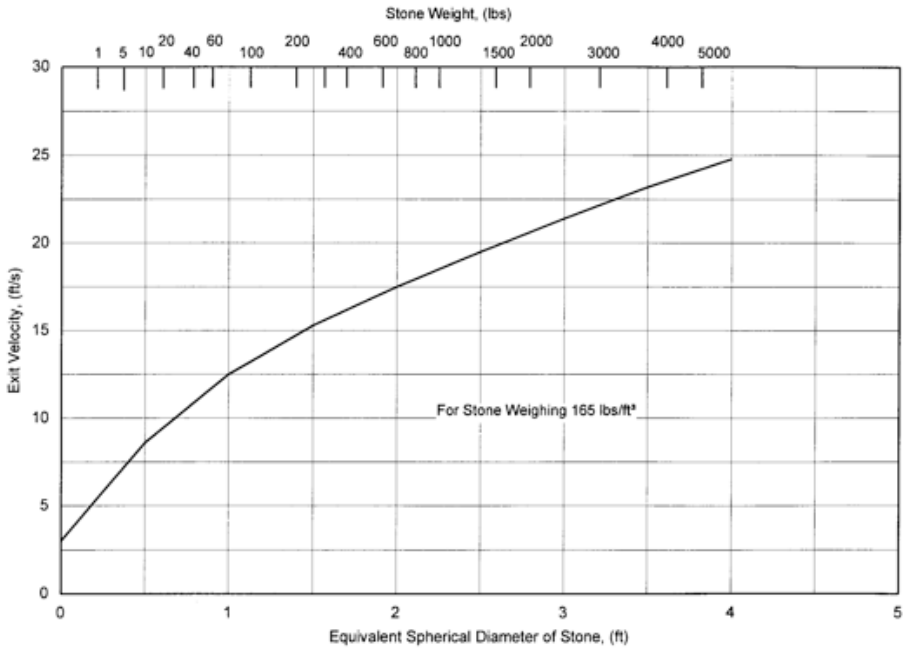


Figure 5.5-1 Riprap Size for Use Downstream of Energy Dissipator
(Source: Searcy, 1967)

5.5.4 Riprap Aprons

5.5.4.1 DESCRIPTION

A riprap-lined apron is a commonly used practice for energy dissipation because of its relatively low cost and ease of installation. A flat riprap apron can be used to prevent erosion at the transition from a pipe or box culvert outlet to a natural channel. Protection is provided primarily by having sufficient length and flare to dissipate energy by expanding the flow. Riprap aprons are appropriate when the culvert outlet Fr is less than or equal to 2.5.

5.5.4.2 DESIGN PROCEDURE

The procedure presented in this section is taken from USDA, SCS (1975). Two sets of curves, one for minimum and one for maximum tailwater conditions, are used to determine the apron size and the median riprap diameter, d_{50}. If tailwater conditions are unknown, or if both minimum and maximum conditions may occur, the apron should be designed to meet criteria for both. Although the design curves are based on round pipes flowing full, they can be used for partially full pipes and box culverts. The design procedure consists of the following steps:

(Step 1) If possible, determine tailwater conditions for the channel. If tailwater is less than one-half the discharge flow depth (pipe diameter if flowing full), minimum tailwater conditions exist and the curves in **Figure 5.5-2** apply. Otherwise, maximum tailwater conditions exist and the curves in **Figure 5.5-3** should be used.

(Step 2) Determine the correct apron length and median riprap diameter, d_{50}, using the appropriate curves from **Figures 5.5-2** and **5.5-3**. If tailwater conditions are uncertain, find the values for both minimum and maximum conditions and size the apron as shown in **Figure 5.5-4**.

» For pipes flowing full:

Use the depth of flow, d, which equals the pipe diameter, in feet, and design discharge, in cfs, to obtain the apron length, L_a, and median riprap diameter, d_{50}, from the appropriate curves.

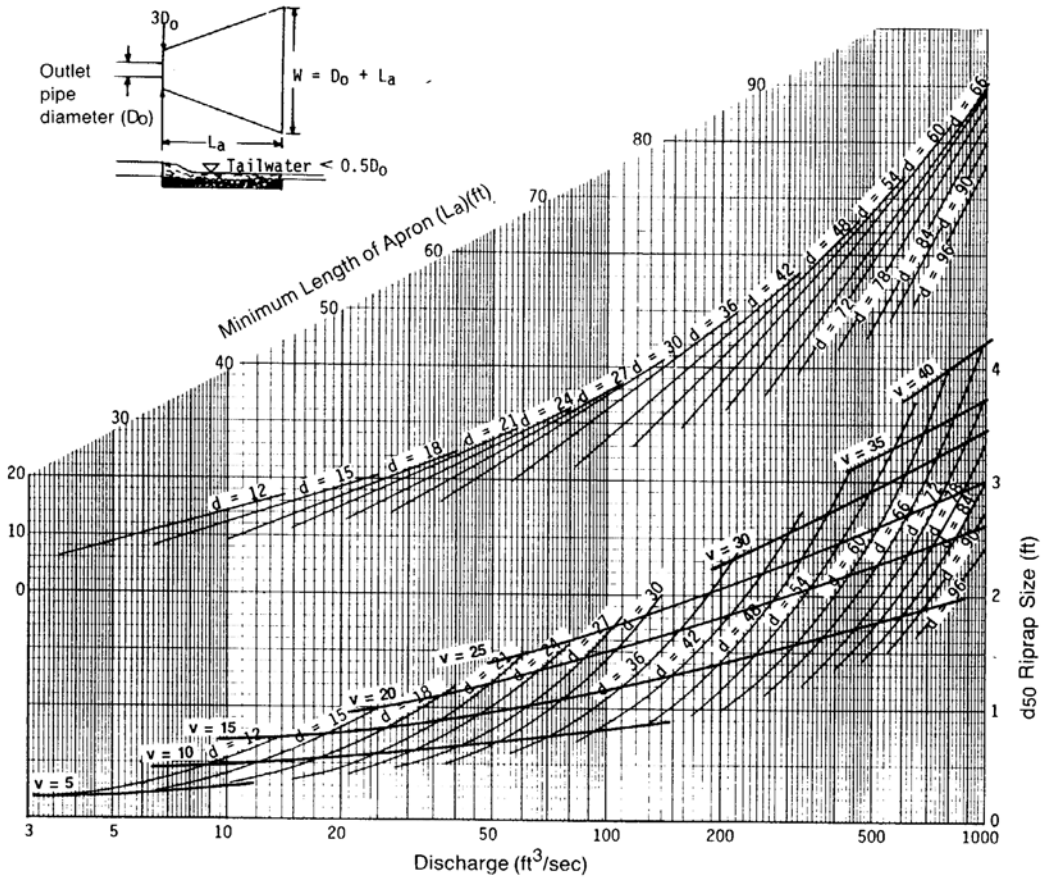
» For pipes flowing partially full:

Use the depth of flow, d, in feet, and velocity, v, in ft/s. On the lower portion of the appropriate figure, find the intersection of the d and v curves, then find the riprap median diameter, d_{50}, from the scale on the right. From the lower d and v intersection point, move vertically to the upper curves until intersecting the curve for the correct flow depth, d. Find the minimum apron length, L_a, from the scale on the left.

» For box culverts:

Use the depth of flow, d, in feet, and velocity, v, in feet/second. On the lower portion of the appropriate figure, find the intersection of the d and v curves, then find the riprap median diameter, d_{50}, from the scale on the right. From the lower d and v intersection point, move vertically to the upper curve until intersecting the curve equal to the flow depth, d. Find the minimum apron length, L_a, using the scale on the left.

(Step 3) If tailwater conditions are uncertain, the median riprap diameter should be the larger of the values for minimum and maximum conditions. The dimensions of the apron will be as shown in **Figure 5.5-4**. This will provide protection under either of the tailwater conditions.



Curves may not be extrapolated.

Figure 5.5-2 Design of Riprap Apron under Minimum Tailwater Conditions

(Source: USDA, SCS, 1975)

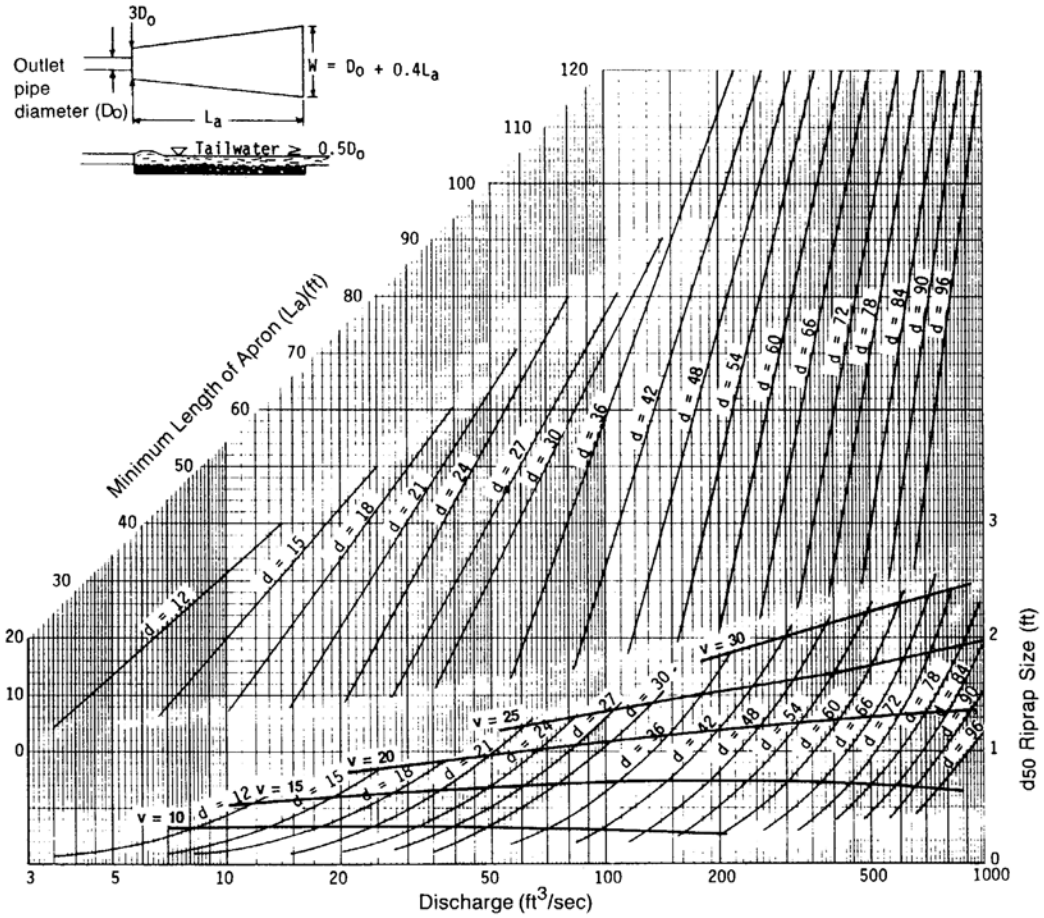


Figure 5.5-3 Design of Riprap Apron under Maximum Tailwater Conditions

(Source: USDA, SCS, 1975)

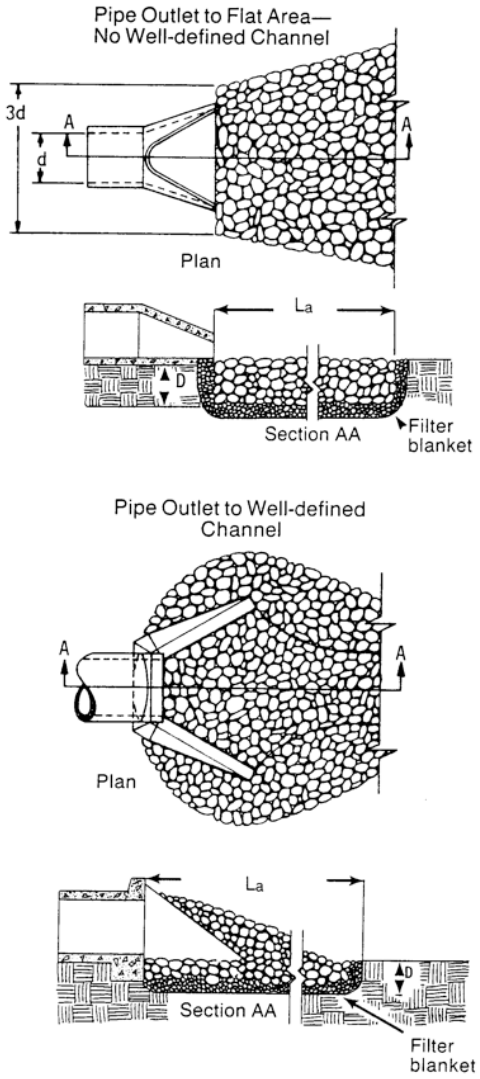


Figure 5.5-4 Riprap Apron

(Source: Manual for Erosion and Sediment Control in Georgia, 2014)

Notes on **Figure 5.5-4***:*

1. L_a is the length of the riprap apron.
2. D = 1.5 times the maximum stone diameter, but not less than 6".
3. In a well-defined channel, extend the apron up to the channel banks to an elevation of 6" above the maximum tailwater depth or to the top of the bank, whichever is less.
4. A filter blanket or filter fabric should be installed between the riprap and soil foundation.

5.5.4.3 DESIGN CONSIDERATIONS

The following items should be considered during riprap apron design:

- The maximum stone diameter should be 1.5 times the median riprap diameter. d_{max} = 1.5 x d_{50} , d_{50} = the median stone size in a well-graded riprap apron.
- The riprap thickness should be 1.5 times the maximum stone diameter or 6 inches, whichever is greater. Apron thickness = 1.5 x d_{max} (Apron thickness may be reduced to 1.5 x d_{50} when an appropriate filter fabric is used under the apron.)
- The apron width at the discharge outlet should be at least equal to the pipe diameter or culvert width, d_w. Riprap should extend up both sides of the apron and around the end of the pipe or culvert at the discharge outlet at a maximum slope of 2:1 and a height not less than the pipe diameter or culvert height, and should taper to the flat surface at the end of the apron.
- If there is a well-defined channel, the apron length should be extended as necessary so that the downstream apron width is equal to the channel width. The sidewalls of the channel should not be steeper than 2:1.
- If the ground slope downstream of the apron is steep, channel erosion may occur. The apron should be extended as necessary until the slope is gentle enough to prevent further erosion.
- The potential for vandalism should be considered if the rock is easy to carry. If vandalism is a possibility, the rock size must be increased or the rocks held in place using concrete or grout.

5.5.4.4 EXAMPLE DESIGNS

Example 1 Riprap Apron Design for Minimum Tailwater Conditions

A flow of 280 cfs discharges from a 66-in pipe with a tailwater of 2 ft above the pipe invert. Find the required design dimensions for a riprap apron.

1. Minimum tailwater conditions = 0.5 d_o, d_o = 66 in = 5.5 ft; therefore, 0.5 d_o = 2.75 ft.
2. Since TW = 2 ft, use **Figure 5.5-2** for minimum tailwater conditions.
3. **Figure 5.5-2**, the apron length, L_a, and median stone size, d_{50}, are 38 ft and 1.2 ft, respectively.

4. The downstream apron width equals the apron length plus the pipe diameter:
   - $W = d + L_a = 5.5 + 38 = 43.5$ ft

5. Maximum riprap diameter is 1.5 times the median stone size:
   - 1.5 (d_{50}) = 1.5 (1.2) = 1.8 ft

6. (Riprap depth = 1.5 (d_{max}) = 1.5 (1.8) = 2.7 ft.

Example 2 Riprap Apron Design for Maximum Tailwater Conditions

A concrete box culvert 5.5 ft high and 10 ft wide conveys a flow of 600 cfs at a depth of 5.0 ft. Tailwater depth is 5.0 ft above the culvert outlet invert. Find the design dimensions for a riprap apron.

1. Compute 0.5 d_o = 0.5 (5.0) = 2.5 ft.
2. Since TW = 5.0 ft is greater than 2.5 ft, use **Figure 5.5-3** for maximum tailwater conditions.
   - $v = Q/A = [600/(5)\ (10)] = 12$ ft/s
3. On **Figure 5.5-3**, at the intersection of the curve, do = 60 in and v = 12 ft/s, d_{50} = 0.4 ft. Reading up to the intersection with d = 60 in, find L_a = 40 ft.
4. Apron width downstream = $d_w + 0.4\ L_a = 10 + 0.4\ (40) = 26$ ft.
5. Maximum stone diameter = 1.5 d_{50} = 1.5 (0.4) = 0.6 ft.
6. Riprap depth = 1.5 dmax = 1.5 (0.6) = 0.9 ft.

5.5.5 Riprap Basins

5.5.5.1 DESCRIPTION

Another method to reduce the exit velocities from stormwater outlets is through the use of a riprap basin. A riprap outlet basin is a preshaped scourhole lined with riprap that functions as an energy dissipator by forming a hydraulic jump.

5.5.5.2 BASIN FEATURES

General details of the basin recommended in this section are shown in **Figure 5.5 5**. Principal features of the basin are:

- The basin is preshaped and lined with riprap of median size (d_{50}).
- The floor of the riprap basin is constructed at an elevation of hs below the culvert invert. The dimension h_s is the approximate depth of scour that would occur in a thick pad of riprap of size d_{50} if subjected to design discharge. The ratio of h_s to d_{50} of the material should be between 2 and 4.
- The length of the energy dissipating pool is 10 x h_s or 3 x W_o, whichever is larger. The overall length of the basin is 15 x h_s or 4 x W_o, whichever is larger.

5.5.5.3 DESIGN PROCEDURE

The following procedure should be used for the design of riprap basins.

(Step 1) Estimate the flow properties at the brink (outlet) of the culvert. Establish the outlet invert elevation such that $TW/y_o \leq 0.75$ for the design discharge.

(Step 2) For subcritical flow conditions (culvert set on mild or horizontal slope) use **Figure 5.5-6** or **Figure 5.5-7** to obtain y_o/D, then obtain V_o by dividing Q by the wetted area associated with y_o. D is the height of a box culvert. If the culvert is on a steep slope, V_o will be the normal velocity obtained by using the Manning equation for appropriate slope, section, and discharge.

(Step 3) For channel protection, compute the Froude number for brink conditions with $y_e = (A/2)^{1.5}$. Select d_{50}/y_e appropriate for locally available riprap (usually the most satisfactory results will be obtained if $0.25 < d_{50}/y_e < 0.45$). Obtain h_s/y_e from **Figure 5.5-8**, and check to see that $2 < h_s/d_{50} < 4$. Recycle computations if hs/d_{50} falls out of this range.

(Step 4) Size basin as shown in **Figure 5.5-5**.

(Step 5) Where allowable dissipator exit velocity is specified:

» Determine the average normal flow depth in the natural channel for the design discharge.

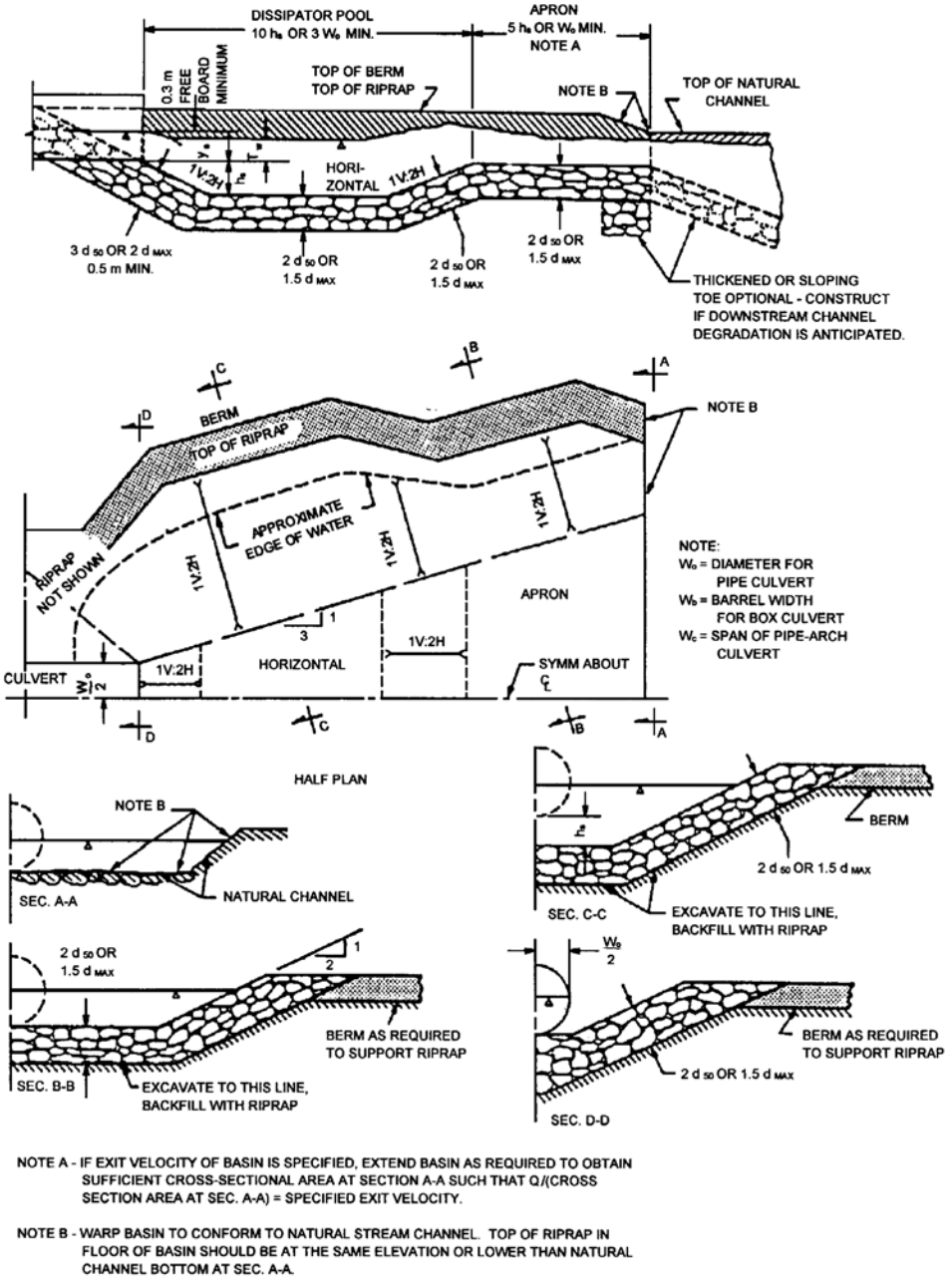
» Extend the length of the energy basin (if necessary) so that the width of the energy basin at section A A, **Figure 5.5-5**, times the average normal flow depth in the natural channel is approximately equal to the design discharge divided by the specified exit velocity.

(Step 6) In the exit region of the basin, the walls and apron of the basin should be warped (or transitioned) so that the cross section of the basin at the exit conforms to the cross section of the natural channel. Abrupt transition of surfaces should be avoided to minimize separation zones and resultant eddies.

(Step 7) If high tailwater is a possibility and erosion protection is necessary for the downstream channel, the following design procedure is suggested:

- Design a conventional basin for low tailwater conditions in accordance with the instructions above.
- Estimate centerline velocity at a series of downstream cross sections using the information shown in **Figure 5.5-9**.
- Shape downstream channel and size riprap using **Figure 5.5-1** and the stream velocities obtained above.

Material, construction techniques, and design details for riprap should be in accordance with specifications in the Federal Highway publication HEC No. 11 entitled *Use of Riprap For Bank Protection*.



NOTE A - IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQUIRED TO OBTAIN SUFFICIENT CROSS-SECTIONAL AREA AT SECTION A-A SUCH THAT Q/(CROSS SECTION AREA AT SEC. A-A) = SPECIFIED EXIT VELOCITY.

NOTE B - WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.

Figure 5.5-5 Details of Riprap Outlet Basin

(Source: HEC-14, 2012)

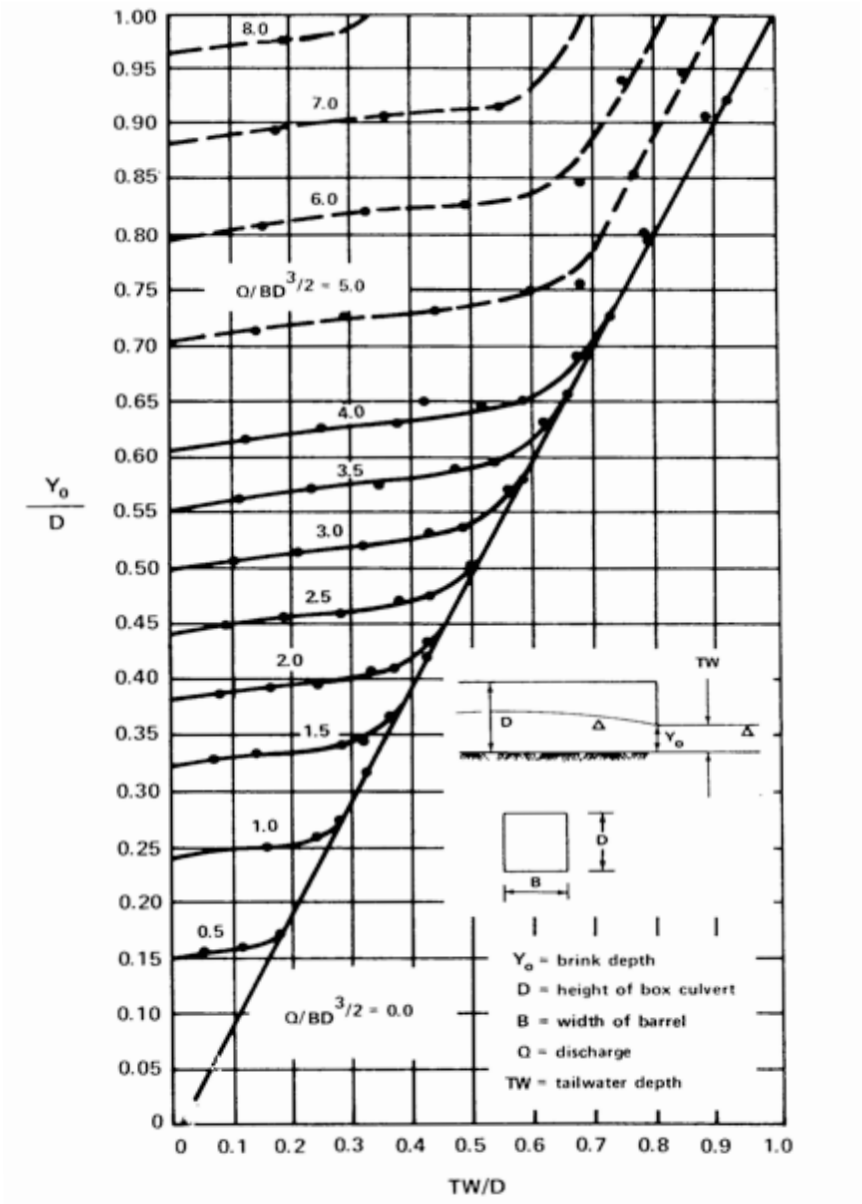


Figure 5.5-6 Dimensionless Rating Curves for the Outlets of Rectangular Culverts on Horizontal and Mild Slopes

(Source: USDOT, FHWA, HEC-14, 2012)

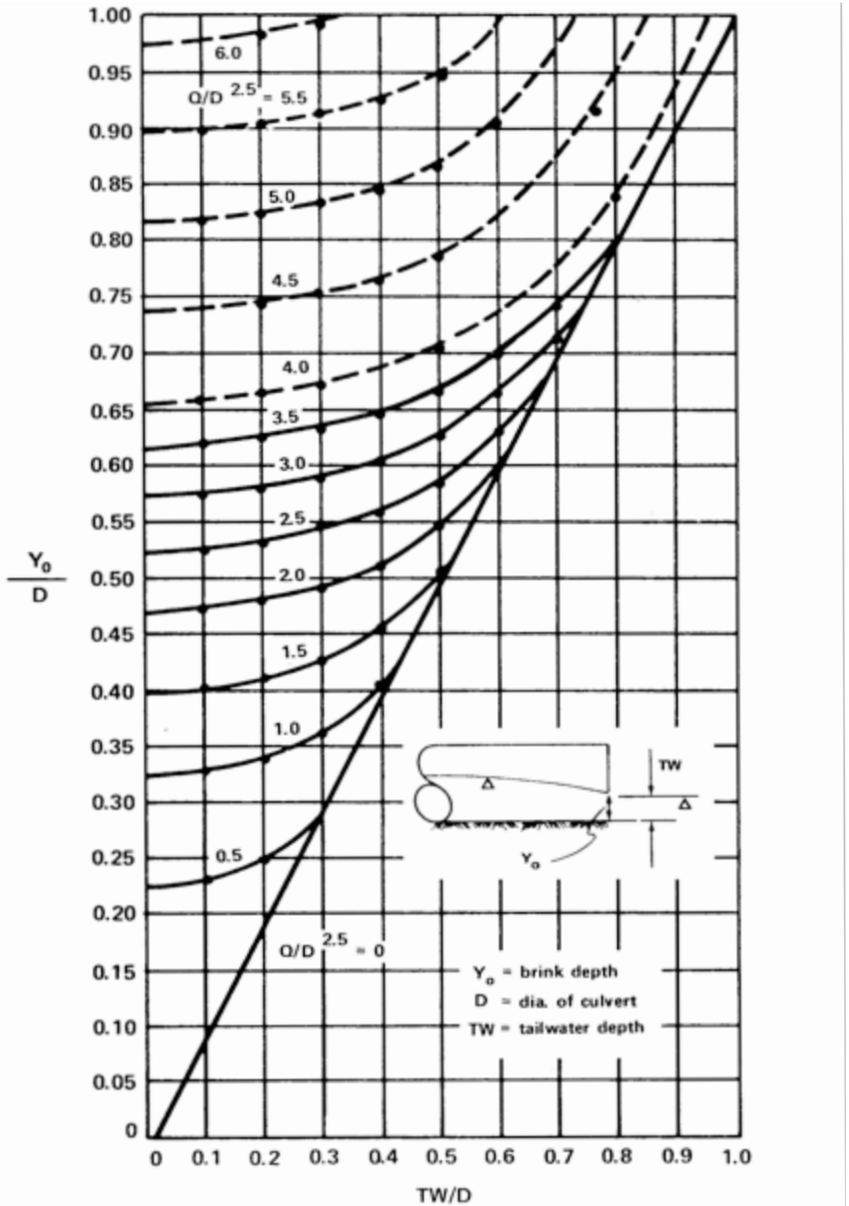


Figure 5.5-7 Dimensionless Rating Curves for the Outlets of Circular Culverts on Horizontal and Mild Slopes

(Source: USDOT, FHWA, HEC-14, 2012)

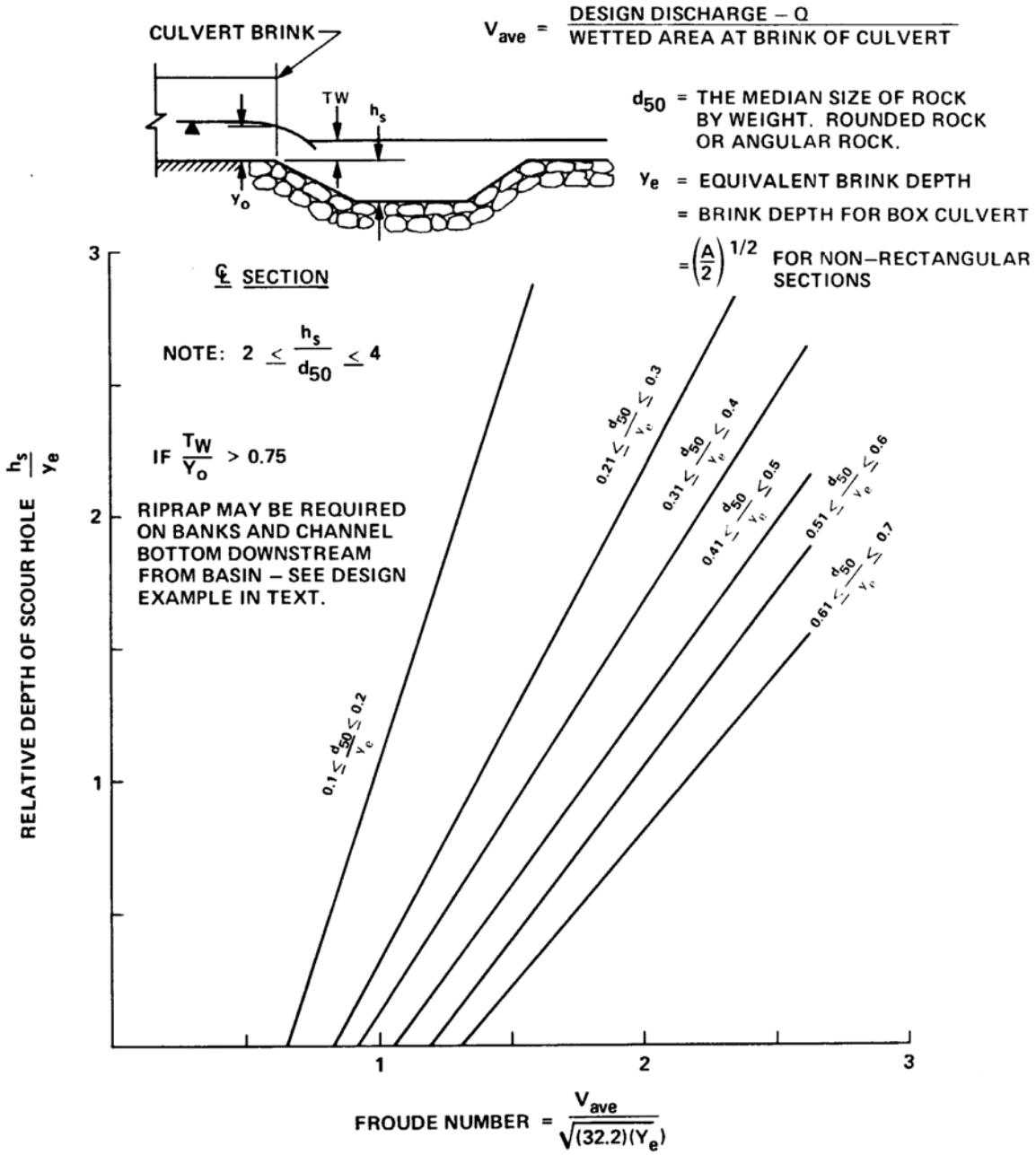


Figure 5.5-8 Relative Depth of Scour Hole Versus Froude Number at Brink of Culvert with Relative Size of Riprap as a Third Variable

(Source: USDOT, FHWA, HEC-14, 2012)

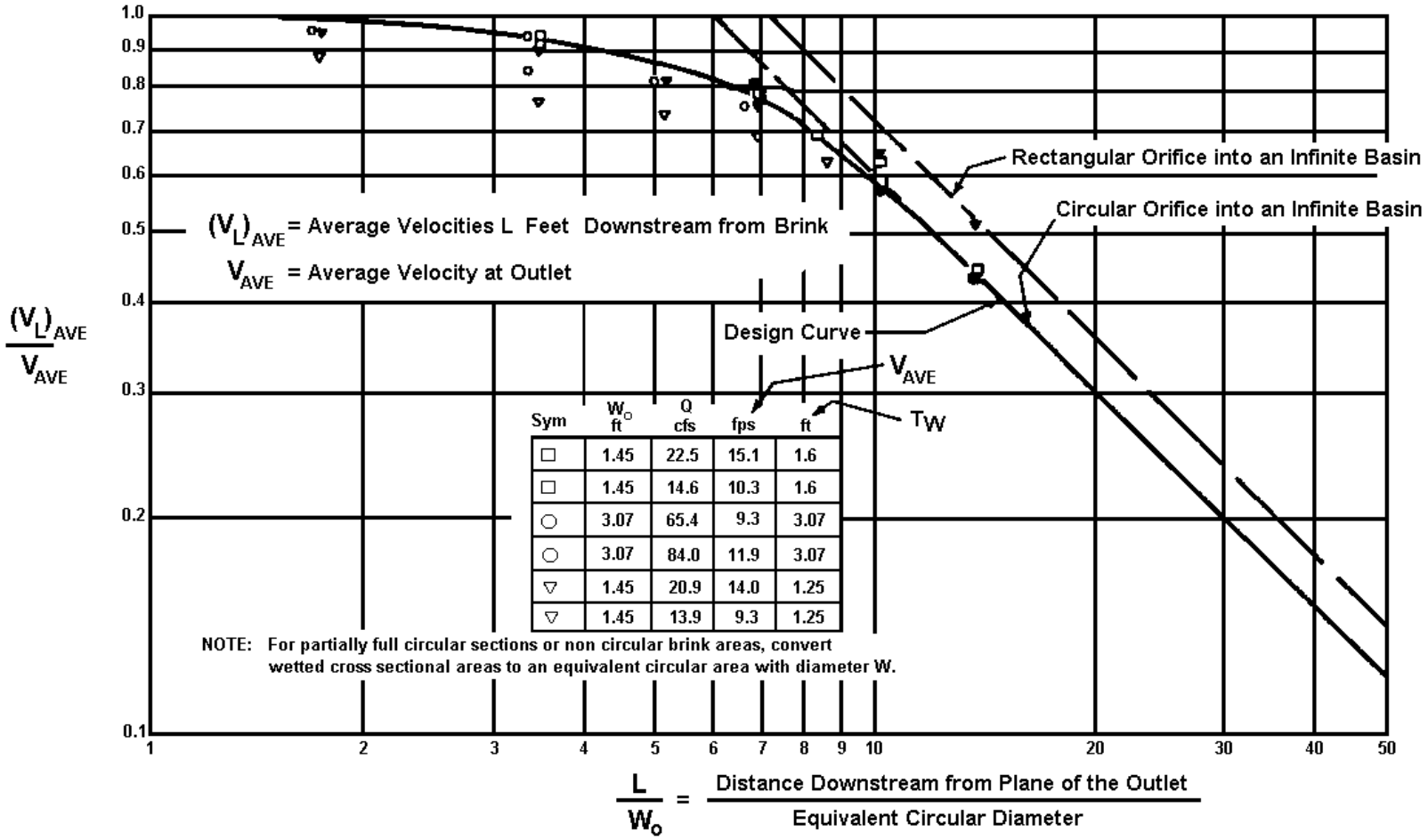


Figure 5.5-9 Distribution of Centerline Velocity for Flow from Submerged Outlets to Be Used for Predicting Channel Velocities Downstream from Culvert Outlet Where High Tailwater Prevails

(Source: USDOT, FHWA, HEC-14, 2012)

5.5.5.4 DESIGN CONSIDERATIONS

Riprap basin design should include consideration of the following:

- The dimensions of a scourhole in a basin constructed with angular rock can be approximately the same as the dimensions of a scourhole in a basin constructed of rounded material when rock size and other variables are similar.
- When the ratio of tailwater depth to brink depth, TW/y_o, is less than 0.75 and the ratio of scour depth to size of riprap, h_s/d_{50}, is greater than 2.0, the scourhole should function very efficiently as an energy dissipator. The concentrated flow at the culvert brink plunges into the hole, a jump forms against the downstream extremity of the scourhole, and flow is generally well dispersed leaving the basin.
- The mound of material formed on the bed downstream of the scourhole contributes to the dissipation of energy and reduces the size of the scourhole; that is, if the mound from a stable scoured basin is removed and the basin is again subjected to design flow, the scourhole will enlarge.
- For high tailwater basins (TW/y_o greater than 0.75), the high velocity core of water emerging from the culvert retains its jet-like character as it passes through the basin and diffuses similarly to a concentrated jet diffusing in a large body of water. As a result, the scourhole is much shallower and generally longer. Consequently, riprap may be required for the channel downstream of the rock-lined basin.
- It should be recognized that there is a potential for limited degradation to the floor of the dissipator pool for rare event discharges. With the protection afforded by the $2(d_{50})$ thickness of riprap, the heavy layer of riprap adjacent to the roadway prism, and the apron riprap in the downstream portion of the basin, such damage should be superficial.
- See Standards in the in FHWA HEC No. 11 for details on riprap materials and use of filter fabric.
- Stability of the surface at the outlet of a basin should be considered using the methods for open channel flow as outlined in Section 5.4, *Open Channel Design*.

5.5.5.5 EXAMPLE DESIGNS

Following are some example problems to illustrate the design procedures outlined.

Example 1

Given:

Box culvert- 8 ft by 6 ft
Supercritical flow in culvert
Y_o = 4 ft
Design Discharge Q = 800 cfs
Normal flow depth = brink depth
Tailwater Depth, TW = 2.8 ft

Find:

Riprap basin dimensions for these conditions

Solution:

Definition of terms in Steps 1 through 5 can be found in **Figures 5.5-5** and **5.5-8**.

1. $y_o = y_e$ for rectangular section; therefore, with y_o given as 4 ft, y_e = 4 ft.
2. $V_o = Q/A = 800/(4 \times 8) = 25$ ft/s
3. Froude Number = $Fr = V/(g \times y_e)^{0.5}$ $(g = 32.3 \text{ ft/s}^2)$

   $Fr = 25/(32.2 \times 4)^{0.5} = 2.20 < 2.5$ O.K.
4. $TW/y_e = 2.8/4.0 = 0.7$ Therefore, $TW/y_e < 0.75$ OK
5. Try $d_{50}/y_e = 0.45$, $d_{50} = 0.45 \times 4 = 1.80$ ft

   From **Figure 5.5-8**, $h_s/y_e = 1.6$, $h_s = 4 \times 1.6 = 6.4$ ft

   $h_s/d_{50} = 6.4/1.8 = 3.6$ ft, $2 < h_s/d_{50} < 4$ OK
6. $L_s = 10 \times h_s = 10 \times 6.4 = 64$ ft (L_s = length of energy dissipator pool); L_s min = $3 \times W_o = 3 \times 8 = 24$ ft; therefore, use L_s = 64 ft

   . $L_B = 15 \times h_s = 15 \times 6.4 = 96$ ft (L_B = overall length of riprap basin); L_B min = $4 \times W_o = 4 \times 8 = 32$ ft; therefore, use L_B = 96 ft
7. Thickness of riprap: On the approach = $3 \times d_{50} = 3 \times 1.8 = 5.4$ ft

   Remainder = $2 \times d_{50} = 2 \times 1.8 = 3.6$ ft

   Other basin dimensions designed according to details shown in **Figure 5.5-5**.

Example 2

Given:

Same design data as Example 1 except:

- Tailwater depth TW = 4.2 ft
- Downstream channel can tolerate only 7 ft/s discharge

Find:

Riprap basin dimensions for these conditions

Solutions:

Note- High tailwater depth, $TW/y_o = 4.2/4 = 1.05 > 0.75$

1. From Example 1: $d_{50} = 1.8$ ft, $h_s = 6.4$ ft, $L_s = 64$ ft, $L_B = 96$ ft.
2. Design riprap for downstream channel. Use **Figure 5.5-9** for estimating average velocity along the channel. Compute equivalent circular diameter D_e for brink area from:
   - $A = 3.14D_e^2/4 = y_o \times W_o = 4 \times 8 = 32$ ft^2
   - $D_e = ((32 \times 4)/3.14)^{0.5} = 6.4$ ft
   - $V_o = 25$ ft/s (From Example 1)
3. Set up the following table:

L/D_e	L (ft)	V_L/V_O	v_1 (ft/s)	Rock Size d_{50} (ft)
(Assume) $D_e = W_o$	(Compute)	(**Fig. 5.5-9**)		(**Fig. 5.5-1**)
10	64	0.59	14.7	1.4
15*	96	0.37	9.0	0.6
20	128	0.30	7.5	0.4
21	135	0.28	7.0	0.4

*L/W_o is on a logarithmic scale so interpolations must be done logarithmically.

Riprap should be at least the size shown but can be larger. As a practical consideration, the channel can be lined with the same size rock used for the basin. Protection must extend at least 135 ft downstream from the culvert brink. Channel should be shaped and riprap should be installed in accordance with details shown in the HEC No. 11 publication.

Example 3

Given:

6-ft diameter CMC — Design discharge Q = 135 cfs
Slope channel So = 0.004 — Manning's n = 0.024
Normal velocity is 5.9 ft/s — Flow is subcritical
Tailwater depth TW = 2.0 ft
Normal depth in pipe for Q = 135 cfs is 4.5 ft

Find:

Riprap basin dimensions for these conditions.

Solution:

1. Determine y_o and V_o

   From Figure 5.5-7, $y_o/D = 0.45$

. $Q/D^{2.5} = 135/6^{2.5} = 1.53$

   $TW/D = 2.0/6 = 0.33$

   $y_o = .45 \times 6 = 2.7$ ft

   $TW/y_o = 2.0/2.7 = 0.74$ $TW/y_o < 0.75$ O.K.

   Determine Brink Area (A) for $y_o/D = 0.45$

   From Uniform Flow in Circular Sections Table (from Section 5.3)

   For $y_o/D = d/D = 0.45$

   $A/D^2 = 0.3428$; therefore, $A = 0.3428 \times 6^2 = 12.3$ f^{t2}

   $V_o = Q/A = 135/12.3 = 11.0$ ft/s

2. For Froude number calculations at brink conditions,

   $y_e = (A/2)^{1/2} = (12.3/2)^{1/2} = 2.48$ ft

3. Froude number = $Fr = V_o/(32.2 \times y_e)^{1/2} = 11/(32.2 \times 2.48)^{1/2} = 1.23 < 2.5$ OK

4. For most satisfactory results $0.25 < d_{50}/y_e < 0.45$

   Try $d_{50}/y_e = 0.25$

   $d_{50} = 0.25 \times 2.48 = 0.62$ ft

   From **Figure 5.5-8**, $h_s/y_e = 0.75$; therefore, $h_s = 0.75 \times 2.48 = 1.86$ ft

   Uniform Flow in Circular Sections Flowing Partly Full (From Section 5.3)

   Check: $h^s/d^{50} = 1.86/0.62 = 3$, $2 < h_s/d_{50} < 4$ OK

5. $L_s = 10 \times hs = 10 \times 1.86 = 18.6$ ft or $L_s = 3 \times W_o = 3 \times 6 = 18$ ft; therefore, use $L_s = 18.6$ ft

   $L_B = 15 \times hs = 15 \times 1.86 = 27.9$ ft or $L_B = 4 \times W_o = 4 \times 6 = 24$ ft; therefore, use $L_B = 27.9$ ft

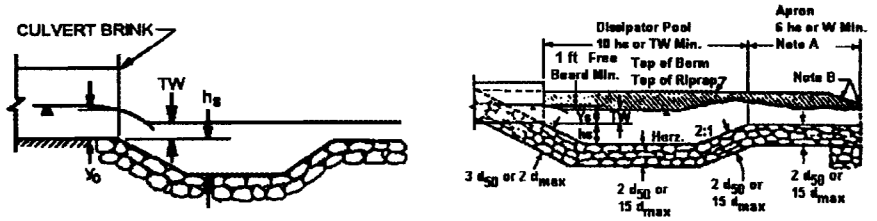
   $d_{50} = 0.62$ ft or use $d_{50} = 8$ in

Other basin dimensions should be designed in accordance with details shown on **Figure 5.5-5**. **Figure 5.5-10** is provided as a convenient form to organize and present the results of riprap basin designs.

Note: When using the design procedure outlined in this section, it is recognized that there is some chance of limited degradation of the floor of the dissipator pool for rare event discharges. With the protection afforded by the 3 x d_{50} thickness of riprap on the approach and the 2 x d_{50} thickness of riprap on the basin floor and the apron in the downstream portion of the basin, the damage should be superficial.

RIPRAP BASIN

Project No. _____
Designer _____ Date _____
Reviewer _____ Date _____



DESIGN VALUES	TRIAL 1	FINAL TRIAL
Equi. Depth, d_E		
D_{50}/d_E		
D_{50}		
Froude No., Fr		
h_s/d_E		
h_s		
h_s/D_{50}		
$2 < h_s/D_{50} < 4$		

BASIN DIMENSIONS		FEET	
Pool length is the larger of:	$10h_s$		
	$3W_o$		
Basin length is the larger of:	$15h_s$		
	$4W_o$		
Approach Thickness	$3D_{50}$		
Basin Thickness	$2D_{50}$		

TAILWATER CHECK	
Tailwater, TW	
Equivalent depth, d_E	
TW/d_E	
IF $TW/d_E > 0.75$, calculate riprap downstream	
$D_E = (4A_c/\pi)^{0.5}$	

DOWNSTREAM RIPRAP				
L/D_E	L	V_L/V_o	V_L	D_{50}

Figure 5.5-10 Riprap Basin Design Form
(Source: USDOT, FHWA, HEC-14, 2012)

5.5.6 Baffled Outlets

5.5.6.1 DESCRIPTION

The baffled outlet (also known as the Impact Basin - USBR Type VI) is a boxlike structure with a vertical hanging baffle and an end sill, as shown in **Figure 5.5-11**. Energy is dissipated primarily through the impact of the water striking the baffle and, to a lesser extent, through the resulting turbulence. This type of outlet protection has been used with outlet velocities up to 50 feet per second and with Froude numbers from 1 to 9. Tailwater depth is not required for adequate energy dissipation, but a tailwater will help smooth the outlet flow.

5.5.6.2 DESIGN PROCEDURE

The following design procedure is based on physical modeling studies summarized from the U.S. Department of Interior (1978). The dimensions of a baffled outlet as shown in **Figure 5.5-11** should be calculated as follows:

(Step 1) Determine input parameters, including:

- **h** = Energy head to be dissipated, in ft (can be approximated as the difference between channel invert elevations at the inlet and outlet)
- **Q** = Design discharge (cfs)
- **v** = Theoretical velocity (ft/s = 2gh)
- **A** = Q/v = Flow area (ft^2)
- **d** = $A^{0.5}$= Representative flow depth entering the basin (ft) *assumes square jet*
- **Fr** = $v/(gd)^{0.5}$ = Froude number, dimensionless

(Step 2) Calculate the minimum basin width, W, in ft, using the following equation.

$$W/d = 2.88Fr^{0.566} \text{ or } W = 2.88dFr^{0.566} \quad (5.5.2)$$

Where:

W = minimum basin width (ft)
d = depth of incoming flow (ft)
Fr = $v/(gd)^{0.5}$ = Froude number, dimensionless

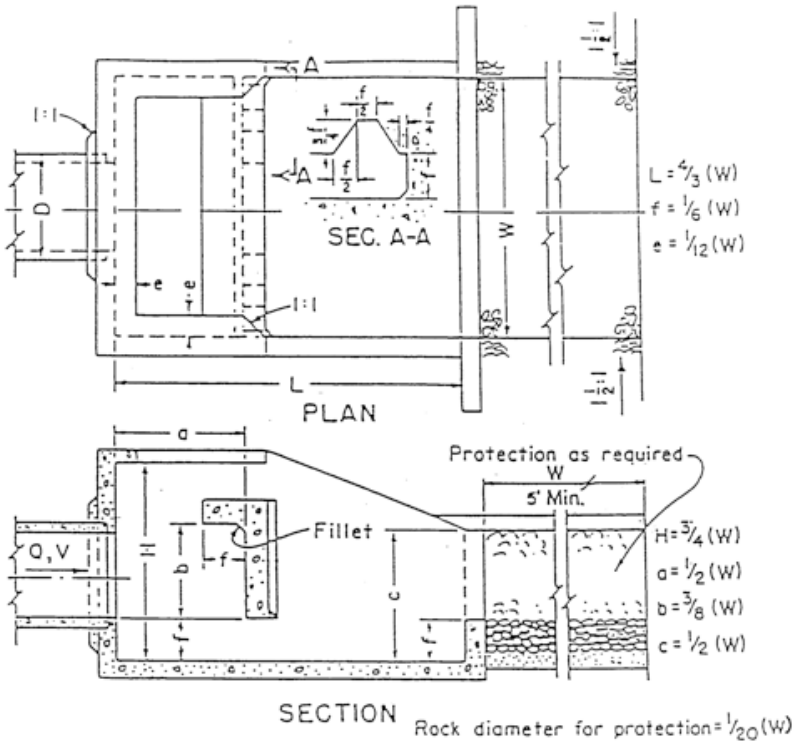


Figure 5.5-11 Schematic of Baffled Outlet

(Source: U.S. Dept. of the Interior, 1978)

If the basin is too large, the incoming jet will pass under the baffle as has occurred at some installations and effective energy dissipation will not occur. For best results, the basin shall be designed for the minimum width.

(Step 3) Calculate the other basin dimensions as shown in **Figure 5.5-11**, as a function of W. Construction drawings for selected widths are available from the U.S. Department of the Interior (1978).

(Step 4) Calculate required protection for the transition from the baffled outlet to the natural channel based on the outlet width. A riprap apron should be added of width W, length W (or a 5-foot minimum), and depth f (W/6). The side slopes should be 1.5:1, and median rock diameter should be at least W/20.

(Step 5) Calculate the baffled outlet invert elevation based on expected tailwater. The maximum distance between expected tailwater elevation and the invert should be b + f or some flow will go over the baffle with no energy dissipation. If the tailwater is known and fairly controlled, the baffled outlet invert should be a distance, b/2 + f, below the calculated tailwater elevation. If tailwater is uncontrolled, the baffled outlet invert should be a distance, f, below the downstream channel invert.

(Step 6) Calculate the outlet pipe diameter entering the basin assuming a velocity of 12 ft/s flowing full.

(Step 7) If the entrance pipe slopes steeply downward, the outlet pipe should be turned horizontal for at least 3 ft before entering the baffled outlet.

(Step 8) If it is possible that both the upstream and downstream ends of the pipe will be submerged, provide an air vent approximately 1/6 the pipe diameter near the upstream end to prevent pressure fluctuations and possible surging flow conditions.

5.5.6.3 EXAMPLE DESIGN

A cross-drainage pipe structure has a design flow rate of 150 cfs, a head, h, of 15 ft from invert of pipe, and a tailwater depth, TW, of 3 ft above ground surface. Find the baffled outlet basin dimensions and inlet pipe requirements.

1. Compute the theoretical velocity from

   . $v = (2gh)^{0.5} = [2(32.2\ ft/sec^2)(15\ ft)]^{0.5} = 31.1\ ft/s$

   This is less than 50 ft/s, so a baffled outlet is suitable.

2. Determine the flow area using the theoretical velocity as follows:

   $A = Q/v = 150\ cfs/31.1\ ft/sec = 4.8\ ft^2$

3. Compute the flow depth using the area from Step 2.

   $d = (A)^{0.5} = (4.8\ ft^2)^{0.5} = 2.12\ ft$

4. Compute the Froude number using the results from Steps 1 and 3.

   $Fr = v/(gd)^{0.5} = 31.1\ ft/sec/[(32.2\ ft/sec^2)(2.12\ ft)]^{0.5} = 3.8$

5. Determine the basin width using **equation 5.5.2** with the Froude number from Step 4.

   $W = 2.88\ dFr^{0.566} = 2.88\ (2.12)\ (3.8)^{0.566} = 13.0\ ft$ (minimum)

   Use 13 ft as the design width.

6. Compute the remaining basin dimensions (as shown in **Figure 5.5-11**):
   - L = 4/3 (W) = 17.3 ft, use L = 17 ft, 4 in
   - f = 1/6 (W) = 2.17 ft, use f = 2 ft, 2 in
   - e = 1/12 (W) = 1.08 ft, use e = 1 ft, 1 in
   - H = 3/4 (W) = 9.75 ft, use H = 9 ft, 9 in
   - a = 1/2 (W) = 6.5 ft, use a = 6 ft, 6 in
   - b = 3/8 (W) = 4.88 ft, use b = 4 ft, 11 in
   - c = 1/2 (W) = 6.5 ft, use c = 6 ft, 6 in

   Baffle opening dimensions would be calculated as shown in **Figure 5.5-11**.

7. Basin invert should be at b/2 + f below tailwater, or

   (4 ft, 11 in)/2 + 2 ft, 2 in = 4.73 ft

   Use 4 ft 8 in; therefore, invert should be 2 ft, 8 in below ground surface.

8. The riprap transition from the baffled outlet to the natural channel should be 13 ft long by 13 ft wide by 2 ft, 2 in deep (W x W x f). Median rock diameter should be of diameter W/20, or about 8 in.

9. Inlet pipe diameter should be sized for an inlet velocity of about 12 ft/s.

   $(3.14d)^2/4 = Q/v;\ d = [(4Q)/3.14v)]^{0.5} = [(4(150\ cfs)/3.14(12\ ft/sec)]^{0.5} = 3.99\ ft$

   Use 48-in pipe. If a vent is required, it should be about 1/6 of the pipe diameter or 8 in.

References

American Association of State Highway and Transportation Officials, 1982. *Highway Drainage Guidelines*.

American Association of State Highway and Transportation Officials, 1981 and 1998. *Model Drainage Manual*.

Chow, V. T., ed., 1959. *Open Channel Hydraulics*. McGraw Hill Book Co. New York.

Debo, Thomas N. and Andrew J. Reese, 1995. *Municipal Storm Water Management*. Lewis Publishers.

Federal Highway Administration, 1989. *Bridge Waterways Analysis Model (WSPRO), Users Manual*, FHWA IP-89-027.

Federal Highway Administration, 1971. *Debris-Control Structures*. Hydraulic Engineering Circular No. 9.

Federal Highway Administration, 1987. *HY8 Culvert Analysis Microcomputer Program Applications Guide.* Hydraulic Microcomputer Program HY8.

Federal Highway Administration, 1983. *Hydraulic Design of Energy Dissipators for Culverts and Channels*. Hydraulic Engineering Circular No. 14.

Federal Highway Administration, 2012. *Hydraulic Design of Highway Culverts*. Hydraulic Design Series No. 5.

Federal Highway Administration, 1978. *Hydraulics of Bridge Waterways*. Hydraulic Design Series No. 1.

Federal Highway Administration, 1996. *Urban Drainage Design Manual*. Hydraulic Engineering Circular No. 22.

Federal Highway Administration, 1967. *Use of Riprap for Bank Protection*. Hydraulic Engineering Circular No. 11.

French, R. H., 1985. *Open Channel Hydraulics*. McGraw Hill Book Co. New York.

Harza Engineering Company, 1972. *Storm Drainage Design Manual*. Prepared for the Erie and Niagara Counties Regional Planning Bd. Harza Engineering Company, Grand Island, NY.

HYDRAIN Culvert Computer Program (HY8). Available from McTrans Software, University of Florida, 512 Weil Hall, Gainesville, Florida 32611.

Maynord, S. T., 1987. *Stable Riprap Size for Open Channel Flows*. Ph.D. Dissertation. Colorado State University, Fort Collins, CO.

Morris, J. R., 1984. *A Method of Estimating Floodway Setback Limits in Areas of Approximate Study*. In Proceedings of 1984 International Symposium on Urban Hydrology, Hydraulics and Sediment Control. Lexington, Kentucky: University of Kentucky.

Peterska, A. J., 1978. *Hydraulic Design of Stilling Basins and Energy Dissipators*. Engineering Monograph No. 25. U. S. Department of Interior, Bureau of Reclamation. Washington, DC.

Prince George's County, MD, 1999. *Low-Impact Development Design Strategies, An Integrated Design Approach*.

Reese, A. J., 1984. *Riprap Sizing, Four Methods*. In Proceedings of ASCE Conference on Water for Resource Development, Hydraulics Division, ASCE. David L. Schreiber, ed.

Reese, A. J., 1988. *Nomographic Riprap Design*. Miscellaneous Paper HL 88-2. Vicksburg, Mississippi: U. S. Army Engineers, Waterways Experiment Station.

Searcy, James K., 1967. *Use of Riprap for Bank Protection*. Federal Highway Administration.

U. S. Department of Interior, 1983. *Design of Small Canal Structures*.

U.S. Department of Interior, Bureau of Reclamation, 1978. *Design of Small Canal Structures*.

U. S. Department of Transportation, Federal Highway Administration, 1973. *Design Charts For Open Channel Flow*. Hydraulic Design Series No. 3. Washington, DC.

U. S. Department of Transportation, Federal Highway Administration, 1986. *Design of Stable Channels with Flexible Linings*. Hydraulic Engineering Circular No. 15. Washington, DC.

U.S. Department of Transportation, Federal Highway Administration, 1984. *Drainage of Highway Pavements*. Hydraulic Engineering Circular No. 12.

U. S. Department of Transportation, Federal Highway Administration, 1984. *Guide for Selecting Manning's Roughness Coefficients For Natural Channels and Flood Plains*. FHWA-TS-84-204. Washington, DC.

U. S. Department of Transportation, Federal Highway Administration, 1983. *Hydraulic Design of Energy Dissipators for Culverts and Channels*. Hydraulic Engineering Circular No. 14. Washington, DC.

Wright-McLaughlin Engineers, 1969. *Urban Storm Drainage Criteria Manual, Vol. 2*. Prepared for the Denver Regional Council of Governments. Wright-McLaughlin Engineers, Denver, CO

Appendix A: Rainfall Tables for Georgia

The National Oceanic and Atmospheric Administration provides rainfall tables for the State of Georgia on their website:

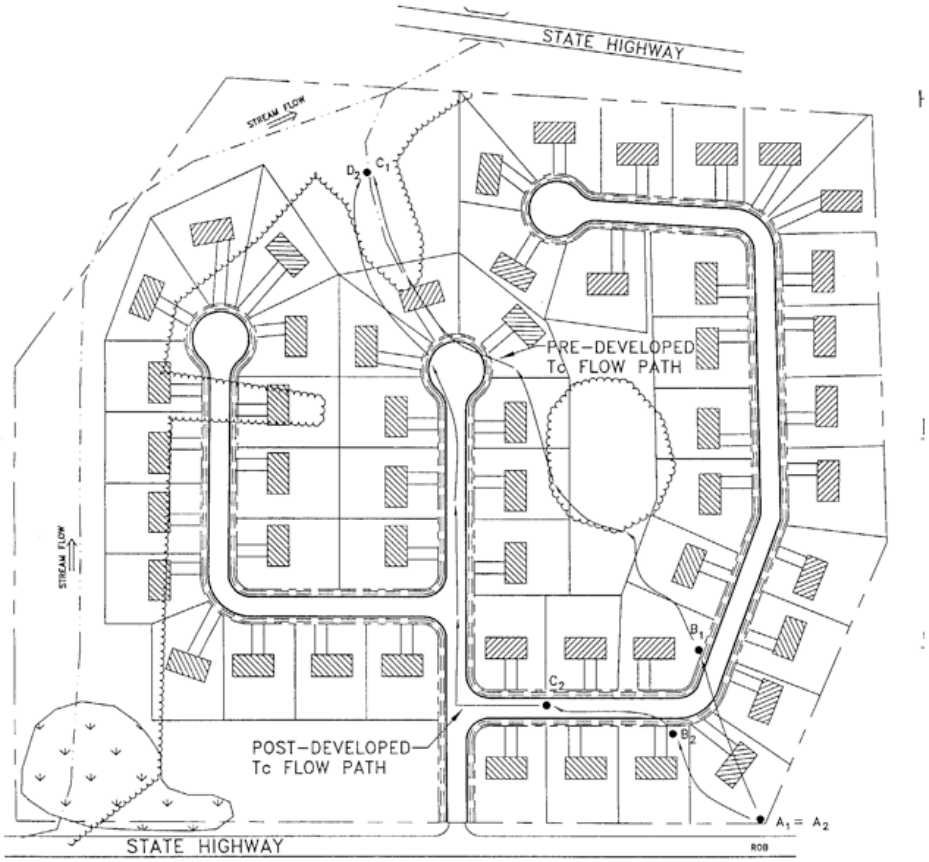
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ga

Data taken from NOAA 14 for the centroid of Gwinnett County was used to develop Table 3.1.3-1.

Appendix B: Best Management Practices Design Examples

Appendix B-1: Stormwater Pond Design Example

The following design example is for a wet extended detention (ED) stormwater pond



Base Data	Hydrologic Data		
Site Area = Total Drainage Area (A) = 38.0 ac (1,655,280 ft²)		Pre	Post
Measured Impervious Area=13.8 ac; or I=13.8/38=36.3%	CN	65	78
Soils Types: 60% "C", 40% "B"	t_c	0.32 hr	0.17 hr
Zoning: Residential (½ acre lots)			

Figure 1. Peachtree Meadows Site Plan

This example focuses on the design of a wet stormwater facility to meet the water quality requirements of the site through the water quality treatment (method 4) requirement. In general, the primary function of stormwater ponds is to provide water quality treatment (TSS removal) and detention. Stormwater ponds do not contribute to a runoff reduction goal.

Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Peachtree Meadows subdivision is shown on the previous page. This example assumes that the local community has adopted the unified stormwater sizing criteria requirements.

STEP 1 - CONFIRM LOCAL DESIGN CRITERIA AND APPLICABILITY

There are no additional requirements for this site.

STEP 2 - DETERMINE IF THE DEVELOPMENT SITE AND CONDITIONS ARE APPROPRIATE FOR THE USE OF A STORMWATER POND

Site Specific Data:

The site area and drainage area to the pond is 38.0 acres (38 ac > min. 25 ac required). Existing ground at the pond outlet is 919 MSL. Soil boring observations reveal that the seasonally high water table is at elevation 918. The underlying soils are SC (sandy clay) and are suitable for earthen embankments and to support a wet pond without a liner. The stream invert at the adjacent stream is at elevation 916.

Other site screening aspects listed in Section 4.25 were assessed and a pond was found to be suitable.

STEP 3 - COMPUTE RUNOFF CONTROL VOLUMES FROM THE UNIFIED STORMWATER SIZING CRITERIA

More detailed hydrologic calculations will be required during the design step – these numbers are preliminary.

Compute Water Quality Volume (WQ_v)

- Compute Runoff Coefficient, R_v

R_v = 0.05 + (I) (0.009)
= 0.05 + (36.3) (0.009) = **0.38**

- Compute WQ_v

WQ_v = (1.2") (R_v) (A) / 12
= (1.2") (0.38) (1,655,280 ft^2) (1ft/12in)
= 62,900 ft^3 (1.44 ac-ft)

Develop Site Hydrologic Input Parameters

Per Figures 2 and 3. Note that any hydrologic models using NRCS TR-55 procedures, such as TR-20, HEC-HMS, or other software platforms, can be used to perform preliminary hydrologic calculations.

Condition	Area *ac*	CN	TC *hrs*
Pre-developed	38	65	0.32
Post-developed	38	78	0.17

Perform Preliminary Hydrologic Calculations

Condition Runoff	$Q_{1\text{-yr}}$ *inches*	$Q_{5\text{-yr}}$ *cfs*	$Q_{25\text{-yr}}$ *cfs*	$Q_{100\text{-yr}}$ *cfs*
Pre-developed	0.70	22	104	148
Post-developed	1.42	67	192	251

COMPUTE CHANNEL PROTECTION VOLUME, (CP_v)

For stream channel protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for channel protection and overbank flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 3.1.5 to determine pre- and post-development peak discharges for the 1-yr, 25-yr, and 100-yr 24-hour return frequency storms.

Utilize NRCS TR-55 approach to Compute Channel Protection Storage Volume

See Section 3.1.5

Initial abstraction (Ia) for CN of 78 is 0.564: [Ia = (200/CN - 2)]

Ia/P = (0.564)/ 3.4 inches = 0.17
T_c = 0.17 hours
q_u = 800 csm/in (From Figure 3.1.5-6)

Knowing q_u and T (extended detention time), find q_o/q_i. For a Type II rainfall distribution.

Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.022 (From Figure 3.3.5-1)

$$Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3 \text{ (Equation 3.3.9)}$$

Where Vs equals channel protection storage (CP_v) and Vr equals the volume of runoff in inches.

Vs/Vr = 0.65 Using Equation 3.3.10, calculate V_s...

Therefore, Vs = CP_v = 0.65(1.42")(1/12)(38ac) = 2.9 ac-ft (126,324 cubic feet)

Define the average CPv-ED Release Rate

The above volume, 2.9 ac-ft (126,324 ft³), is to be released over 24 hours.
(126,324 ft³) / (24 hrs x 3,600 sec/hr) = 1.46 cfs

DETERMINE OVERBANK FLOOD PROTECTION VOLUME, (Q_{P25})

- For a Q_{in} of 192 cfs, and an allowable Q_{out} of 104 cfs, and a runoff volume of 520,364 cubic feet (11.95 ac-ft) the Vs necessary for 25-year control is 3.33 ac-ft, under a developed CN of 78. Note that 6.5 inches of rain fall during this event.
- While the TR-55 short-cut method reports to incorporate multiple stage structures, experience has shown that an additional 10-15% storage is required when multiple levels of extended detention are provided inclusive with the 25-year storm. So, for preliminary sizing purposes add 15% to the required volume for the 25-year storm. Q_{p-25} = 3.33 x 1.15 = 3.8 ac-ft.

ANALYZE SAFE PASSAGE OF 100 YEAR DESIGN STORM (Q_f)

At final design, provide safe passage for the 100-year event, or detain it, depending on downstream conditions and local policy. Based on field observation and review of local requirements no control of the 100-year storm is necessary. If it were storage estimates would have been made similar to the Q_p Volume in the previous sub-step.

Table 1 Summary of General Storage Requirements for Peachtree Meadows

Symbol	Control Volume	Volume Required (ac-ft)	Notes
WQ_v	Water Quality	1.44	
CP_v	Channel Protection	2.9	Average ED release rate is 1.46 cfs over 24 hours
Q_{p25}	Overbank Flood Protection	3.33	3.8 ac-ft will be provided
Q_f	Extreme Flood Protection	NA	Provide safe passage for the 100-year event in final design

Figure 2 Peachtree Meadows Pre-Development Conditions

Peak Discharge Summary

Job:	P'tree Meadows	EWB
Drainage Area Name:	Pre-Developed Conditions	3-Jan-00

Cover Description	Soil Name	Group A,B,C,D?	CN from TABLE 2.1-5.1	Area (in acres)
meadow (good cond.)		C	71	22.80 Ac.
meadow (good cond.)		B	58	9.20 Ac.
wood (good cond.)		B	55	6.00 Ac.
			Area Subtotals:	38.00 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 4.1 In	Surface Cover/ Cross Section	Manning 'n'/ Wetted Per	Flow Length/ Avg Velocity	Slope/ Tt (Hrs)
Sheet Flow	dense grass	'n' = 0.24	150 Ft.	2.50% 0.27 Hrs
Shallow Flow	unpaved		500 Ft. 3.23 F.P.S.	4.00% 0.04 Hrs.
Channel Flow				

Total Area in Acres =	38.00 Ac.	Total Sheet Flow =	Total Shallow Flow =	Total Channel Flow =
Weighted CN =	65	0.27 Hrs.	0.04 Hrs.	0.00 Hrs.
Time of Concentration =	0.31 Hrs.			
Pond Factor =	1		RAINFALL TYPE II	

Storm	Precipitation (P) inches	Runoff (Q)	Qp, Peak Discharge	Total Storm Volumes
1 Year	3.4 In.	0.7 In.	21.9 CFS	93,771 Cu. Ft.
2 Year	4.1 In.	1.1 In.	37.2 CFS	148,313 Cu. Ft
5 Year	4.8 In.	1.5 In.	54 CFS	209,936 Cu. Ft.
10 Year	5.5 In.	2.0 In.	74 CFS	277,081 Cu. Ft.
25 Year	6.5 In.	2.7 In.	101 CFS	373,288 Cu. Ft.
50 Year	7.2 In.	3.3 In.	124 CFS	449,409 Cu. Ft.
100 Year	7.9 In.	3.8 In.	147 CFS	528,261 Cu. Ft.

Figure 3 Peachtree Meadows Post-Development Conditions

Peak Discharge Summary

Job:	P'tree Meadows	EWB
Drainage Area Name:	Post-Developed Conditions	3-Jan-00

Cover Description	Soil Name	Group A,B,C,D?	CN from TABLE 2.1-5.1	Area (in acres)
open space		C	74	13.00 Ac.
open space		B	61	5.20 Ac.
woods (good cond.)		B	55	6.00 Ac.
impervious area		C	98	7.90 Ac.
impervious area		B	98	5.90 Ac.
			Area:	38.00 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 4.1 In	Surface Cover/ Cross Section	Manning 'n'/ Wetted Per	Flow Length/ Avg Velocity	Slope/ Tt (Hrs)
Sheet Flow	short grass	'n' = 0.15	100 Ft.	2.50% 0.13 Hrs.
Shallow	paved		300 Ft. 2.87 F.P.S.	2.00% 0.03 Hrs.
Channel Hydraulic Radius	X-S estimated	'n' = 0.013 WP estimated	600 Ft. 16.21 F.P.S.	2.00% 0.01 Hrs.

Total Area in Acres =	38.00 Ac.	Total Sheet Flow =	Total Shallow Flow =	Total Channel Flow =
Weighted CN =	78	0.13 Hrs.	0.03 Hrs.	0.01 Hrs.
Time of Concentration =	0.17 Hrs.			
Pond Factor =	1		RAINFALL TYPE	

Storm	Precipitation (P) inches	Runoff (Q)	Qp, Peak Discharge	Total Storm Volumes
1 Year	3.4 In.	1.4 In.	67.1 CFS	198,988 Cu. Ft.
2 Year	4.1 In.	2.0 In.	95.8 CFS	269,103 Cu. Ft.
5 Year	4.8 In.	2.5 In.	127 CFS	350,750 Cu. Ft.
10 Year	5.5 In.	3.2 In.	159 CFS	435,668 Cu. Ft.
25 Year	6.5 In.	4.0 In.	202 CFS	552,584 Cu. Ft.
50 Year	7.2 In.	4.7 In.	234 CFS	642,337 Cu. Ft.
100 Year	7.9 In.	5.3 In.	267 CFS	733,444 Cu. Ft.

STEP 4 - DETERMINE PRETREATMENT VOLUME

Size wet forebay to treat 0.1"/impervious acre. (13.8 ac) (0.1") (1'/12") = **0.12 ac-ft**
(forebay volume is included in WQ_v as part of permanent pool volume)

STEP 5 - DETERMINE PERMANENT POOL VOLUME (AND WATER QUALITY ED VOLUME)

Size permanent pool volume to contain 50% of WQ_v:
0.5 × (1.44 ac-ft) = **0.72 ac-ft.** (includes 0.12 ac-ft of forebay volume)

Size ED volume to contain 50% of WQ_v: 0.5 × (1.44 ac-ft) = **0.72 ac-ft**

Note: This design approach assumes that all of the ED volume will be in the pond at once. While this will not be the case, since there is a discharge during the early stages of storms, this conservative approach allows for ED control over a wider range of storms, not just the target rainfall.

STEP 6 - DETERMINE POND LOCATION AND PRELIMINARY GEOMETRY. CONDUCT POND GRADING AND DETERMINE STORAGE AVAILABLE FOR PERMANENT POOL AND WATER QUALITY EXTENDED DETENTION

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond. Storage must be provided for the permanent pool (including sediment forebays), extended detention (WQ_v-ED), CP_v-ED, and 25-year storm, plus sufficient additional storage to pass the 100-year storm with minimum freeboard. An elevation-storage table and curve is prepared using the average area method for computing volumes. See Figure 4 for pond location on site, Figure 5 grading and Figure 6 for Elevation-Storage Data.

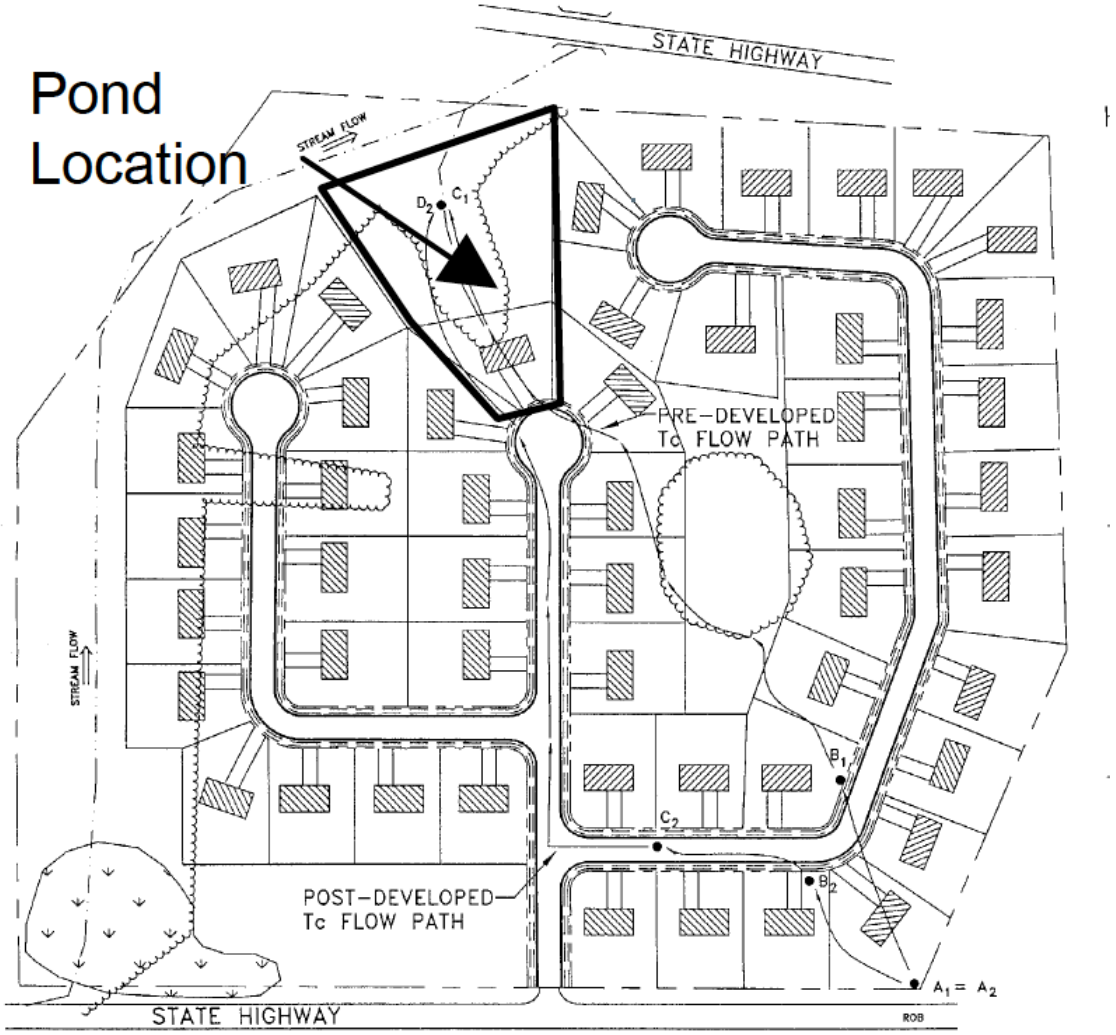


Figure 4. Pond Location on Site

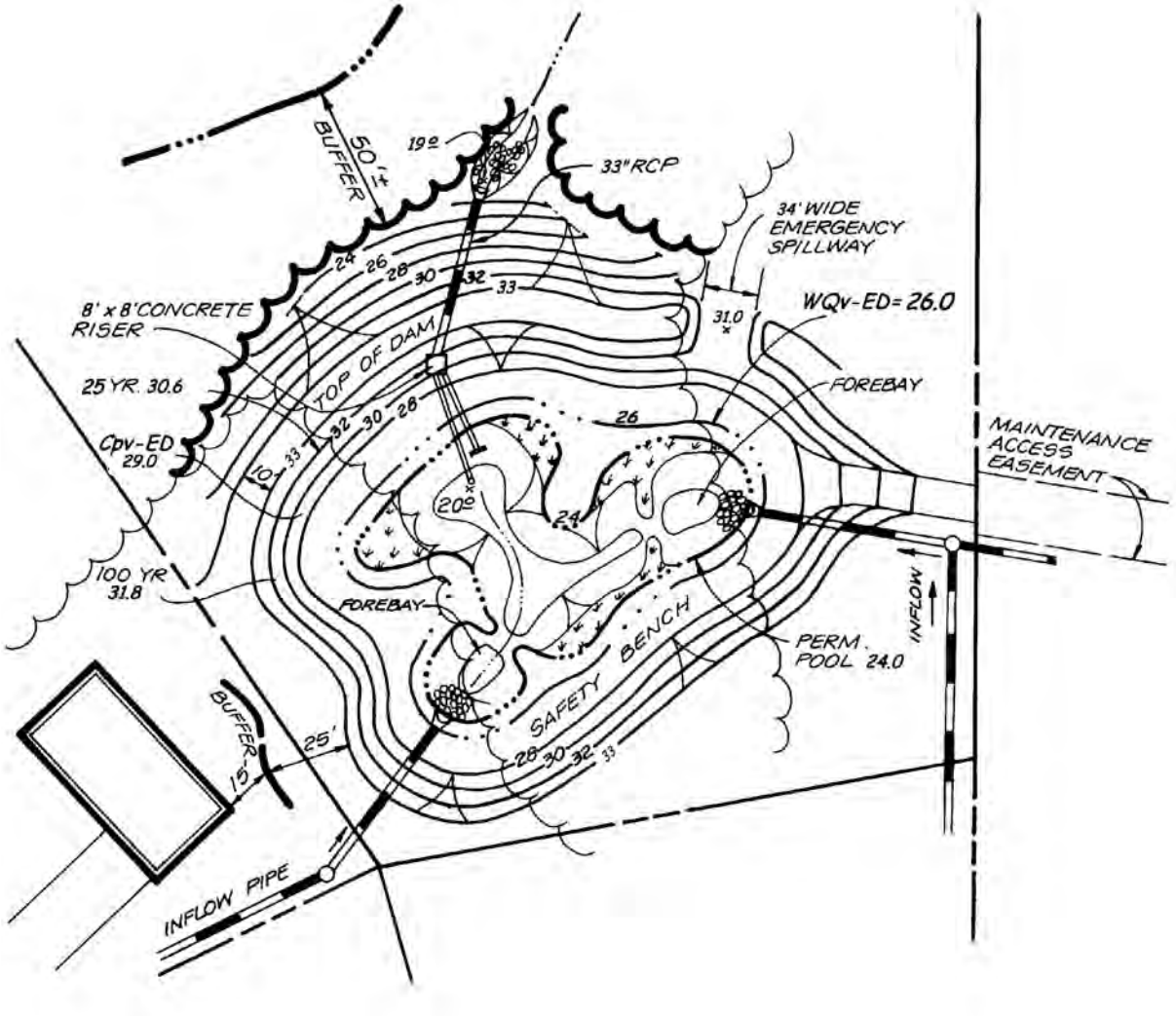


Figure 5. Plan View of Pond Grading (Not to Scale)

Elevation (MSL)	Average Area (ft^2)	Depth (ft)	Volume (ft^3)	Cumulative Volume (ft^3)	Cumulative Volume (ac-ft)	Volume Above Permanent Pool (ac-ft)
920.0						
921.0	7838	1	7838	7838	0.18	
923.0	11450	2	22900	30738	0.71	
924.0	14538	1	14538	45275	1.04	0
925.0	15075	1	15075	60350	1.39	0.35
925.5	16655	0.5	8328	68678	1.58	0.54
926.0	17118	0.5	8559	77236	1.77	0.73
926.5	21000	0.5	10500	87736	2.01	0.97
927.0	25000	0.5	12500	100236	2.30	1.26
927.5	30000	0.5	15000	115236	2.65	1.61
928.0	36000	0.5	18000	133236	3.06	2.02
928.5	38000	0.5	19000	152236	3.49	2.46
929.0	41000	0.5	20500	172736	3.97	2.93
929.5	43000	0.5	21500	194236	4.46	3.42
930.0	45000	0.5	22500	216736	4.98	3.94
930.5	47000	0.5	23500	240236	5.52	4.48
931.0	49000	0.5	24500	264736	6.08	5.04
931.5	52000	0.5	26000	290736	6.67	5.64
932.0	55000	0.5	27500	318236	7.31	6.27
932.5	58000	0.5	29000	347236	7.97	6.93
933.0	61000	0.5	30500	377736	8.67	7.63
933.5	65000	0.5	32500	410236	9.42	8.38
934.0	69000	0.5	34500	444736	10.21	9.17
935.0	74000	1	74000	518736	11.91	10.87

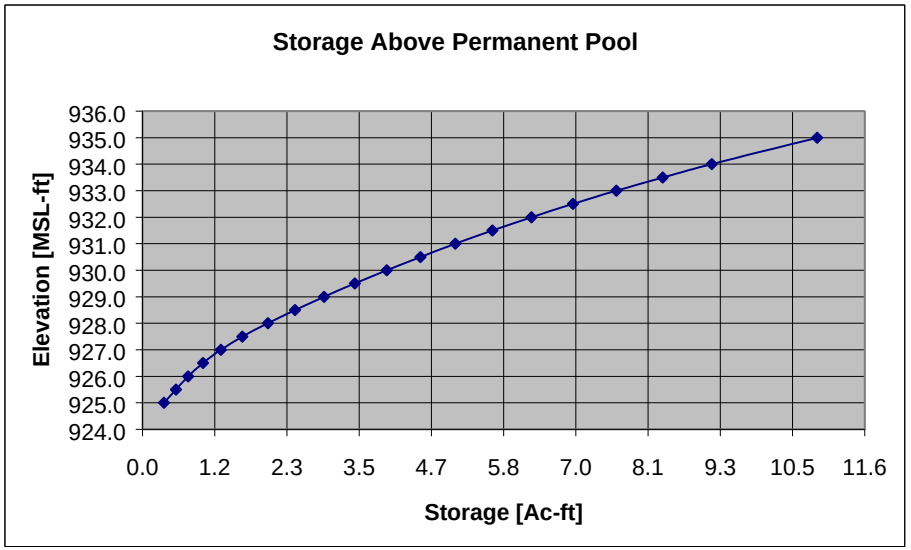


Figure 6. Storage-Elevation Table/ Curve

Set basic elevations for pond structures

- The pond bottom is set at elevation 920.0.
- Provide gravity flow to allow for pond drain, set riser invert at 919.5
- Set barrel outlet elevation at 919.0.

Set water surface and other elevations

- Required permanent pool volume = 50% of WQv = 0.72 ac-ft. From the elevation-storage table, read elevation 924.0 (1.04 ac-ft > 0.72 ac-ft) site can accommodate it and it allows a small safety factor for fine sediment accumulation - OK
- Forebay volume provided in two pools with avg. vol. = 0.08 ac-ft each (0.16 ac-ft > 0.12 ac-ft) OK
- Required extended detention volume (WQv-ED)= 0.72 ac-ft. From the elevation-storage table (volume above permanent pool), read elevation 926.0 (0.73 ac-ft > 0.72 ac-ft) OK. Set ED wsel = 926.0

Note: Total storage at elevation 926.0 = 1.77 ac-ft (greater than required WQv of 1.44 ac-ft)

Compute the required WQv-ED orifice diameter to release 0.72 ac-ft over 24 hours

- Avg. ED release rate = (0.72 ac-ft)(43,560 ft2/ac)/(24 hr)(3600 sec/hr) = 0.36 cfs
- Average head = (926.0 - 924.0)/ 2 = 1.0'
- Use orifice equation to compute cross-sectional area and diameter
  - » Q = CA(2gh)$^{0.5}$, for Q=0.36 cfs h = 1.0 ft; C = 0.6 = discharge coefficient solve for A
  - » A = 0.36 cfs / [(0.6)((2)32.2 ft/s2)(1.0 ft))$^{0.5}$] A = 0.075 ft^2, A =πd^2 / 4; dia. = 0.31 ft = 3.7"
  - » Use 4" pipe with 4" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 3.7" dia. WQv orifice

- $Q_{WQv\text{-}ED}$ = CA(2gh)$^{0.5}$ = (0.6) (0.075 ft^2) [((2)(32.2 ft/s2))$^{0.5}$] (h$^{0.5}$),
- $Q_{WQv\text{-}ED}$ = (0.36) h$^{0.5}$, where: h = wsel - 924.16

(Note: account for one half of orifice diameter when calculating head)

STEP 7 - COMPUTE EXTENDED DETENTION ORIFICE RELEASE RATE(S) AND SIZE(S), AND ESTABLISH CP_v ELEVATION

Set the CP_v pool elevation

- Required CP_v storage = 2.9 ac-ft (see Table 1).
- From the elevation-storage table, read elevation 929 (this includes the WQ_v).
- Set CP_v wsel = 929

Size CP_v orifice

- Size to release average of 1.46 cfs.
  - » Average WQ_v-ED orifice release rate is 0.66 cfs, based on average head of 3.34' (926 – 924.16 + (929 – 926)/2)
  - » CP_v-ED orifice release = 1.46 -0.66 = 0.80 cfs
- Head = (929 - 926.0)/2 = 1.5'

Use orifice equation to compute cross-sectional area and diameter

- Q = CA(2gh)$^{0.5}$, for h = 1.5'
  - » A = 0.80 cfs / [(0.6)((2)(32.2'/s^2)(1.5'))$^{0.5}$]
  - » A = 0.14 ft^2, A =πd^2 / 4;
  - » dia. = 0.42 ft = 5.0"
- Use 6" pipe with 6" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 5.0" dia. CP_v orifice

- $Q_{CPv\text{-}ED}$ = CA(2gh)$^{0.5}$ = (0.6) (0.14 ft^2) [((2) (32.2'/s^2))$^{0.5}$] (h$^{0.5}$),
- $Q_{CPv\text{-}ED}$ = (0.67) (h$^{0.5}$), where: h = wsel - 926.21

(Note: account for one half of orifice diameter when calculating head)

STEP 8 - CALCULATE Q_{P25} (25-YEAR STORM) RELEASE RATE AND WATER SURFACE ELEVATION

In order to calculate the 25 year release rate and water surface elevation, the designer must set up a stage-storage-discharge relationship for the control structure for each of the low flow release pipes (WQ_v-ED and CP_v-ED) plus the 25 year storm.

Develop basic data and information

- The 25 year pre-developed peak discharge = 104 cfs,
- The post developed inflow = 192 cfs, from Table 1,
- From previous estimate Q_{p-25} = 3.33 ac-ft. Adding 15% to account for ED storage yields a preliminary volume of 3.8 ac-ft.
- From elevation-storage table (Figure 6), read elevation 930.1.

Size 25 year slot to release 104 cfs at elevation 930.1.

- @ wsel 930.1:
  - » WQ_v-ED orifice releases 0.88 cfs,
  - » CP_v-ED orifice releases 1.32 cfs, therefore;
  - » Allowable Q_{p-25} = 104 cfs - (.88 + 1.32) = 101.8 cfs, say 102 cfs.
- Max head = (930.1 – 929) = 1.1'
- Use weir equation to compute slot length
  - » $Q = CLH^{3/2}$
  - » L = 102 cfs / (3.1) (1.13/2) = 28 ft
- Use four 7ft x 1.5 ft slots for 25-year release (opening should be slightly larger than needed so as to have the barrel control before slot goes from weir flow to orifice flow).

Check orifice equation using cross-sectional area of opening

- $Q = CA(2gh)^{0.5}$, for h = 0.75' (For orifice equation, h is from midpoint of slot)
- $A = 4\ (7.0')\ (1.5') = 42.0ft^2$
- $Q = 0.6\ (42.0ft^2)\ [(64.4)(0.75)]^{0.5} = 175$ cfs > 104 cfs, so use weir equation

$Q_{25} = (3.1)\ (28')\ H^{3/2}$ $Q_{25} = (86.8)\ H^{3/2}$, where H = wsel – 929.0

Size barrel to release approximately 104 cfs at elevation 930.1

- Check inlet condition: (use Section 5.3 culvert charts)
  - » H_w = 930.1-919.5 = 10.6 ft
  - » Try 33" diameter RCP, Using Figure 5.3-1a
  - » H_w / D = 10.6/2.75 = 3.85, Discharge = 88 cfs
- Check outlet condition:
  - $Q = a\ [(2gH)/(1+k_m+k_pL)]^{0.5}$

  where: Q = discharge in cfs
  a = pipe cross sectional area in ft^2
  g = acceleration of gravity in ft/sec^2
  H = head differential (wsel - downstream centerline of pipe or tailwater elev.)
  k_m = coefficient of minor losses (use 1.0)
  k_p = pipe friction loss coef. (= $5087n^2/d^{4/3}$, d in ", n is Manning's n)
  L = pipe length in ft
  - » H = 930.1 - (919.0 + 1.38) = 9.72'
  - » for 33" RCP, 70 feet long:
  - » $Q = 7.1\ [(64.4)\ (9.72) / 1+1+(.007)\ (70)]^{0.5} = 112.6$ cfs
  - » 88 cfs < 112.6 cfs, so barrel is inlet controlled.

Note: pipe will control flow before high stage inlet reaches max head.

Complete stage-storage-discharge summary (Figure 7) up to preliminary 25-year wsel (930.1) and route 2-25 year post-developed condition inflow hydrographs using computer software. If any of the post-developed routed flows for the 2-25 year storms exceed the pre-developed flow, then additional controls (orifices and/or weirs) may be needed. Determine what additional controls are necessary and repeat the routing procedure until the 2-25 year post developed flows are less than the pre-developed flows. Pond routing computes 25-year wsel at 930.8 with discharge = 92.4 cfs.

Elevation (MSL)	Storage (ac-ft)	Low Flow WQ_v-ED 3.7" eq dia		Riser						Barrel				Emergency Spillway		Total Discharge
				CP_v-ED 5.0" eq. dia		High Stage Slot				Inlet		Pipe				
						Orifice		Weir								
		H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	H	Q	Q
		ft	cfs	ft	cfs	ft	cfs	ft	cfs	ft	cfs	ft	cfs	ft	cfs	cfs
924.0	0.00	0	0													0.00
925.0	0.35	0.8	0.33													0.33
925.5	0.54	1.3	0.42													0.42
926.0	0.73	1.8	0.49	0	0											0.49
926.5	0.97	2.3	0.55	0.3	0.36											0.91
927.0	1.26	2.8	0.61	0.8	0.60											1.20
927.5	1.61	3.3	0.66	1.3	0.76											1.42
928.0	2.02	3.8	0.71	1.8	0.90											1.60
928.5	2.46	4.3	0.75	2.3	1.01											1.76
929.0	2.93	4.8	0.79	2.8	1.12	N/A	-	0.0	0.0							1.91
929.5	3.42	5.3	0.83	3.3	1.22			0.5	30.7							32.7
930.0	3.94	5.8	0.87	3.8	1.30			1.0	86.8							89.0
930.1	4.10	5.9	0.88	3.9	1.32			1.1	100.1	10.6	88	9.7	112.6			90.2
930.5	4.48	6.3	0.91	4.3	1.39	0.75	175	1.5	159.5	11.0	90	10.1	114.9			92.3
931.0	5.04	-	-	-	-	-	-	-	-	11.5	92.5	10.6	117.7	0.0	0.0	92.5
931.5	5.64	-	-	-	-	-	-	-	-	12.0	95	11.1	120.4	0.5	24.0	119.0
932.0	6.27	-	-	-	-	-	-	-	-	12.5	97	11.6	123.1	1.0	79.0	176.0
932.5	6.93	-	-	-	-	-	-	-	-	13.0	100	12.1	125.7	1.5	154.0	253.5
933.0	7.63	-	-	-	-	-	-	-	-	13.5	101.7	12.6	128.3	2.0	252.0	353.7

Figure 7 Stage-Storage-Discharge Summary

Note: Adequate outfall protection must be provided in the form of a riprap channel, plunge pool, or combination to ensure non-erosive velocities.

STEP 9 - DESIGN EMBANKMENT(S) AND SPILLWAY(S)

The 25-year wsel is at 930.8. Set the emergency spillway at elevation 931.0 and use design information and criteria Earth Spillways (not included in this manual)

- Q_{100} inflow = 251 cfs.
- Try 34' wide vegetated emergency spillway with 3:1 side slopes.
- @ elevation 932.6, H = 1.5', Emergency spillway, Q_{ES} = 172 cfs. Primary spillway, Q_{PS} 100 cfs
- Q_{ES} + Q_{PS} = 272 cfs, will be able to safely convey Q_f = 251. (use computer routing for exact elevations and discharges).
- 100 year wsel = 931.7, say 932, so set top of embankment with 1 foot of freeboard at elevation 933.

STEP 10 - INVESTIGATE POTENTIAL POND HAZARD CLASSIFICATION

Refer to Georgia Department of Natural Resources Rules for Dam Safety in Appendix H to establish preliminary classification of embankment and whether special design criteria need to be met.

Per Chapter 391-3-8.04, Dam safety rules do not apply to artificial barriers that are:

- Classified as a Category II Dam – dams where improper operation or dam failure would not expect to result in probable loss of human life
- Not in excess of 6 feet in height regardless of storage capacity, or which has a storage capacity at maximum water storage elevation not in excess of 15 acre-feet, regardless of height.

Check pond classification: Height = 931 -919 = 12', equals assumed embankment height, Pond will remain Category II or lower.

As reported in Table 1, the preliminary maximum storage volume required is about 3.33 acre-feet, which is substantially less than the 15 acre-feet exempt limit. Therefore, for initial design considerations, no additional dam safety requirements will apply. Once final design elevations and storage volumes have been determined, a final check for dam rules exemption should be made by the designer.

STEP 11 - DESIGN INLETS, SEDIMENT FOREBAY(S), OUTLET STRUCTURES, MAINTENANCE ACCESS, AND SAFETY FEATURES.

Table 2 Summary of Controls Provided

Control Element	Type/Size of Control	Storage Provided	Elevation	Discharge	Remarks
Units		*Acre-feet*	*MSL*	*cfs*	
Permanent Pool		0.86	924.0	0	part of WQ_v
Forebay	submerged berm	0.12	924.0	0	included in permanent pool volume
Water Quality Extended Detention (WQ_v-ED)	4" pipe, sized to 3.7" equivalent diameter	0.72	926.0	0.36	part of WQ_v above perm. pool, discharge is average release rate over 24 hours
Channel Protection (CP_v-ED)	6" pipe sized to 5.0" equivalent diameter	2.9	929.0	1.46	volume above perm. pool, discharge is average release rate over 24 hours
Overbank Flood Protection (Q_{p25})	Four 7' x 1.5' slots on a 8' x 8' riser, 36"barrel.	3.8	930.8	92.4	volume above perm. pool
Extreme Flood Protection ($Q_{f\text{-}100}$)	34' wide earth spillway	6.3	931.7	141	volume above perm. pool

See Figure 8 for profile through principal spillway of the facility.
See Figure 9 for a schematic of the riser.

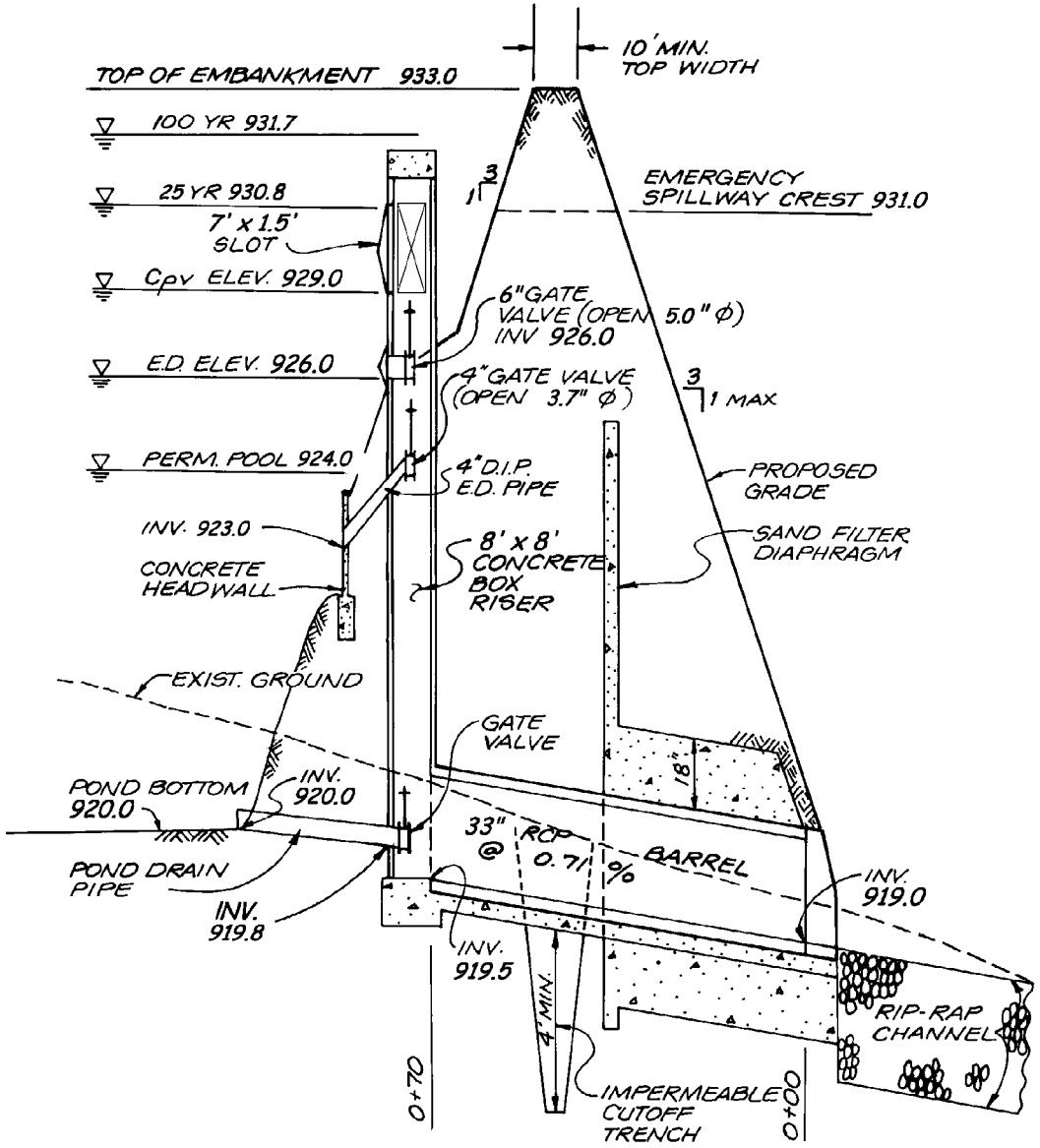


Figure 8. Profile of Principle Spillway

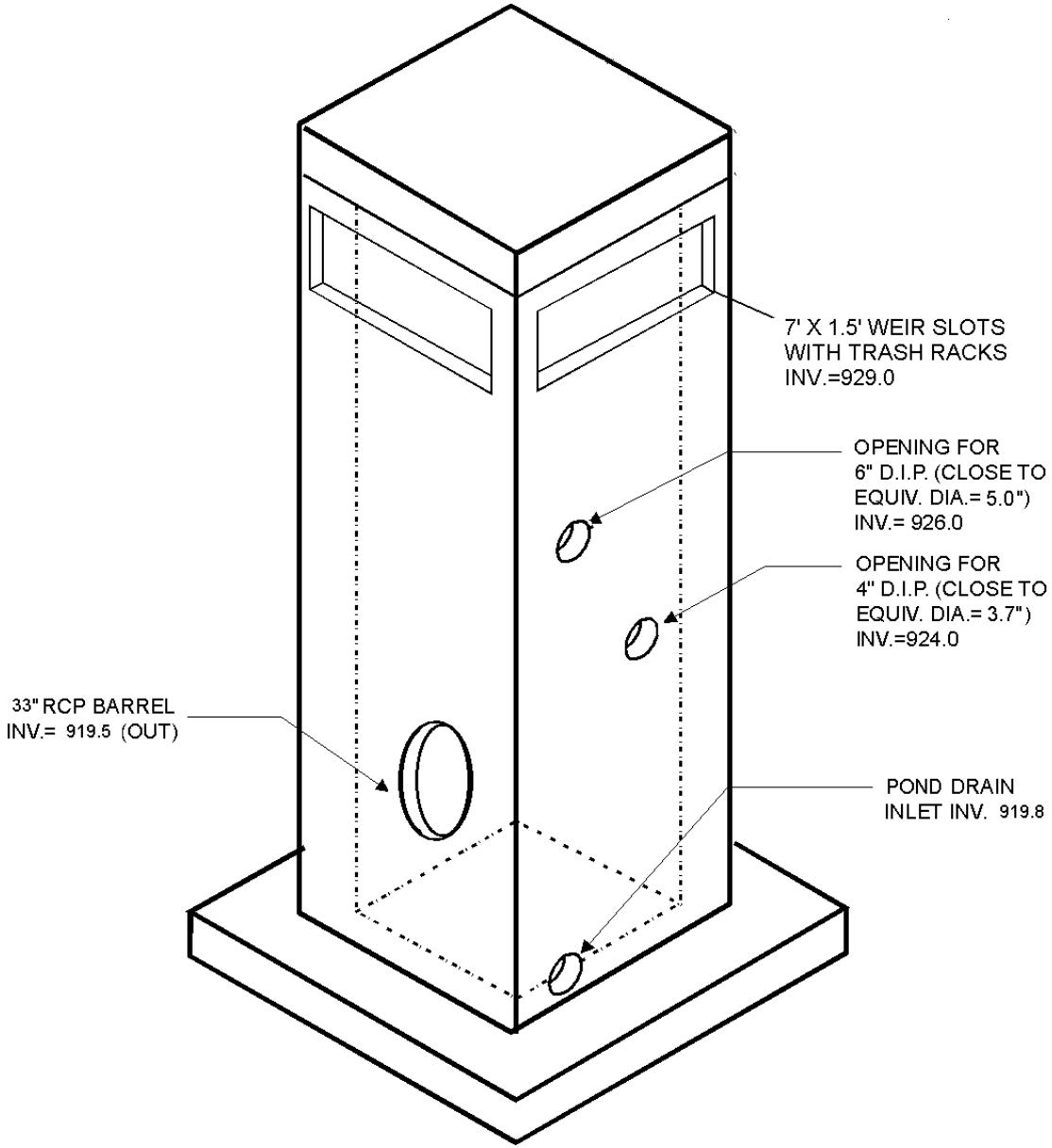
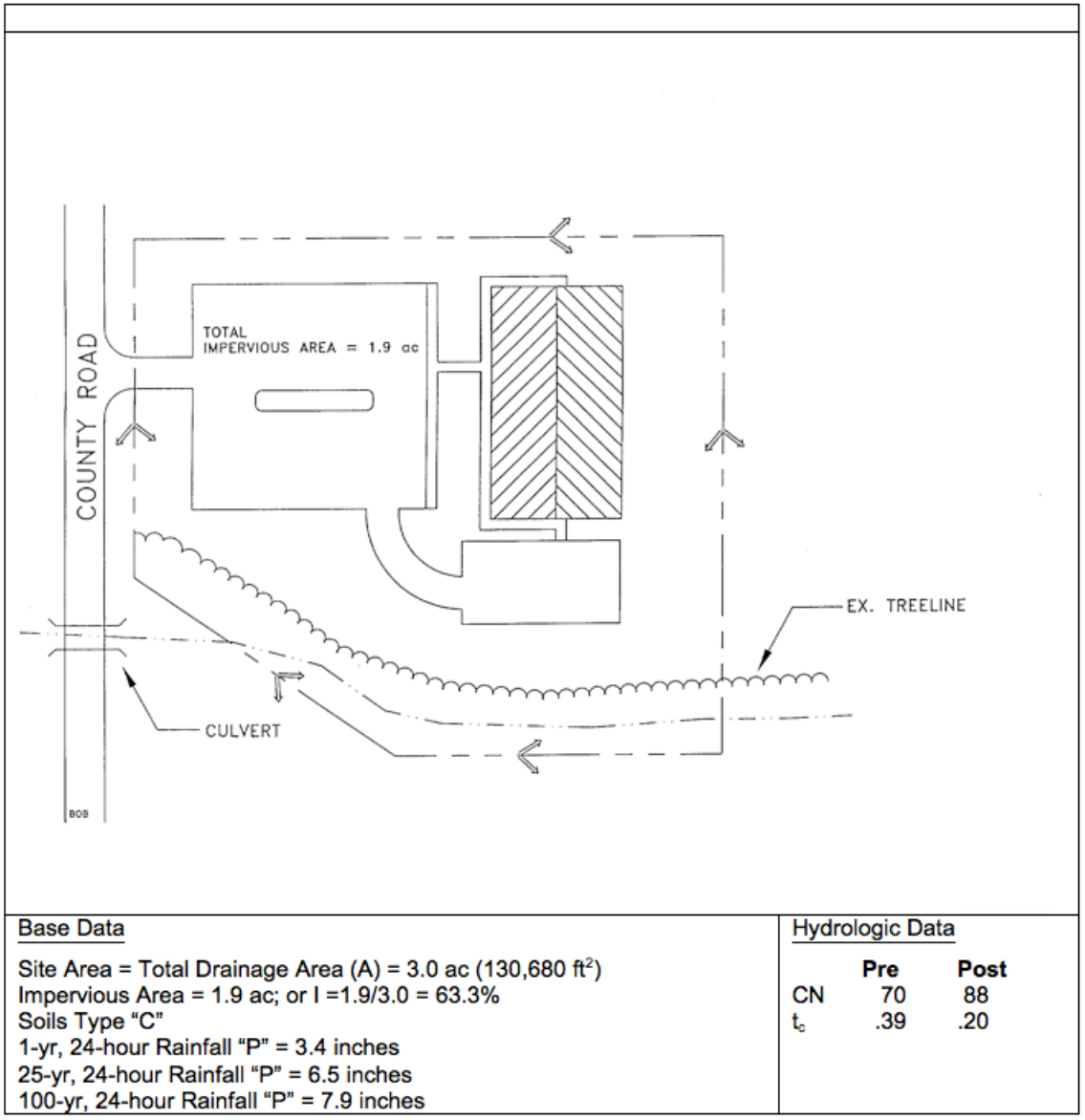


Figure 9. Schematic of Riser Detail

Appendix B-2: Bioretention Area Design Example



Base Data

Site Area = Total Drainage Area (A) = 3.0 ac (130,680 ft^2)
Impervious Area = 1.9 ac; or I =1.9/3.0 = 63.3%
Soils Type "C"
1-yr, 24-hour Rainfall "P" = 3.4 inches
25-yr, 24-hour Rainfall "P" = 6.5 inches
100-yr, 24-hour Rainfall "P" = 7.9 inches

Hydrologic Data

	Pre	Post
CN	70	88
t_c	.39	.20

Figure 1. Etowah Recreation Center Site Plan

This example focuses on the design of a bioretention facility to meet the water quality requirements of the site. Channel protection and overbank flood control are not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of bioretention is to provide water quality through runoff reduction or treatment (TSS removal) and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility or pass through the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). Under some conditions, channel protection storage can be provided by bioretention facilities. Due to the Class C soils identified on-site, an underdrain will be provided in this practice that will provide a runoff reduction volume credit of 50%.

Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Etowah Recreation Center is shown in Figure 1. This example assumes that the local community has adopted the unified stormwater sizing criteria requirements.

STEP 1 – CONFIRM LOCAL DESIGN REQUIREMENTS AND DETERMINE THE GOAL AND FUNCTION OF THE BMP

It was determined by the local municipality that this best management practice would be designed by the runoff reduction volume calculation approach (described as Step 3 in Section 4.2)

The total designed volume of the practice must be provided to retain or remove the stormwater volume associated with the 1.0 inch storm event (this examples target runoff reduction). Runoff reduction credit will then be utilized by the designer through an adjusted curve number calculations.

STEP 2 - DETERMINE IF THE DEVELOPMENT SITE AND CONDITIONS ARE APPROPRIATE FOR THE USE OF A BIORETENTION AREA.

Existing ground elevation at the facility location is 922.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 913.0 feet and underlying soil is silt loam (ML). Adjacent creek invert is at 912.0 feet.

STEP 3 - COMPUTE RUNOFF CONTROL TARGET VOLUMES FROM THE UNIFIED STORMWATER SIZING CRITERIA (EITHER METHOD 3 OR 4 AS DESCRIBED IN THE DESIGN STEPS)

Method 3) Compute Runoff Reduction Volume (RR_V):

- Compute Runoff Coefficient, Rv

  $R_V = 0.05 + (63.3)\ (0.009) = 0.62$

- Compute the target Runoff Reduction Volume (RR_V):

  $RR_V = (1.0")\ (R_V)\ (A) / 12$
  $= (1.0")\ (0.62)\ (130{,}680\ ft^2)\ (1ft/12in)$
  $= \underline{6{,}752}\ ft^3$

- Using the RR_V calculated above, Compute the minimum volume of the practice (VP_{MIN}):

  $(VP_{MIN}) \geq RR_V$ (target) / (RR%)
  $= (6{,}752\ ft^3) / (50\%)$
  $= \underline{13{,}504}\ ft^3$

Note: The Volume Provided (VP) of this practice must be a minimum of 13,504 ft^3.

- Calculate the amount of Runoff Reduction (RR_V provided) by the bioretention area with an underdrain. This information will be needed in the adjusted curve number calculation, Compute the RR_V provided:

  RR_V (provided) = (RR%) (VP)
  $= (50\%)\ (13{,}504\ ft^3)$ *
  $= 6{,}752\ ft^3$ *

Compute Stream Channel Protection Volume (CP_v):
For stream channel protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for channel protection and overbank flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 3.1.5 to determine pre- and post-development peak discharges for the 1-yr, 25-yr, and 100-yr 24-hour return frequency storms.

- Hydrologic output based on the given information provided

Condition	CN	$Q_{1\text{-year}}$		$Q_{25\text{-year}}$		$Q_{100\text{-year}}$	
		inches	*cfs*	*inches*	*cfs*	*inches*	*cfs*
Pre-Developed	70	0.95	2.6	3.21	9.8	4.38	13.5
Post-Developed	88	2.18	8.2	5.12	18.5	6.48	23.2
* Post-Developed (Adjusted CN for RR_V)	1-yr 80.1 25-yr 82.4 100-yr 82.8	1.56	5.9	4.50	16.7	5.86	21.5

- *Adjusted Curve Number Procedure for Peak Flow Reduction of CP_V (Section 3.1.7.5)

  Given Q = 2.18 in. and P = 3.4 in., Find "R" and "S" to back calculate an adjusted CN

$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$ Modified Equation 3.1.5)

  Retention storage (expressed in inches) for this basin is calculated by the following formula:

  $R = RR_V$ (provided) / Basin Area
  $= (6{,}752\ ft^3) / A$
  $= 6{,}752\ ft^3 / 130{,}680\ ft^2\ (12\ in / 1\ ft) =$ **0.62 inches**

$$1.56 = \frac{(3.4 - 0.2S)^2}{(3.4 + 0.8S)}$$

  Solve for "S" to back calculate CN: S = 2.49

  S = 1000/CN-10: therefore, CN = 80.1

- Utilize modified TR-55 approach to compute channel protection storage volume (based on adjusted CN value calculated above)

  Initial abstraction (Ia) for CN of 80.1 is 0.5: [Ia = (200/CN - 2)]

  Ia/P = (0.50)/ 3.4 inches = 0.15
  T_c = 0.20 hours
  q_u = 770 csm/in (From Figure 3.1.5-6)

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

  Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.023
  (From Figure 3.3.5-1)

  For a Type II rainfall distribution,
  $Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$
  (Equation 3.3.9)

Where Vs equals channel protection storage (CP_v) and Vr equals the volume of runoff in inches.

  Vs/Vr = 0.65 Using Equation 3.3.10, calculate V_S...

  Therefore, Vs = CP_v = 0.65 (1.56 in) (3 ac) (43,560 ft^2 / ac) (1 ft / 12 in)
  = 11,043 ft^3

Determine Overbank Flood Protection Volume (Qp25) based on the adjusted CN: For a Q_{in} of 16.7 cfs, and an allowable Q_{out} of 9.8 cfs, the Vs necessary for 25-year control is 10,942 ft^3, under an adjusted post-developed CN of 82.4. Note that 6.5 inches of rainfall occurs during this event.

Analyze for Safe Passage of 100 Year Design Storm (Q_f):
At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure, typically the same one used for the overbank flood protection control.

Table 1 Summary of General Design Information for Etowah Recreation Center

Symbol	Control Volume	Volume Required (cubic feet)	Notes
RR_V	Runoff Reduction	6,752	6,752 cf provided (100%)
WQ_V	Water Quality	8,102	Not used in this example
CP_V	Channel Protection	11,043	
Q_{p25}	Overbank Flood Protection	10,942	
Q_f	Extreme Flood Protection	N/A	Provide safe passage for the 100-year event in final design

STEP 4 - COMPUTE WQ_V PEAK DISCHARGE (Q_{WQ})

STEP 5 - SIZE FLOW DIVERSION STRUCTURE, IF NEEDED

Bioretention areas can be either on or off-line. On-line facilities are generally sized to receive, but not necessarily treat, the 25-year event. Off-line facilities are designed to receive a more or less exact flow rate through a weir, channel, manhole, "flow splitter", etc. This facility is situated to receive direct runoff from grass areas and parking lot curb openings and piping for the 25-year event (16.7 cfs – adjusted flow rate), and *no special flow diversion structure is incorporated.*

STEP 6 - DETERMINE SIZE OF BIORETENTION PONDING / FILTER AREA BASED ON VP_{MIN}

$$VP_{MIN} = PV + (VES)(N)$$

Where: VP_{MIN} = Volume Provided
(Calculated above, 13,504 ft^3)
PV = Ponding Volume (Ponding depth typically 9 inches)
VES = Volume of Engineered Soils
(Media depth typically 36 inches)
N = Porosity of engineered soils, typically 0.25

13,504 ft^3 = (Surface Area x 0.75 ft) + (Surface Area x 3 ft x 0.25)

13,504 ft^3 = (Surface Area x 1.5 ft)

9,003 ft^2 = Surface Area

STEP 7 - SET DIMENSIONS OF FACILITY

Assume a roughly 2 to 1 rectangular shape. Given a filter area requirement of 9,003 sq ft, say facility is roughly 67' by 135' for constructability.

STEP 8 - DESIGN CONVEYANCE TO FACILITY (OFF-LINE SYSTEMS)

This facility is not designed as an off-line system.

STEP 9 - SIZE UNDERDRAIN AREA

Base underdrain design on 10% of the Surface Area or 900 sq ft. Using 6" perforated plastic pipes surrounded by a three-foot-wide gravel bed, 10' on center (o.c.). See Figure 2.

(900 sq ft)/3' per foot of underdrain = 300' of perforated underdrain

STEP 10 - DESIGN EMERGENCY OVERFLOW

The parking area, curb and gutter is sized to convey the 25-year event to the facility. Should filtering rates become reduced due to facility age or poor maintenance, an overflow weir is provided to pass the 25-year event. Size this weir with 6" of head, using the weir equation.

$Q = CLH^{3/2}$

Where C = 2.65 (smooth crested grass weir)

Q = 16.7 cfs

H = 6"

Solve for L: $L = Q / [(C) (H^{3/2})]$ or (16.7 cfs) / [(2.65) $(.5^{1.5})$] = 17.8' (say 18')

Outlet protection in the form of riprap or a plunge pool/stilling basin should be provided to ensure non-erosive velocities.

STEP 11 - PREPARE VEGETATION AND LANDSCAPING PLAN

Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on center planting distances) so species will not "shade out" one another. Do not plant trees and shrubs with extensive root systems near pipe work. A potential plant list is presented in Appendix D.

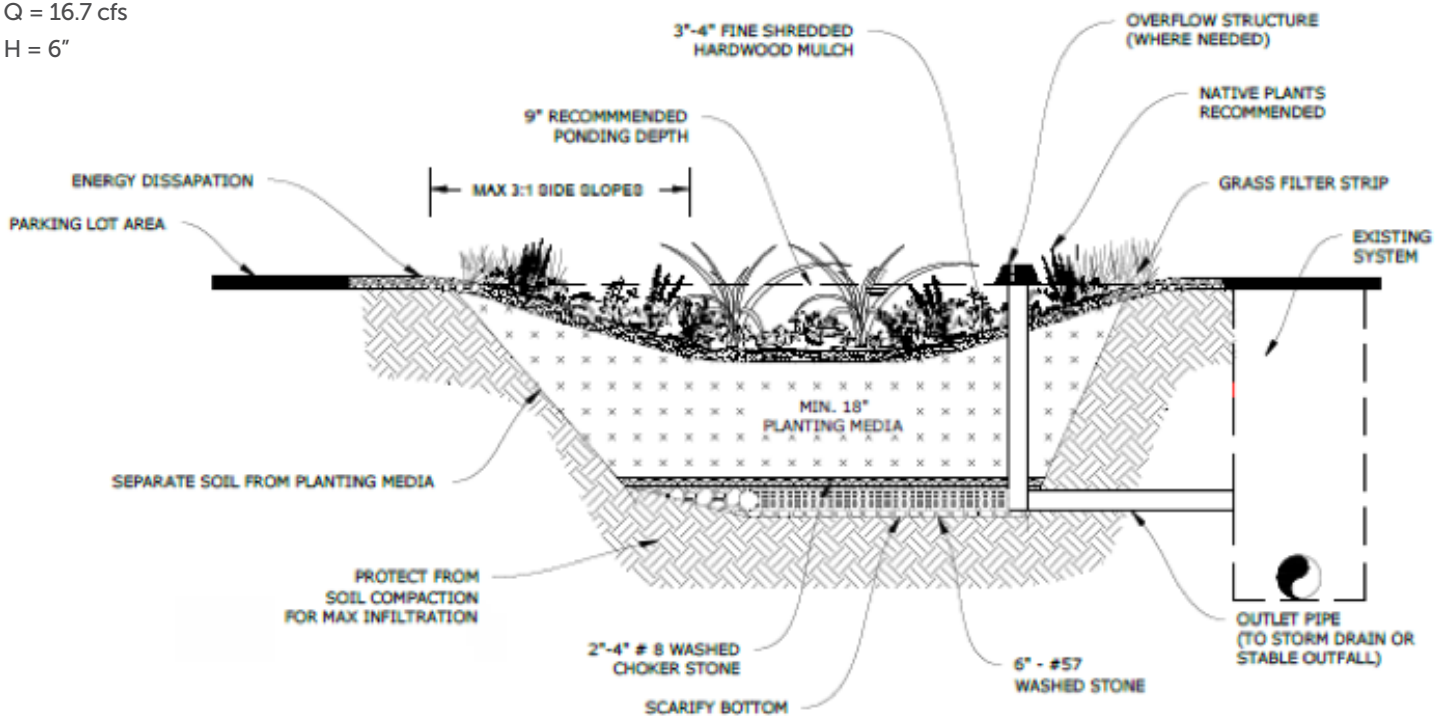
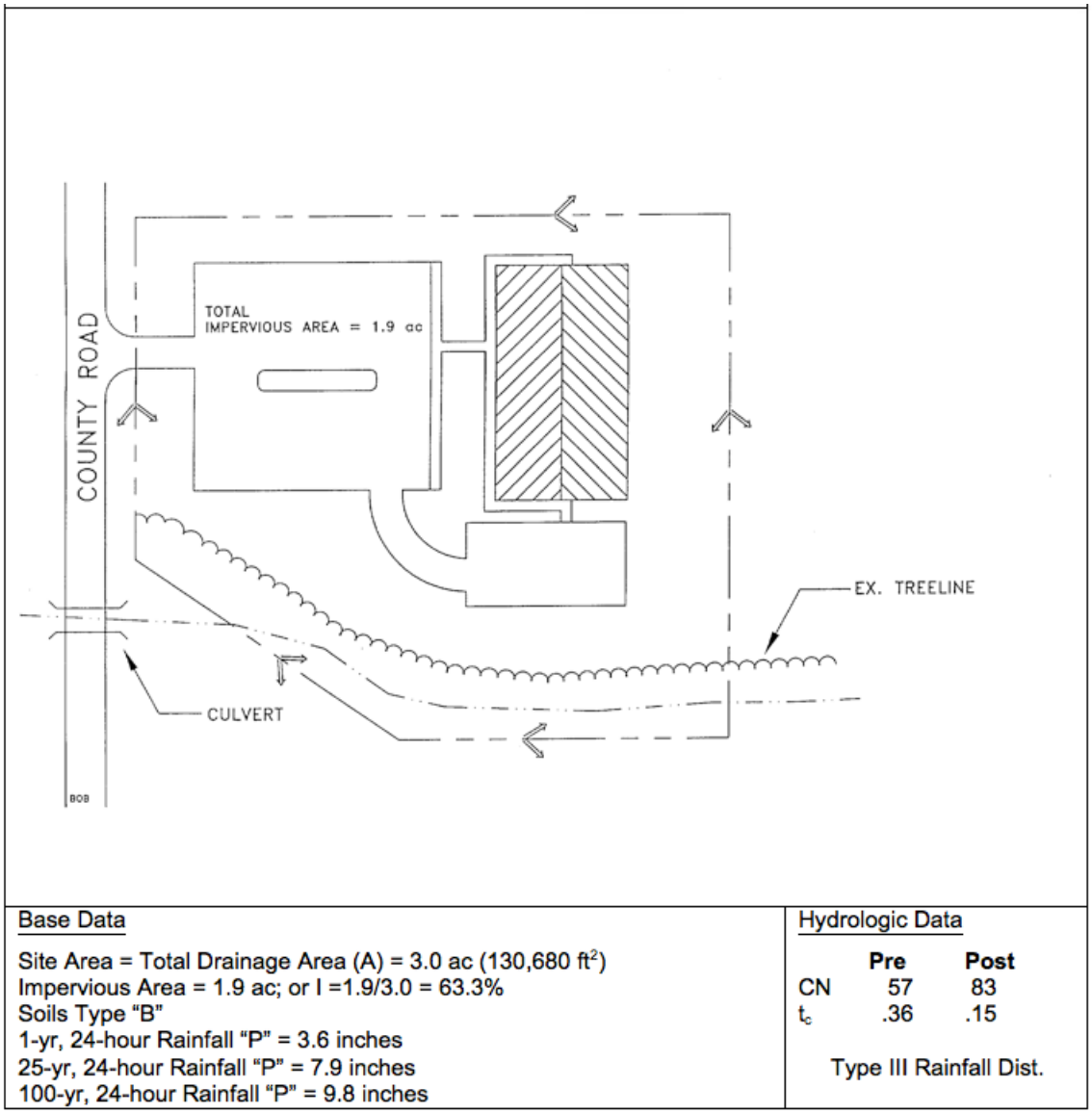


Figure 2. Typical Section of Bioretention Facility

Appendix B-3: Sand Filter Design Example



Base Data	Hydrologic Data
Site Area = Total Drainage Area (A) = 3.0 ac (130,680 ft^2) Impervious Area = 1.9 ac; or I =1.9/3.0 = 63.3% Soils Type "B" 1-yr, 24-hour Rainfall "P" = 3.6 inches 25-yr, 24-hour Rainfall "P" = 7.9 inches 100-yr, 24-hour Rainfall "P" = 9.8 inches	**Pre** **Post** CN 57 83 t_c .36 .15 Type III Rainfall Dist.

Figure 1. Georgia Pines Community Center Site Plan

This example focuses on the design of a surface sand filter to meet the water quality treatment (TSS removal) requirements of the site. Channel protection and overbank flood control is not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of sand filters is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). Sand filters do not contribute to a runoff reduction goal.

Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Georgia Pines Community Center is shown in Figure 1. This example assumes that the local community has adopted the unified stormwater sizing criteria requirements.

STEP 1 - CONFIRM LOCAL DESIGN CRITERIA AND APPLICABILITY.

There are no additional requirements for this site.

STEP 2 - DETERMINE IF THE DEVELOPMENT SITE AND CONDITIONS ARE APPROPRIATE FOR THE USE OF A SURFACE SAND FILTER.

Site Specific Data:

The site area and drainage area to the sand filter is 3.0 acres (3 ac < 10 ac max.) Existing ground elevation at the facility location is 22.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 13.0 feet. Adjacent creek invert is at 12.0.

STEP 3 - COMPUTE RUNOFF CONTROL VOLUMES FROM THE UNIFIED STORMWATER SIZING CRITERIA

Method 4) Compute Water Quality Volume (WQ_v):

- Compute Runoff Coefficient, Rv

$$R_v = 0.05 + (63.3)\,(0.009) = 0.62$$

- Compute WQ_v

$$WQ_v = (1.2'')\,(Rv)\,(A) / 12$$
$$= (1.2'')\,(0.62)\,(130{,}680\ ft^2)\,(1ft/12in)$$
$$= \underline{8{,}102}\ ft^3$$

Compute Stream Channel Protection Volume, (CP_v):

For stream channel protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for channel protection and overbank flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 3.1.5 to determine pre- and post-development peak discharges for the 1-yr, 25-yr, and 100-yr 24-hour return frequency storms.

- Hydrologic output based on the given information provided

Note that any hydrologic models using NRCS TR-55 procedures, such as TR-20, HEC-HMS, or other software platforms, can be used to perform preliminary hydrologic calculations.

Condition	CN	$Q_{1\text{-year}}$		$Q_{25\text{-year}}$	$Q_{100\text{-year}}$
		inches	*cfs*	*cfs*	*cfs*
Pre-Developed	57	0.45	0.7	6.4	9.7
Post-Developed	83	1.94	5.0	14.6	18.9

- Utilize modified TR-55 approach to compute channel protection storage volume

  Initial abstraction (Ia) for CN of 83 is 0.41: (TR-55) [Ia = (200/CN - 2)]

  Ia/P = (0.41)/ 3.6 inches = 0.11
  T_c = 0.15 hours
  q_u = 605 csm/in (From Figure 3.1.5-7)

Knowing q_u and T (extended detention time), find q_o/q_i for a Type III rainfall distribution.

Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.03
(From Figure 3.3.5-1)

$Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(qo/qi)^2 - 0.804(q_o/q_i)^3$
(Equation 3.3.9)

Where Vs equals channel protection storage (CP_v) and Vr equals the volume of runoff in inches.

Vs/Vr = 0.64 Using Equation 3.3.10, calculate V_S...

Therefore, Vs = CP_v = 0.64(1.94")(1/12)(3 ac) (43,560 ft^2 / ac) = 13,521 ft^3

- Define the average ED Release Rate

  The above volume, 13,521 ft^3, is to be released over 24 hours.
  (13,521 ft^3) / (24 hrs × 3,600 sec/hr) = 0.16 cfs

Determine Overbank Flood Protection Volume (Q_{p25}):
For a Q_{in} of 14.6 cfs, and an allowable Q_{out} of 6.4 cfs, the Vs necessary for 25-year control is 40,981 ft^3, under a developed CN of 83. Note that 7.9 inches of rain fall during this event.

Analyze for Safe Passage of 100 Year Design Storm (Q_f):
At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure, typically the same one used for the overbank flood protection control.

Table 1 Summary of General Design Information for Georgia Pines Community Center

Symbol	Control Volume	Volume Required (cubic feet)	Notes
WQ_v	Water Quality	8,102	
CP_v	Channel Protection	13,521	
Q_{p25}	Overbank Flood Protection	40,981	
Q_f	Extreme Flood Protection	N/A	Provide safe passage for the 100-year event in final design

STEP 4 - COMPUTE WQ_v PEAK DISCHARGE (Q_{WQ}) & HEAD

- Water Quality Volume:

  WQ_v previously determined to be 8,102 cubic feet.

- Determine available head (See Figure 3)

Low point at parking lot is 23.5. Subtract 2' to pass Q25 discharge (21.5) and a half foot for channel to facility (21.0). Low point at stream invert is 12.0. Set outfall underdrain pipe 2' above stream invert and add 0.5' to this value for drain (14.5). Add to this value 8" for the gravel blanket over the underdrains, and 18" for the sand bed (16.67). The total available head is 21.0 - 16.67 or 4.33 feet. Therefore, the average depth, hf, is (hf) = 4.33' / 2, and hf = 2.17'.

The peak rate of discharge for the water quality design storm is needed for the sizing of off-line diversion structures, such as sand filters and grass channels. Conventional NRCS TR-55 methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2". This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the filtering treatment practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels.

The following equation can be used to estimate peak discharges for small storm events.

- Using the water quality volume (WQ_v), a corresponding Curve Number (CN) is computed utilizing the following equation (See Section 3.1.7.2):

$$CN = 1000/[10 + 5P + 10Q_{wv} - 10(Q_{wv}^{\ 2} + 1.25\ Q_{wv}\ P)^{½}]$$

where P = rainfall, in inches (use 1.2" for the Water Quality Storm)
and QWV = runoff volume, in inches (equal to 1.2 x R_V = 0.744)

- Once a CN is computed (CN = 95), the time of concentration (t_c) is computed
- Using the computed CN, t_c and drainage area (A), in acres; the peak discharge (Q_{wq}) for the Water Quality Storm is computed (based on the procedures identified in Section 3.1.5 (Type III for this example).

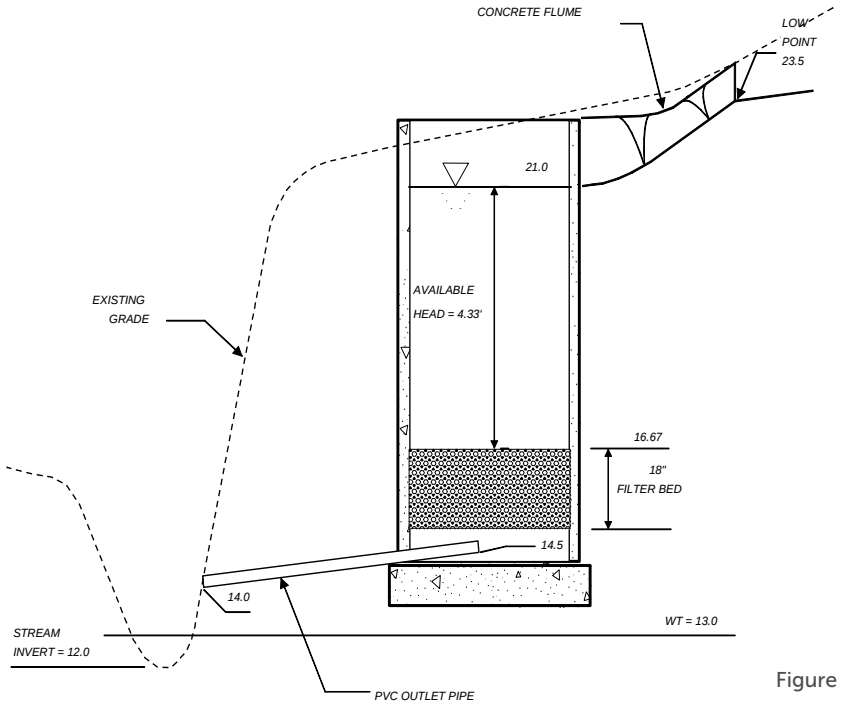


Figure 3. Available Head Diagram

- Read initial abstraction (I_a), compute I_a/P (I_a/P = 0.09)
- Read the unit peak discharge (q_u) for appropriate t_c (q_u = 625)
- Using the water quality volume (WQ_v), compute the water quality peak discharge (Q_{wq})

$$Q_{wq} = q_u * A * WQ_V$$

where Q_{wq} = the peak discharge, in cfs
q_u = the unit peak discharge, in cfs/mi^2/inch
A = drainage area, in square miles
WQ_v = Water Quality Volume, in watershed inches

For this example, the steps are as follows:
Compute modified CN for 1.2" rainfall

P = 1.2"
Q = 1.2 R_v = 1.2 * 0.62 = 0.74"
CN = 1000/[10+5P+10Q-10(Q^2+1.25*Q*P)^{½}]
= 1000/[10+5*1.2+10*0.74-10(0.74^2+1.25*0.74*$1.2^{)½}$]
= 95.01
Use CN = 95

For CN = 95 and the T_c = 0.15 hours, compute the Q_p for a 1.2" storm. With the CN = 95, a 1.2" storm will produce 0.74" of runoff. I_a = 0.105, therefore Ia/P = 0.105/1.2 = 0.088. From Section 3.1.5.7 q_u = 625 csm/in, and therefore Q_{wq} = (625 csm/in) (3.0 ac/640ac/sq mi.) (0.74") = 2.2 cfs.

STEP 5 - SIZE FLOW DIVERSION STRUCTURE (SEE FIGURE 4):

Size a low flow orifice to pass 2.2 cfs with 1.5' of head using the Orifice equation.

$Q = CA(2gh)^{1/2}$; 2.2 cfs = (0.6) (A) [(2) (32.2 ft/s^2) (1.5')]$^{1/2}$

A = 0.37 sq ft = $\varpi d^2/4$: d = 0.7' or 8.5"; use 9 inches

Size the 25-year overflow as follows: the 25-year wsel is set at 23.0. Use a concrete weir to pass the 25-year flow (14.6 cfs) into a grassed overflow channel using the Weir equation. Assume 2' of head to pass this event. Overflow channel should be designed to provide sufficient energy dissipation (e.g., riprap, plunge pool, etc.) so that there will be non-erosive velocities.

$Q = CLH^{3/2}$

$14.6 = 3.1 (L) (2')^{1.5}$

L = 1.66'; use L = 2'-0" which sets flow diversion chamber dimension.

Weir wall elev. = 21.0. Set low flow invert at 21.0 -
[1.5' + (0.5*9"*1ft/12")] = 19.13.

STEP 6 - SIZE FILTRATION BED CHAMBER (SEE FIGURE 6):

From Darcy's Law: $A_f = WQ_v (d_f) / [k (h_f + d_f) (t_f)]$

where d_f = 18"

k = 3.5 ft/day

h_f = 2.17'

t_f = 40 hours

A_f = (8,102 cubic feet) (1.5') / [3.5 (2.17' + 1.5') (40hr/24hr/day)]

A_f = 567.7 sq ft; using a 2:1 ratio, say filter is 17' by 34' (= 578 sq ft)

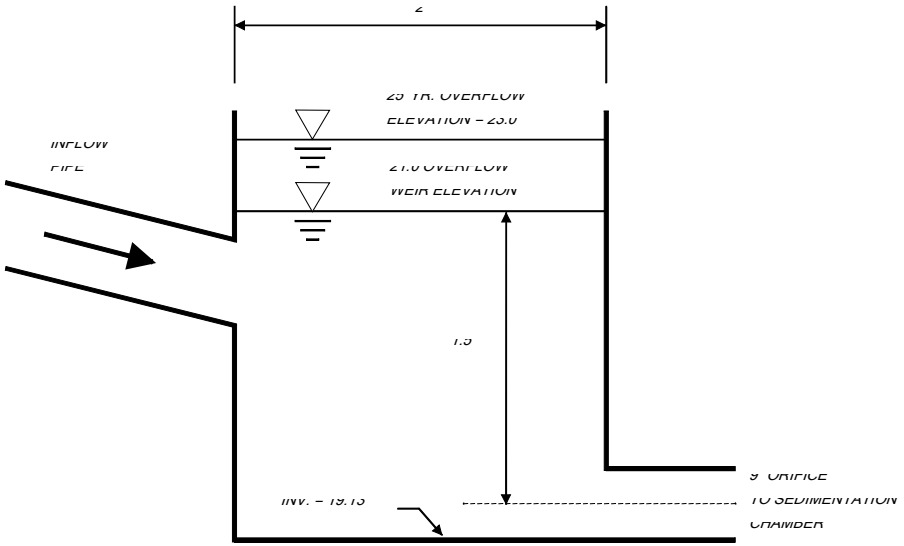


Figure 4. Flow Diversion Structure

STEP 7- SIZE SEDIMENTATION CHAMBER

From Camp-Hazen equation, for I < 75%: $A_s = 0.066 (WQ_v)$

A_s = 0.066 (8,102 cubic ft) or 535 sq ft

given a width of 17 feet, the length will be 535'/17' or 31.5 feet (use 17'x32')

STEP 8 - COMPUTE V_{MIN}

V_{min} = 0.75 (WQ_v) or 0.75 (8,102 cubic feet) = 6,077 cubic feet

STEP 9. COMPUTE STORAGE VOLUMES WITHIN ENTIRE FACILITY AND SEDIMENTATION CHAMBER ORIFICE SIZE:

Volume within filter bed (V_f): $V_f = A_f (d_f) (n)$; n = 0.4 for sand

V_f = (578 sq ft) (1.5') (0.4) = 347 cubic feet

Temporary storage above filter bed (Vf-temp): $V_{f\text{-}temp} = 2h_fA_f$

$V_{f\text{-}temp}$ = 2 (2.17') (578 sq ft) = 2,509 cubic feet

Compute remaining volume for sedimentation chamber (V_s):

$V_s = V_{min} - [V_f + V_{f\text{-}temp}]$ or 6,077 - [347 + 2,509] = 3,221 cubic feet

Compute height in sedimentation chamber (h_s): $h_s = V_s/A_s$

(3,221 cubic ft)/(17' x 32') = 5.9' which is larger than the head available (4.33'); increase the size of the settling chamber, using 4.33 as the design height;

(3,221 cubic ft)/4.33' = 744 sq ft; 744'/17' yields a length of 43.8 feet (say 44')

New sedimentation chamber dimensions are 17' by 44'

With adequate preparation of the bottom of the settling chamber (rototil earth, place gravel, then surge stone), the bottom can infiltrate water into the substrate. The runoff will enter the groundwater directly without treatment. The stone will eventually clog without protection from settling solids, so use a removable geotextile to facilitate maintenance. Note that there is 2.17' of freeboard between bottom of recharge filter and water table.

Provide perforated standpipe with orifice sized to release volume (within sedimentation basin) over a 24 hr period (see Figure 6). Average release rate equals 3,221 ft^3/24 hr = 0.04 cfs

Equivalent orifice size can be calculated using orifice equation:

$Q = CA(2gh)^{1/2}$, where h is average head, or 4.33'/2 = 2.17'.
0.04 cfs = $0.6*A*(2*32.2\ ft/s^2*2.17\ ft)^{1/2}$
$A = 0.005\ ft^2 = \pi D^2/4$: therefore equivalent orifice diameter equals 1".

Recommended design is to cap stand pipe with low flow orifice sized for 24 hr detention. Over-perforate pipe by a safety factor of 10 to account for clogging. Note that the size and number of perforations will depend on the release rate needed to achieve 24 hr detention. A multiple orifice stage-discharge relation needs to be developed for the proposed perforation configuration. Stand pipe should discharge into a flow distribution chamber prior to filter bed. Distribution chamber should be between 2 and 4 feet in length and same width as filter bed. Flow distribution to the filter bed can be achieved either with a weir or multiple orifices at constant elevation. See Figure 7 for stand pipe details.

STEP 10 -DESIGN INLETS, PRETREATMENT FACILITIES, UNDERDRAIN SYSTEM, AND OUTLET STRUCTURES

STEP 11 - COMPUTE OVERFLOW WEIR SIZES

Assume overflow that needs to be handled is equivalent to the 9" orifice discharge under a head of 3.5 ft (i.e., the head in the diversion chamber associated with the 25-year peak discharge).

$Q = CA(2gh)^{½}$
$Q = 0.6(0.44\ ft^2)[(2)(32.2\ ft/s^2)(3.5\ ft)]^{½}$
Q = 3.96 cfs, say 4.0 cfs

For the overflow from the sediment chamber to the filter bed, size to pass 4 cfs.

Weir equation: $Q = CLh^{3/2}$, assume a maximum allowable head of 0.5'
$4.0 = 3.1 * L * (0.5\ ft)^{3/2}$
L = 3.65 ft, Use L = 3.75 ft.

Similarly, for the overflow from the filtration chamber to the outlet of the facility, size to pass 4.0 cfs.

Weir equation: $Q = CLh^{3/2}$, assume a maximum allowable head of 0.5'
$4.0 = 3.1 * L * (0.5\ ft)^{3/2}$
L = 3.65 ft, Use L = 3.75 ft.

Adequate outlet protection and energy dissipation (e.g., riprap, plunge pool, etc.) should be provided for the downstream overflow channel.

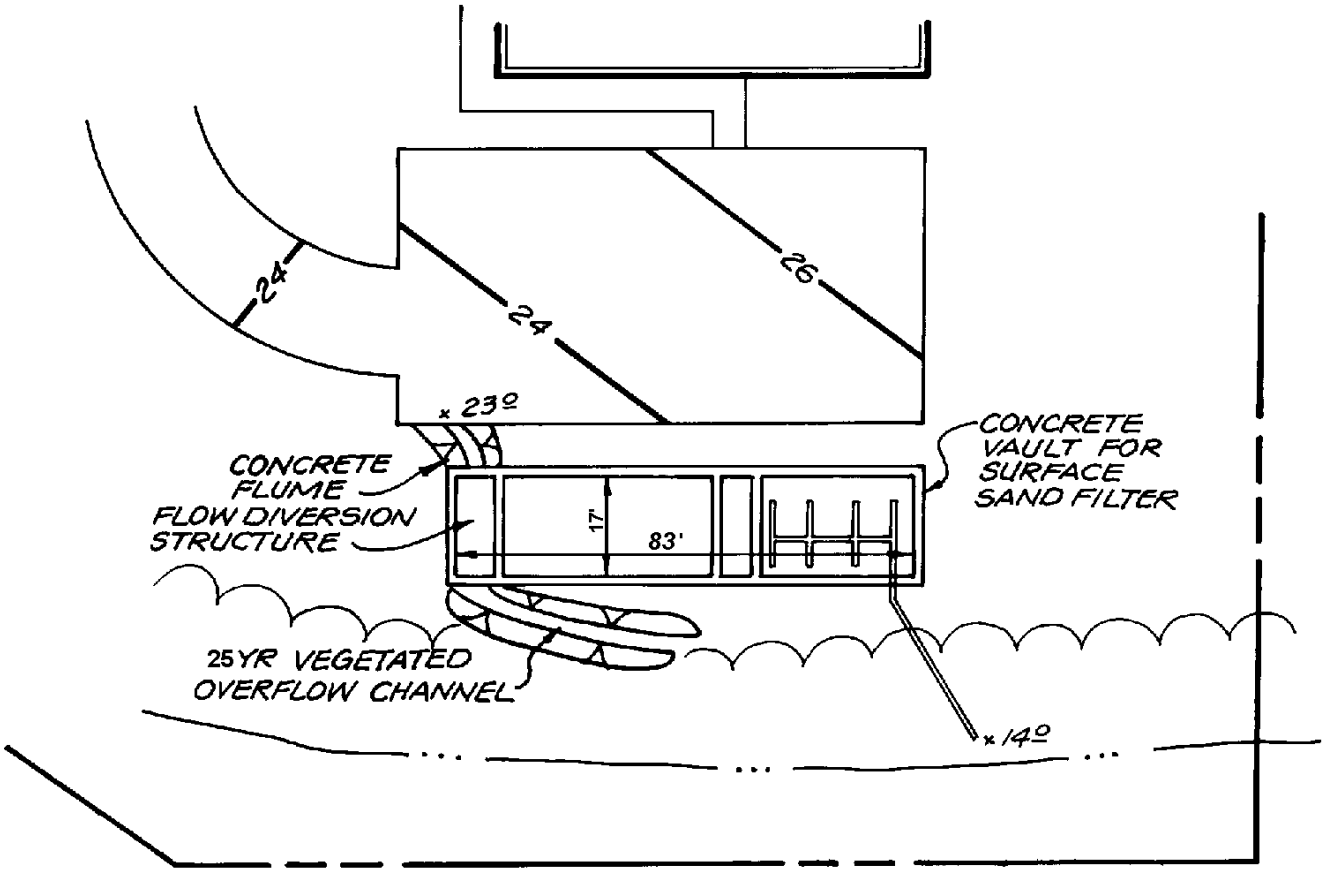


Figure 5. Surface Sand Filter Site Plan

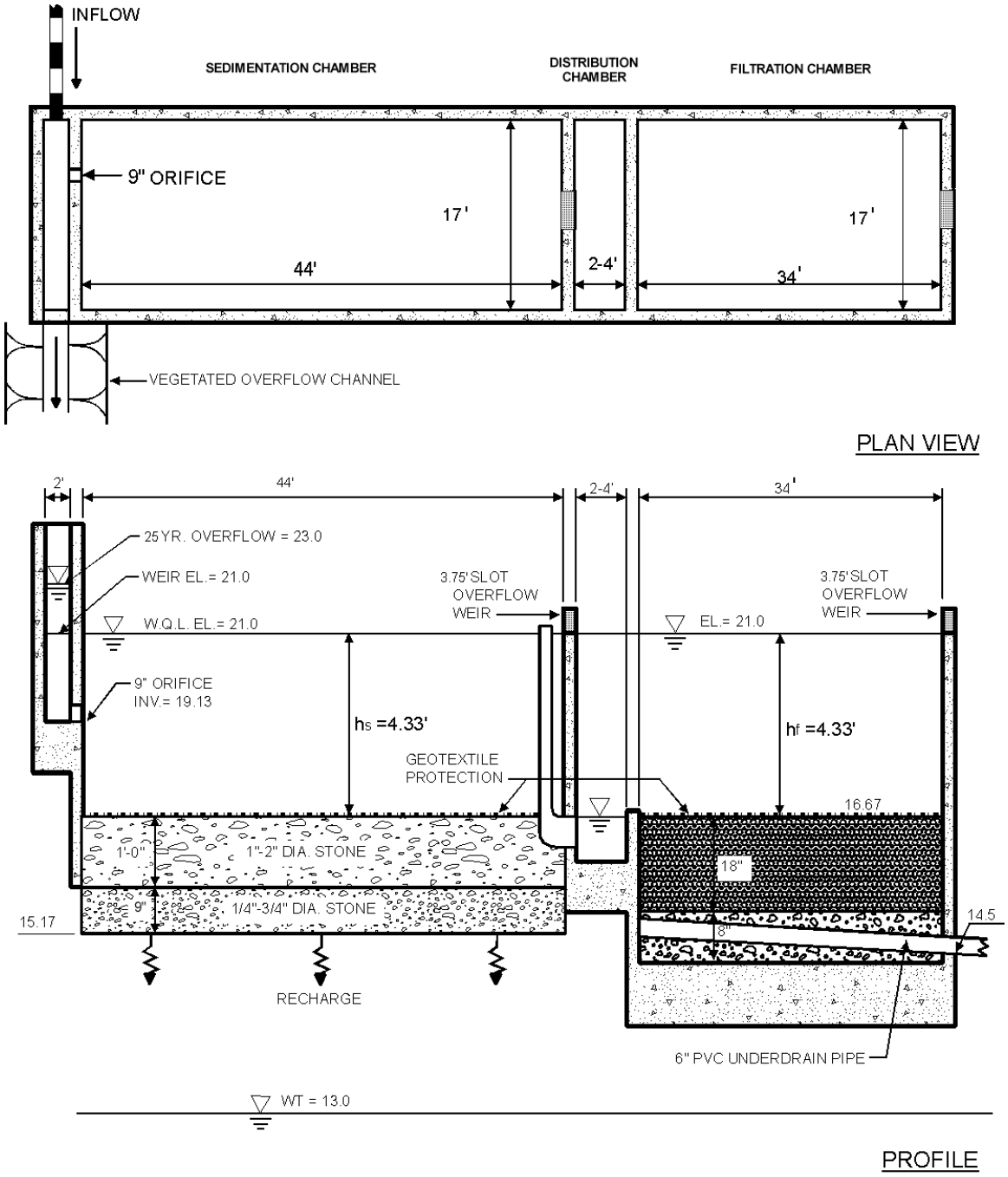


Figure 6. Plan and Profile of Surface Sand Filter

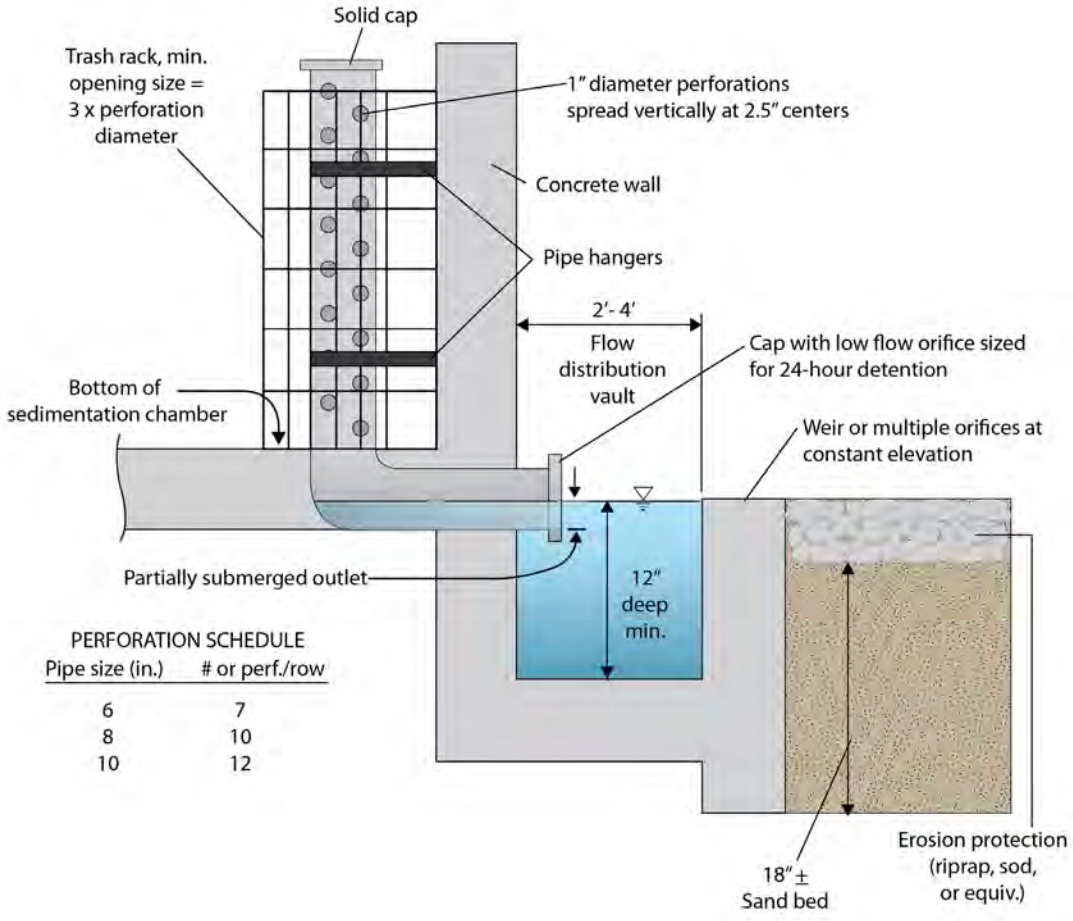
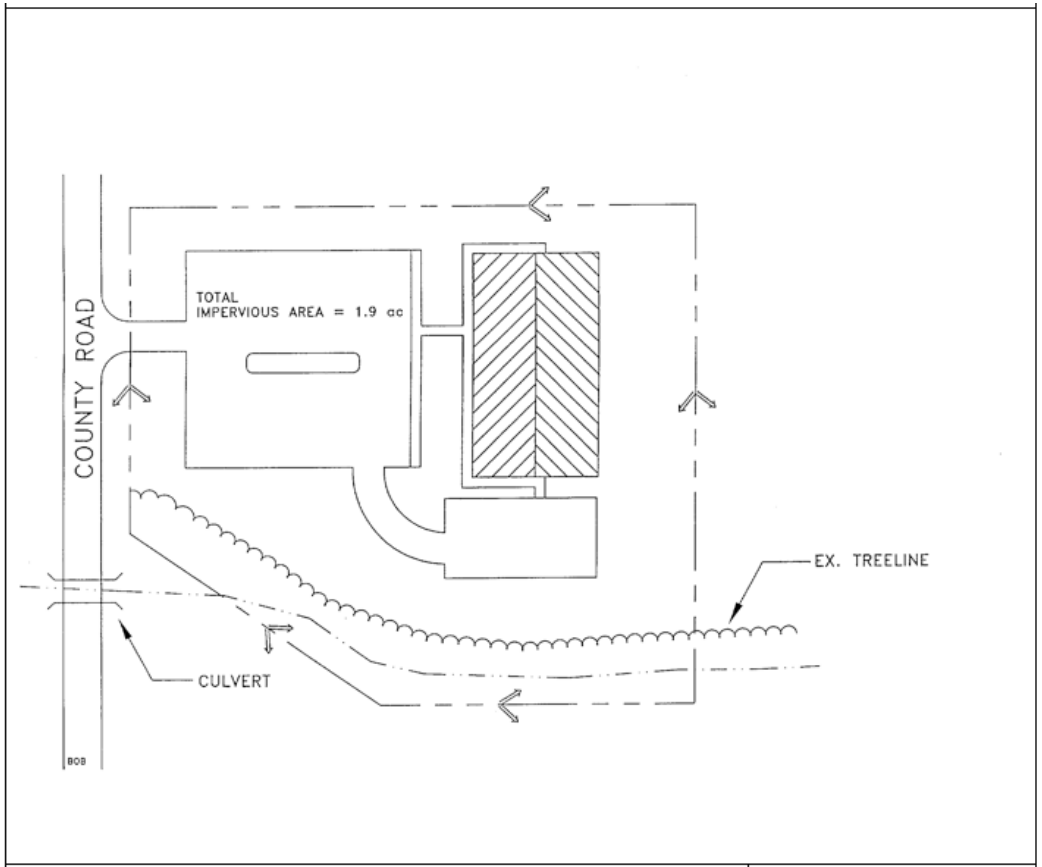


Figure 7. Perforated Stand Pipe Detail

Appendix B-4: Infiltration Trench Design Example



Base Data	Hydrologic Data
Site Area = Total Drainage Area (A) = 3.0 ac (130,680 ft^2) Impervious Area = 1.9 ac; or I =1.9/3.0 = 63.3% Soils Type "B" 1-yr, 24-hour Rainfall "P" = 3.6 inches 25-yr, 24-hour Rainfall "P" = 7.9 inches 100-yr, 24-hour Rainfall "P" = 9.8 inches	**Pre** **Post** CN 57 83 t_c .36 .15 Type III Rainfall Dist.

Figure 1. Georgia Pines Community Center Site Plan

This example focuses on the design of an infiltration trench to meet the runoff reduction goals and water quality requirements of the site. Channel protection and overbank flood control is not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of infiltration trenches is to provide water quality treatment and/or runoff reduction and groundwater recharge, not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). The layout of the Georgia Pines Community Center is shown in Figure 1. Due to the Class B soils identified on-site, the infiltration trench will be designed for runoff reduction. The runoff reduction credit given for infiltration trenches is 100%.

Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Georgia Pines Community Center is shown in Figure 1.

STEP 1 - CONFIRM LOCAL DESIGN CRITERIA AND APPLICABILITY

It was determined by the local municipality that this best management practice would be designed by the runoff reduction volume calculation approach (described as Step 3 in Section 4.12)

The total designed volume of the practice must be provided to retain or remove the stormwater volume associated with the 1.0 inch storm event (this examples target runoff reduction). Runoff reduction credit will then be utilized by the designer through an adjusted curve number calculations.

Table 1, below, summarizes the requirements that need to be met to successfully implement infiltration practices. On this site, infiltration is feasible, with restrictions on the depth and width of the trench.

Table 1 Infiltration Feasibility

Criteria	Status
Infiltration rate (f_c) greater than or equal to 0.5 inches/hour.	Infiltration rate is 1.0 inches/hour. OK.
Soils have a clay content of less than 20% and a silt/clay content of less than 40%.	Sandy Loam meets both criteria.
Infiltration cannot be located on slopes greater than 6% or in fill soils.	Slope is <1%; not fill soils. OK.
Hotspot runoff should not be infiltrated.	Not a hotspot land use. OK.
Infiltration is prohibited in karst topography.	Not in karst. OK.
The bottom of the infiltration facility must be separated by at least two feet vertically from the seasonally high water table.	Elevation of seasonally high water table: 13' Elevation of BMP location: 20'. The difference is 7'. Thus, the trench can be up to 5' deep. OK.
Infiltration facilities must be located 100 feet horizontally from any water supply well.	No water supply wells nearby. OK.
Maximum contributing area generally less than 2 or 5 acres. (Optional)	3 acres. OK.
Setback 25 feet down-gradient from structures.	Fifty feet straight-line distance between the parking lot and the tree line. OK if the trench is 25' wide or narrower.

STEP 2 - DETERMINE IF THE DEVELOPMENT SITE AND CONDITIONS ARE APPROPRIATE FOR THE USE OF AN INFILTRATION TRENCH

Site Specific Data:

Table 2 presents site-specific data, such as soil type, percolation rate, and slope, for consideration in the design of the infiltration trench.

Table 2 Site Specific Data

Criteria	Value
Soil	Sandy Loam
Percolation Rate	1"/hour
Ground Elevation at BMP	20'
Seasonally High Water Table	13'
Stream Invert	12'
Soil slopes	<1%

STEP 3 - COMPUTE RUNOFF CONTROL TARGET VOLUMES FROM THE UNIFIED STORMWATER SIZING CRITERIA (EITHER METHOD 3 OR 4 AS DESCRIBED IN THE DESIGN STEPS)

Method 3) Compute Runoff Reduction Volume (RR_V):

- Compute Runoff Coefficient, R_v

  $R_V = 0.05 + (63.3)\,(0.009) = 0.62$

- Compute the target Runoff Reduction Volume (RR_V):

  $RR_V = (1.0")\,(R_V)\,(A) / 12$
  $= (1.0")\,(0.62)\,(130{,}680\ ft^2)\,(1ft/12in)$
  $= \underline{6{,}752}\ ft^3$

- Using the RR_V calculated above, Compute the minimum volume of the practice (VP_{MIN}):

  $(VP_{MIN}) \geq RR_V$ (target) / (RR%)
  $= (6{,}752\ ft^3) / (100\%)$
  $= \underline{6{,}752}\ ft^3$

- Calculate the amount of Runoff Reduction (RR_V provided) by the infiltration practice. This information will be needed in the adjusted curve number calculation, Compute the RR_V provided:

  RR_V (provided) = (RR%) (VP)
  $= (100\%)\,(6{,}752\ ft^3)$*
  $= \underline{6{,}752}\ ft^3$ *

Compute Stream Channel Protection Volume (CP_V):
For stream channel protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for channel protection and overbank flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 3.1.5 to determine pre- and post-development peak discharges for the 1-yr, 25-yr, and 100-yr 24-hour return frequency storms.

- Hydrologic output based on the given information provided

Condition	CN	$Q_{1\text{-year}}$		$Q_{25\text{-year}}$		$Q_{100\text{-year}}$	
		inches	*cfs*	*inches*	*cfs*	*inches*	*cfs*
Pre-Developed	57	0.45	0.7	2.93	6.4	4.34	9.7
Post-Developed	83	1.94	5.0	5.88	14.6	7.71	18.9
* Post-Developed (Adjusted CN for RR_V)	1-yr 74.2 25-yr 78 100-yr 78	1.32	3.3	5.26	13.4	7.09	17.7

- *Adjusted Curve Number Procedure for Peak Flow Reduction of CP_V (Section 3.1.7.5)

  Given Q = 1.94 in. and P = 3.6 in., Find "R" and "S" to back calculate an adjusted CN

$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{(Modified Equation 3.1.5)}$$

  Retention storage (expressed in inches) for this basin is calculated by the following formula:

  R = RR_V (provided) / Basin Area
  $= (6{,}752\ ft^3) / A$
  $= 6{,}752\ ft^3 / 130{,}680\ ft^2$ (12 in / 1 ft) = **0.62 inches**

$$1.32 = \frac{(3.6 - 0.2S)^2}{(3.6 + 0.8S)}$$

  Solve for "S" to back calculate CN: S = 3.48

  S = 1000/CN-10: therefore, CN = 74.2

- Utilize modified TR-55 approach to compute channel protection storage volume (based on adjusted CN value calculated above)

  Initial abstraction (Ia) for CN of 74.2 is 0.7: [Ia = (200/CN - 2)]

  Ia/P = (0.70)/ 3.6 inches = 0.19
  T_c = 0.15 hours
  q_u = 575 csm/in (From Figure 3.1.5-7)

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.035
(From Figure 3.3.5-1)

For a Type III rainfall distribution,

$Vs/Vr = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$
(Equation 3.3.9)

Where Vs equals channel protection storage (CP_v) and Vr equals the volume of runoff in inches.

Vs/Vr = 0.63 Using Equation 3.3.10, calculate V_s...

Therefore, Vs = CP_v = 0.63 (1.32 in) (3 ac) (43,560 ft^2 / ac) (1 ft / 12 in = 9,056 ft^3

Determine Overbank Flood Protection Volume (Q_{p25}) based on the adjusted CN:
For a Q_{in} of 13.4 cfs, and an allowable Q_{out} of 6.4 cfs, the Vs necessary for 25-year control is 22,175 ft^3, under an adjusted developed CN of 78. Note that 7.9 inches of rain fall during this event.

Analyze for Safe Passage of 100 Year Design Storm (Q_f):
At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure, typically the same one used for the overbank flood protection control.

Table 3 Summary of General Design Information for Georgia Pines Community Center

Symbol	Control Volume	Volume Required (cubic feet)	Notes
RR_V	Runoff Reduction	6,752	100% provided
WQ_V	Water Quality	8,102	Not required in this example
CP_V	Channel Protection	9,056	
Q_{p25}	Overbank Flood Protection	22,175	
Q_f	Extreme Flood Protection	N/A	Provide safe passage for the 100-year event in final design

STEP 4 - COMPUTE WQ_V PEAK DISCHARGE (Q_{WQ})

STEP 5 - SIZE FLOW DIVERSION STRUCTURE, IF NEEDED

Infiltration areas can be either on or off-line. On-line facilities are generally sized to receive, but not necessarily treat, the 25-year event. Off-line facilities are designed to receive a more or less exact flow rate through a weir, channel, manhole, "flow splitter", etc. This facility is situated to receive direct runoff from grass areas and parking lot curb openings and piping for the 25-year event (14.6 cfs – unadjusted flow rate), and *no special flow diversion structure is incorporated.*

STEP 6 - SIZE THE INFILTRATION TRENCH BASED ON V_{PMIN}

$$VP_{MIN} = PV + (V_G)(N)$$

Where: VP_{MIN} = Volume Provided (Calculated above, 6,752 ft^3)
PV = Ponding Volume (Ponding depth typically 9 inches)
V_G = Volume of Gravel (depth typically 2-10 feet)
N = Porosity of gravel, typically 0.4

Note: Assume a maximum depth value of 5 feet, and work through iterations as needed to fit the practice to the available space within the site. Recall that Table 1 indicates the practice cannot exceed 5 feet due to the proximity of the water table.

$$6{,}752\ ft^3 = (\text{Surface Area} \times 0.75\ ft) + (\text{Surface Area} \times 5\ ft \times 0.4)$$
$$6{,}752\ ft^3 = (\text{Surface Area} \times 2.75\ ft)$$
$$2{,}456\ ft^2 = \text{Surface Area}$$

STEP 7 - SET DIMENSIONS OF FACILITY

Since the width can be no greater than 25' (see Table 1; feasibility), determine the length:

L = 2,456 ft^2 / 25 ft

L = 98.25 feet

Say this facility is roughly 25' wide x 98.25' long x 5' deep

STEP 8 - SIZE PRETREATMENT VOLUME AND DESIGN PRETREATMENT MEASURES

As rule of thumb, size pretreatment to treat 10% of the WQ_v. Therefore, treat 8,102 × 0.10 = 810.2 ft^3.

For pretreatment, use a pea gravel filter layer with filter fabric, a plunge pool and a grass channel.

Pea Gravel Filter

The pea gravel filter layer covers the entire trench with 2" (see Figure 2). Assuming a porosity of 0.32, the water quality treatment in the pea gravel filter layer is:

WQ_{filter} = (0.32)(2")(1 ft/12 inches)(2,456 ft^2) = 131 ft^3

Plunge Pools

Use a 10'X10' plunge pool with average depths of 2'.

Total WQ_{pool} = (10' x 10')(2') = 200 ft^3

Grass Channel

Thus, the grass channel needs to treat at least (810.2 – 131 - 200) ft^3 = 479.2 ft^3

Use a Manning's equation nomograph or software to size the swale.

The channel should treat 479.2 ft^3

- Assume a trapezoidal channel with 10' channel bottom, 5H:1V side slopes, and a Manning's n value of 0.30. Use a nomograph to size the swale; assume a 0.5% slope.
- Use a peak discharge of 1.71 cfs (Peak flow for WQv, or 8102 ft3)
- Compute velocity: V=0.99 ft/s
- To retain the RRv (6,752 ft^3) for 5 minutes, the length would be 300 feet.
- Since the swale needs to treat the 10% of the water quality volume minus the treatment provided by the plunge pool and the gravel layer, or 479.2 ft^3, the length should be pro-rated to reflect this reduction.

Therefore, adjust length:

L= (300 ft)(479.2 ft^3/8,102 ft^3) =17.7 feet. Use 20 feet.

STEP 8 - DESIGN SPILLWAY(S)

Adequate stormwater outfalls should be provided for the overflow associated with the 25-year and larger design storm events, ensuring non-erosive velocities on the down slope.

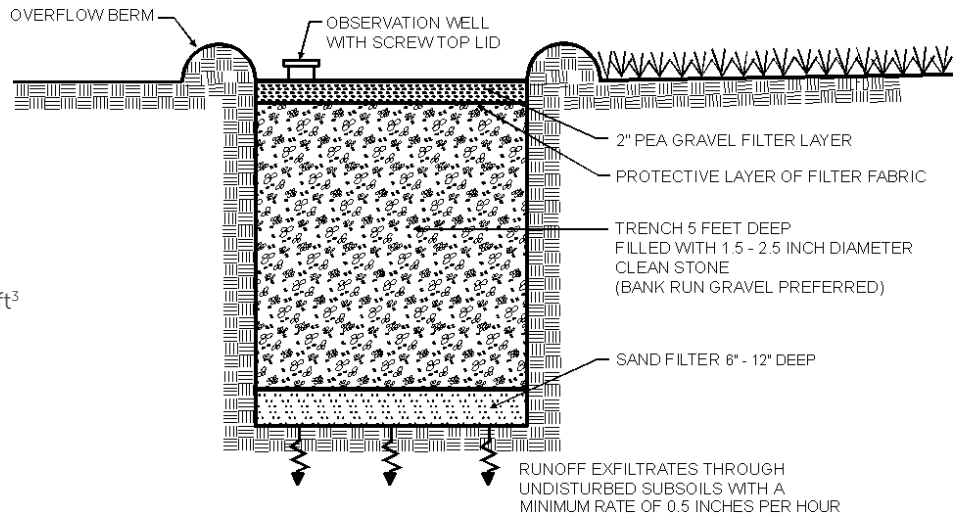
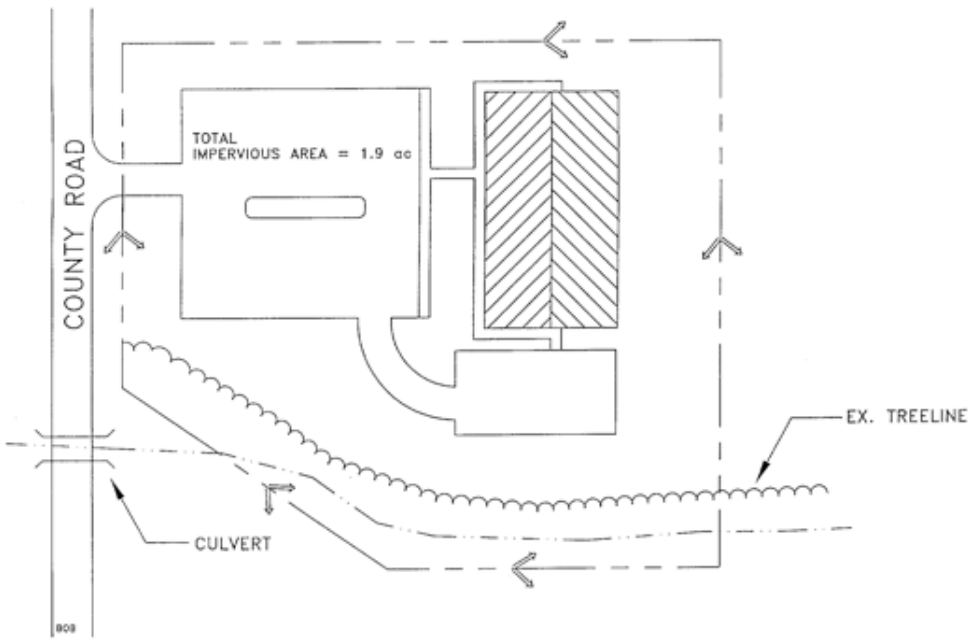


Figure 2. Infiltration Trench Cross Section

Appendix B-5: Enhanced Swale Design Example



Base Data	Hydrologic Data		
Site Area = Total Drainage Area (A) = 3.0 ac (130,680ft^2)		Pre	Post
Impervious Area = 1.9 ac; or I = 1.9/3.0 = 63.3%	CN	70	88
Soils Type "C"	t_c	.39	.20
1-yr, 24-hour Rainfall "P" = 3.4 inches			
25-yr, 24-hour Rainfall "P" = 6.5 inches			
100-yr, 24-hour Rainfall "P" = 7.9 inches			

Figure 1. Etowah Recreation Center Site Plan

This example focuses on the design of a dry enhanced swale to meet the water quality treatment requirements of the site. Channel protection and overbank flood control is not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of dry swales is to provide water quality treatment and groundwater recharge and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). Due to the Class C soils identified on-site, an underdrain will be provided in this practice that will provide a runoff reduction volume credit of 50%.

Computation of Preliminary Stormwater Storage Volumes and Peak Discharges

The layout of the Etowah Recreation Center is shown in Figure 1. This example assumes that the local community has adopted the unified stormwater sizing criteria requirements.

STEP 1 - CONFIRM LOCAL DESIGN REQUIREMENTS AND DETERMINE THE GOAL AND FUNCTION OF THE BMP

It was determined by the local municipality that this best management practices would be designed by the water quality volume calculation approach (described as Step 4 in Section 4.8)

The total designed volume of the practice must be provided to remove 80% TSS from the 1.2 inch storm event. Runoff reduction credit may still be utilized by the designer through an adjusted curve number calculations.

There is also a local requirement that the 25-year storm is contained within the top of banks of all channels, including these enhanced swale controls.

STEP 2 - DETERMINE IF THE DEVELOPMENT SITE AND CONDITIONS ARE APPROPRIATE FOR THE USE OF AN ENHANCED DRY SWALE SYSTEM

Existing ground elevation at the facility location is 922.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 913.0 feet and underlying soils are silt loams (ML). Adjacent creek invert is at 912.0 feet.

Two swales will be designed to carry flow to the existing stream, one around each side of the development.

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STEP 3 - COMPUTE RUNOFF CONTROL TARGET VOLUMES FROM THE UNIFIED STORMWATER SIZING CRITERIA (EITHER METHOD 3 OR 4 AS DESCRIBED IN THE DESIGN STEPS)

Method 4) Compute Water Quality Volume (WQ_V):

- Compute Runoff Coefficient, R_v

  $R_V = 0.05 + (63.3)\ (0.009) = 0.62$

- Compute Water Quality Volume (WQ_V):

  $WQ_V = (1.2")\ (R_V)\ (A) / 12$
  $= (1.2")\ (0.62)\ (130{,}680\ ft^2)\ (1ft/12in)$
  $= \underline{8{,}102}\ ft^3$

Note: The Volume Provided (VP) of this practice must be a minimum of 8,102 ft^3.

- Even though the water quality volume calculation approach was used in this design, some amount of Runoff Reduction (RR_V provided) is provided by the enhanced dry swale with an underdrain. This information will be needed in the adjusted curve number calculation, Compute the RR_V provided:

  RR_V (provided) = (RR%) (VP)
  $= (50\%)\ (8{,}102\ ft^3)$ *
  $= \underline{4{,}051}\ ft^3$ *

Compute Stream Channel Protection Volume (CP_v):
For stream channel protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for channel protection and overbank flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 3.1.5 to determine pre- and post-development peak discharges for the 1-yr, 25-yr, and 100-yr 24-hour return frequency storms.

- Hydrologic output based on the given information provided

Condition	CN	$Q_{1\text{-year}}$		$Q_{25\text{-year}}$		$Q_{100\text{-year}}$	
		inches	*cfs*	*inches*	*cfs*	*inches*	*cfs*
Pre-Developed	70	0.95	2.6	3.21	9.8	4.38	13.5
Post-Developed	88	2.18	8.2	5.12	18.5	6.48	23.2
* Post-Developed (Adjusted CN for RR_v)	1-yr 83.5 25-yr 84.7 100-yr 84.9	1.81	6.9	4.75	17.5	6.11	22.2

- *Adjusted Curve Number Procedure for Peak Flow Reduction of CP_v (Section 3.1.7.5)

  Given Q = 2.18 in. and P = 3.4 in., Find "R" and "S" to back calculate an adjusted CN

$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$ (Modified Equation 3.1.5)

  Retention storage (expressed in inches) for this basin is calculated by the following formula:

  R = RR_v (provided) / Basin Area
  = [(RR%)(VP)] / A
  = 4,051 ft^3/130,680 ft^2 (12 in / 1 ft) = **0.37 inches**

$$1.81 = \frac{(3.4 - 0.2S)^2}{(3.4 + 0.8S)}$$

  Solve for "S" to back calculate CN: S = 1.98
  S = 1000/CN-10: therefore, CN = 83.5

- Utilize modified TR-55 approach to compute channel protection storage volume (based on adjusted CN value calculated above)

  Initial abstraction (Ia) for CN of 83.5 is 0.4: [Ia = (200/CN - 2)]

  Ia/P = (0.40)/ 3.4 inches = 0.12
  T_c = 0.20 hours
  q_u = 800 csm/in (From Figure 3.1.5-6)

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

  Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.023
  (From Figure 3.3.5-1)

  For a Type II rainfall distribution,

  Vs/Vr = 0.683 - 1.43(qo/qi) +1.64(q_o/q_i) ^{2} - 0.804(qo/qi) ^{3}
  (Equation 3.3.9)
  Where Vs equals channel protection storage (CP_v) and Vr equals the volume of runoff in inches.

  Vs/Vr = 0.65 Using Equation 3.3.10, calculate V_s...

  Therefore, Vs = CP_v = 0.65 (1.81 in) (3 ac) (43,560 ft^2 / ac) (1 ft / 12 in)
  = 12,812 ft^3

Determine Overbank Flood Protection Volume (Qp_{25}) based on the adjusted CN:
For a Q_{in} of 17.5 cfs, and an allowable Q_{out} of 9.8 cfs, the Vs necessary for 25-year control is 13,498 ft^3, under an adjusted post-developed CN of 84.7. Note that 6.5 inches of rainfall occurs during this event.

Analyze for Safe Passage of 100 Year Design Storm (Q_f):
At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure, typically the same one used for the overbank flood protection control.

Table 1 Summary of General Design Information for Etowah Recreation Center

Symbol	Control Volume	Volume Required (cubic feet)	Notes
RR_V	Runoff Reduction	6,752	4,051 cf provided (60%)
WQ_V	Water Quality	8,102	Swale sized for this volume
CP_V	Channel Protection	12,812	
Q_{p25}	Overbank Flood Protection	13,498	
Q_f	Extreme Flood Protection	N/A	Provide safe passage for the 100-year event in final design

STEP 4 - DETERMINE PRETREATMENT VOLUME AND STORAGE VOLUME
Size two shallow forebays at the head of the swales equal to 0.05" per impervious acre of drainage (each) (Note, total recommended pretreatment requirement is 0.1"/imp acre). (1.9 ac) (0.05") (1ft/12") (43,560 sq ft/ac) = 344.9 ft^3 for each forebay.

Use a 2' deep pea gravel drain at the head of the swale to provide erosion protection and to assist in the distribution of the inflow. There will be no side inflow nor need for pea gravel diaphragm along the sides.

Required: bottom width, depth, length, and slope necessary to store required volume with less than 18" of ponding (see Figure 2 for representative site plan).

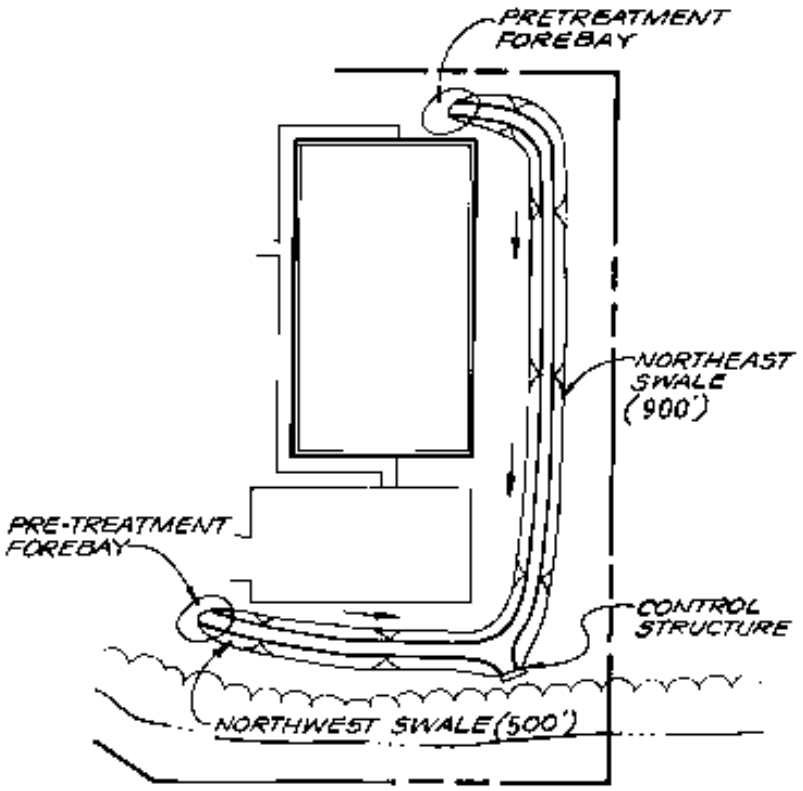


Figure 2. Enhanced Dry Swale Site Plan

Assume a trapezoidal channel with an average WQ_v depth of 9" and a maximum WQ_v depth of 18". Control for this swale will be a shallow concrete wall with a low flow orifice, trash rack located per Figures 2 and 3. Per the site plan, we have about 1,400' of swale available, if the swale is put in with two tails. The outlet control will be set at the existing invert minus three feet (922.0 - 3.0 = 919.0). The existing uphill invert for the northwest fork is 924.0 (length of 500'), the invert for the northeast fork is 928.0 (at a length of 900').

Slope of northwest fork is (924 - 919)/500' = 0.01 or 1.0%
Slope of northeast fork is (928 - 919)/900' = 0.01 or 1.0%

Minimum slope is 1.0 % [okay]

For an enhanced swale, use the following equation to calculate volume provided (VP):

VP = (PV + VES (N))

Where:

- **VP** = Volume provided (temporary storage)
- **PV** = Ponding Volume
- **VES** = Volume of Engineered Soils
- **N** = Porosity (typically 0.25 for soil media)

To calculate the ponding volume (PV), use the trapezoidal section with a bottom width of 6', an average depth of 9", 3:1 side slopes, compute a cross-sectional area of (6') (0.75') + (0.75') (2.25') = 6.2 ft^2 (see Figure 4). Using this cross-sectional area, multiply by the provided length to find the total ponding volume: (6.2 ft^2) x (1,400 ft) = **8,680 ft^3**

To calculate the volume of engineered soil media (VES), use the base width and depth of media and compute a cross-sectional area of (6') (2.5') = 15 ft^2 (See Figure 4). Using this cross-sectional area, multiply by the provided length to find the total volume of engineered soils: (15 ft2)(1,400 ft) = **21,000 ft^3**

Using a engineered soil porosity of 0.25, the maximum volume able to be provided of the practice can be calculated as follows:

VP_{MAX} = 8,680 ft^3 + (21,000 ft^3 x 0.25) = **13,930 ft^3**

13,930 cubic feet > Minimum required volume of 8,102 ft^3; **OK**

To reduce the footprint of the enhanced swale area, or media portion of the swale, the new minimum required length could be back-calculated by using the minimum required volume above:

(Min. required volume) / (sum of the cross-sectional areas) = Min. length of BMP

8,102 ft^3 / (6.2 ft^2 + (15 ft^2 x 0.25)) = 815 Linear Feet (Revision to Figure 2)

New lengths of the swales would be the following:
Northwest fork: 290 feet
Northeast fork: 525 feet

VP = 8,102 ft^3 **RR_V(Provided) = (RR%)(VP) = (50%)(8,102 ft^3) = 4,051 ft^3**

STEP 5 - COMPUTE NUMBER OF CHECK DAMS (OR SIMILAR STRUCTURE) REQUIRED TO DETAIN WQ_v (SEE FIGURE 4)

For the northwest fork, 290 ft @ 1.0% slope, and maximum depth at 18", place checkdams at: 1.5'/0.01 = 150' place at 150', 1 required

For the northeast fork, 525 ft @ 1.0% slope, and maximum 18" depth, place checkdams at 1.5'/0.01 = 150' place at 150', 3 required

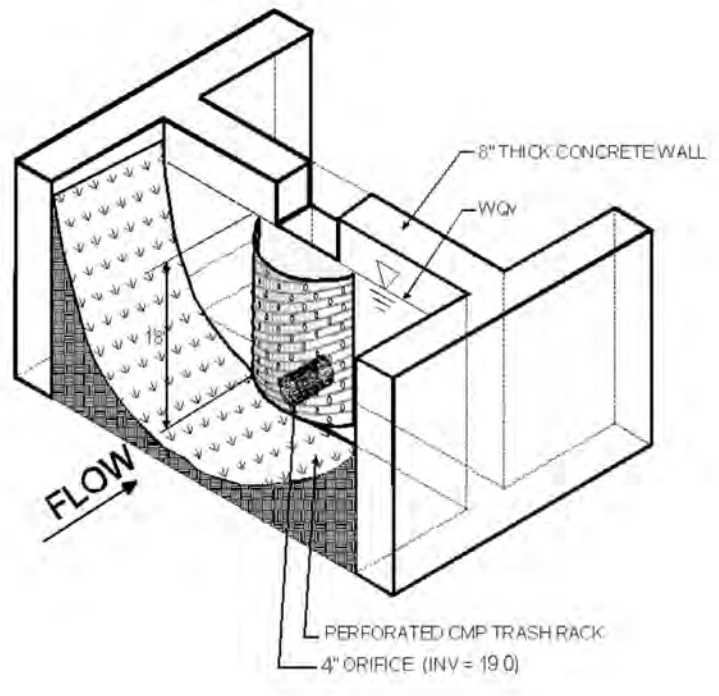


Figure 3 Control Structure at End of Swale

STEP 6 - CALCULATE DRAW-DOWN TIME

In order to ensure that the swale will draw down within 24 hours, the planting soil will need to pass a maximum rate of 1.5' in 24 hours (k = 1.5' per day). Provide 6" perforated underdrain pipe and gravel system below soil bed (see Figure 4)

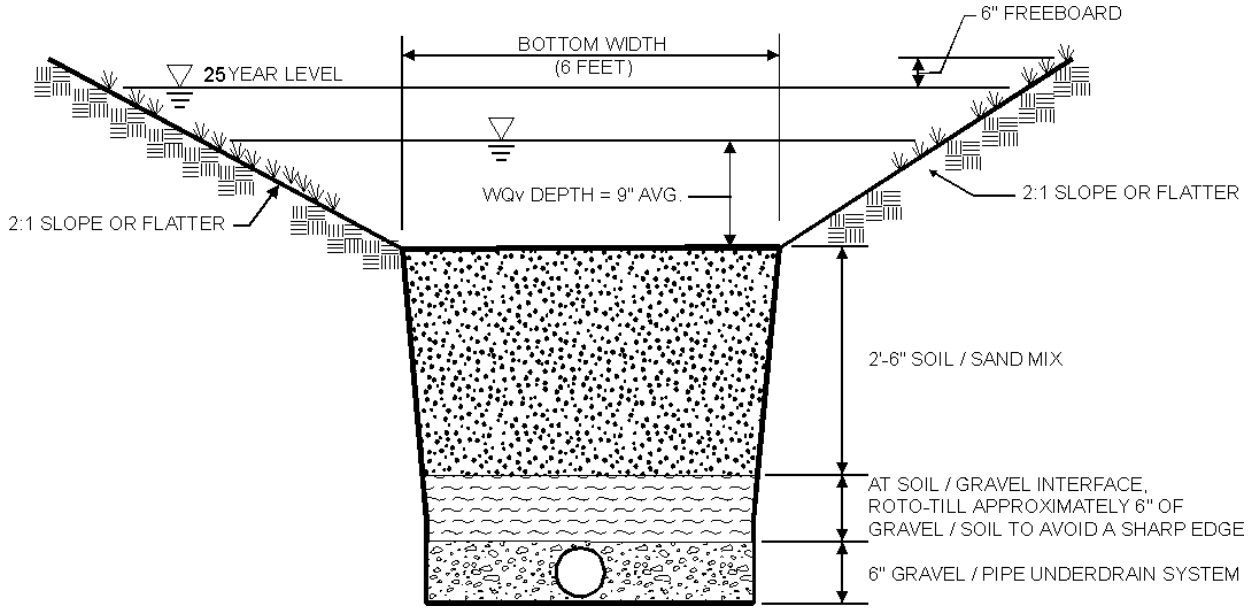


Figure 4 Trapezoidal Dry Swale Section

STEP 7 - CHECK 2-YEAR AND 25-YEAR FLOWS FOR VELOCITY EROSION POTENTIAL AND FREEBOARD

Given the local requirements to contain the 25-year flow within banks with freeboard. In this example only the 25-year flow will be checked assuming that lower flows will be handled. The 25-year flow is 17.1 cfs, assume that 30% goes through northwestern swale (5.1 cfs) and 70% goes through the northeastern swale (12.0 cfs). Design for the larger amount (12.0 cfs). From a separate computer analysis using an open channel flow calculator, with a slope of 1.0%, the 25-year velocity will be 2.8 feet-per-second at a depth of 0.60 feet, provide an additional 0.5' of freeboard above top of checkdams or about 1.1' (total channel depth = 2.6').

Find 25-year overflow weir length required: (weir eq. $Q = CLH^{3/2}$), where C = 3.1, Q_{25} = 17.1 cfs, H =1.1;
Rearranging the equation yields:

$L = 17.1 \text{ cfs} / (3.1 * 1.1^{1.5}) = 4.8'$ Use 5 ft

STEP 8 - DESIGN LOW FLOW ORIFICE AT DOWNSTREAM HEADWALL AND CHECKDAMS (SEE FIGURE 3)

Design orifice to pass 8,102 cubic feet in 6 hours.

8,102 cubic feet/ [(6 hours) (3600 sec/hour)] = 0.38 cfs
Use Orifice equation: $Q = CA(2gh)^{1/2}$

Assume h = 1.5'

$A = (0.38 \text{ cfs}) / [(0.6) ((2) (32.2 \text{ ft/s}^2) (1.5'))^{1/2}]$
A = 0.06 sq ft, dia = 0.29 feet or 3.4" use 3" - 3.5" orifice

Provide 3" v-notch slot in each check dam

STEP 9 - PREPARE VEGETATION AND LANDSCAPING PLAN

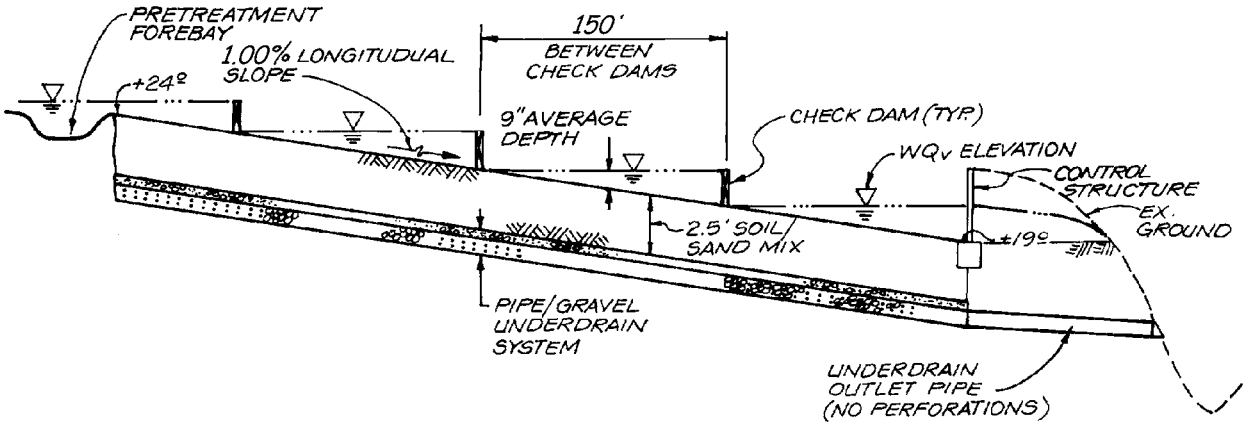


Figure 5 Profile of Northwest Fork Dry Swale

Appendix C: Nomographs & Design Aids

C-1 Culvert Design Charts and Nomographs

All of the figures in this section are from the AASHTO *Model Drainage* 1991.

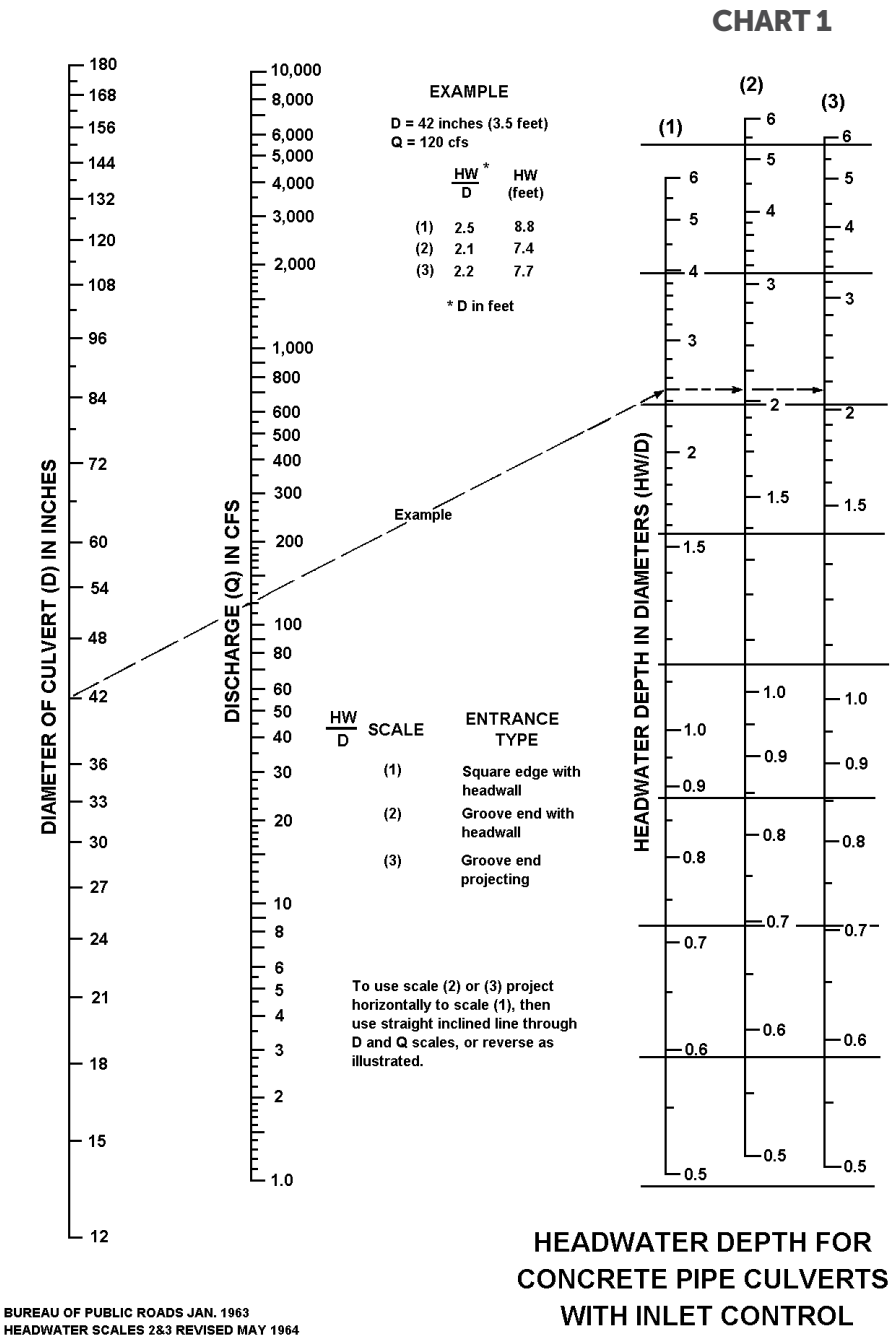
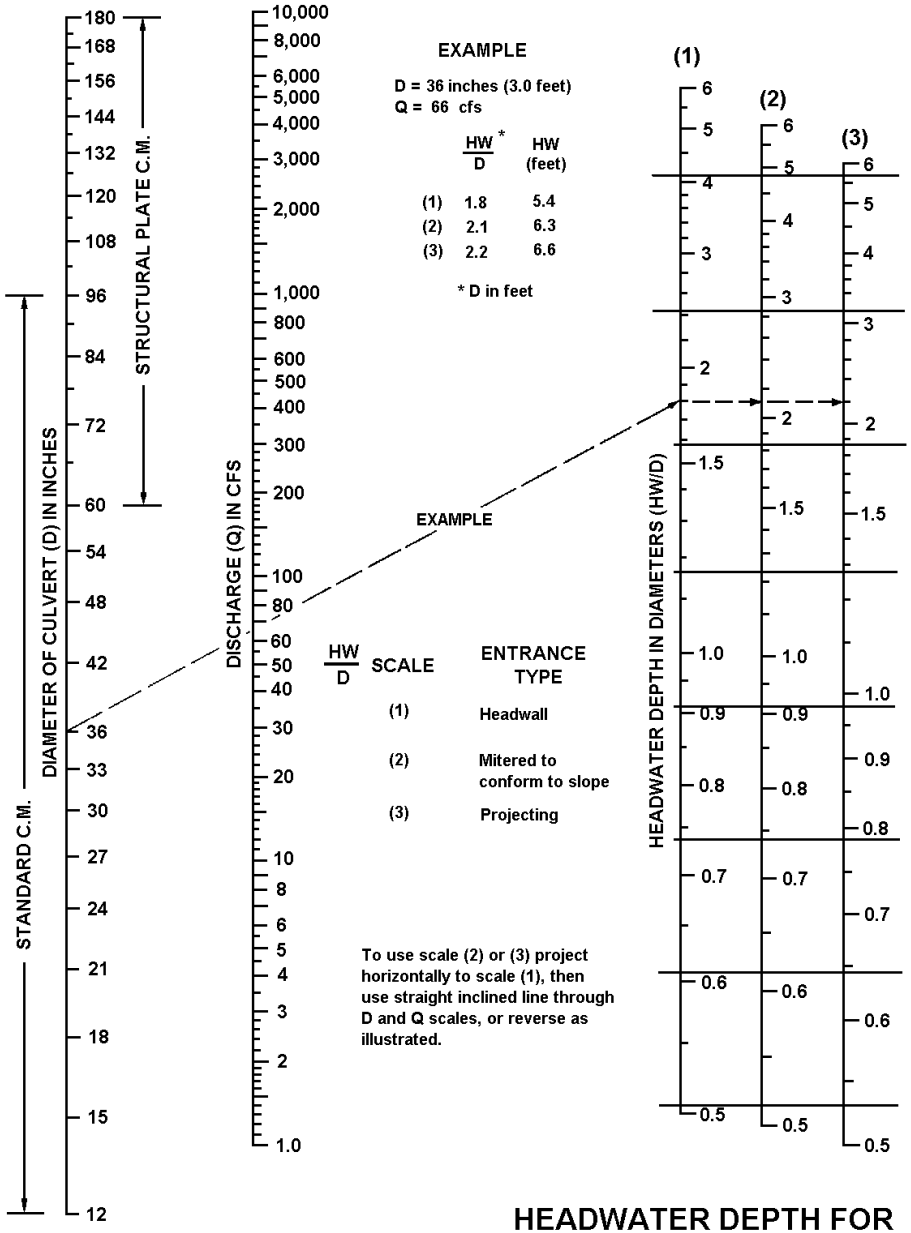


CHART 2

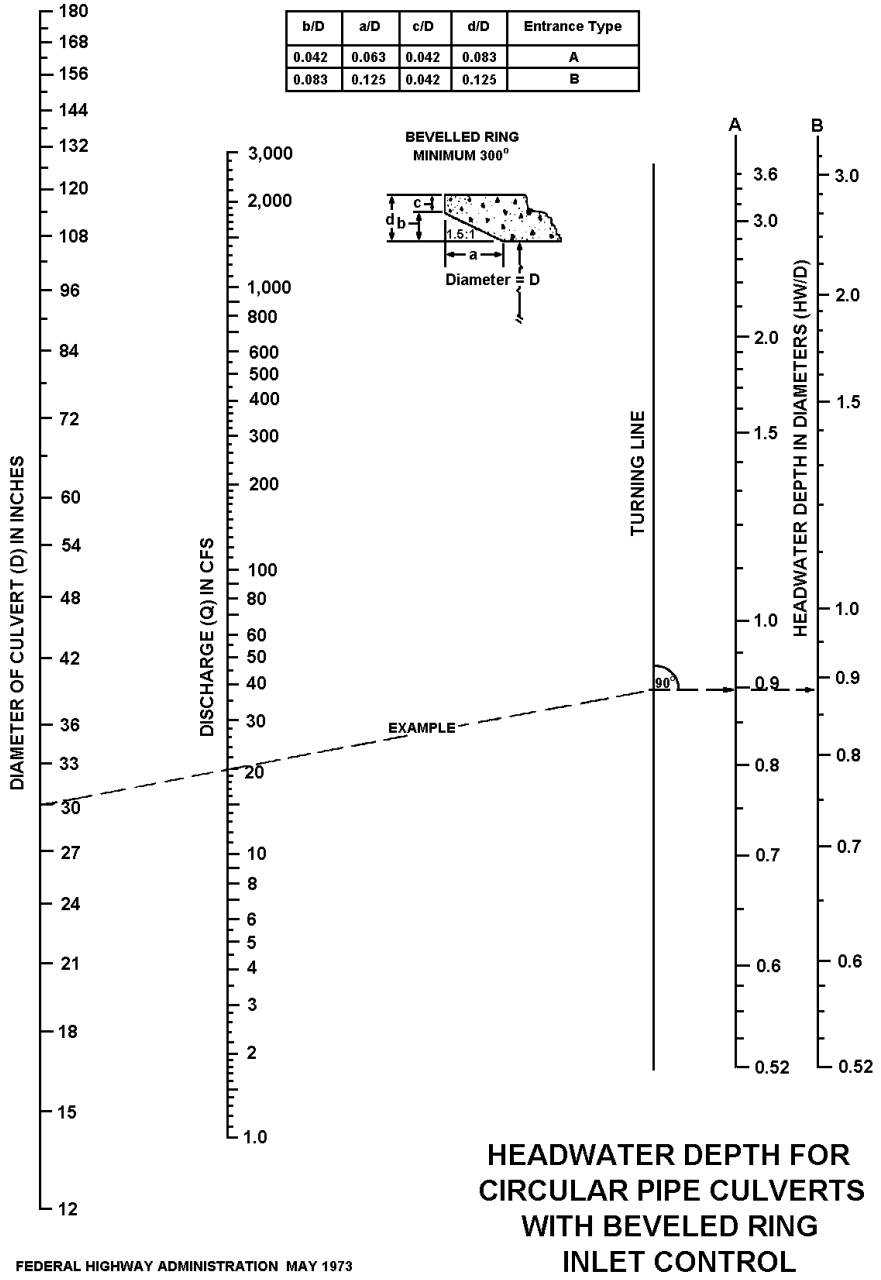


HEADWATER DEPTH FOR C.M. PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 3

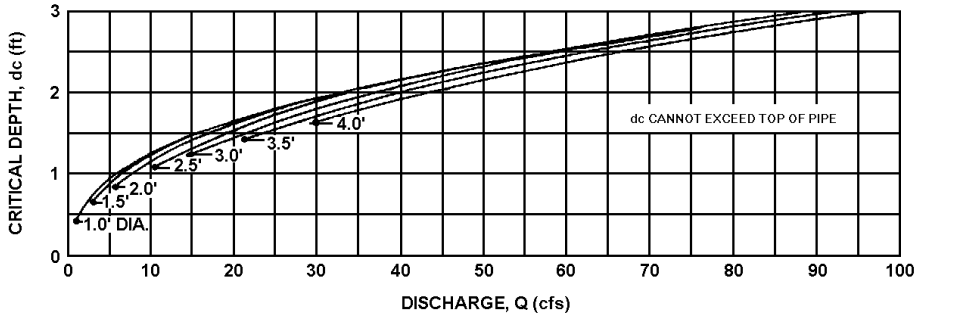
b/D	a/D	c/D	d/D	Entrance Type
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

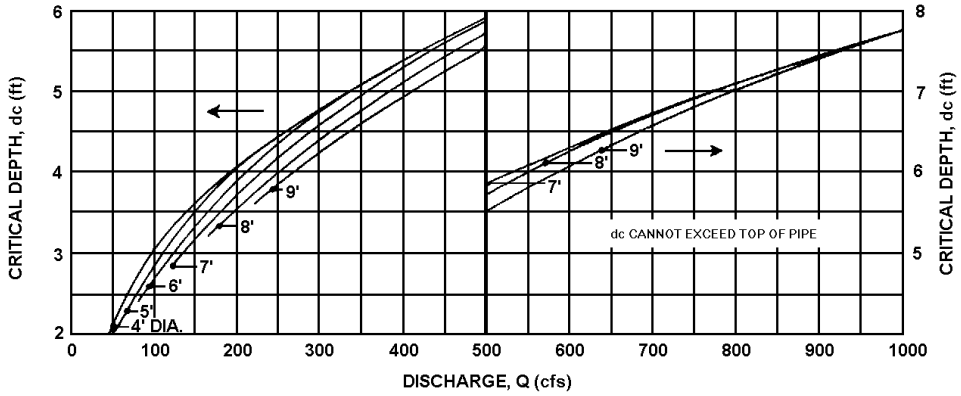


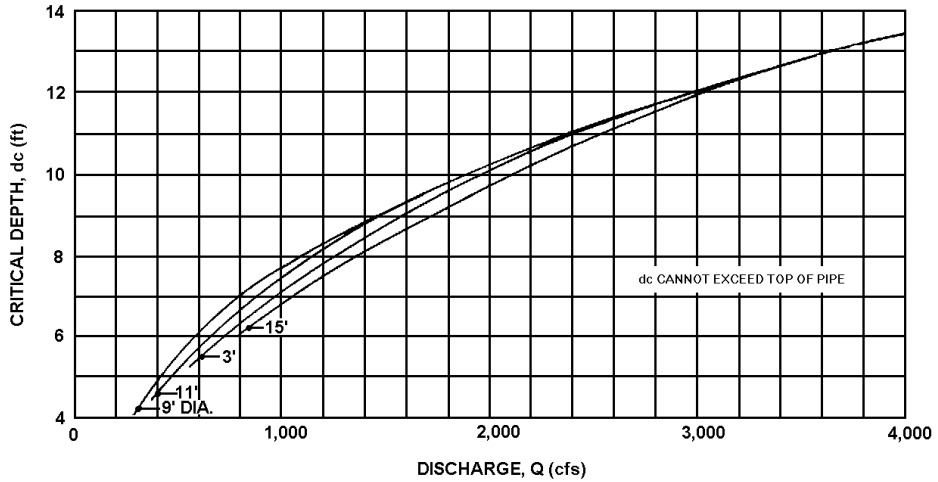
FEDERAL HIGHWAY ADMINISTRATION MAY 1973

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

CHART 4



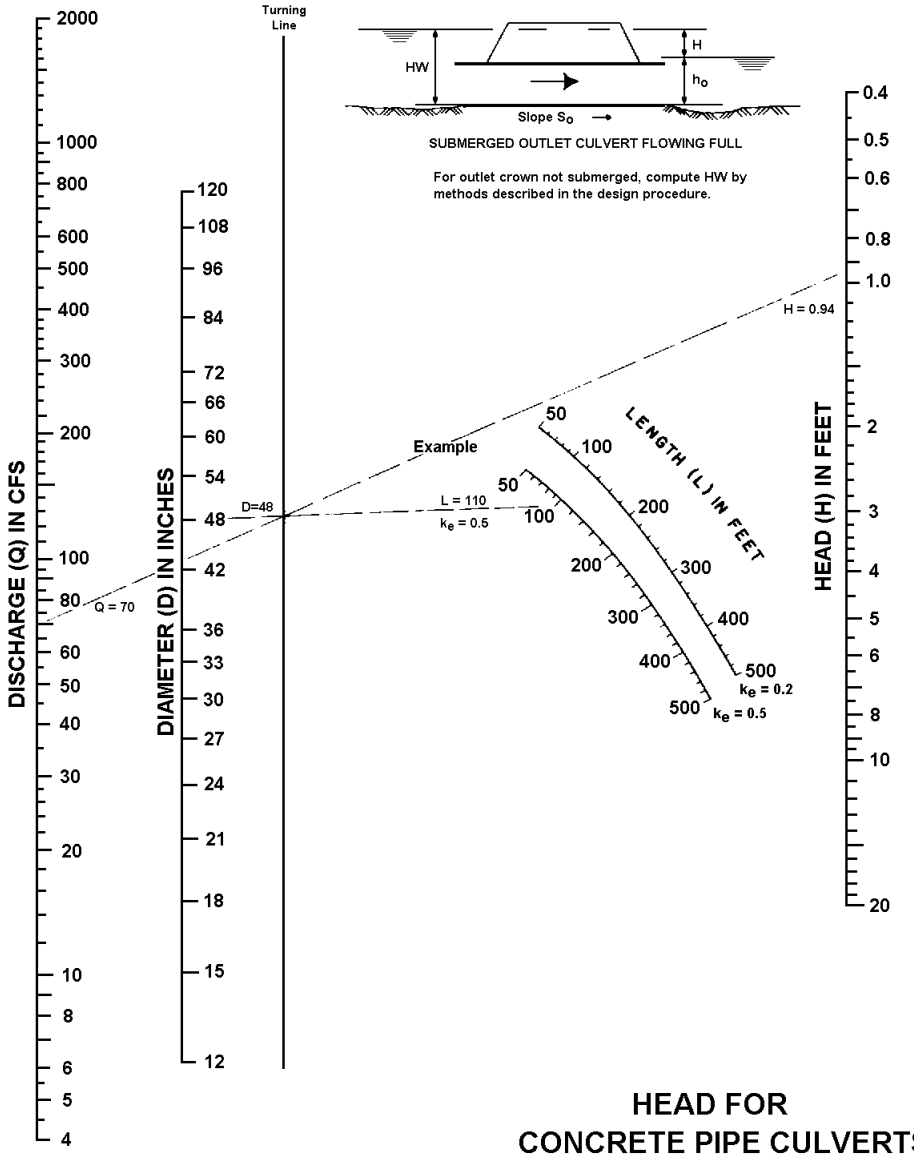




BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

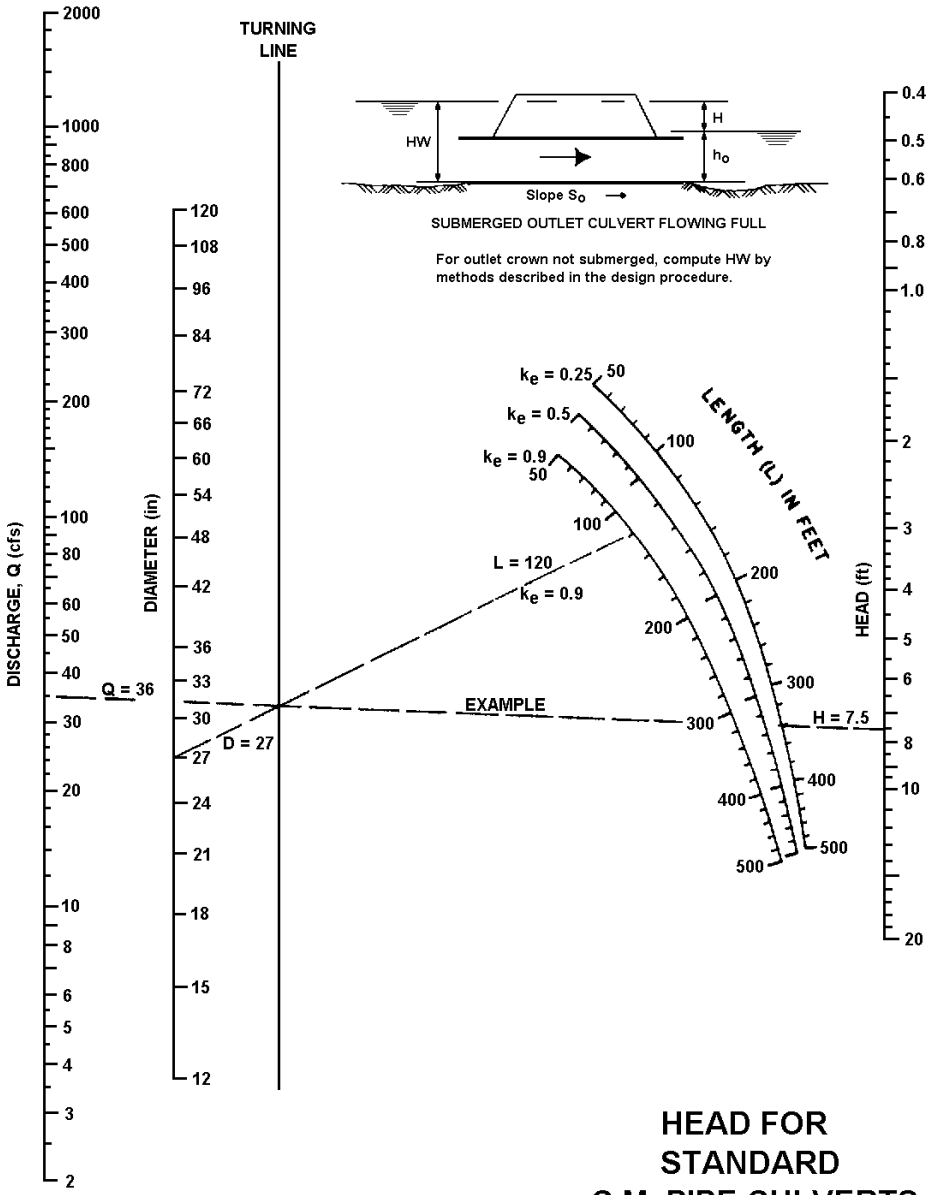
CHART 5



HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

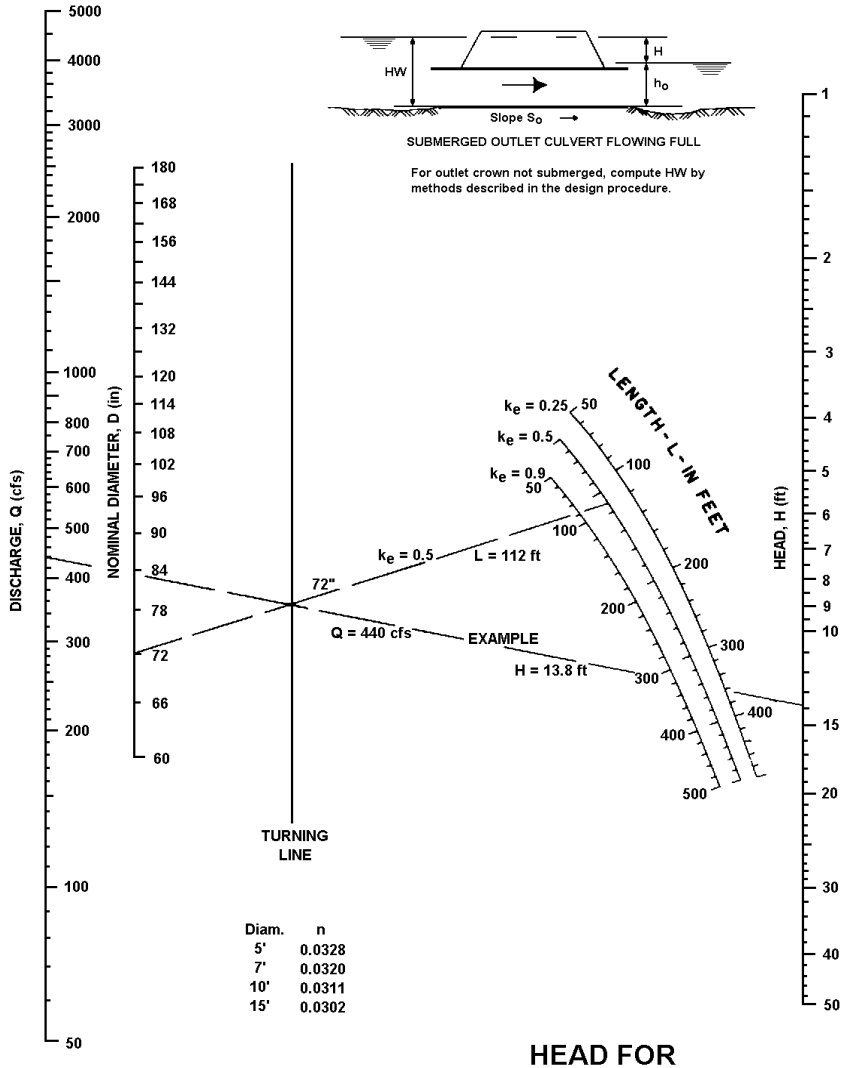
CHART 6



HEAD FOR STANDARD C.M. PIPE CULVERTS FLOWING FULL n = 0.024

BUREAU OF PUBLIC ROADS JAN. 1963

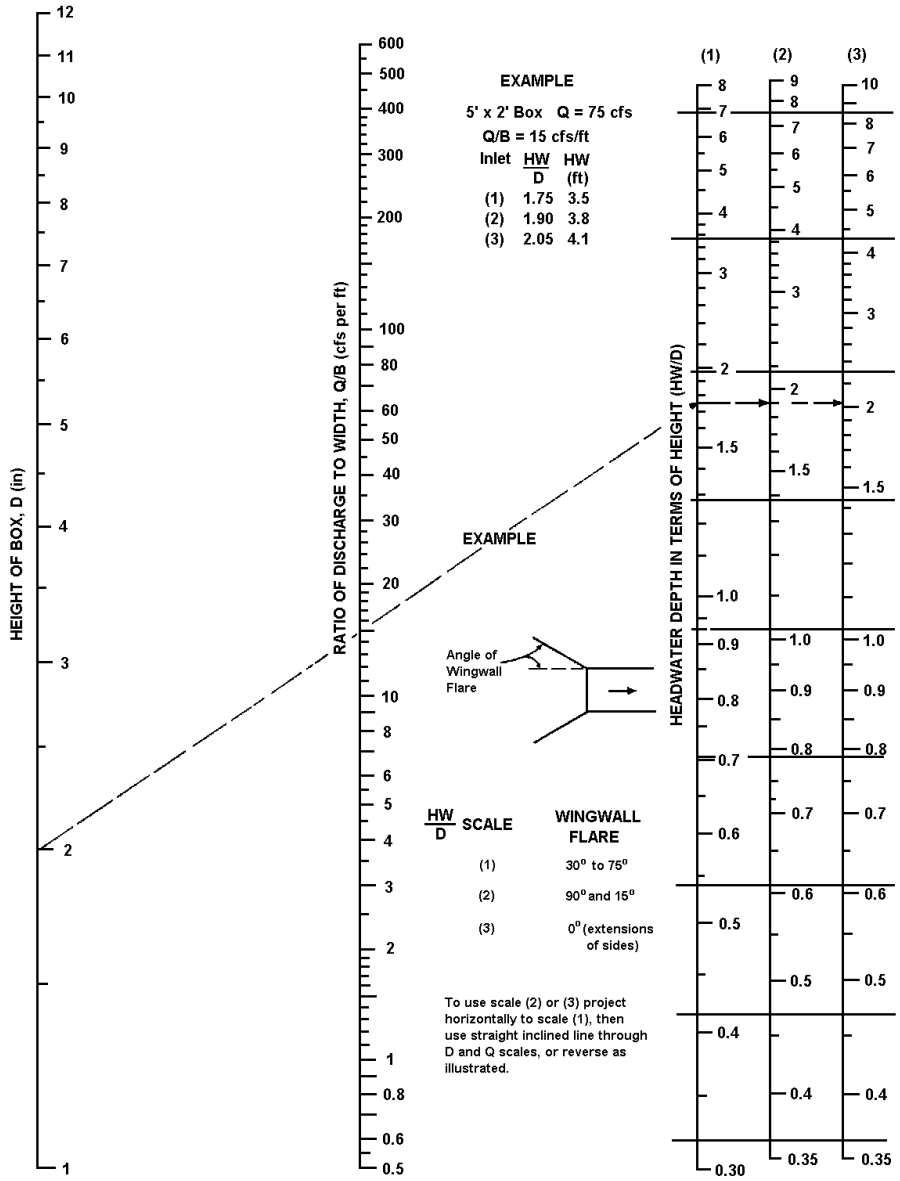
CHART 7



BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR STRUCTURAL PLATE CORR. METAL PIPE CULVERTS FLOWING FULL
n = 0.0328 TO 0.0302

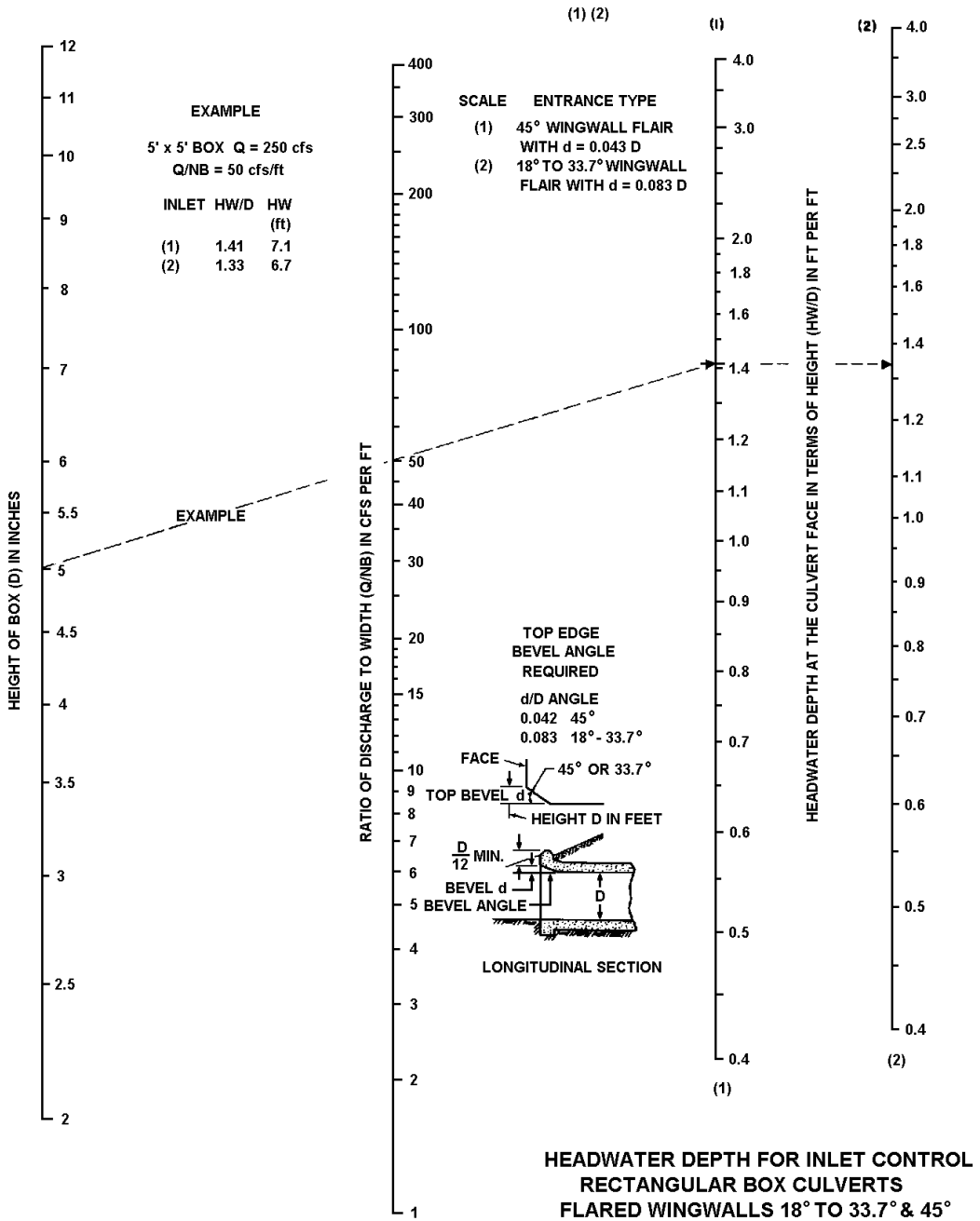
CHART 8



BUREAU OF PUBLIC ROADS JAN. 1963

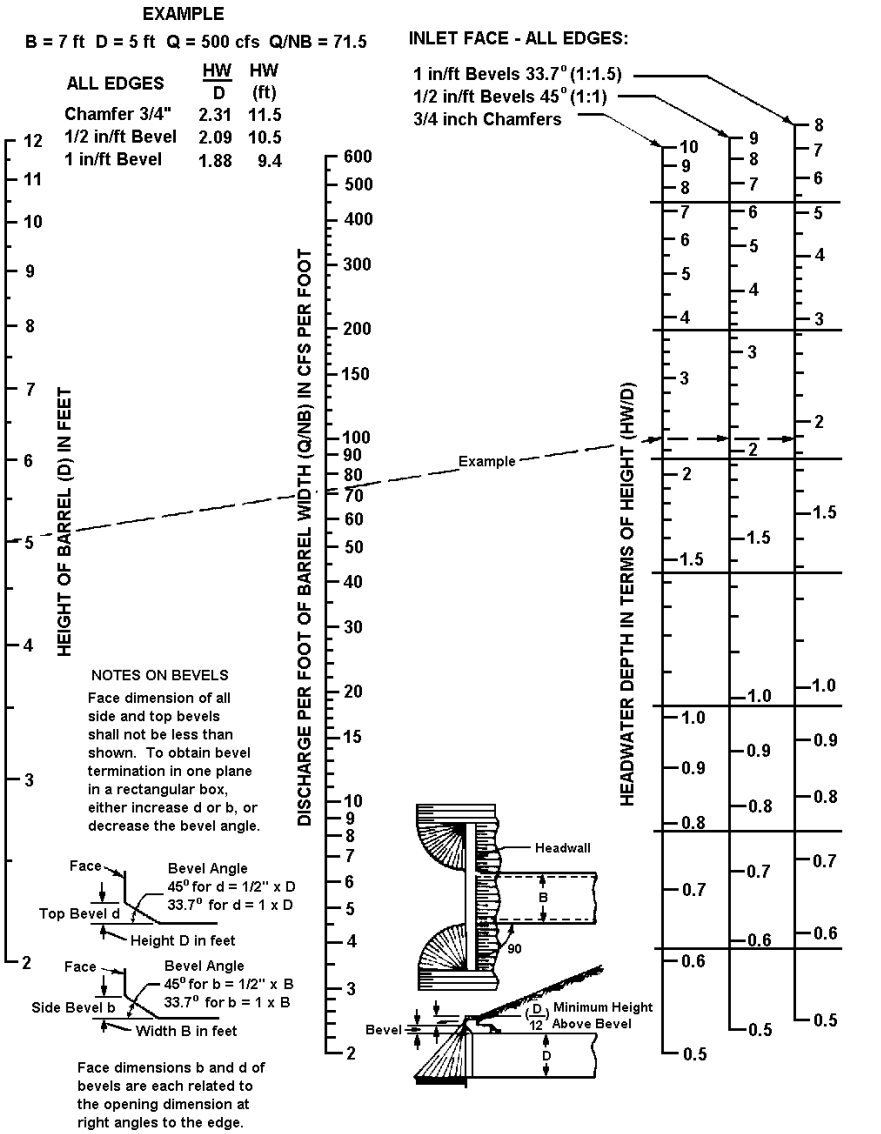
HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

CHART 9



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET

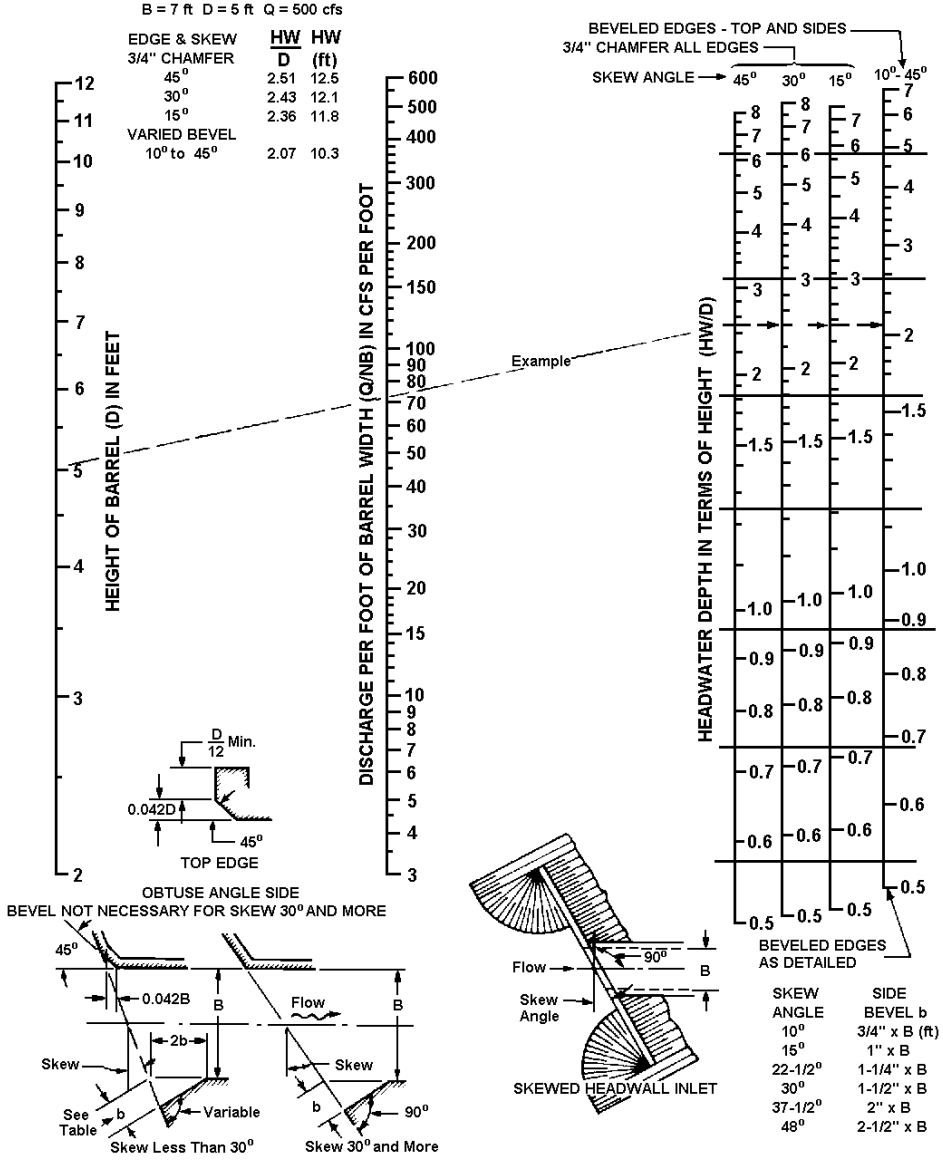
CHART 10



FEDERAL HIGHWAY ADMINISTRATION MAY 1973

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

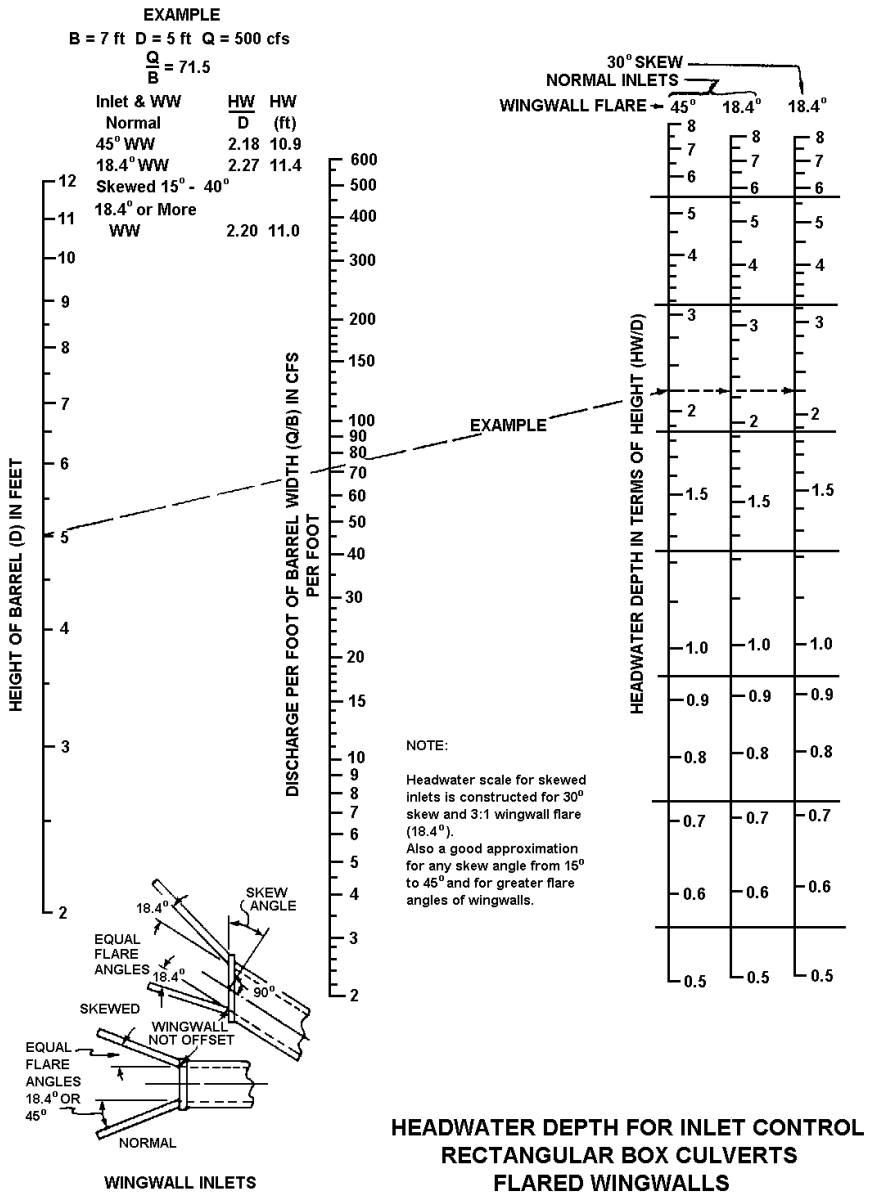
CHART 11



HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKEWED HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION MAY 1973

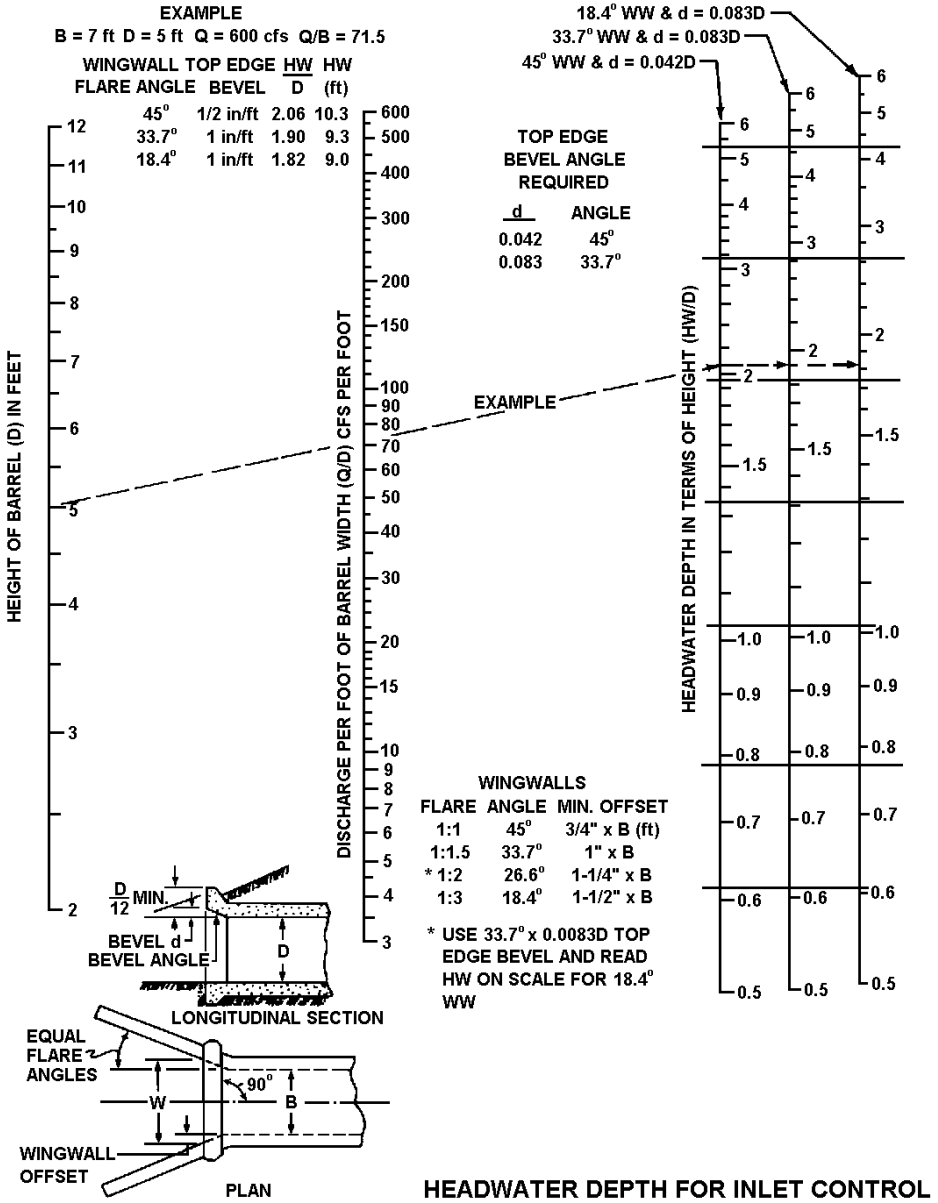
CHART 12



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS
NORMAL AND SKEWED INLETS
3/4" CHAMFER AT TOP OF OPENING

BUREAU OF PUBLIC ROADS
OFFICE OF R&D AUGUST 1968

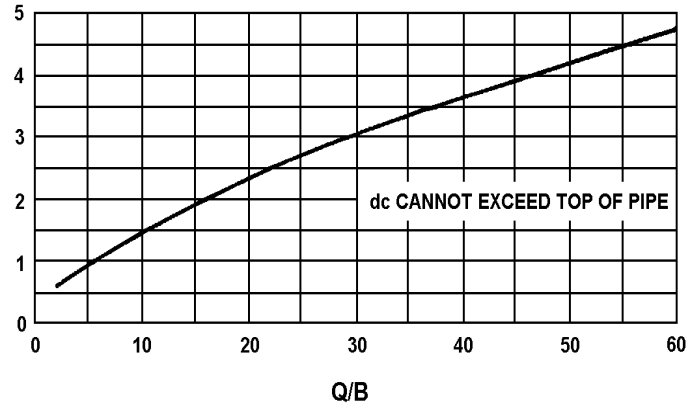
CHART 13

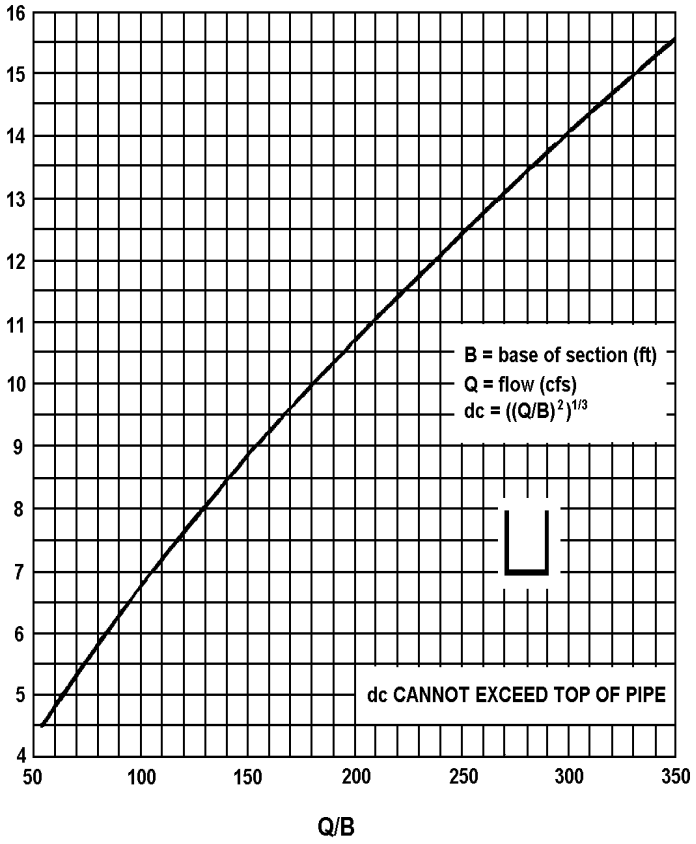


HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
OFFSET FLARED WINGWALLS
AND BEVELED EDGE AT TOP OF INLET

BUREAU OF PUBLIC ROADS
OFFICE OF R&D AUGUST 1968

CHART 14

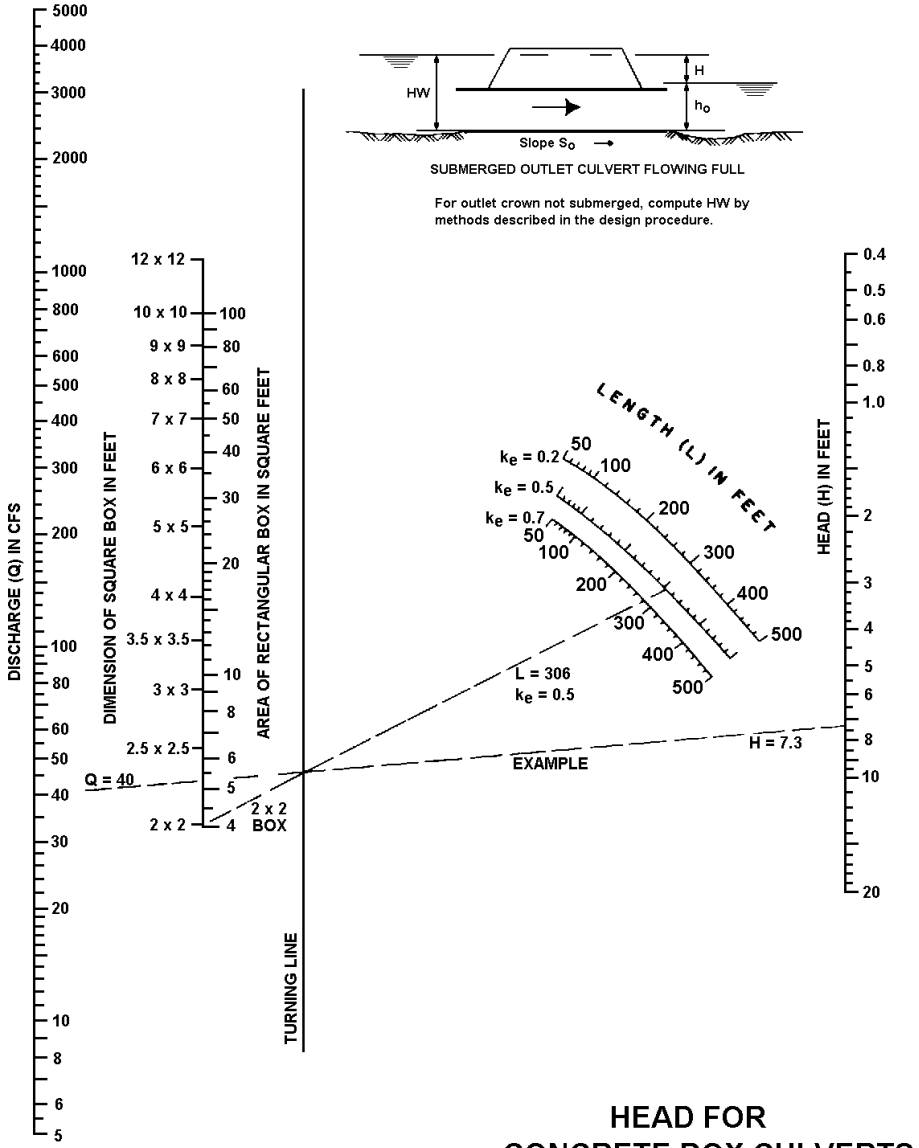




BUREAU OF PUBLIC ROADS JAN. 1963

CRITICAL DEPTH
RECTANGULAR SECTION

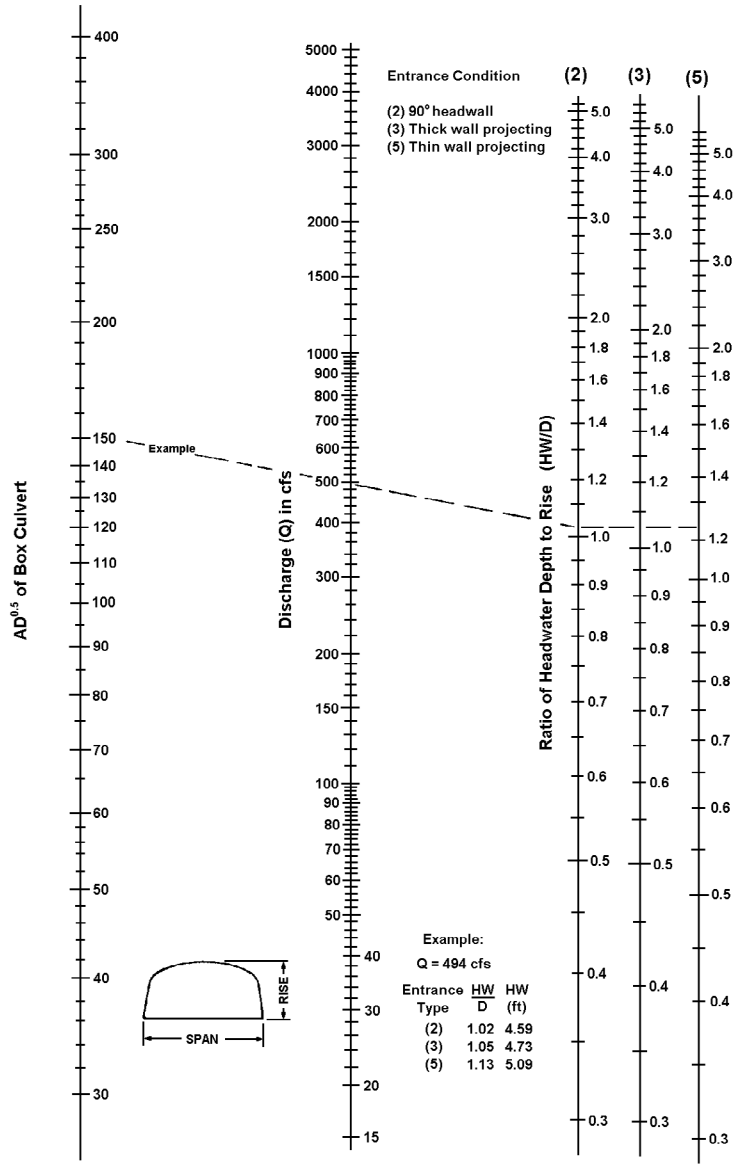
CHART 15



HEAD FOR CONCRETE BOX CULVERTS FLOWING FULL n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

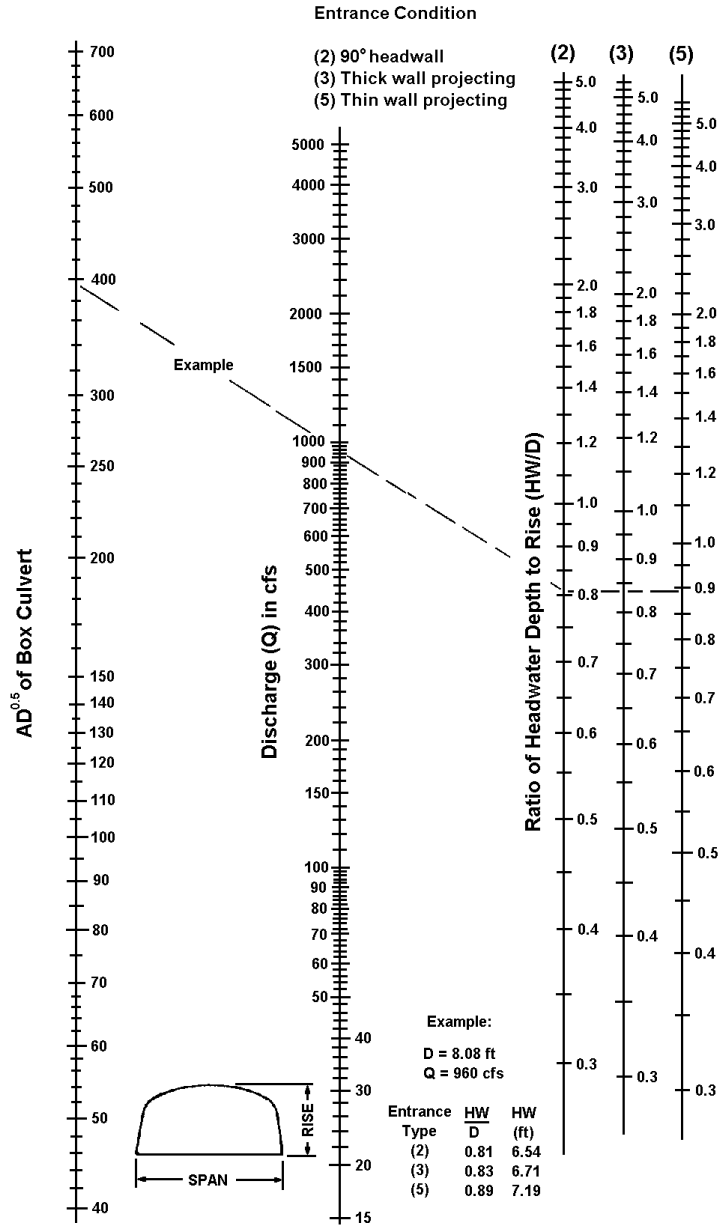
CHART 16



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.

HEADWATER DEPTH FOR C.M. BOX CULVERTS RISE/SPAN < 0.3 WITH INLET CONTROL

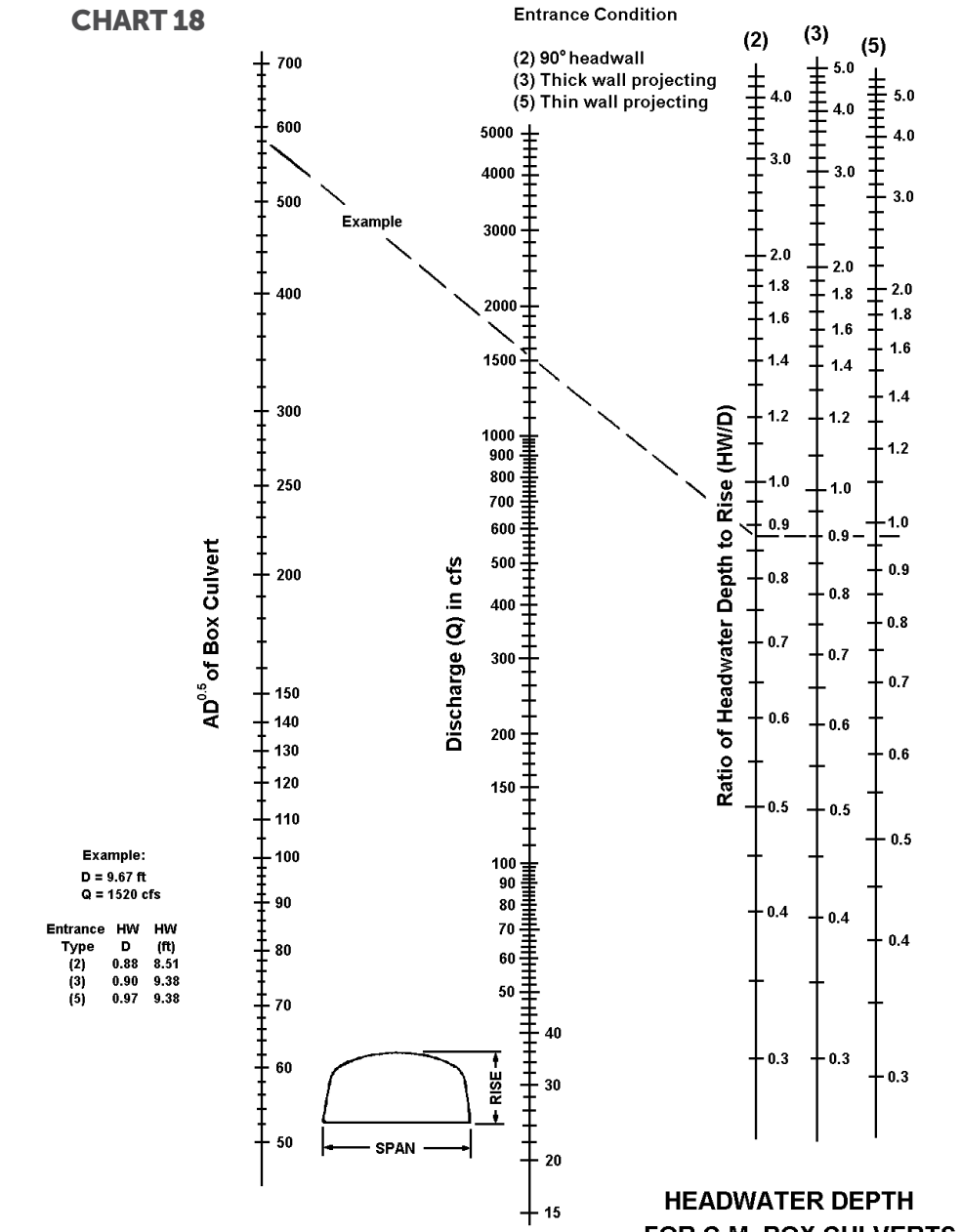
CHART 17



HEADWATER DEPTH FOR C.M. BOX CULVERTS 0.3≤ RISE/SPAN < 0.4 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 18



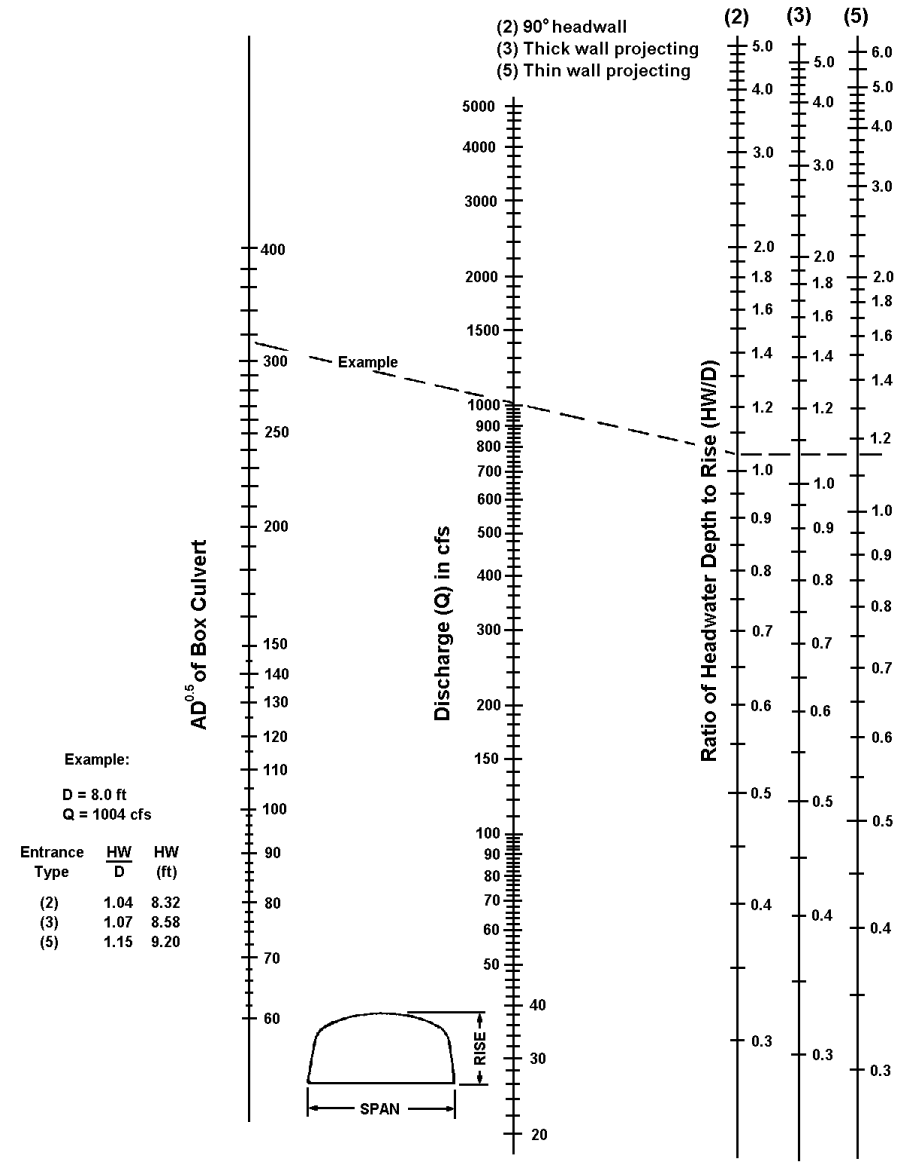
Example:
D = 9.67 ft
Q = 1520 cfs

Entrance Type	HW D	HW (ft)
(2)	0.88	8.51
(3)	0.90	9.38
(5)	0.97	9.38

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

HEADWATER DEPTH FOR C.M. BOX CULVERTS 0.4 ≤ RISE/SPAN < 0.5 WITH INLET CONTROL

CHART 19



Example:

D = 8.0 ft
Q = 1004 cfs

Entrance Type	HW/D	HW (ft)
(2)	1.04	8.32
(3)	1.07	8.58
(5)	1.15	9.20

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.

HEADWATER DEPTH FOR C.M. BOX CULVERTS 0.5 ≤ RISE/SPAN WITH INLET CONTROL

CHART 20

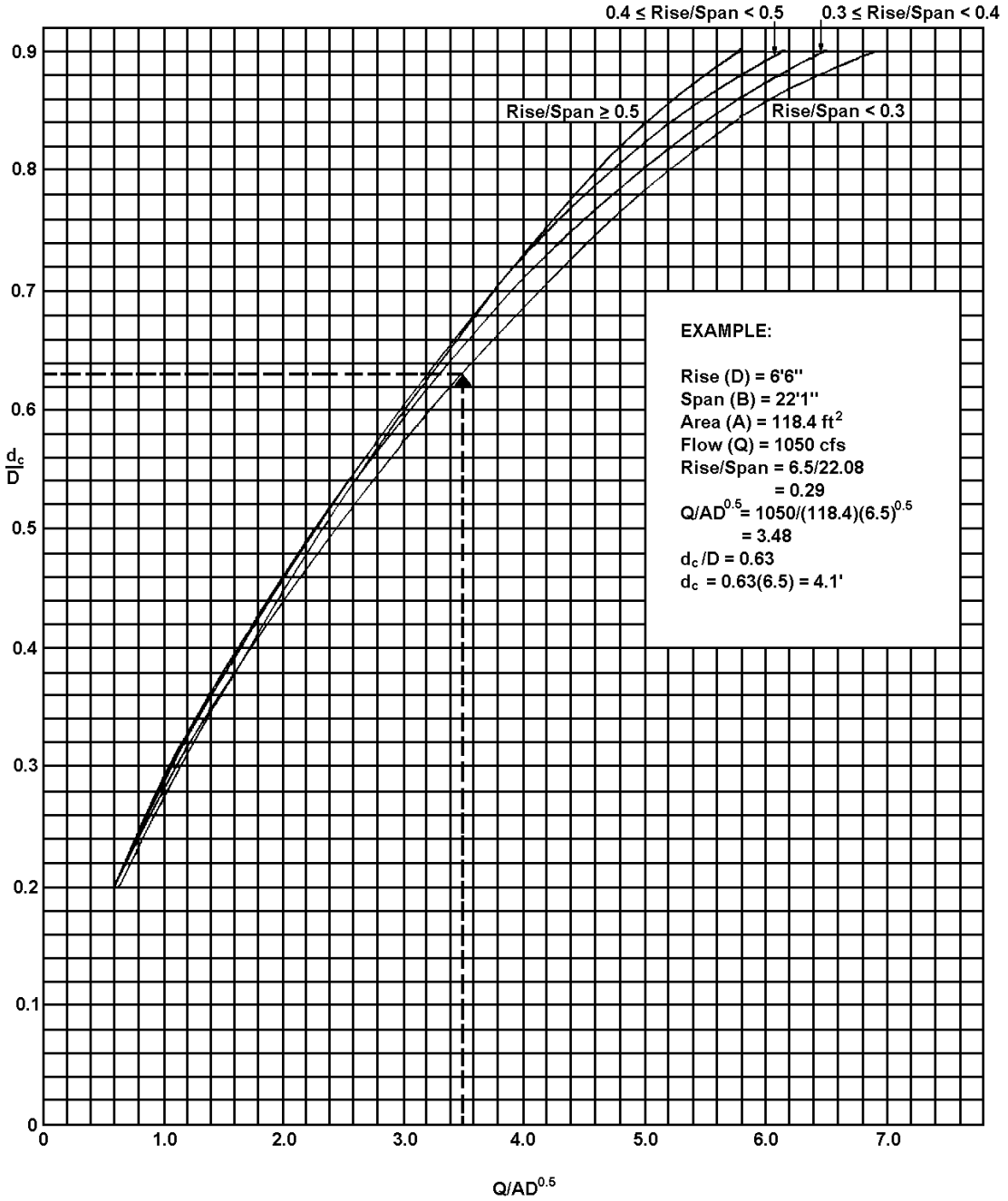
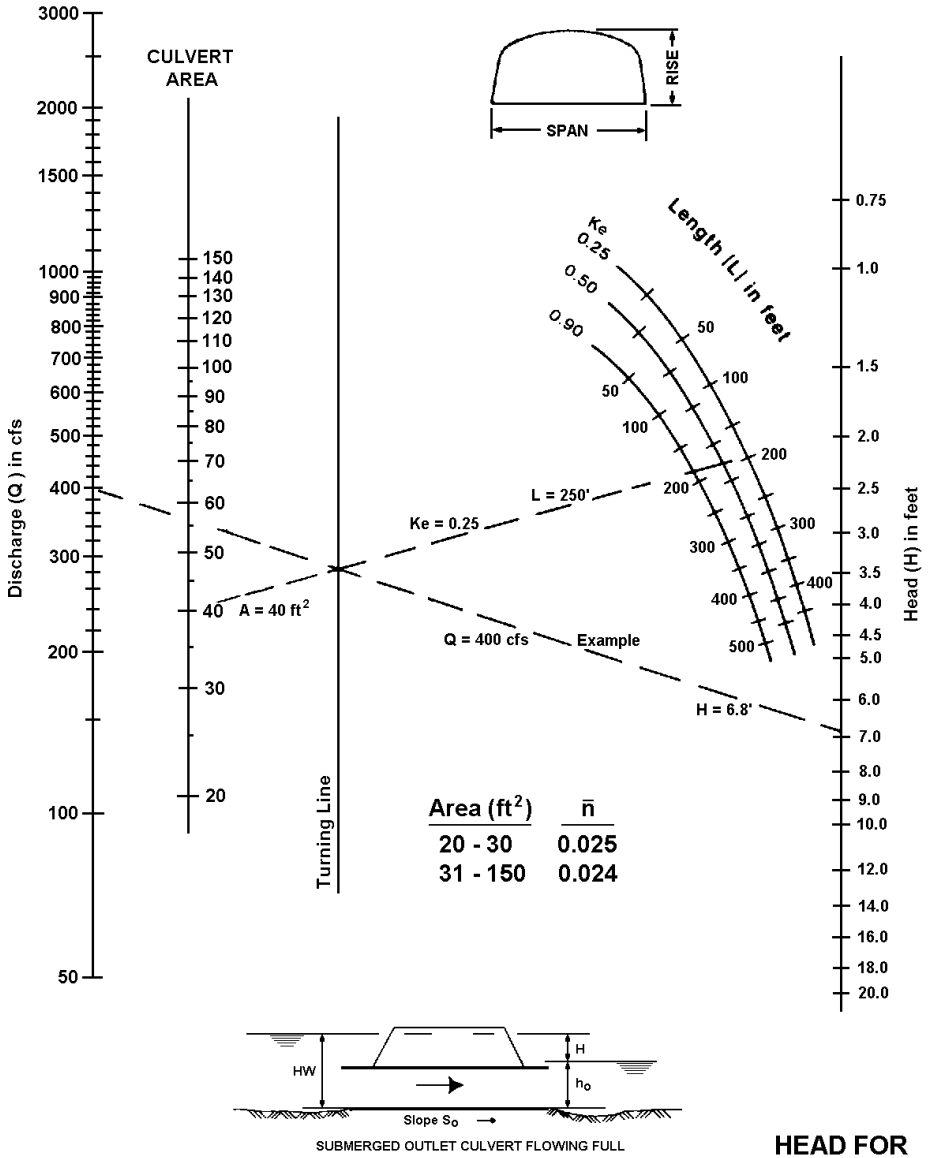

0.4 ≤ Rise/Span < 0.5
0.3 ≤ Rise/Span < 0.4
Rise/Span ≥ 0.5
Rise/Span < 0.3
EXAMPLE:
Rise (D) = 6'6"
Span (B) = 22'1"
Area (A) = 118.4 ft²
Flow (Q) = 1050 cfs
Rise/Span = 6.5/22.08
= 0.29
Q/AD^0.5 = 1050/(118.4)(6.5)^0.5
= 3.48
dc/D = 0.63
dc = 0.63(6.5) = 4.1'
dc/D
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Q/AD^0.5

CHART 21



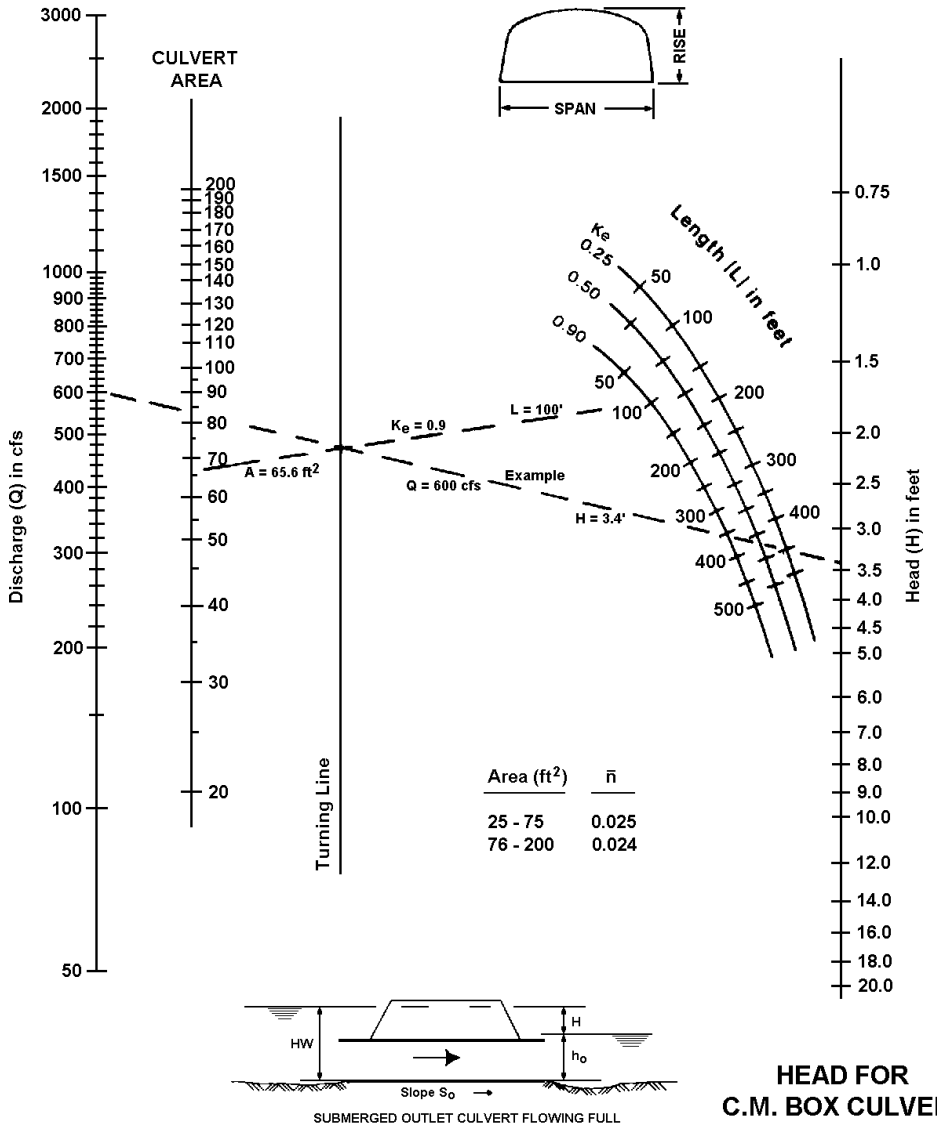
SUBMERGED OUTLET CULVERT FLOWING FULL

For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM RISE/SPAN < 0.3

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

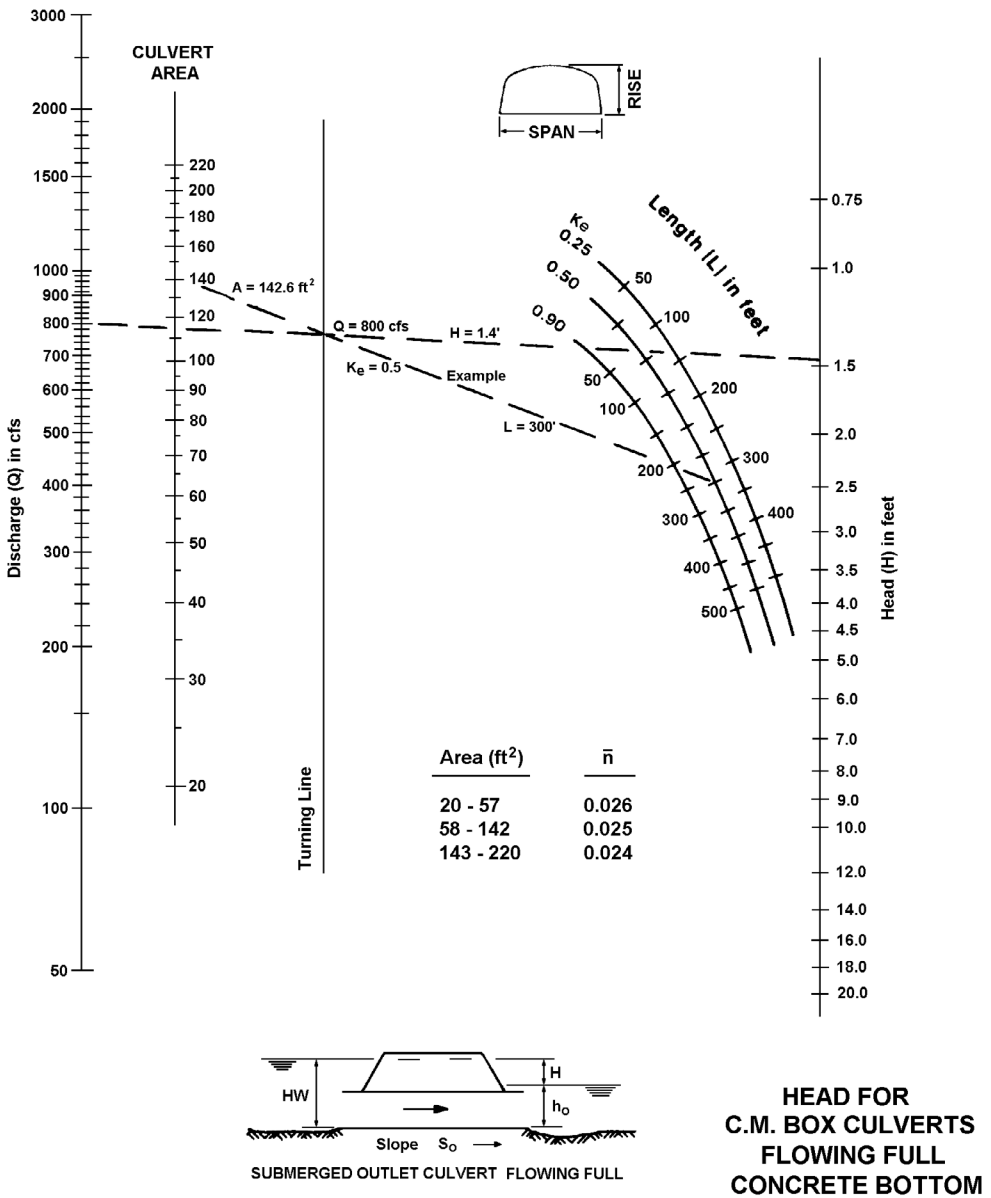
CHART 22



HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM 0.3 ≤ RISE/SPAN < 0.4

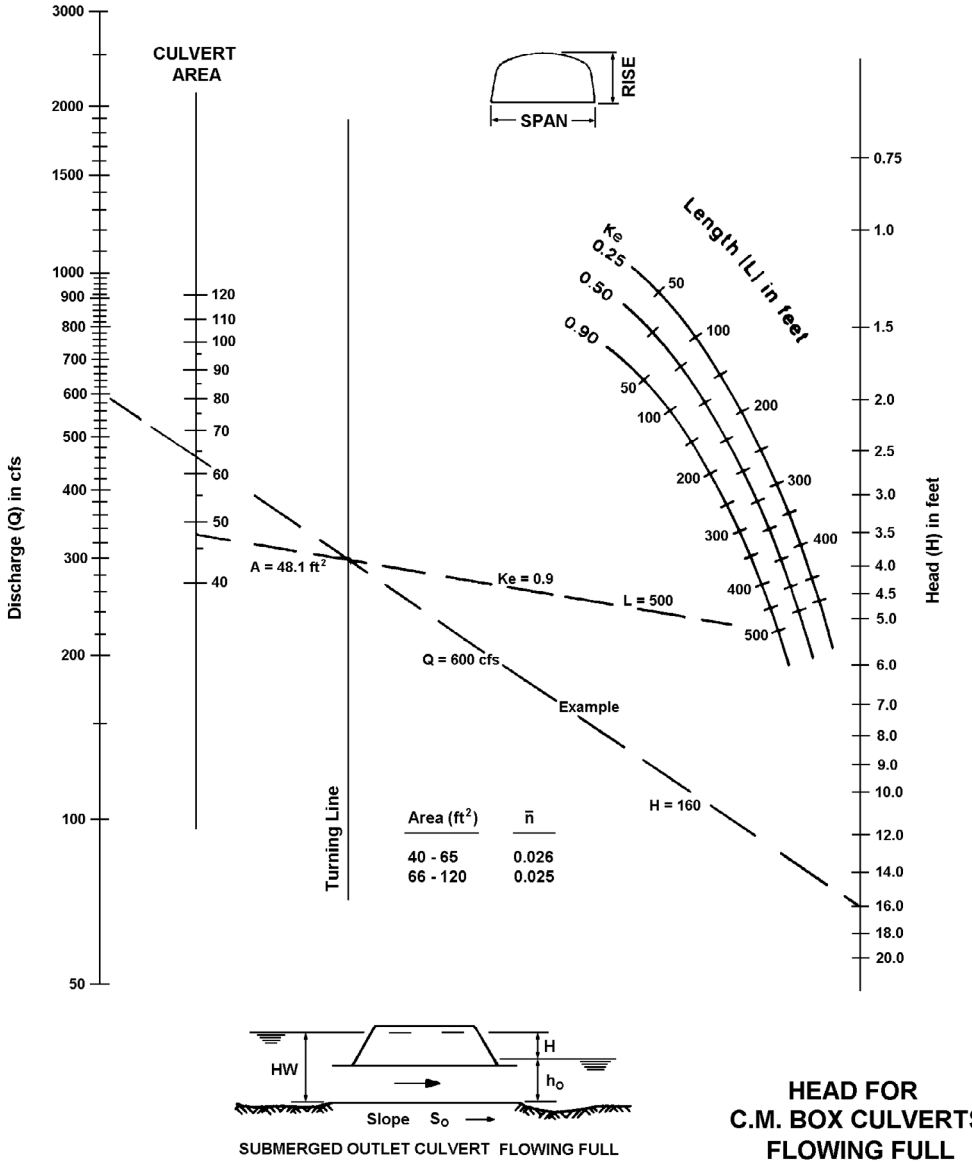
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 23



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

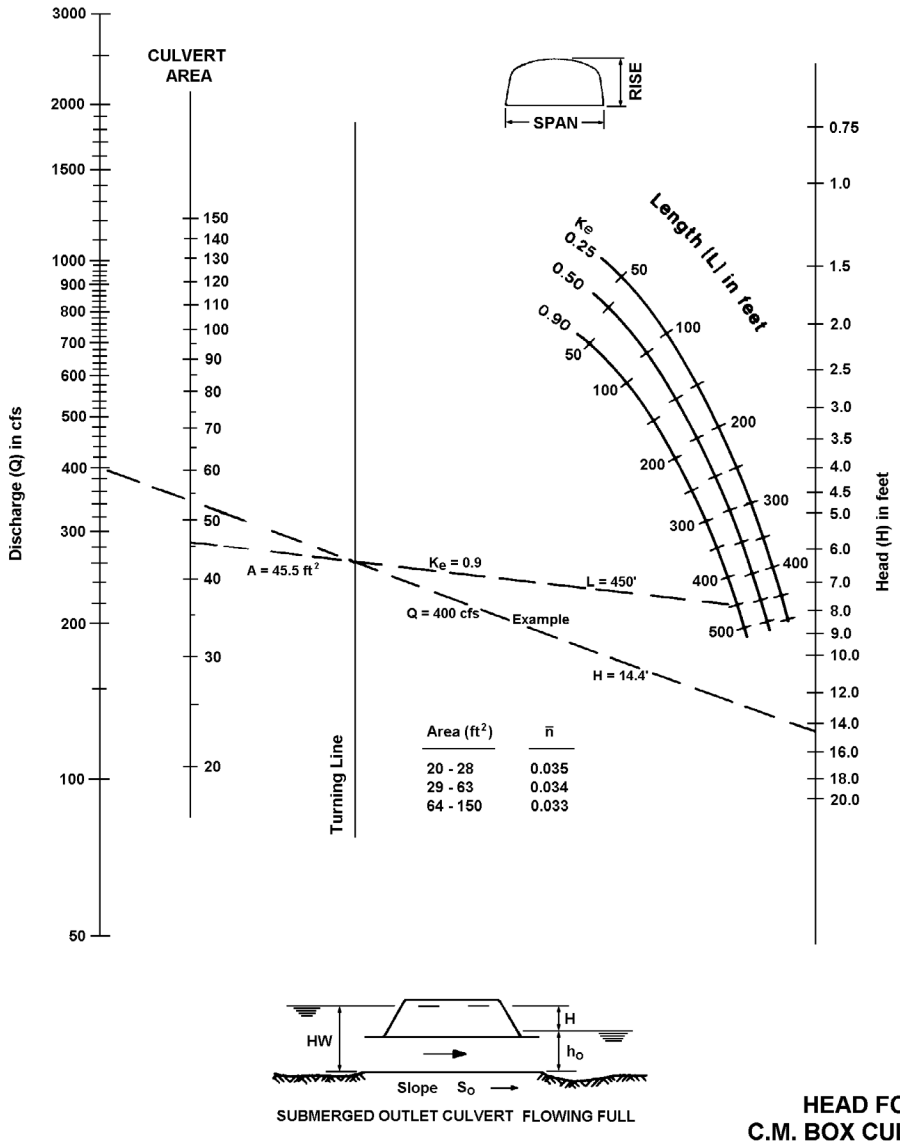
CHART 24



HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM 0.5 ≤ RISE/SPAN

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

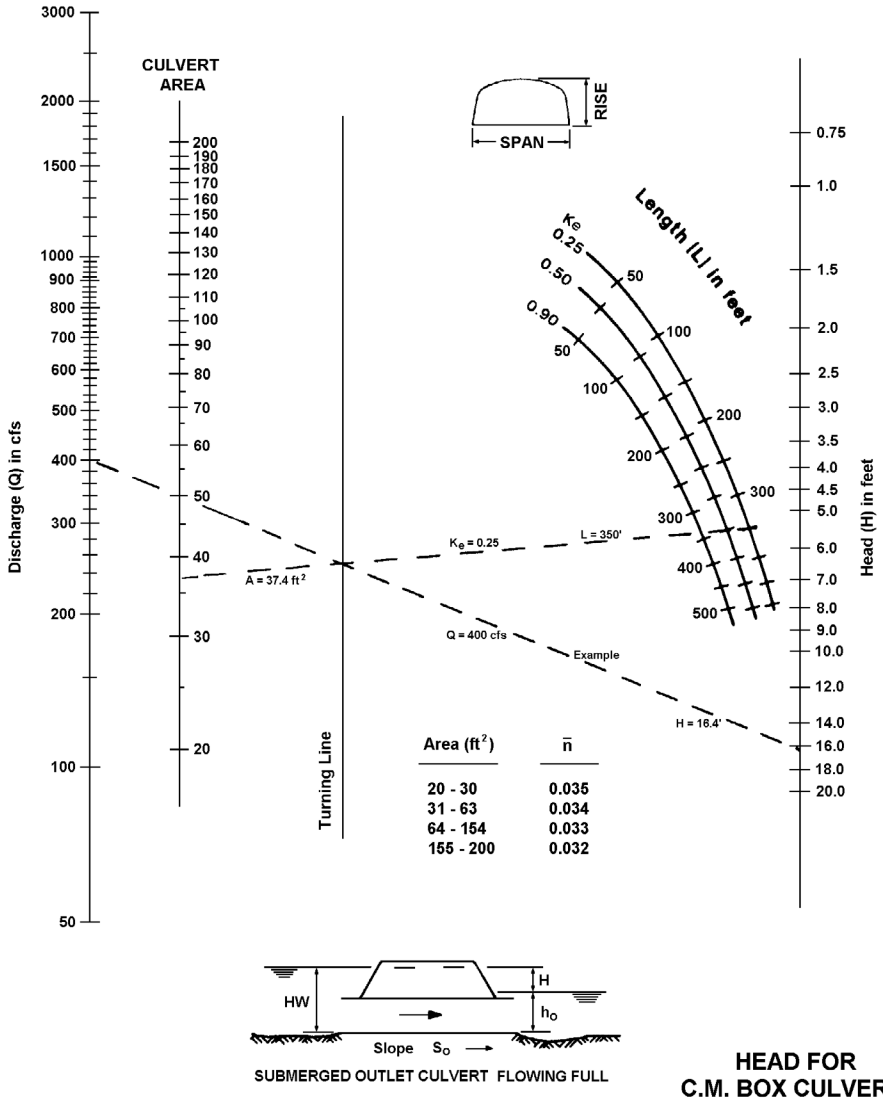
CHART 25



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM 0.3< RISE/SPAN

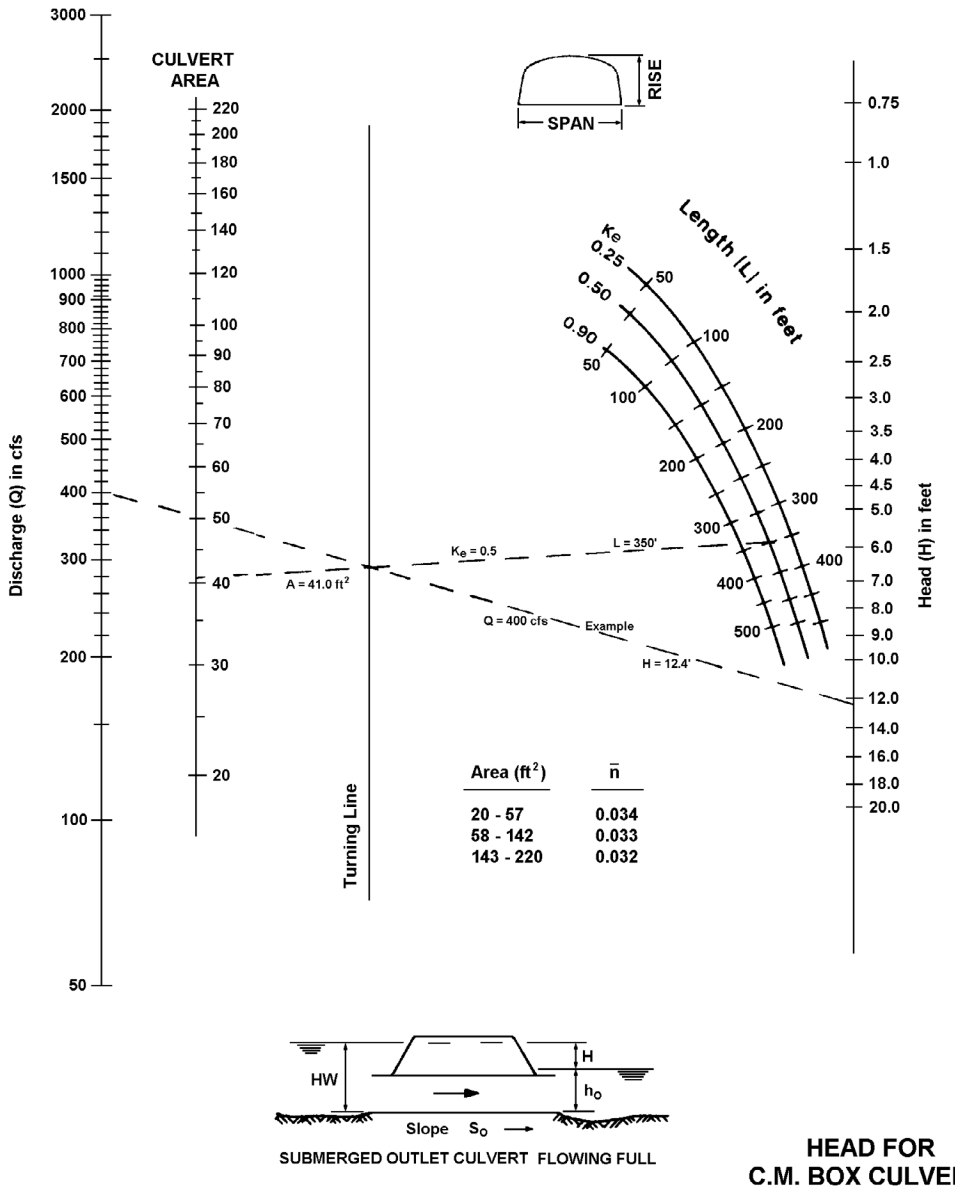
CHART 26



Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.4 ≤ RISE/SPAN < 0.5

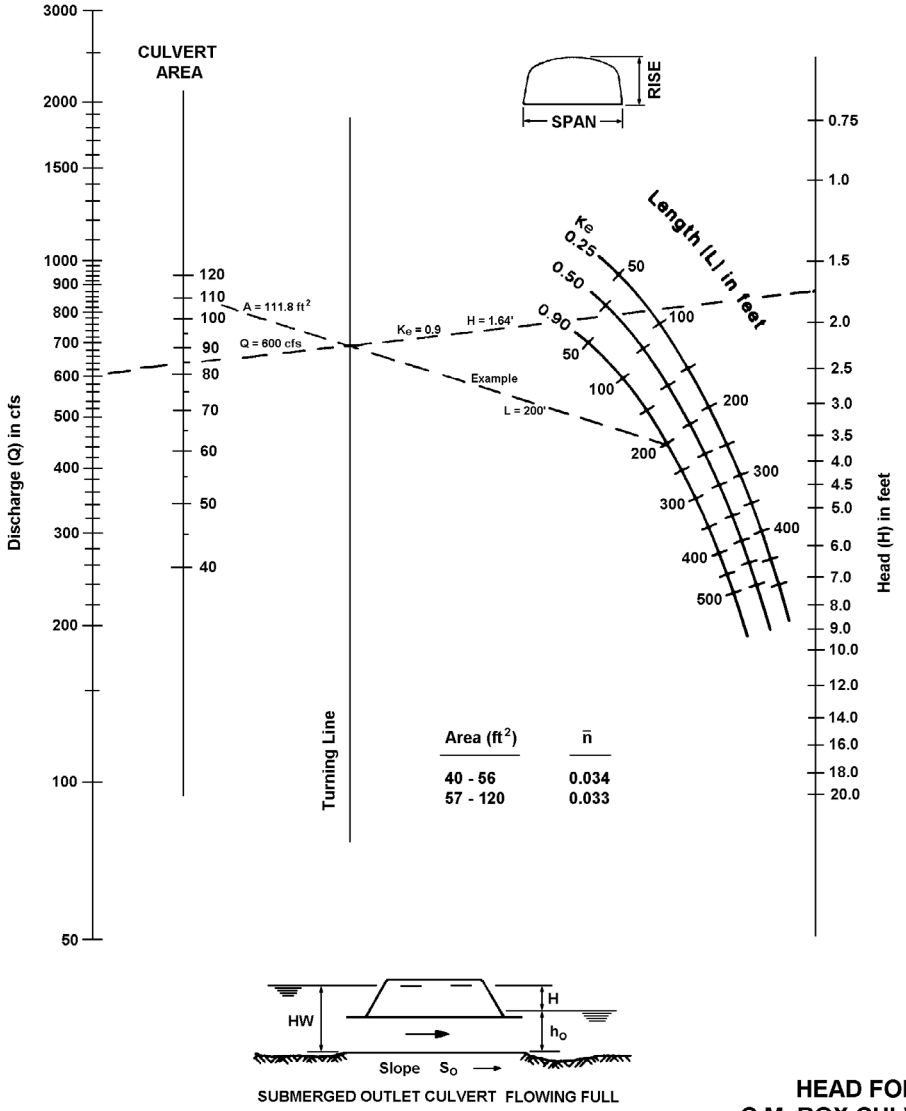
CHART 27



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.4 ≤ RISE/SPAN < 0.5

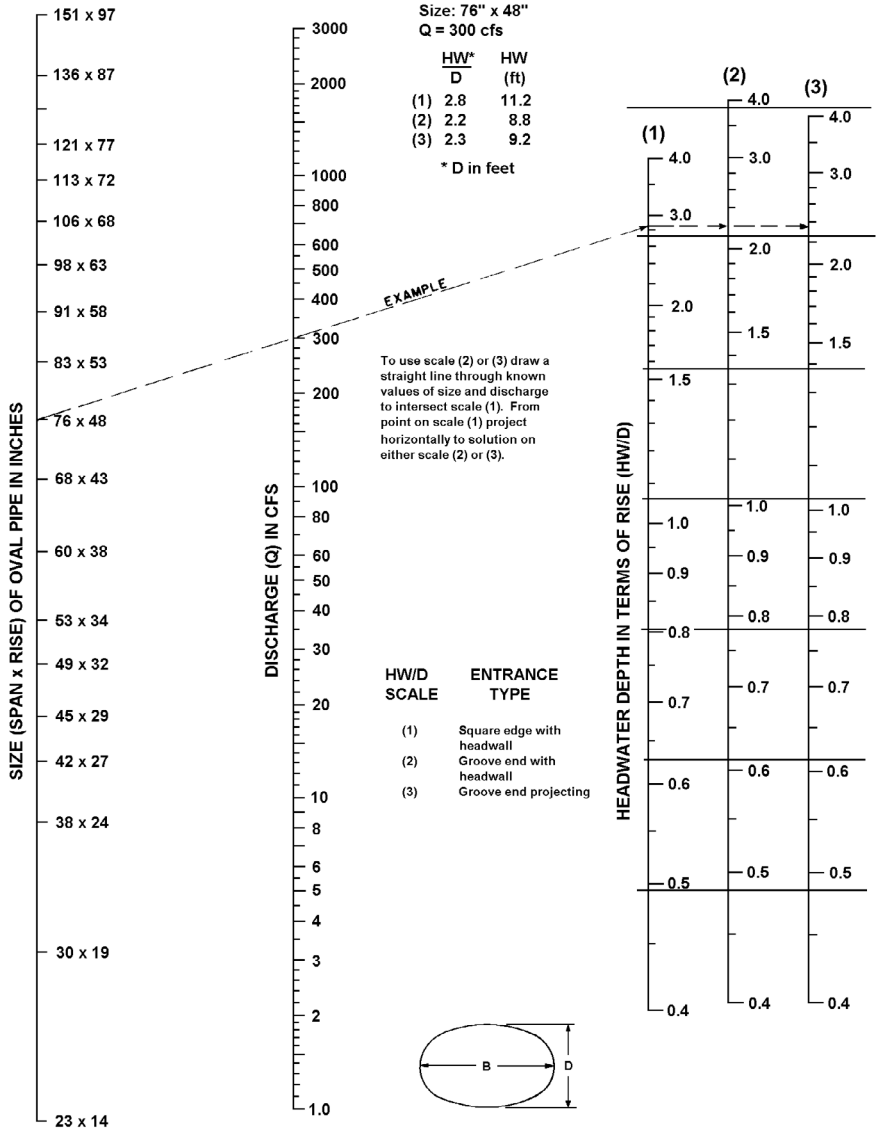
CHART 28



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM 0.5 ≤ RISE/SPAN

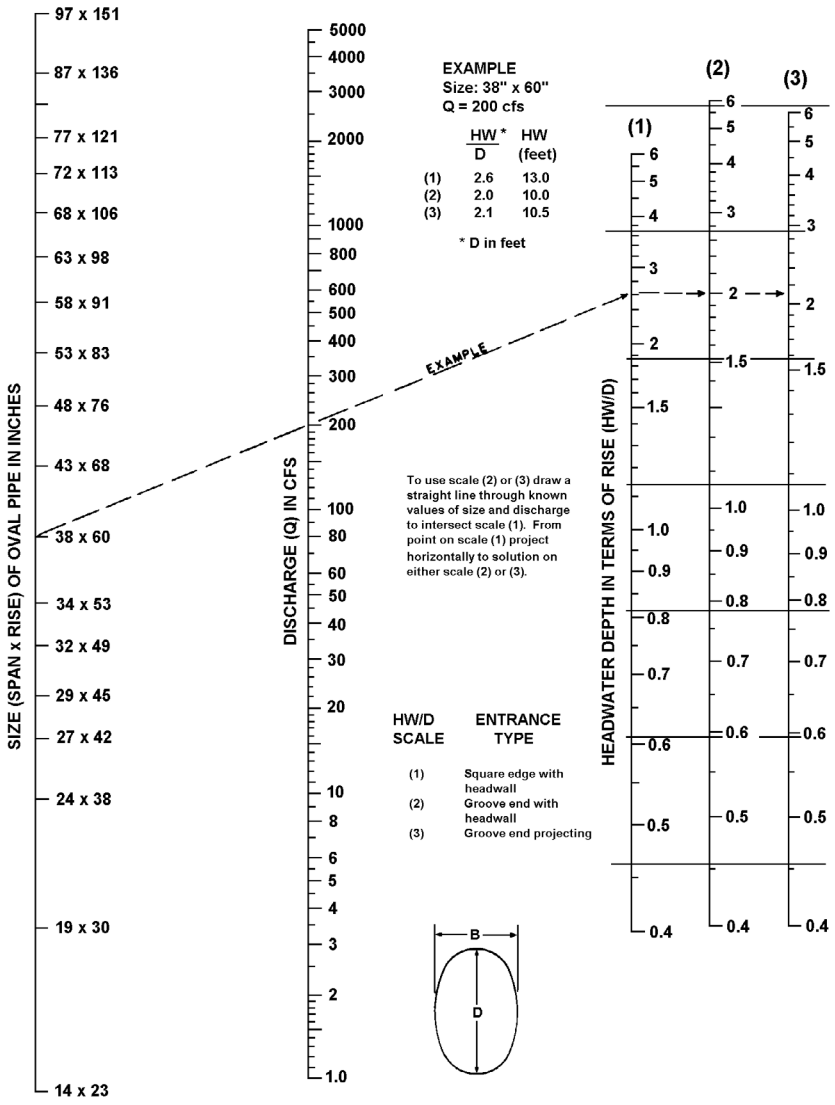
CHART 29



HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

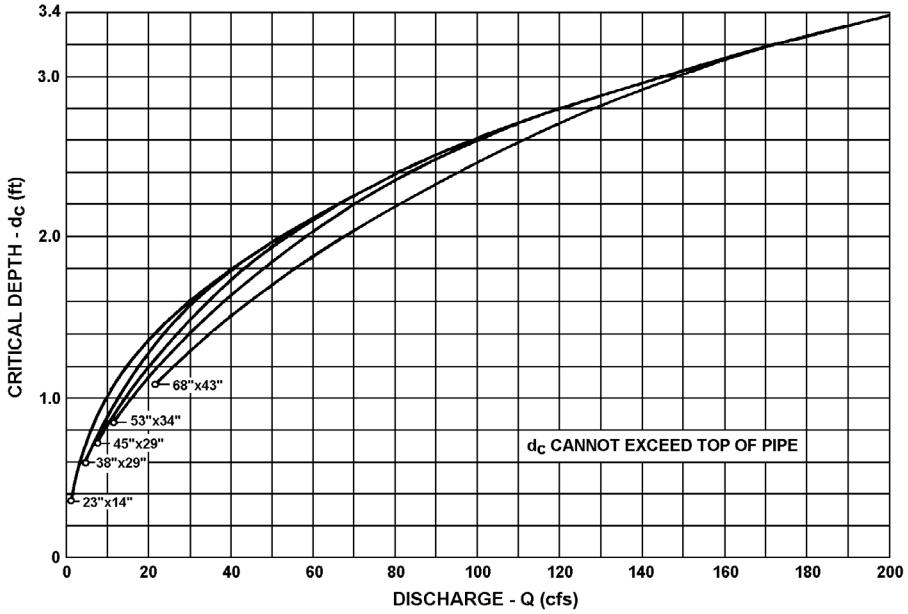
CHART 30

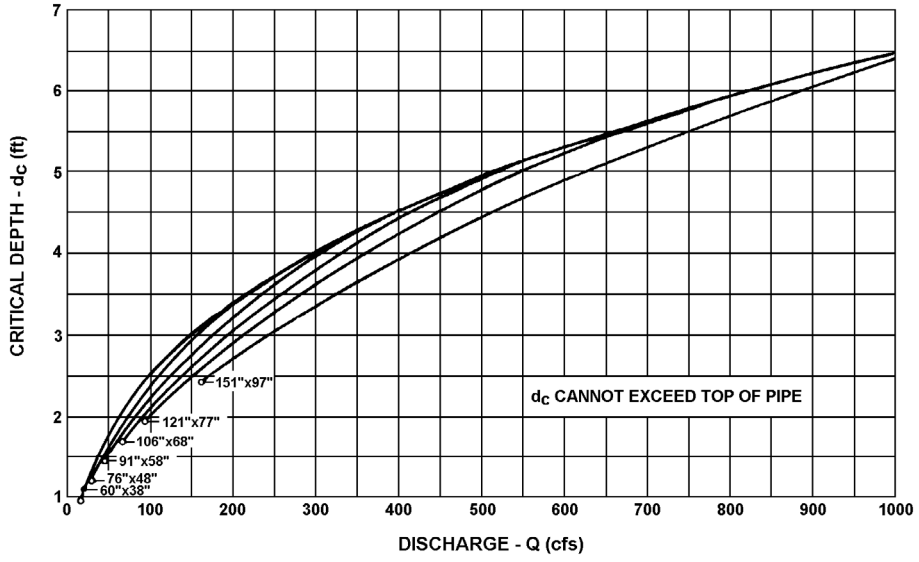


HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS VERTICAL WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 31

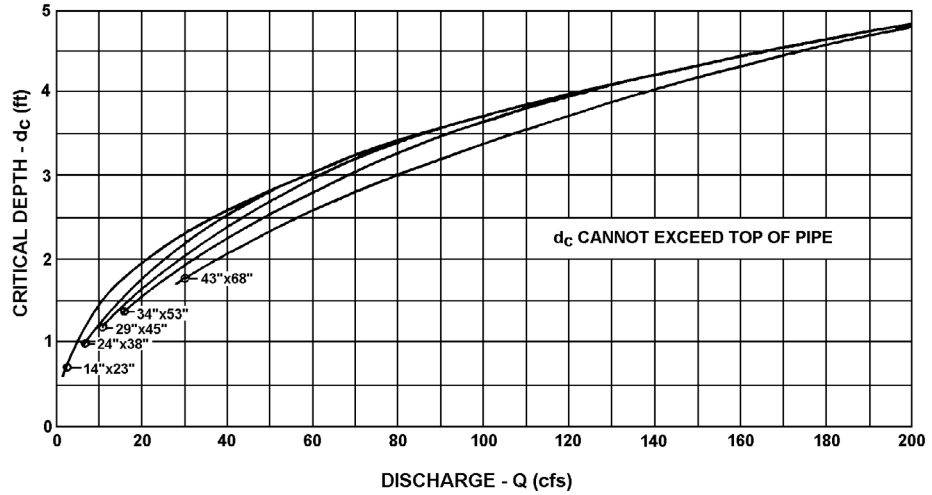


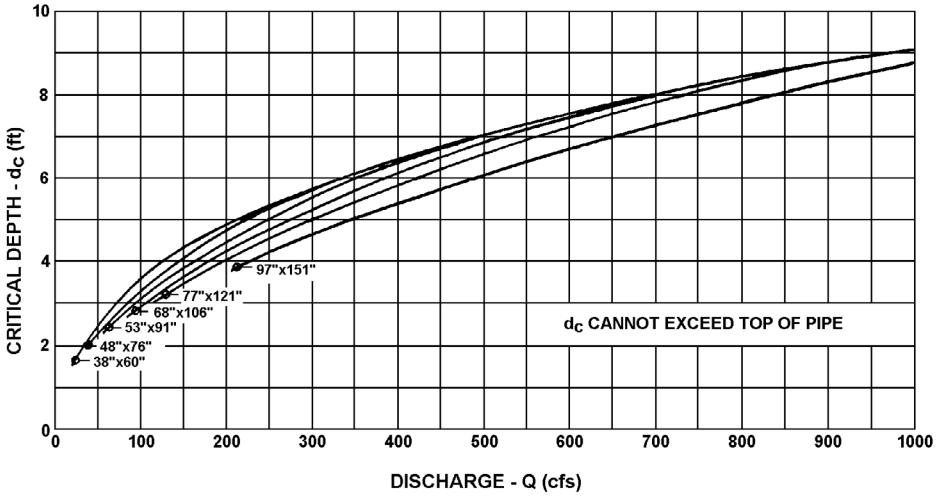


BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

CHART 32

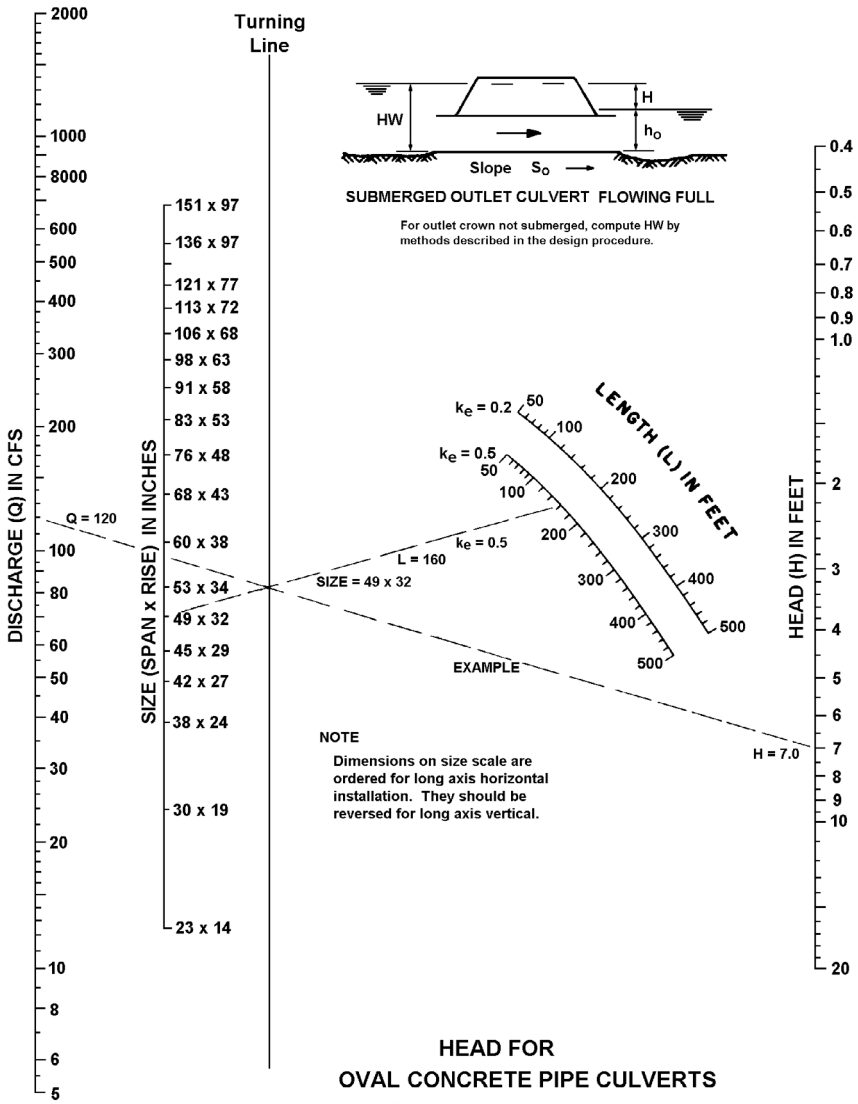




BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

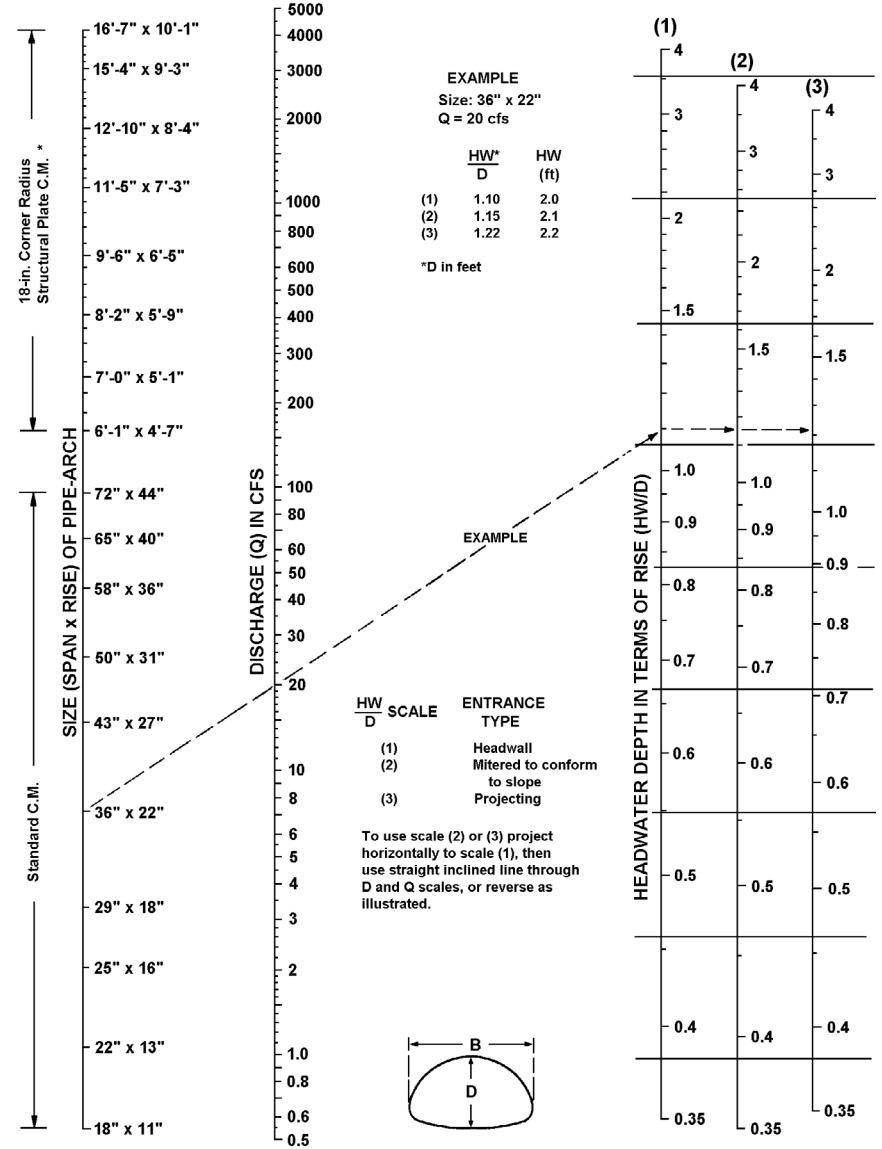
CHART 33



HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 34

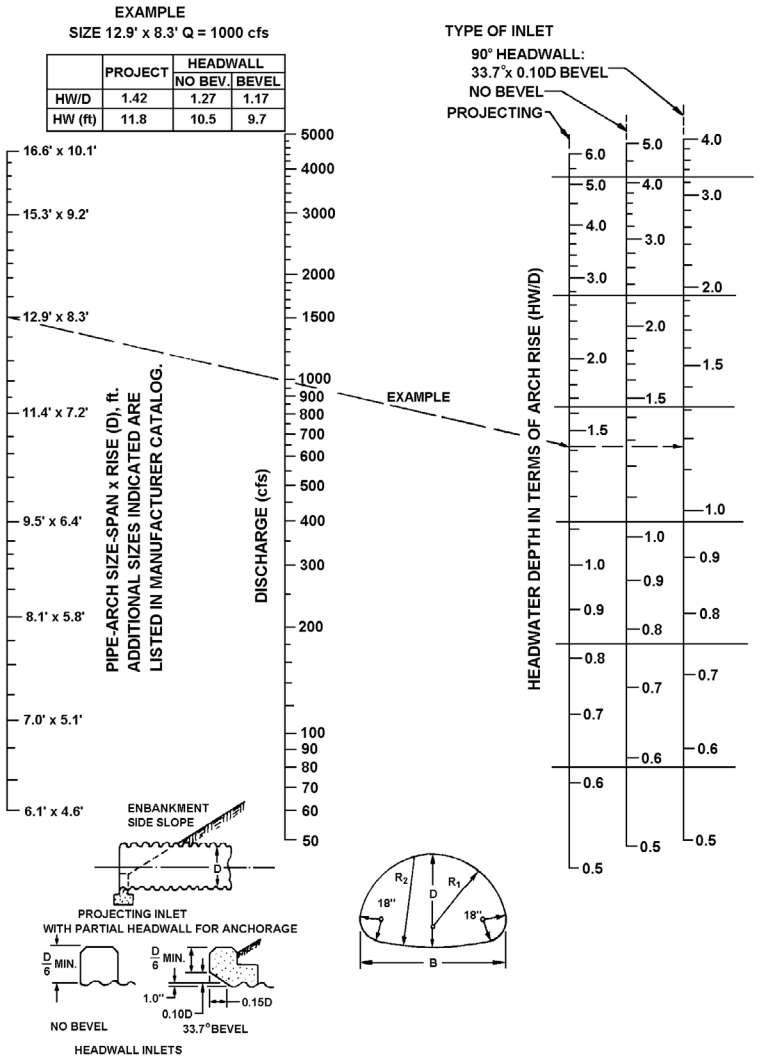


* Additional sizes not dimensioned are listed in fabricator's catalog.

HEADWATER DEPTH FOR C.M. PIPE-ARCH CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

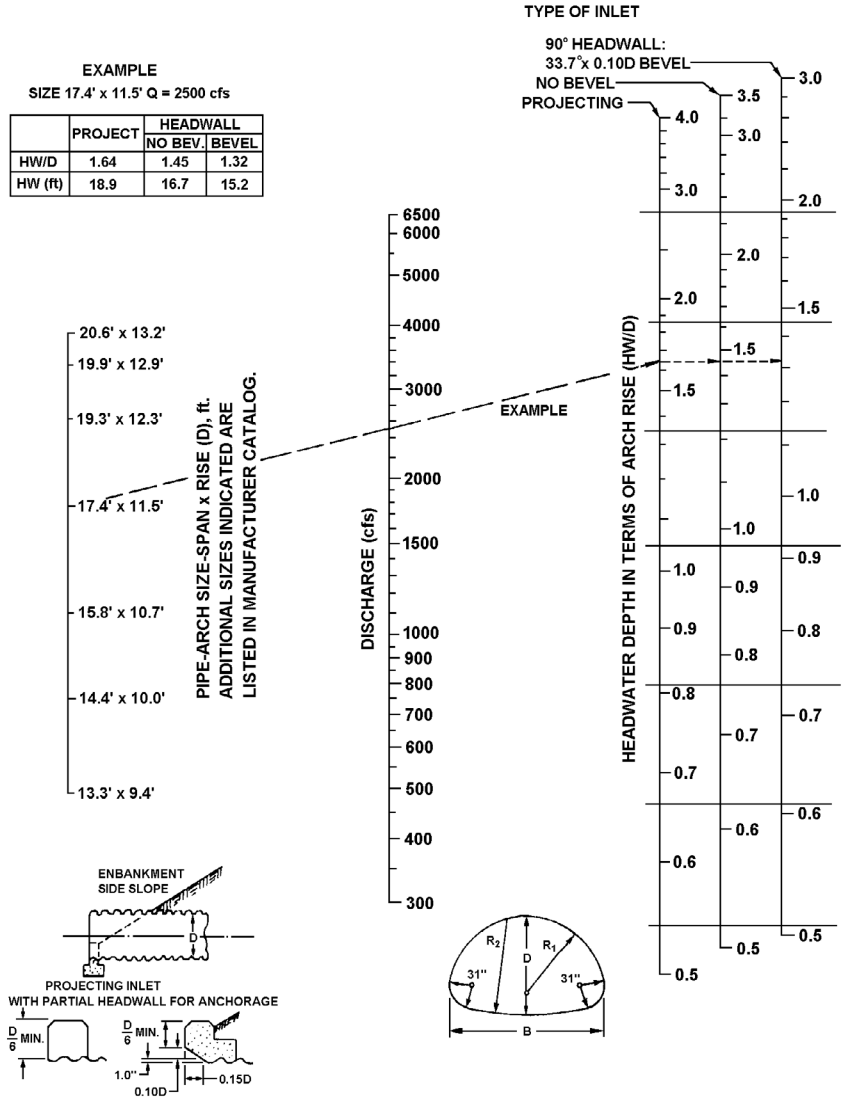
CHART 35



BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1968

HEADWATER DEPTH FOR INLET CONTROLS
STRUCTURAL PLATE PIPE-ARCH CULVERTS
18 in. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

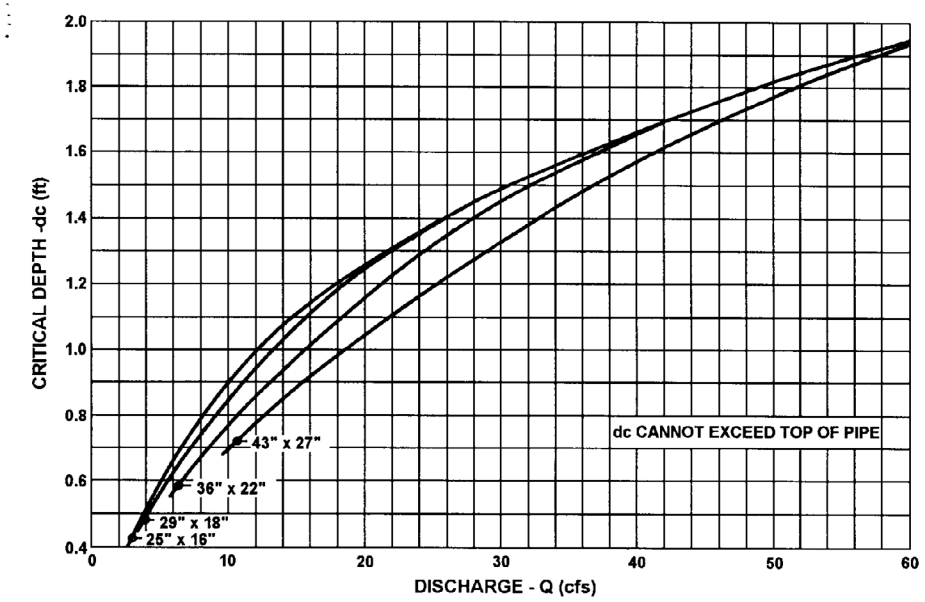
CHART 36

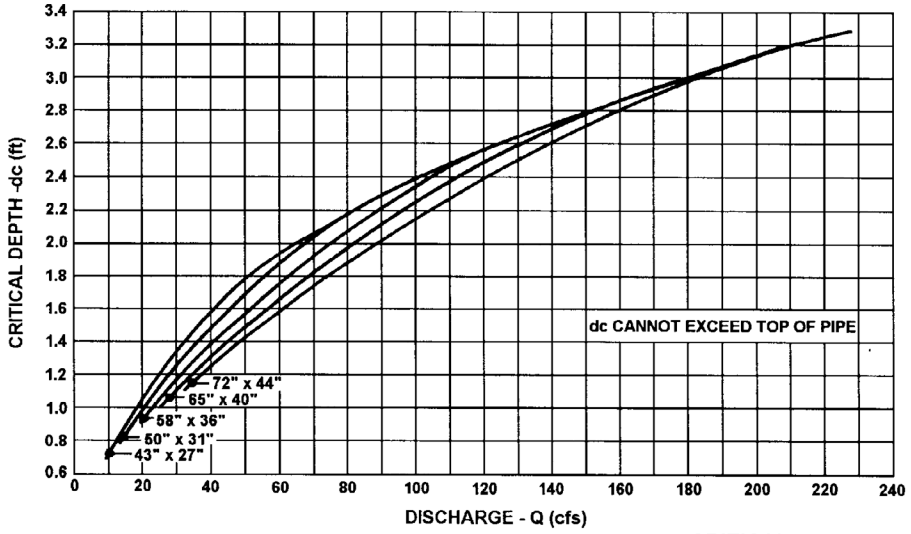


BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1966

HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS
31 in. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

CHART 37

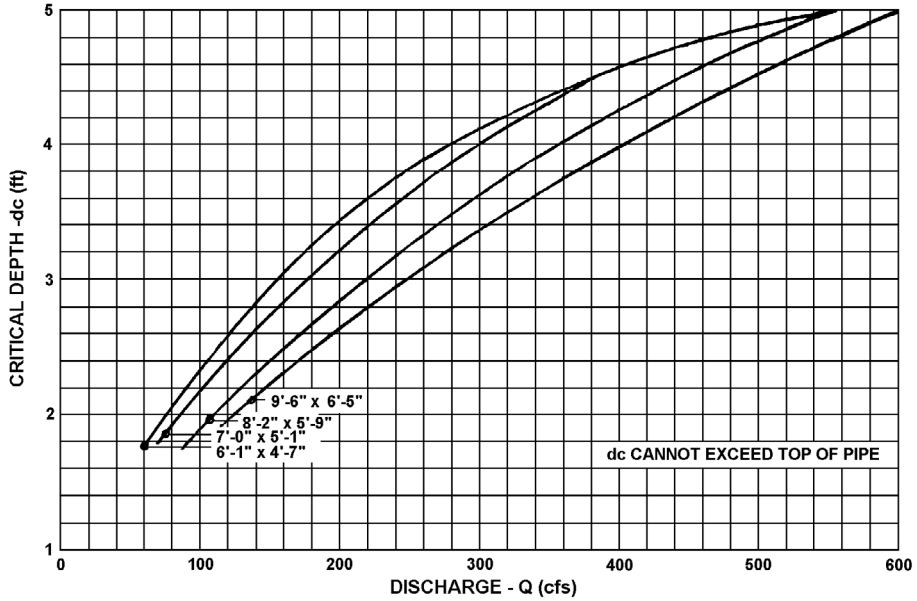


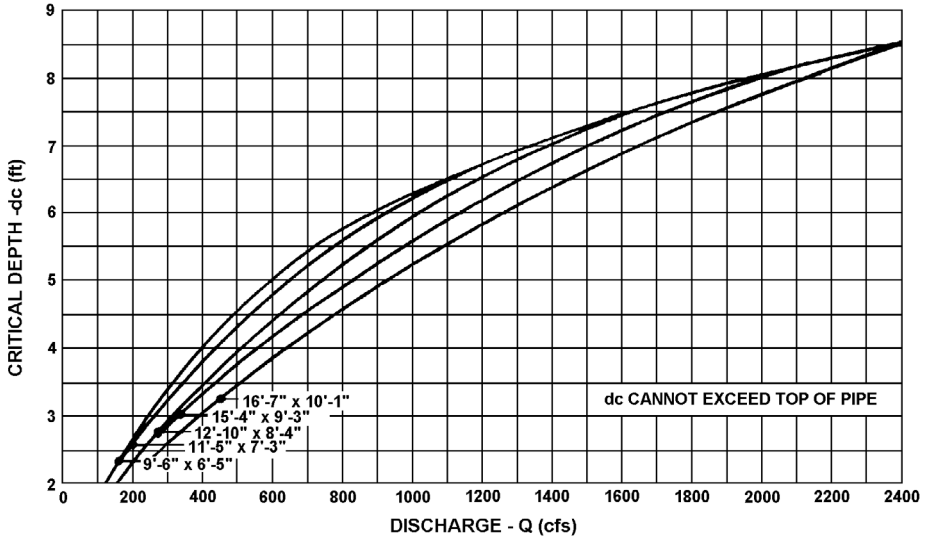


BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
STANDARD C.M. PIPE ARCH

CHART 38

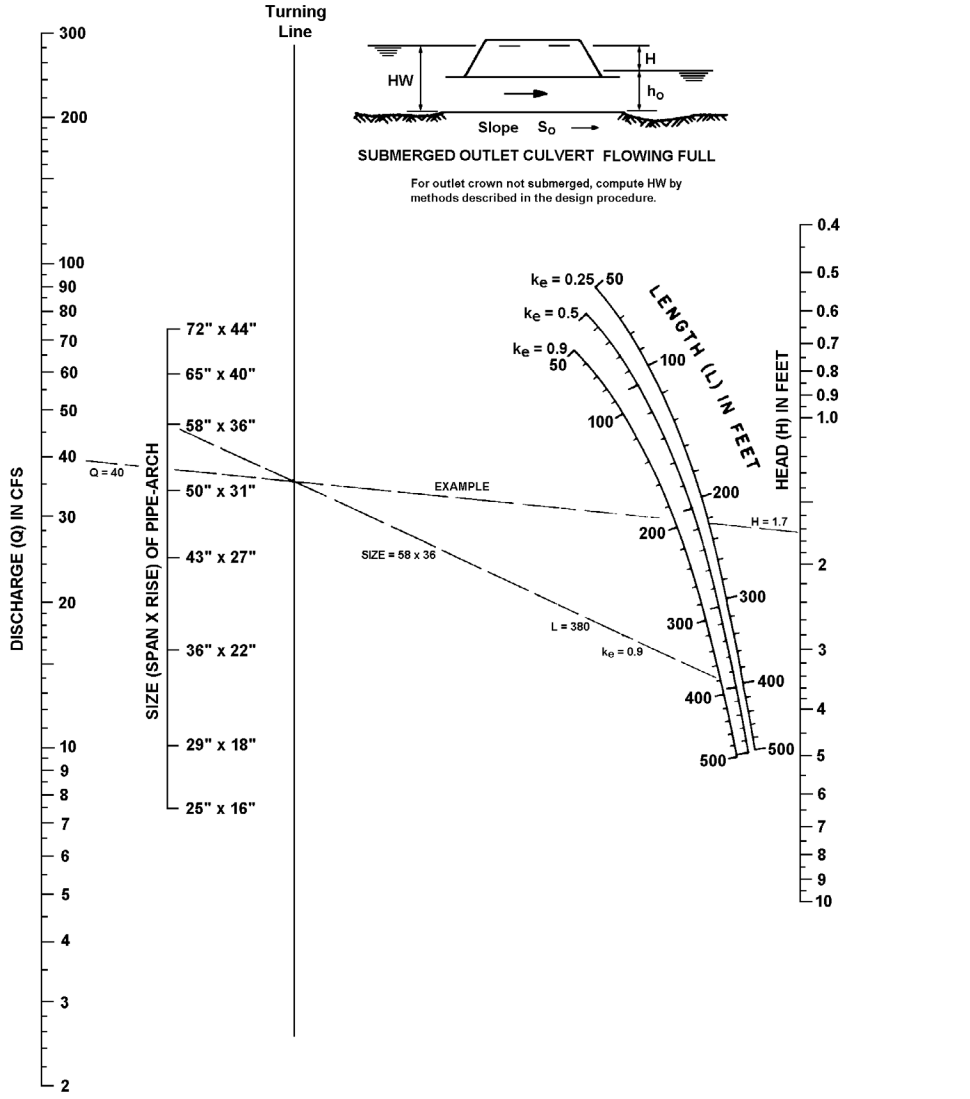




BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
STRUCTURAL PLATE
C.M. PIPE ARCH
18 in. CORNER RADIUS

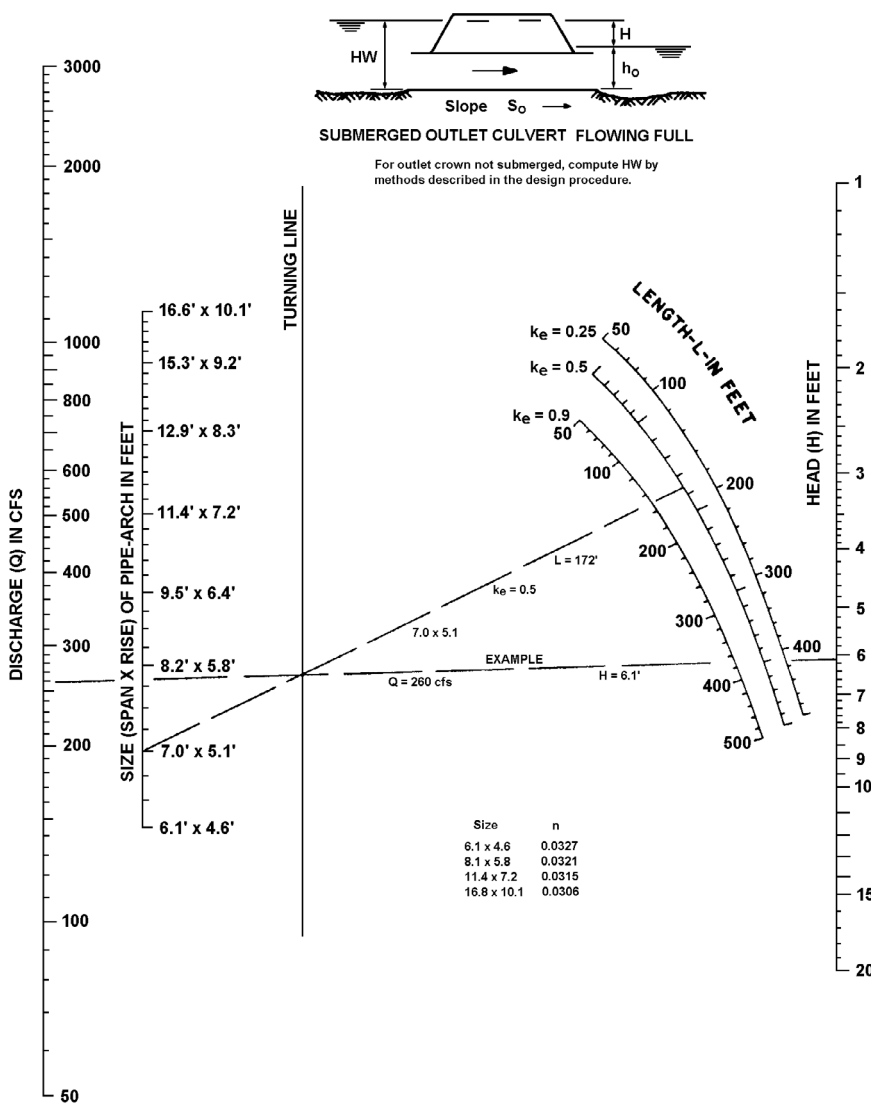
CHART 39



BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR
STANDARD C.M. PIPE-ARCH CULVERTS
FLOWING FULL
n = 0.024

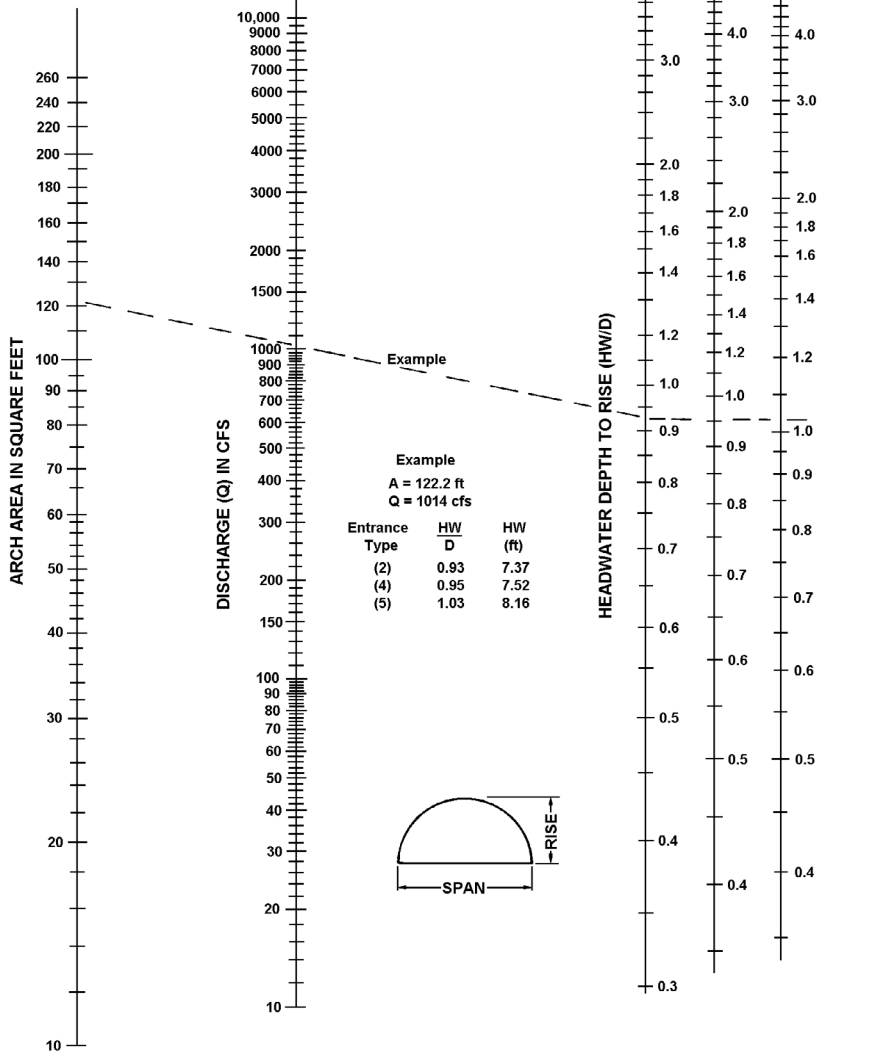
CHART 40



BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR STRUCTURAL PLATE C.M. PIPE ARCH CULVERTS 18 in. CORNER RADIUS FLOWING FULL n = 0.0327 TO 0.0306

CHART 41



HEADWATER DEPTH FOR C.M. ARCH CULVERTS 0.3 ≤ RISE/SPAN < 0.4 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 42

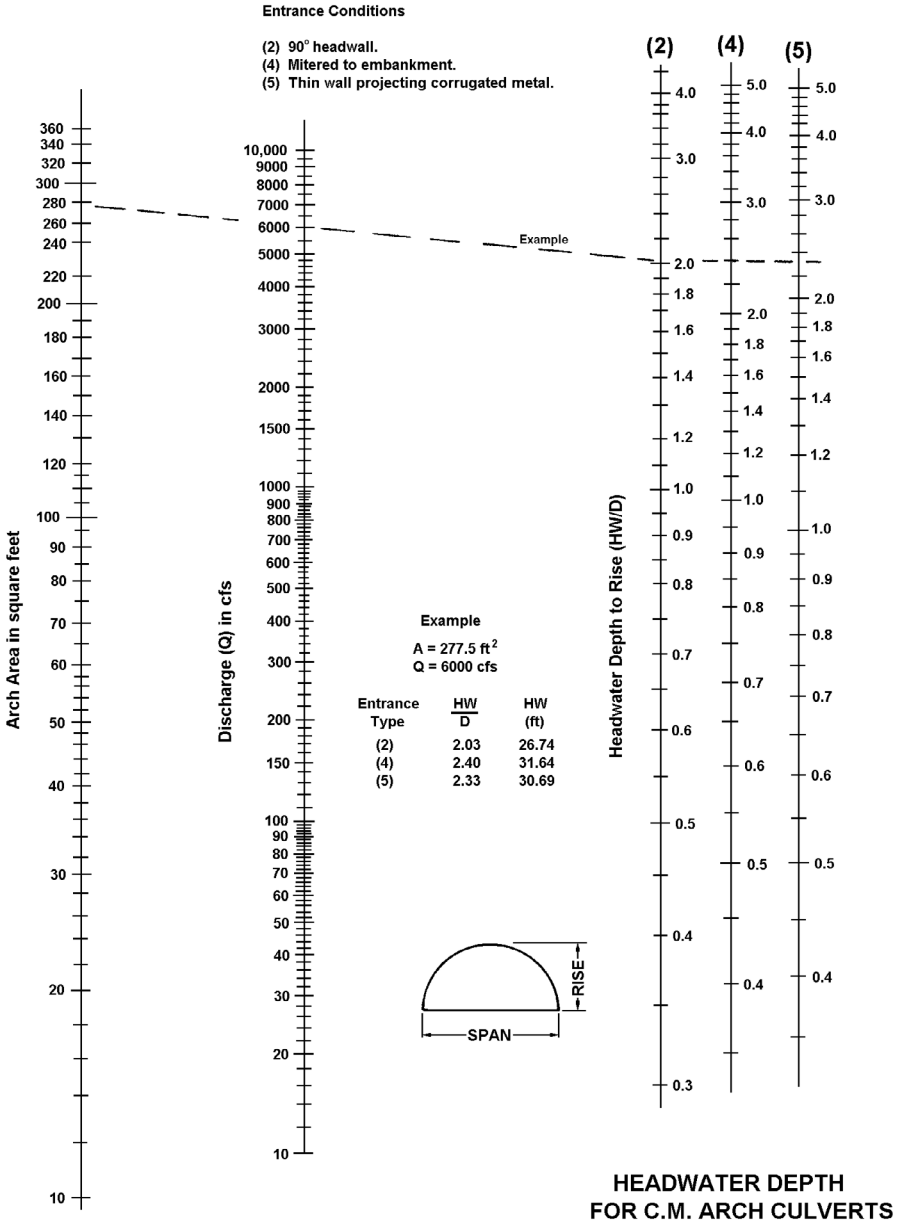
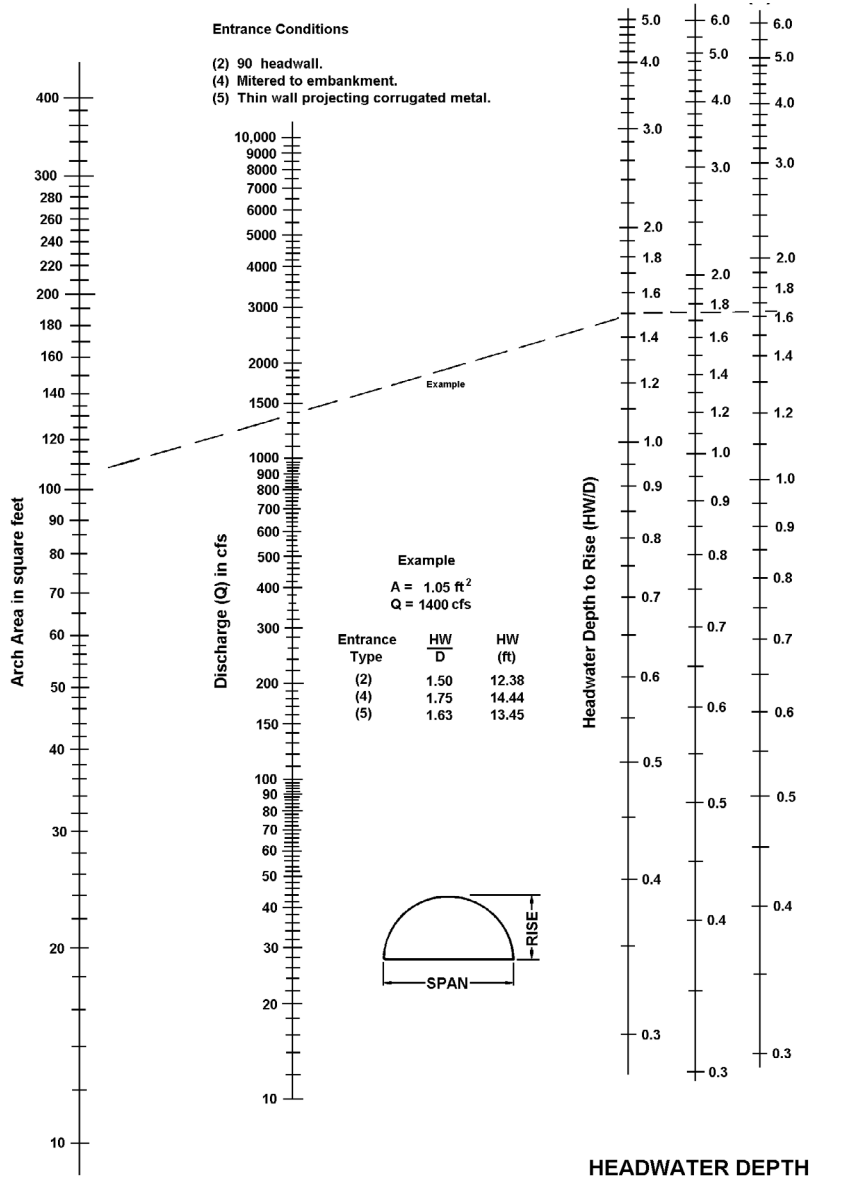

Entrance Conditions
(2) 90° headwall.
(4) Mitered to embankment.
(5) Thin wall projecting corrugated metal.
(2)
(4)
(5)
Arch Area in square feet
Discharge (Q) in cfs
Headwater Depth to Rise (HW/D)
Example
Example
A = 277.5 ft²
Q = 6000 cfs
Entrance Type
HW/D
HW (ft)
(2) 2.03 26.74
(4) 2.40 31.64
(5) 2.33 30.69
RISE
SPAN
HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.4 ≤ RISE/SPAN < 0.5
WITH INLET CONTROL
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

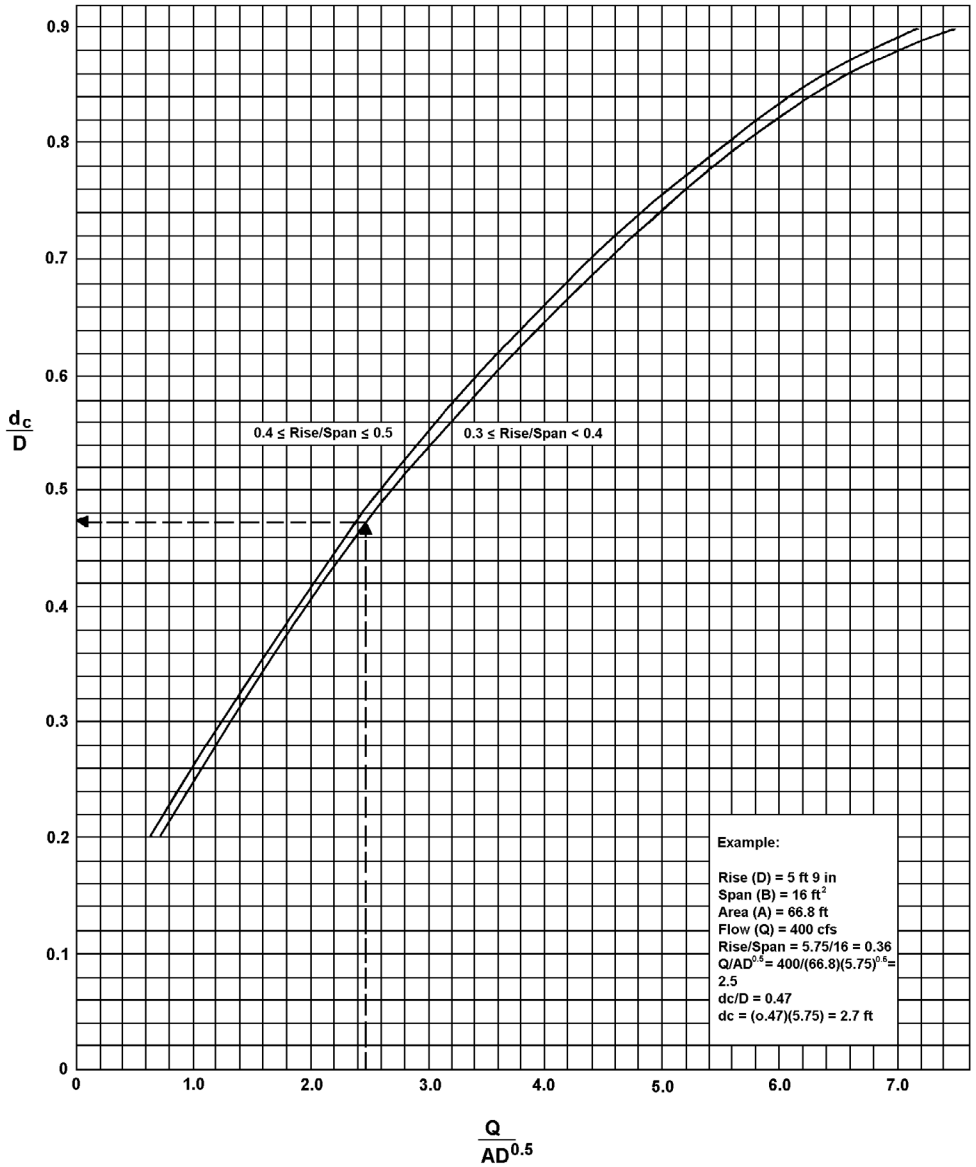
CHART 43



HEADWATER DEPTH FOR C.M. ARCH CULVERTS 0.5 ≤ RISE/SPAN WITH INLET CONTROL

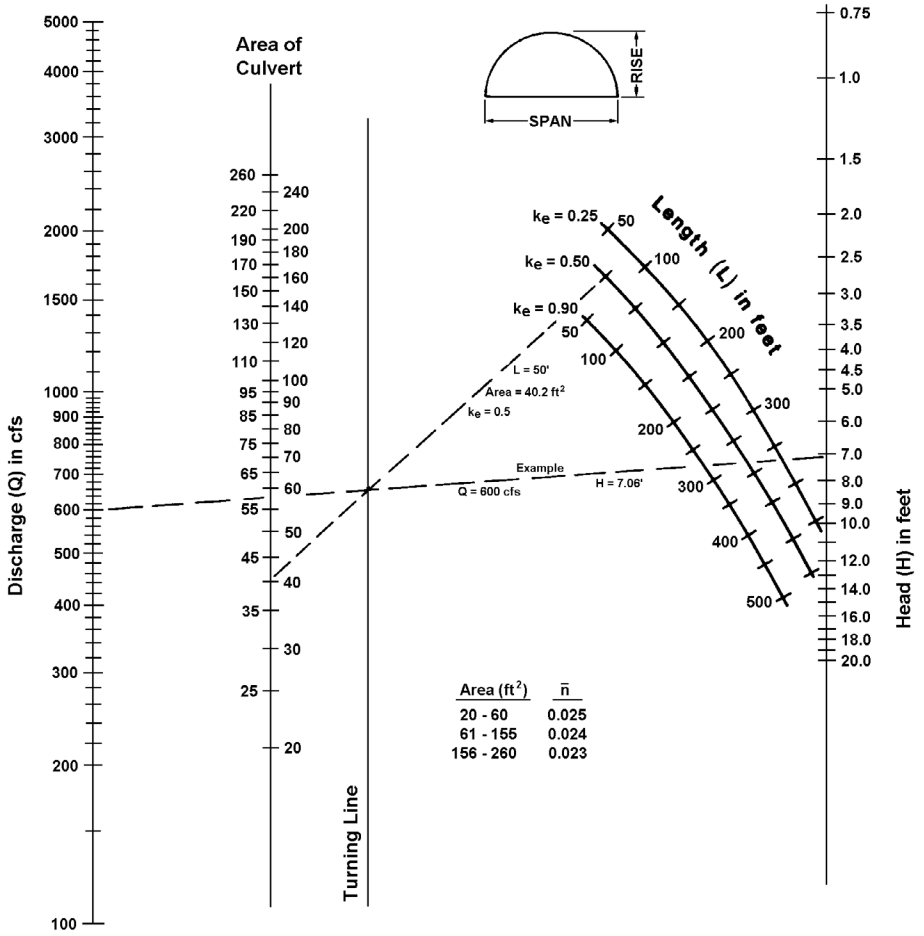
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 44

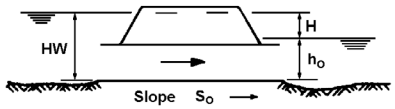


DIMENSIONLESS CRITICAL DEPTH CHART FOR C.M. ARCH CULVERTS

CHART 45



Area (ft^2)	$\bar{n}$
20 - 60	0.025
61 - 155	0.024
156 - 260	0.023

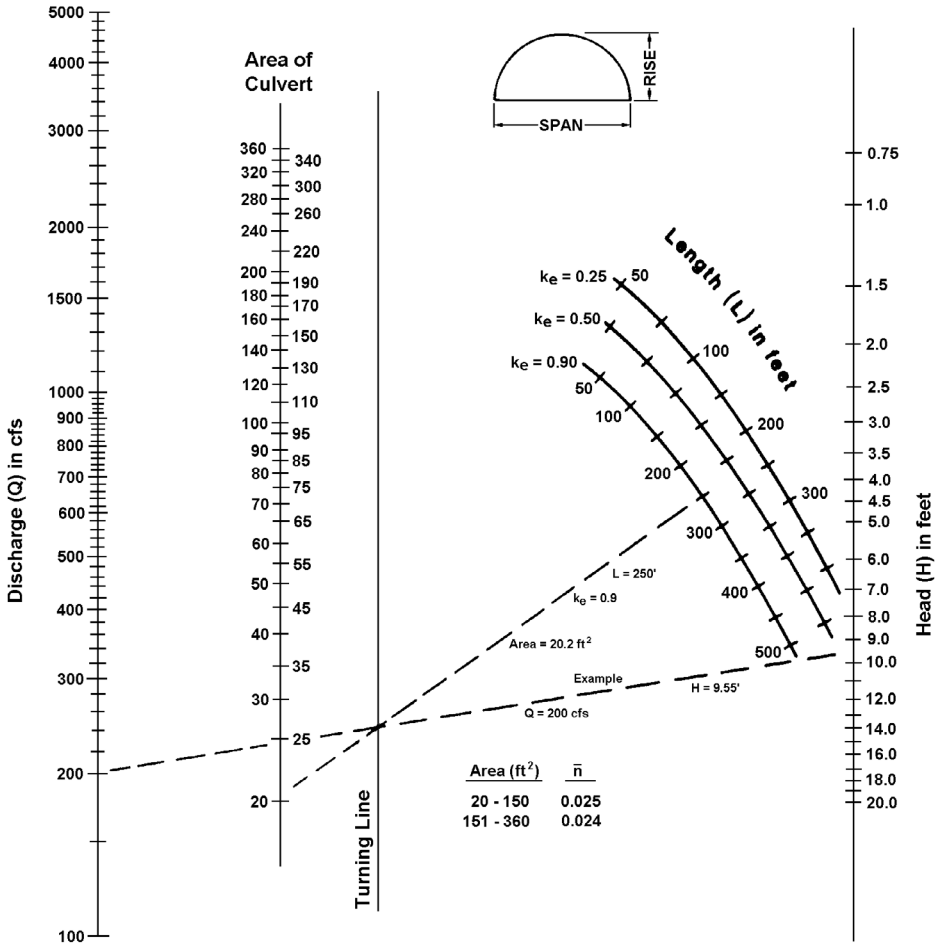


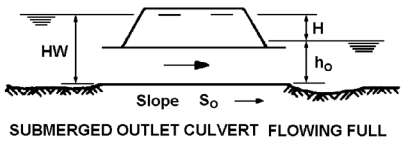
SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL CONCRETE BOTTOM 0.3 ≤ RISE/SPAN < 0.4

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 46



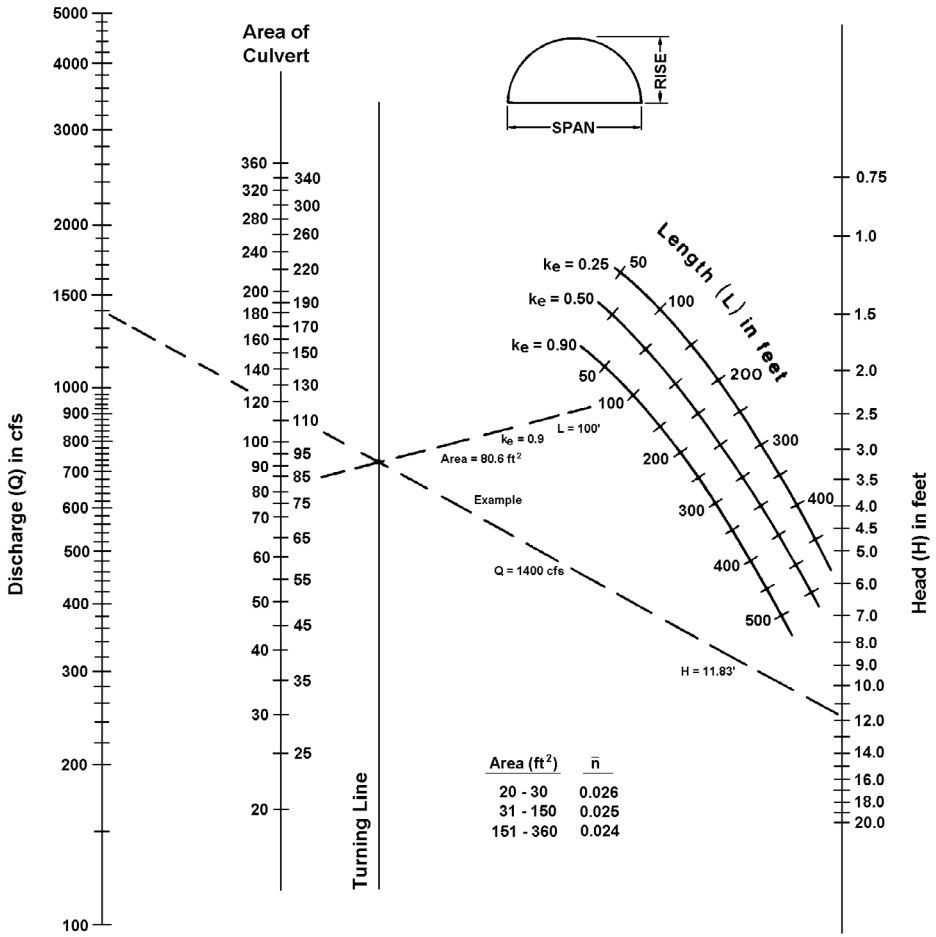


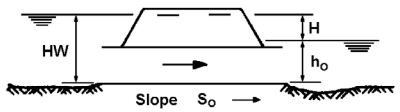
SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL CONCRETE BOTTOM 0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 47



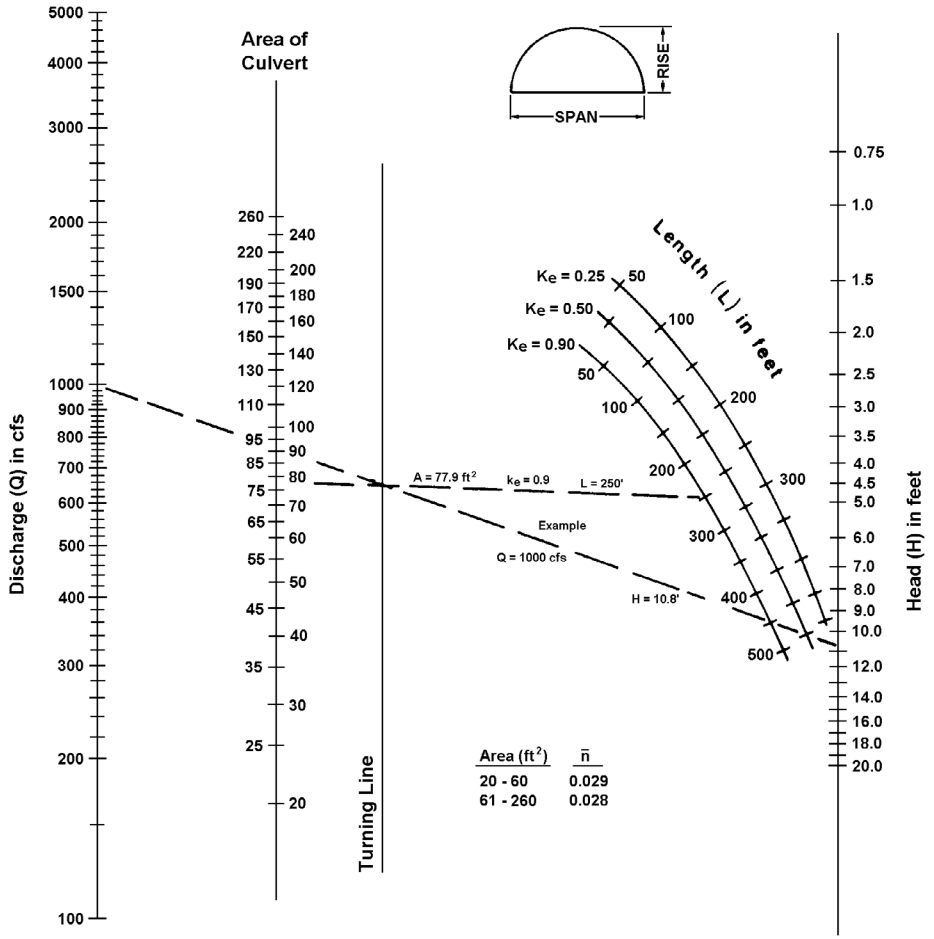


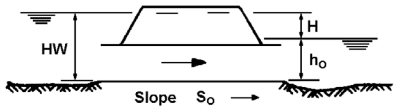
SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL CONCRETE BOTTOM 0.5 ≤ RISE/SPAN

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 48



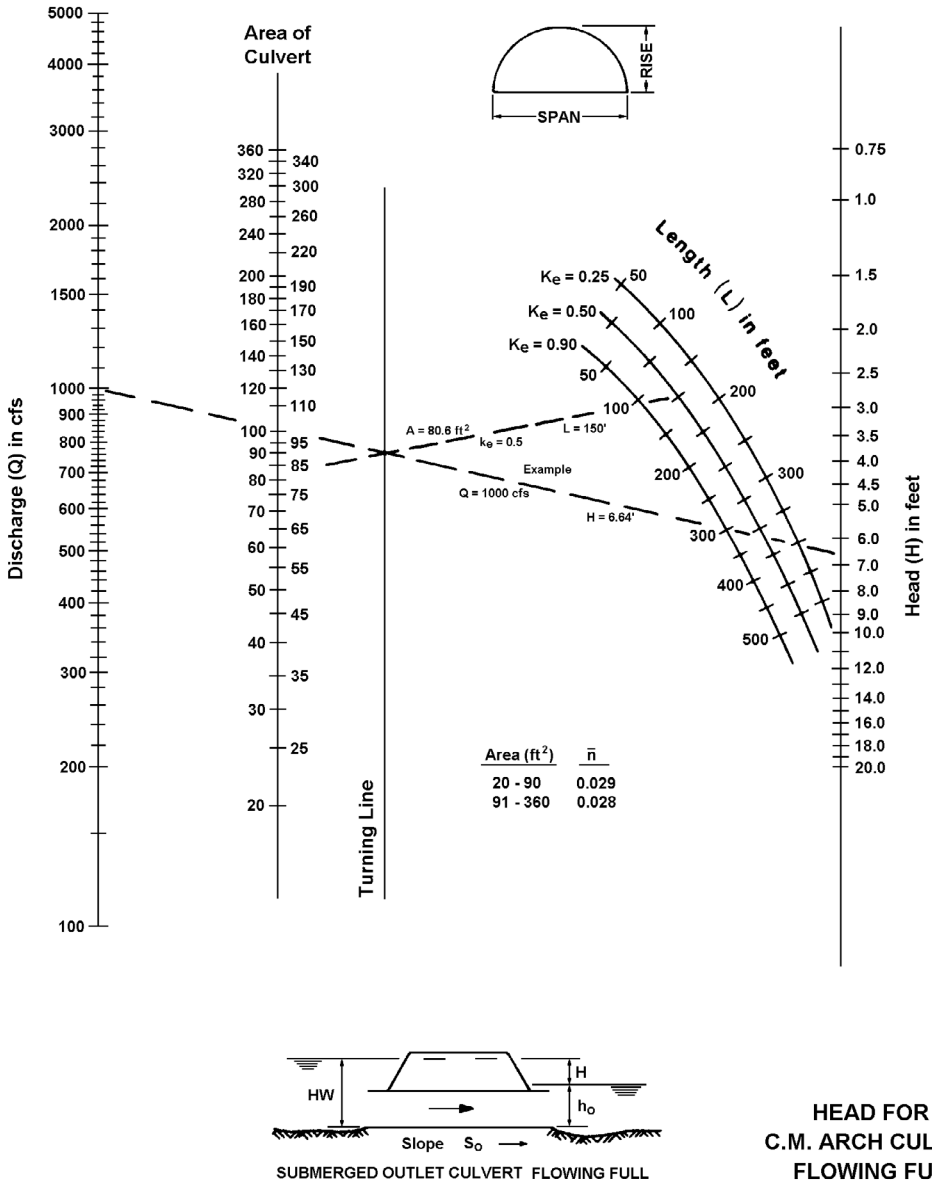


SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.3 ≤ RISE/SPAN < 0.4

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

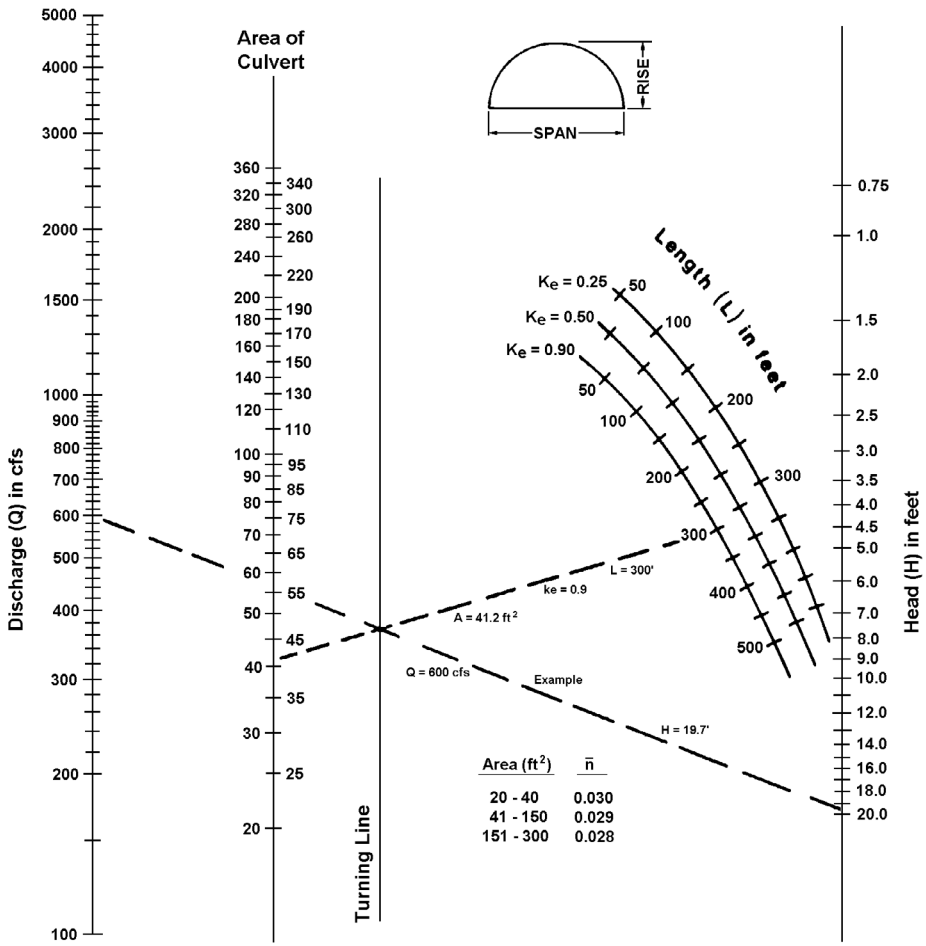
CHART 49

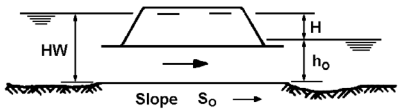


HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 50



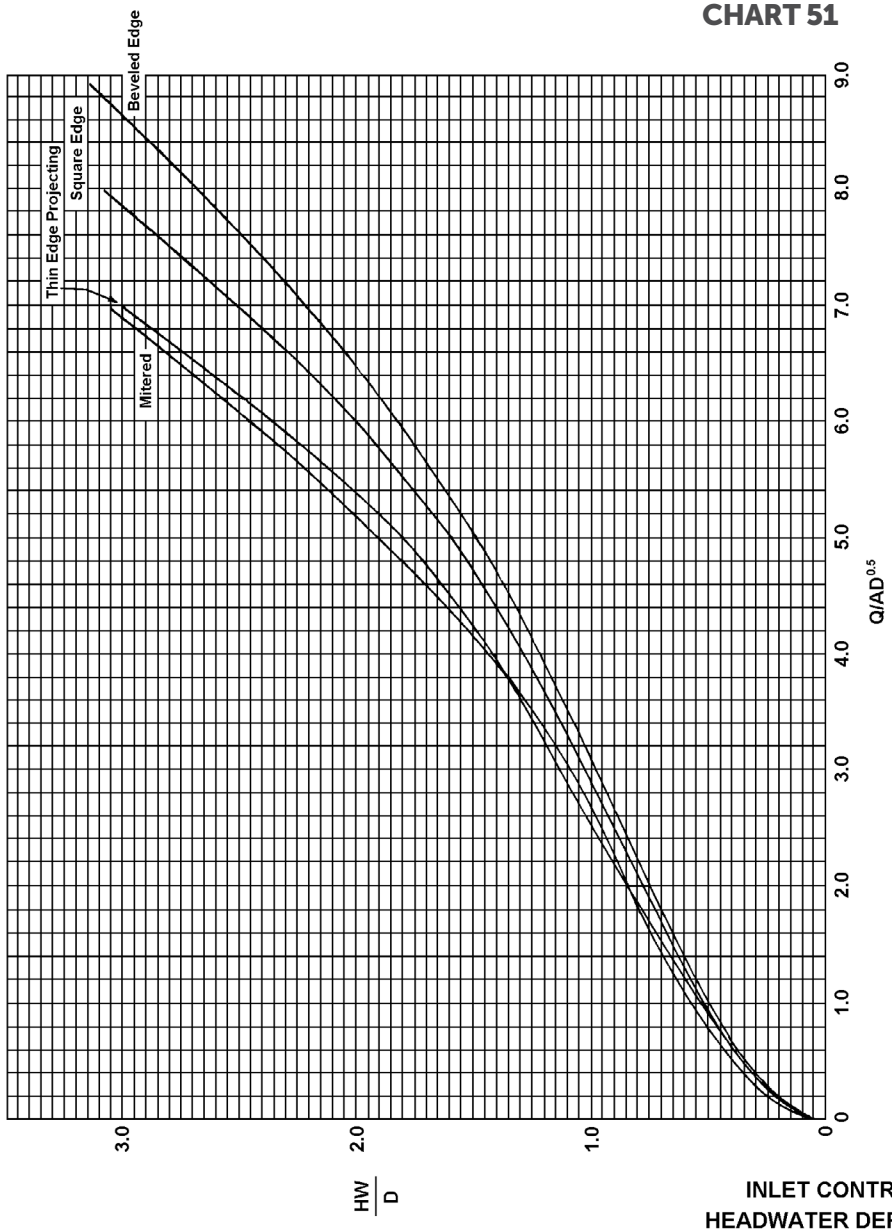


SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.5 ≤ RISE/SPAN

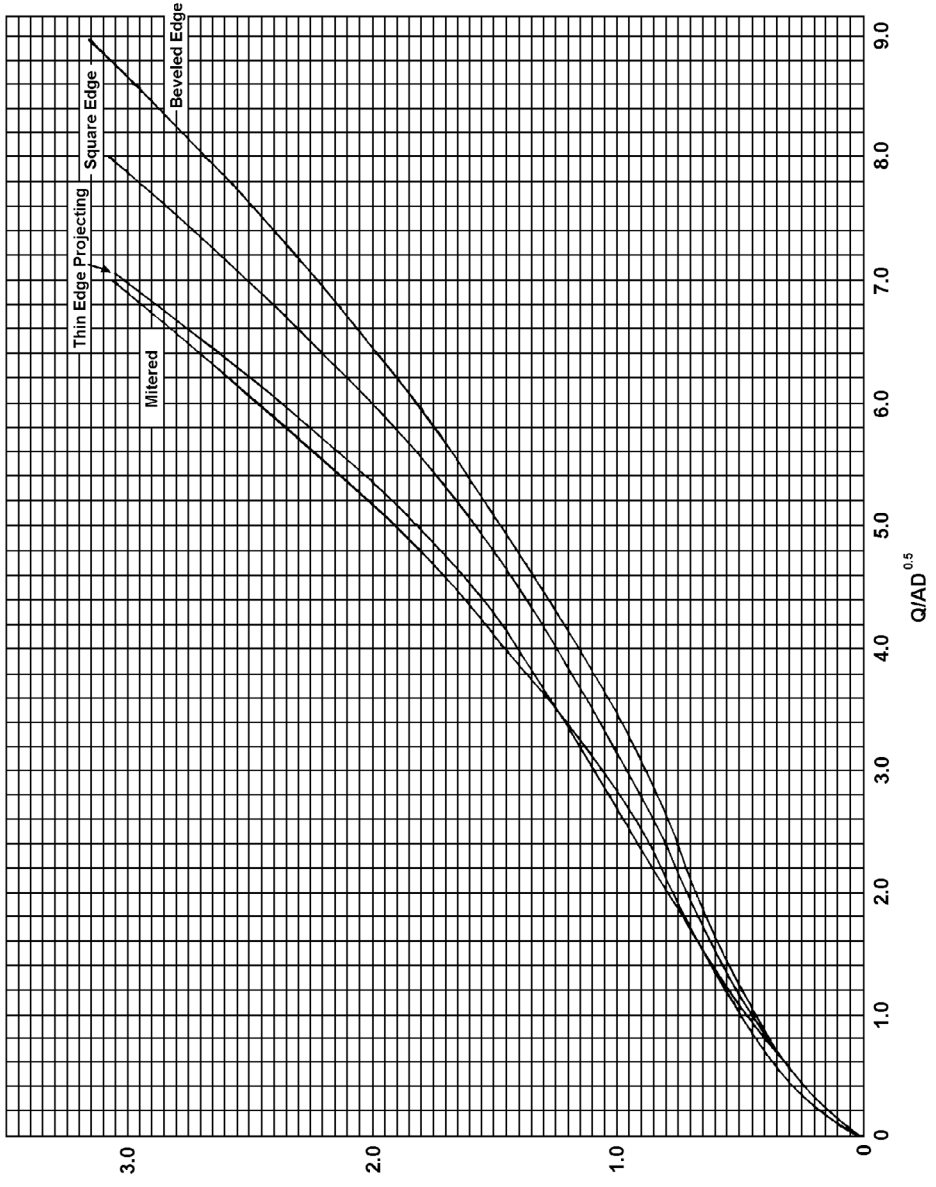
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 51



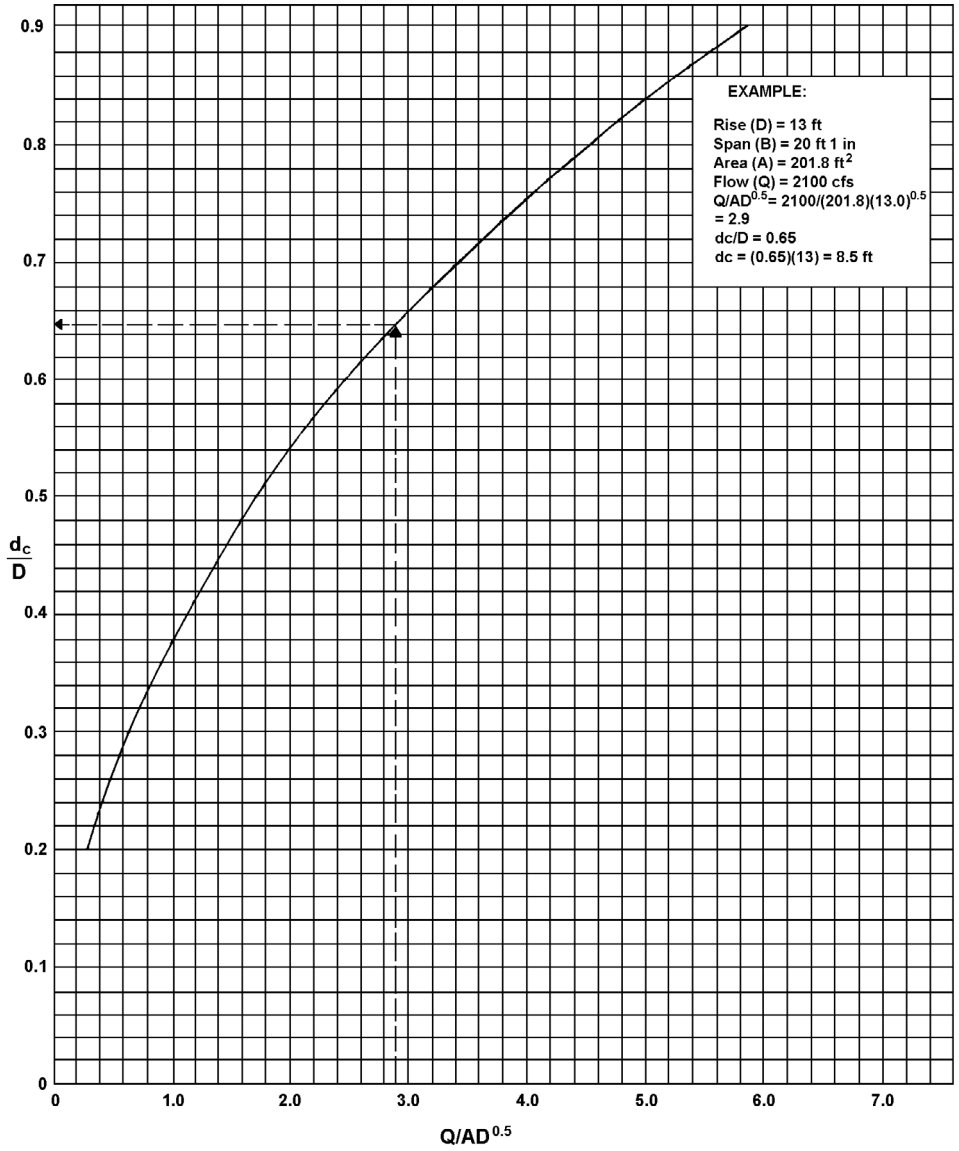
INLET CONTROL
HEADWATER DEPTH FOR
CIRCULAR OR ELLIPTICAL
STRUCTURAL PLATE
C.M. CONDUITS

CHART 52



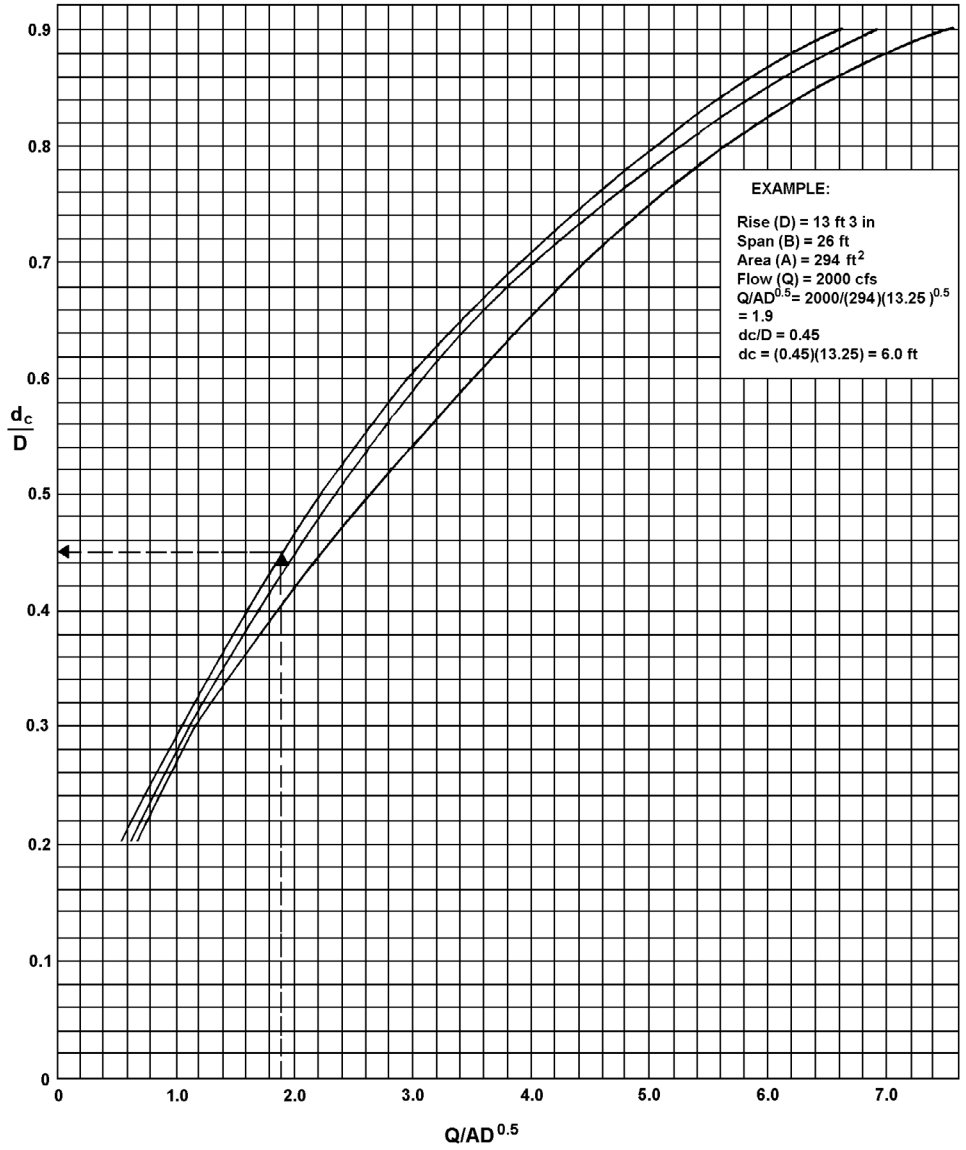
INLET CONTROL
HEADWATER DEPTH FOR
HIGH AND LOW PROFILE
STRUCTURAL PLATE
C.M. ARCH

CHART 53



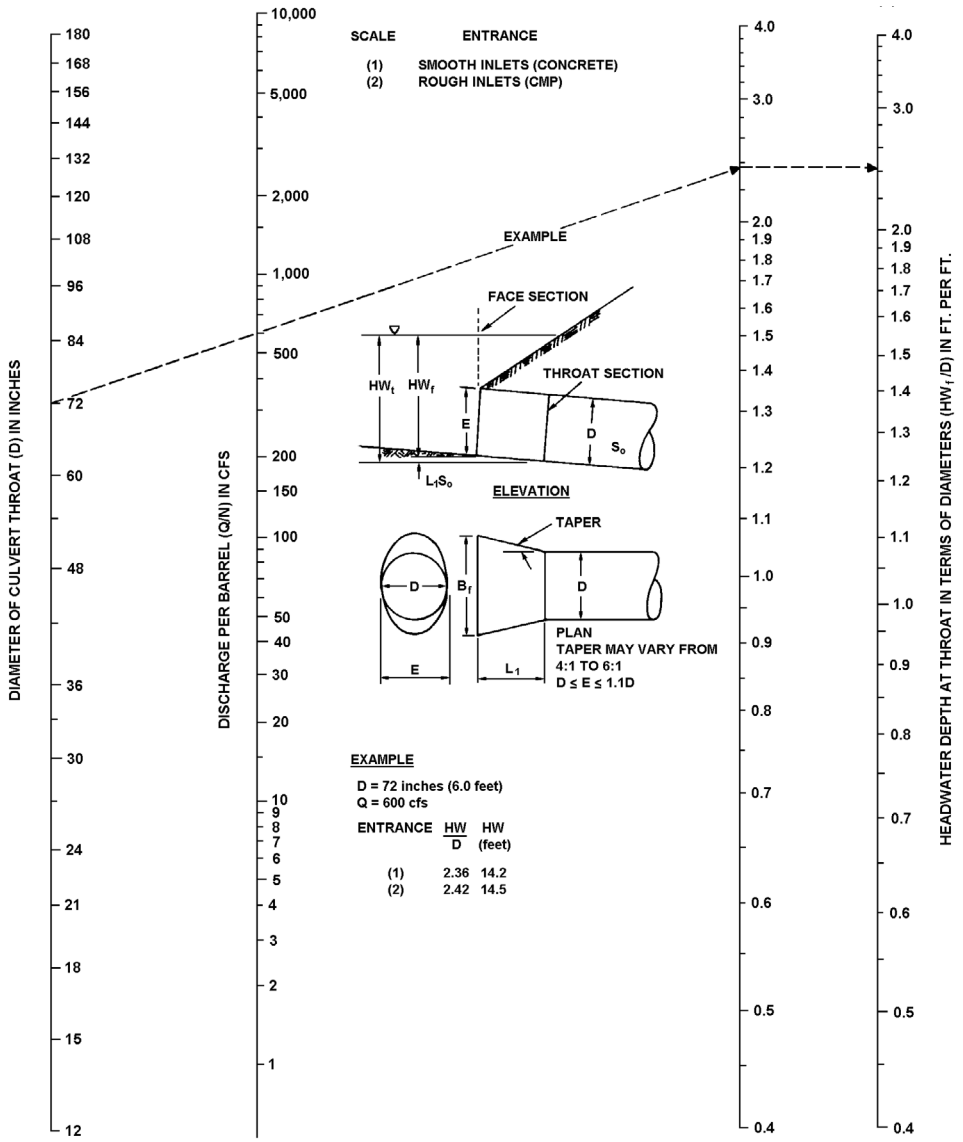
DIMENSIONLESS CRITICAL DEPTH CHART
FOR STRUCTURAL PLATE
ELLIPSE LONG AXIS HORIZONTAL

CHART 54



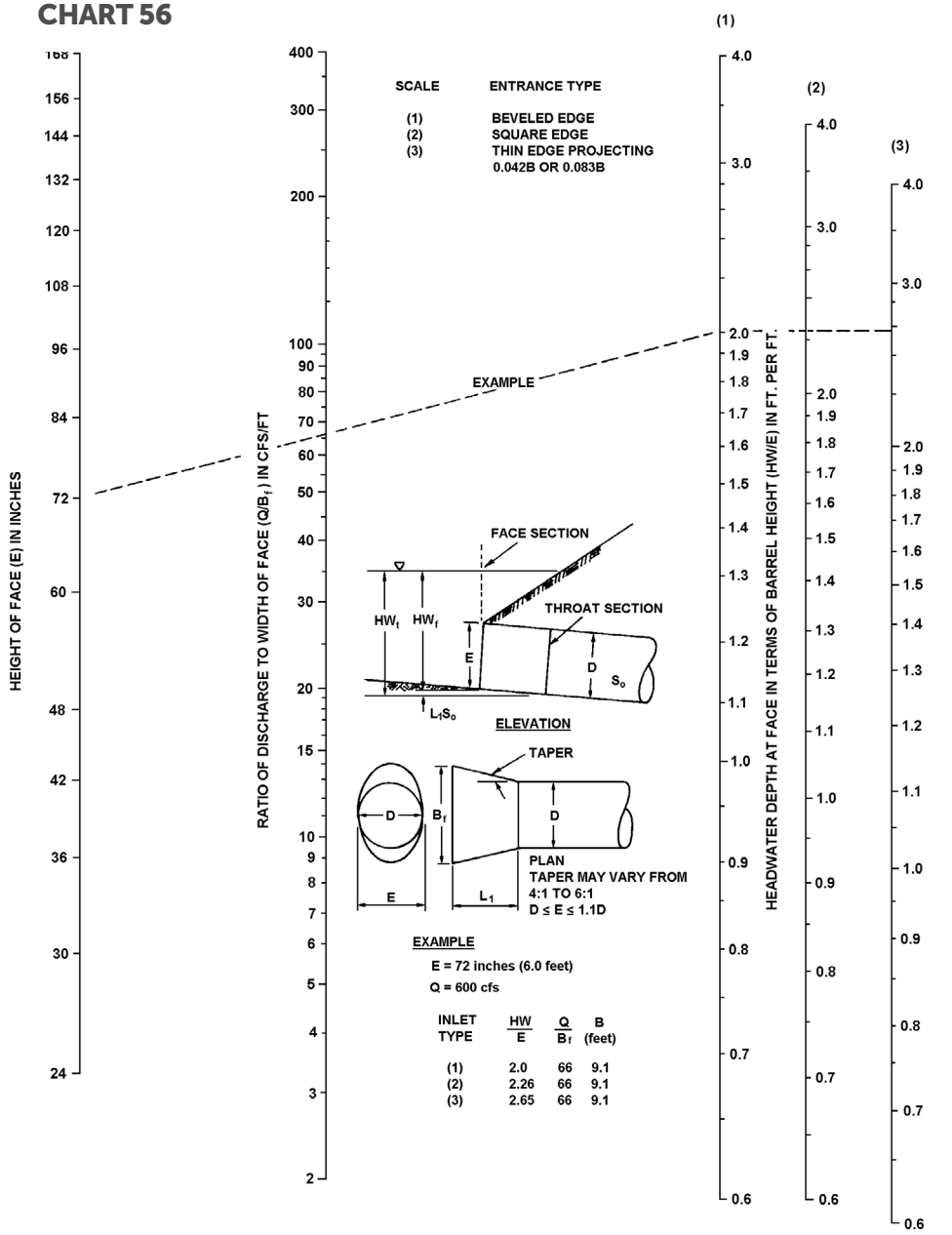
DIMENSIONLESS CRITICAL DEPTH CHART
FOR STRUCTURAL PLATE
LOW- AND HIGH-PROFILE ARCHES

CHART 55

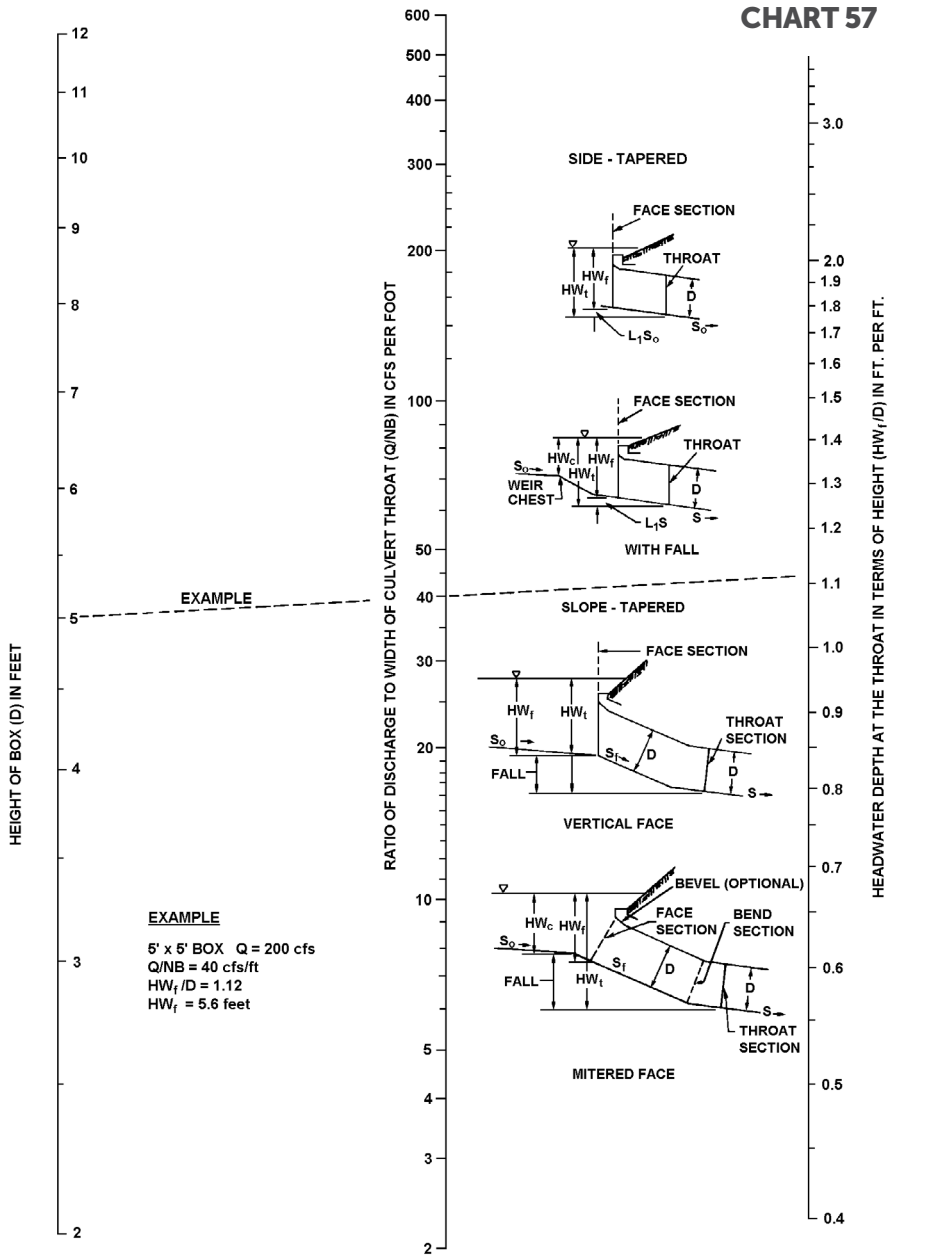


THROAT CONTROL
FOR SIDE-TAPERED INLETS
TO PIPE CULVERT
(CIRCULAR SECTION ONLY)

CHART 56

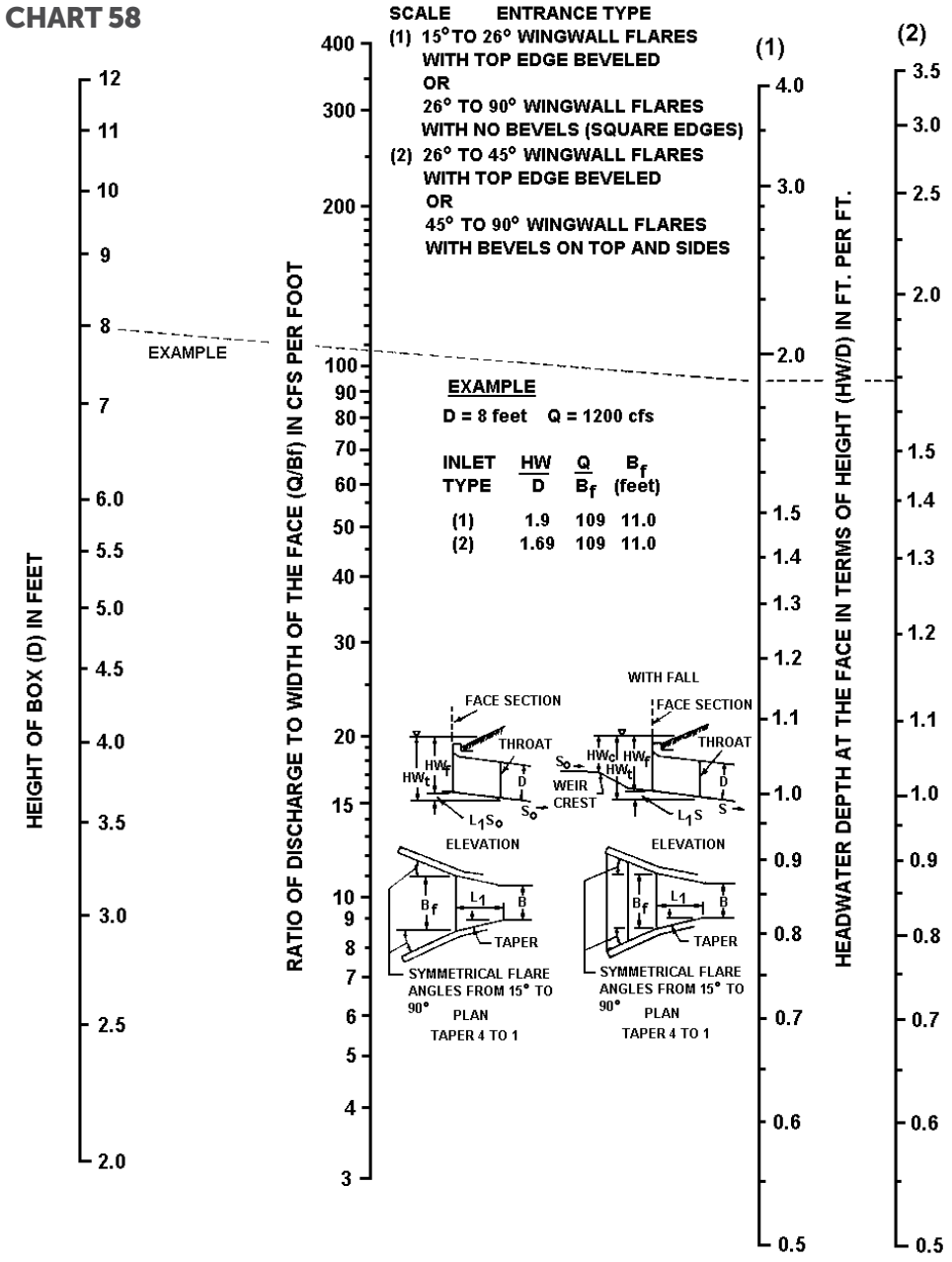


FACE CONTROL FOR SIDE-TAPERED INLETS TO PIPE CULVERTS (NON-RECTANGULAR SECTIONS ONLY)



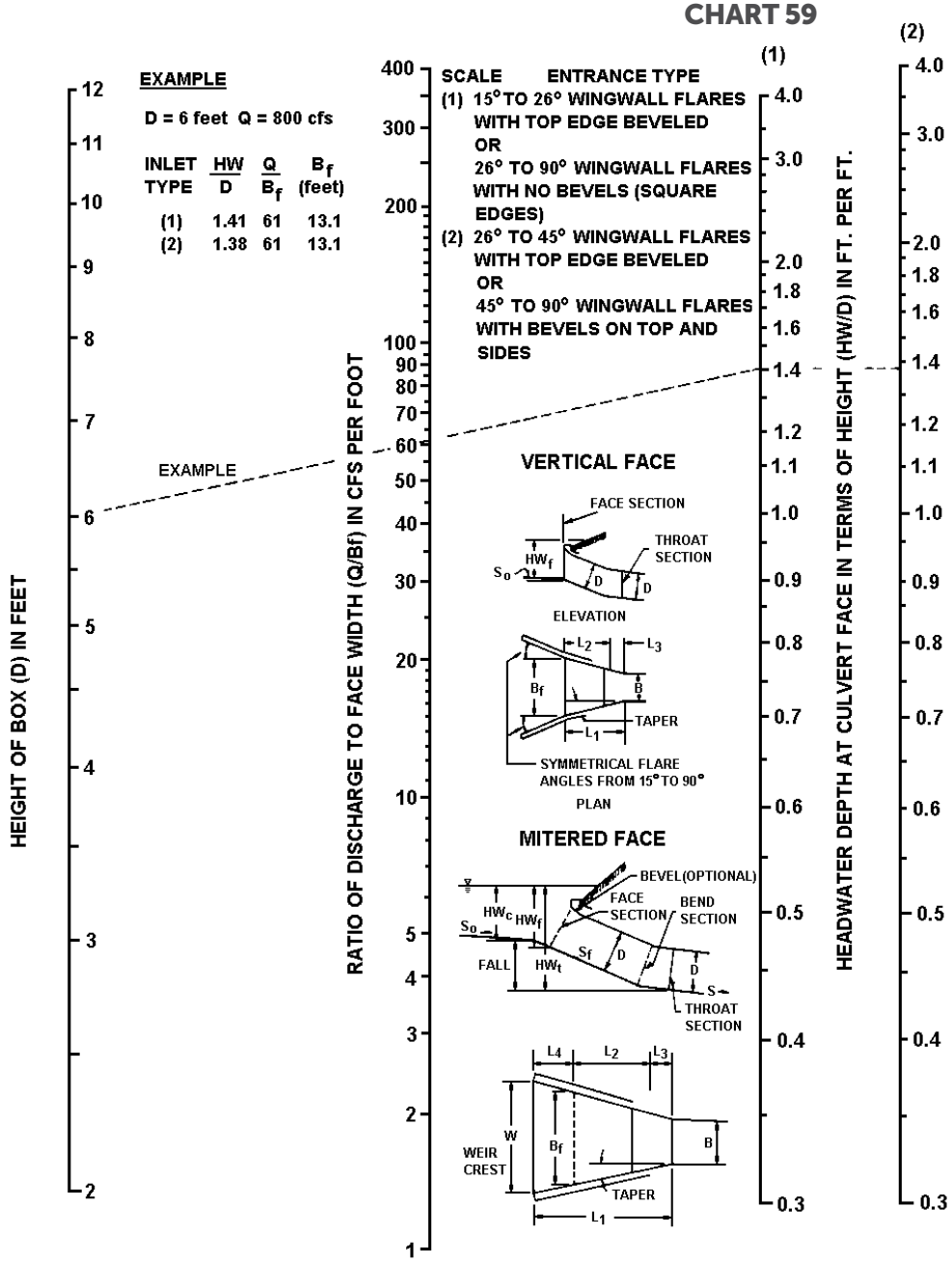
THROAT CONTROL FOR BOX CULVERTS WITH TAPERED INLETS

CHART 58



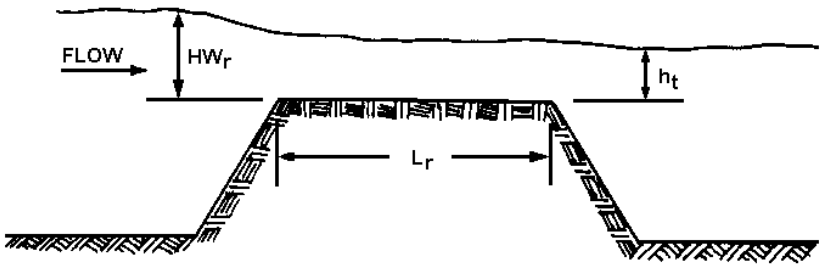
FACE CONTROL FOR BOX CULVERTS
WITH SIDE-TAPERED INLETS

CHART 59



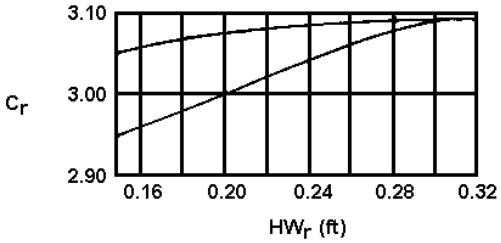
FACE CONTROL FOR BOX CULVERTS
WITH SLOPE TAPERED INLETS

CHART 60

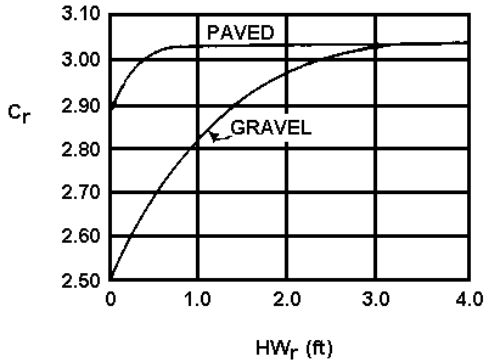


$C_d = k_t C_r$

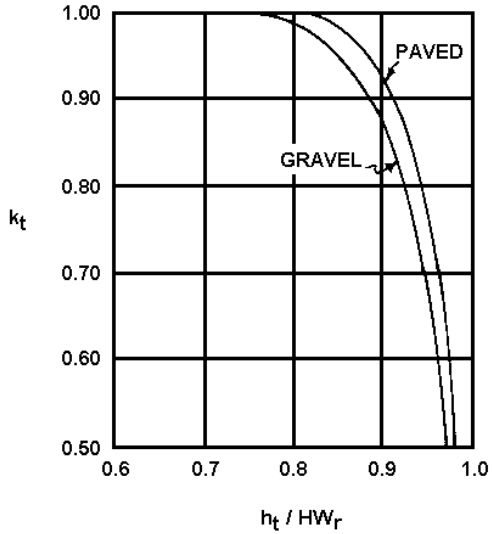
$Q_r = C_d L HW_r^{1.5}$



A) DISCHARGE COEFFICIENT FOR
$HW_r / L_r > 0.15$



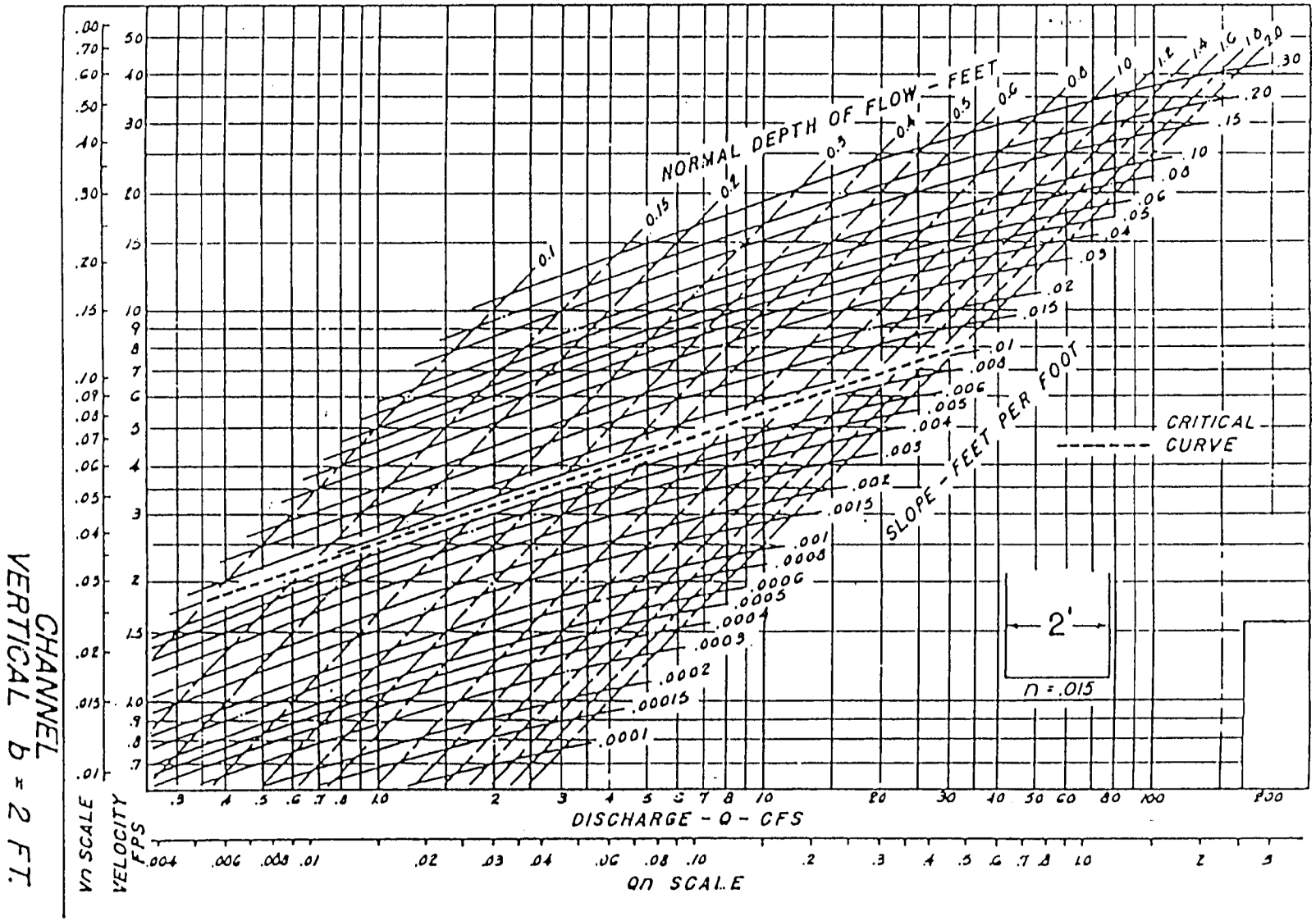
B) DISCHARGE COEFFICIENT FOR
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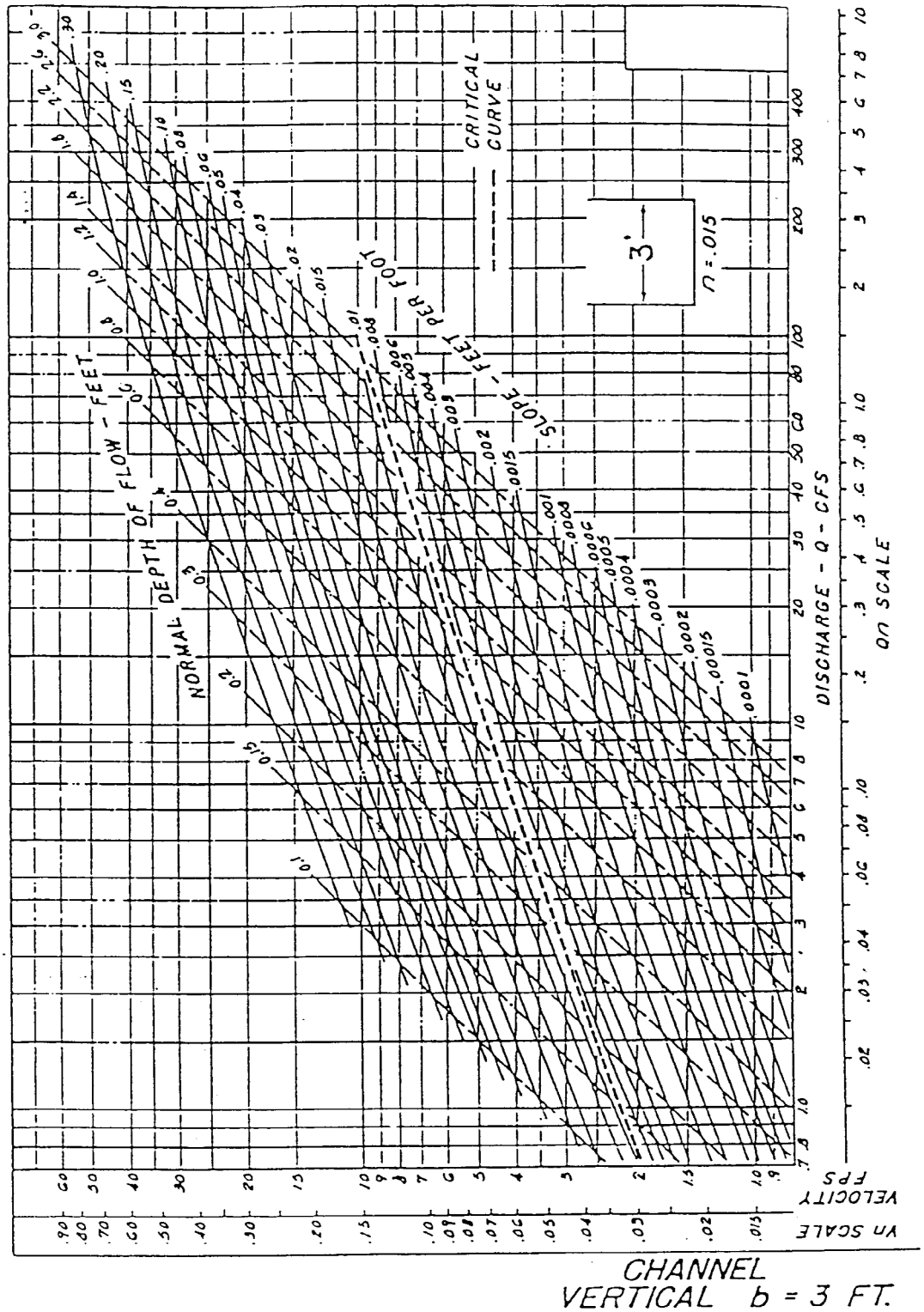
C) SUBMERGENCE FACTOR

DISCHARGE COEFFICIENTS FOR ROADWAY OVERTOPPING

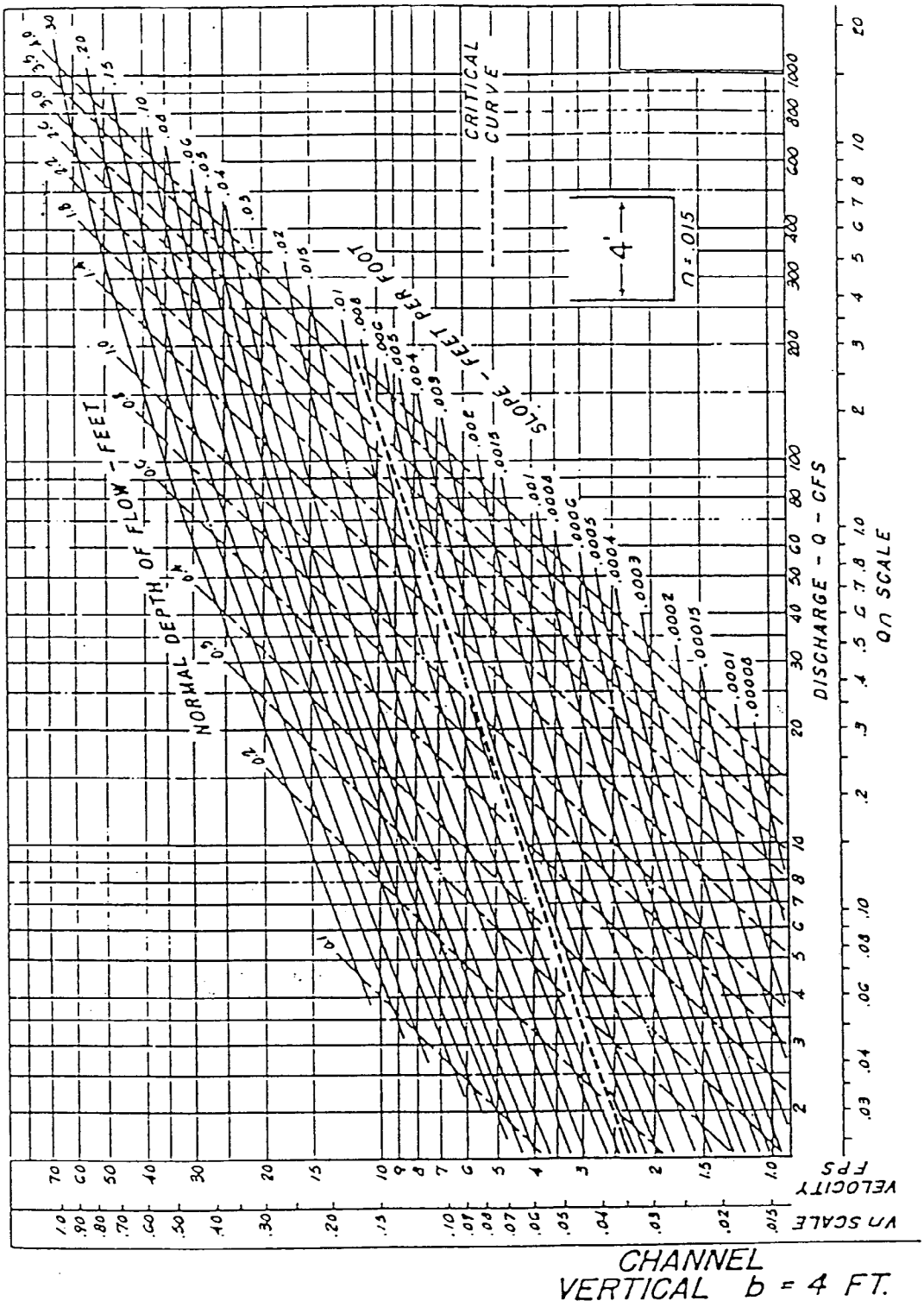
C-2 Open Channel Design Figures



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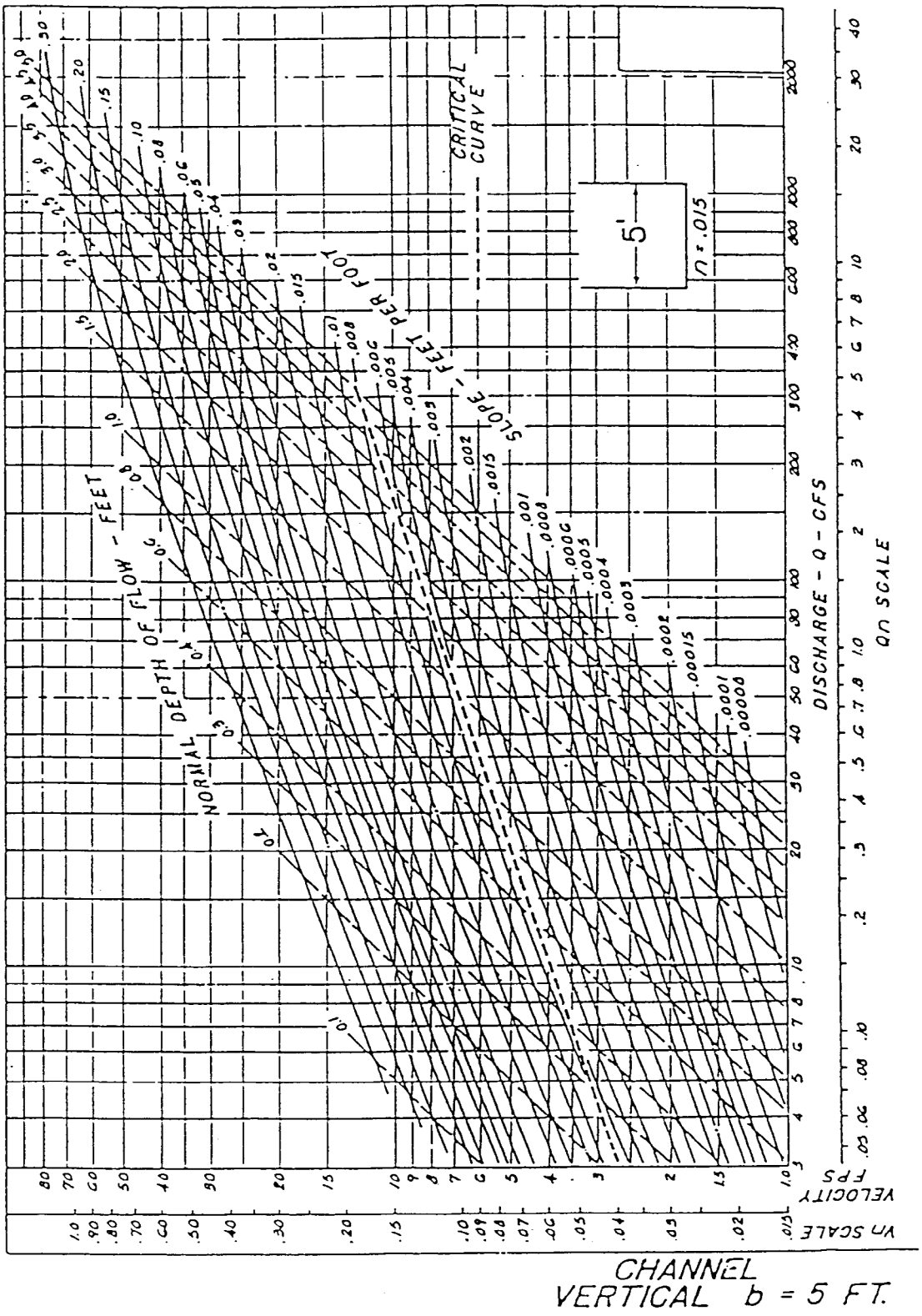


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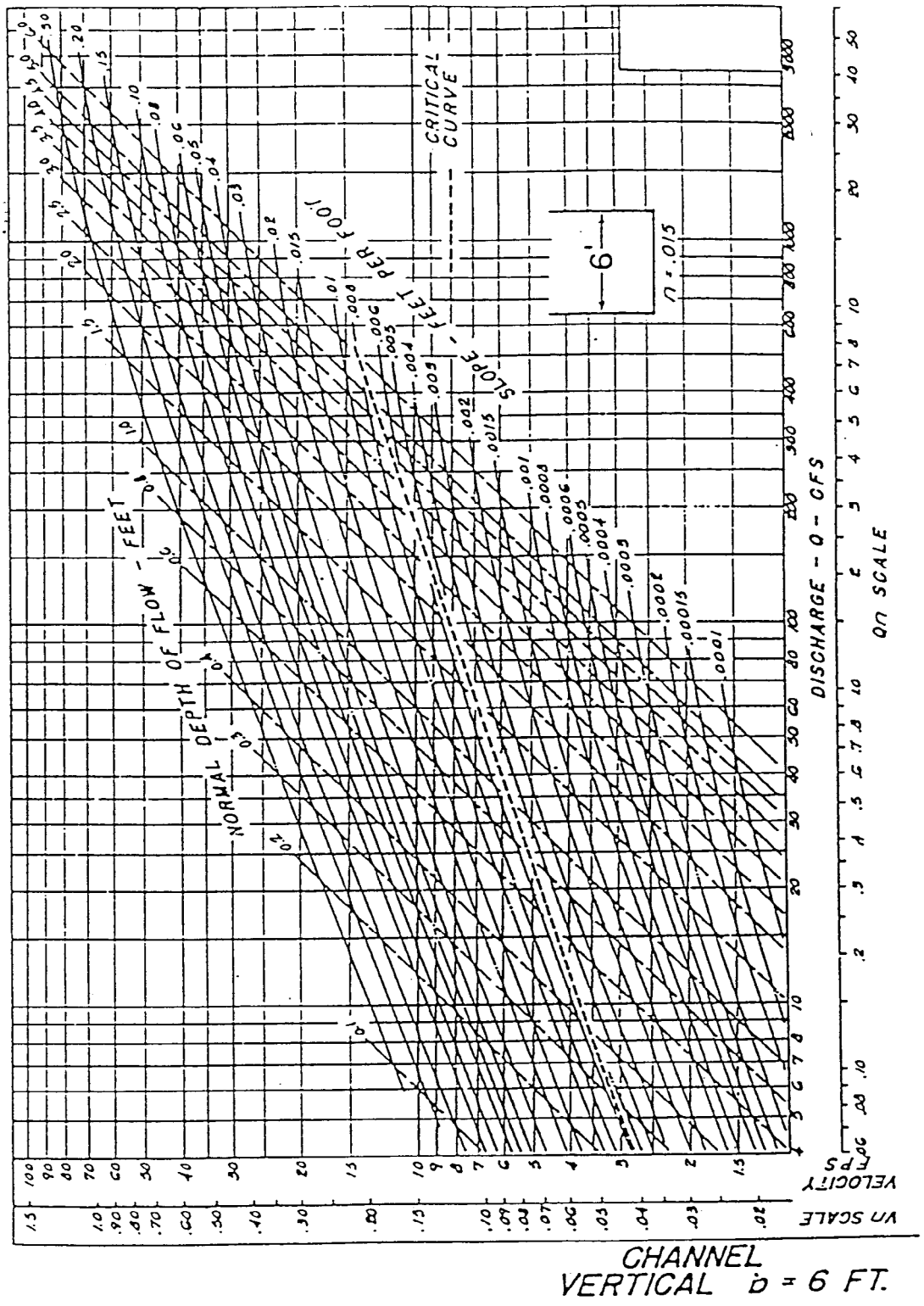
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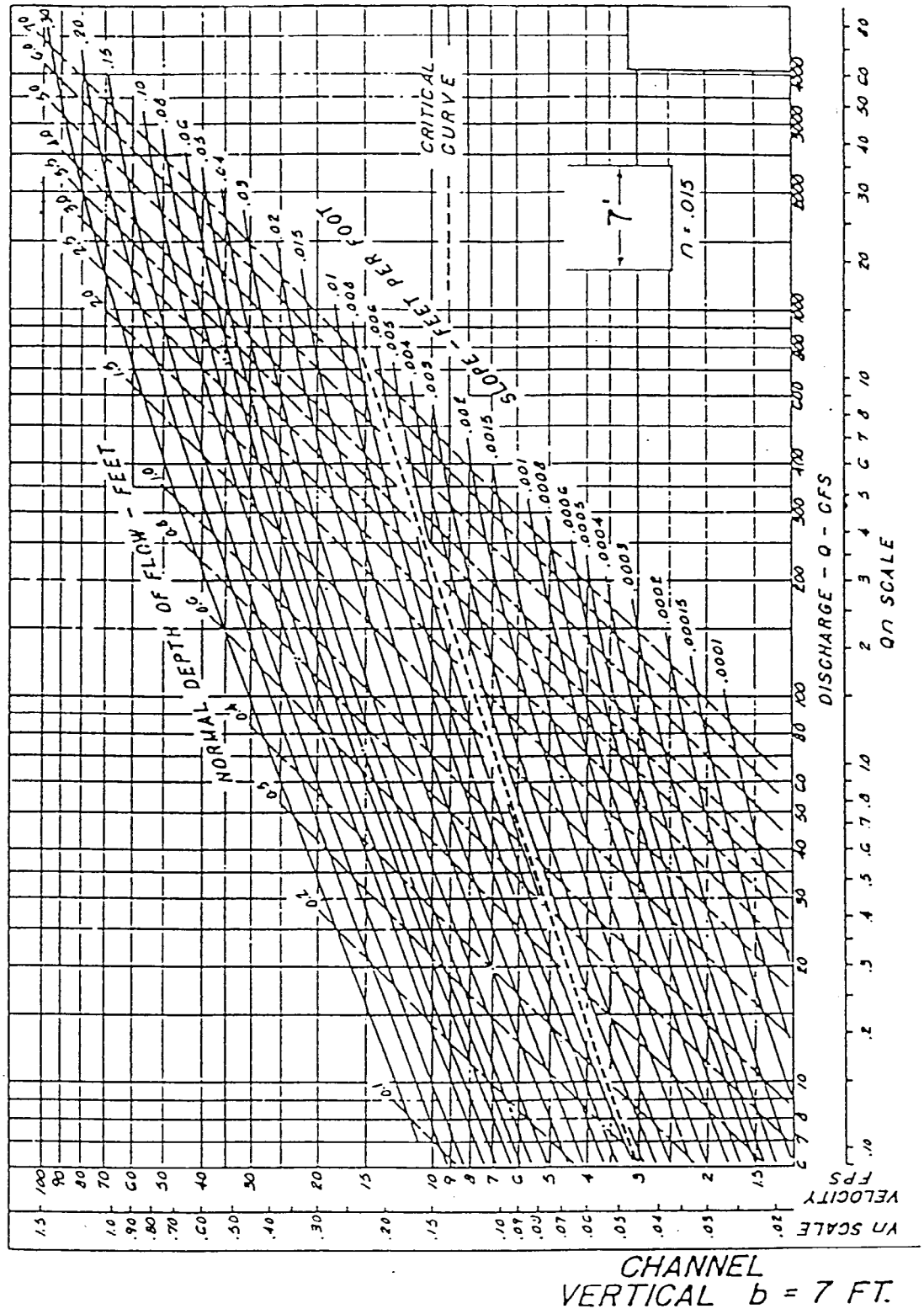
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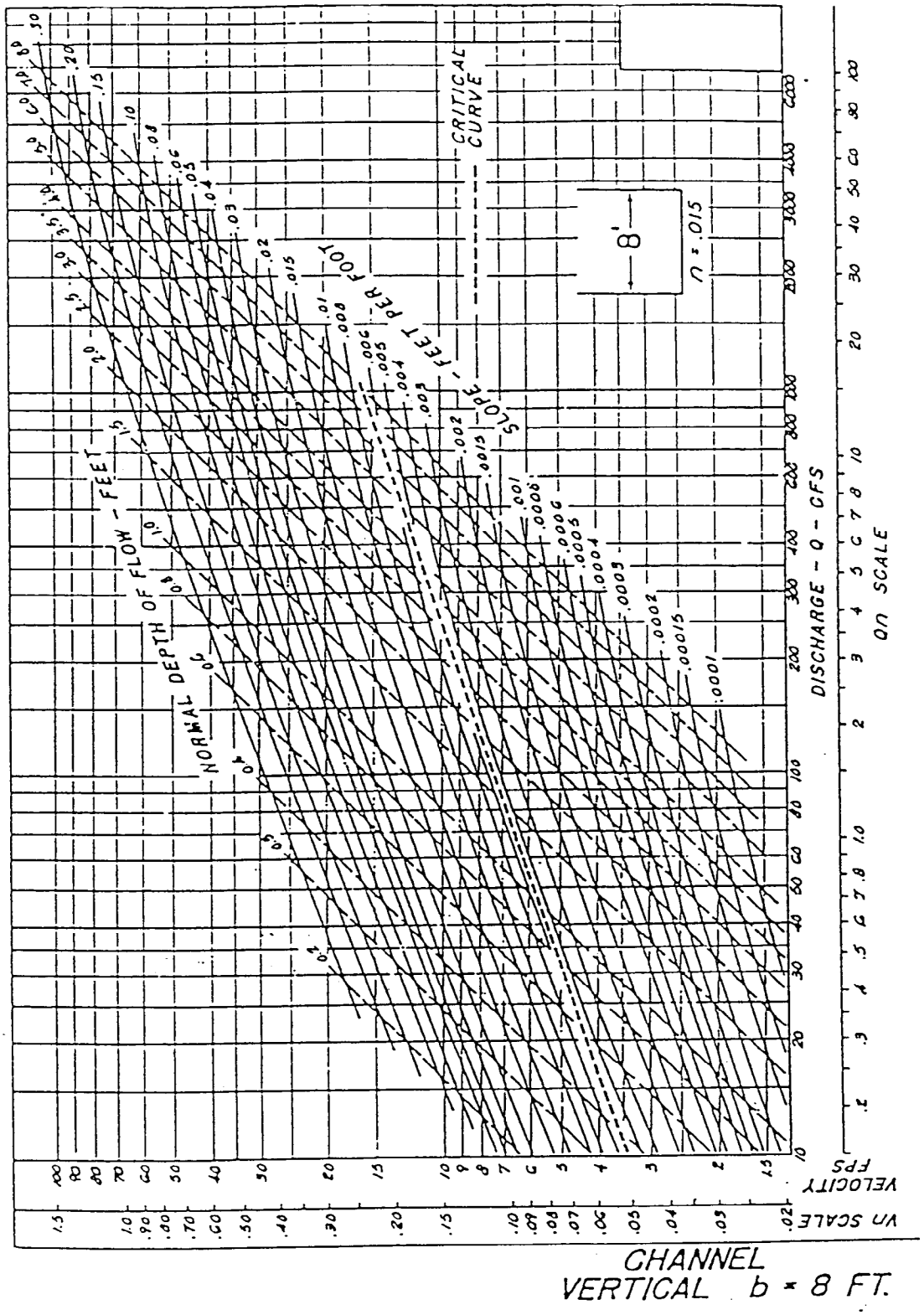


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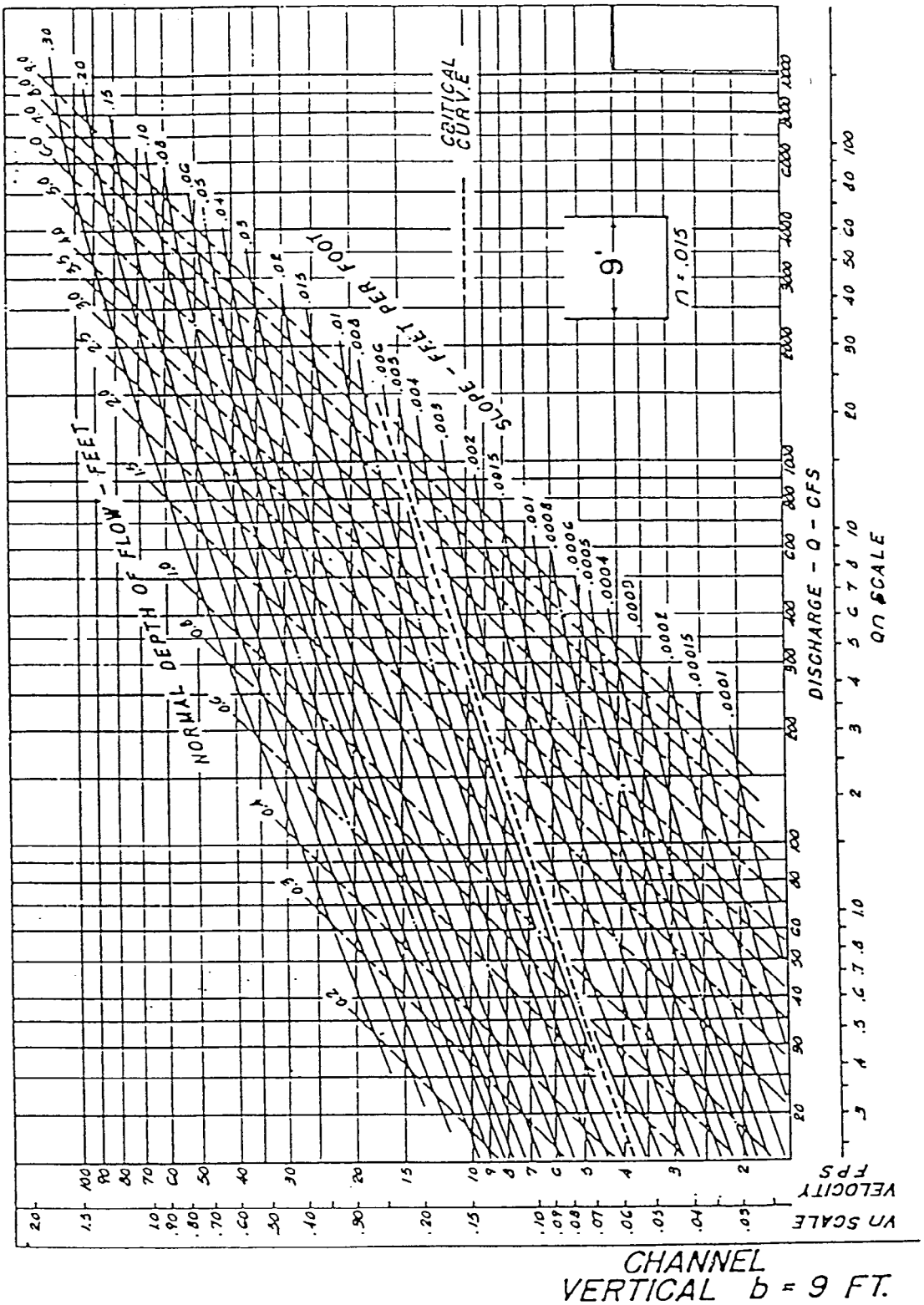
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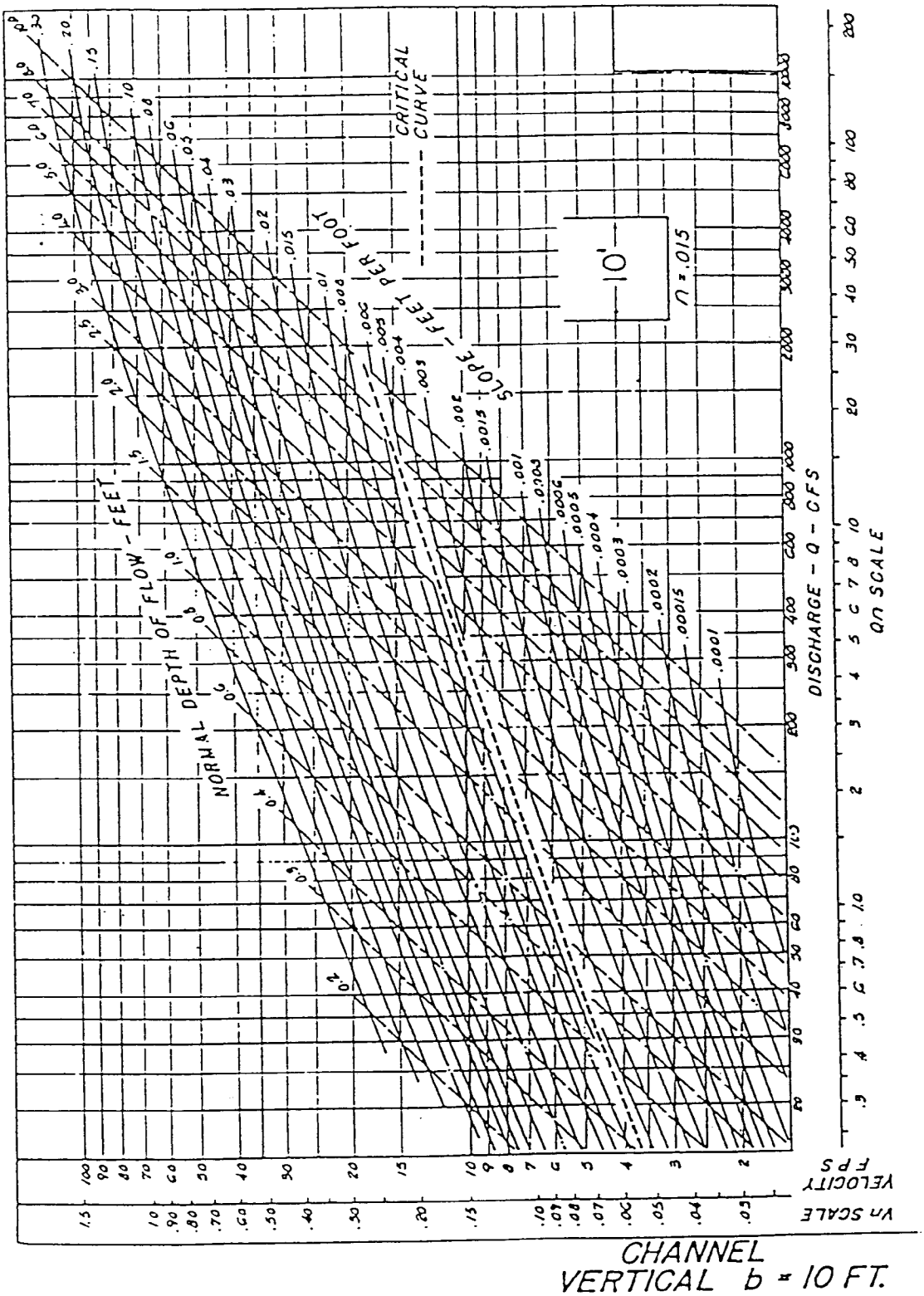
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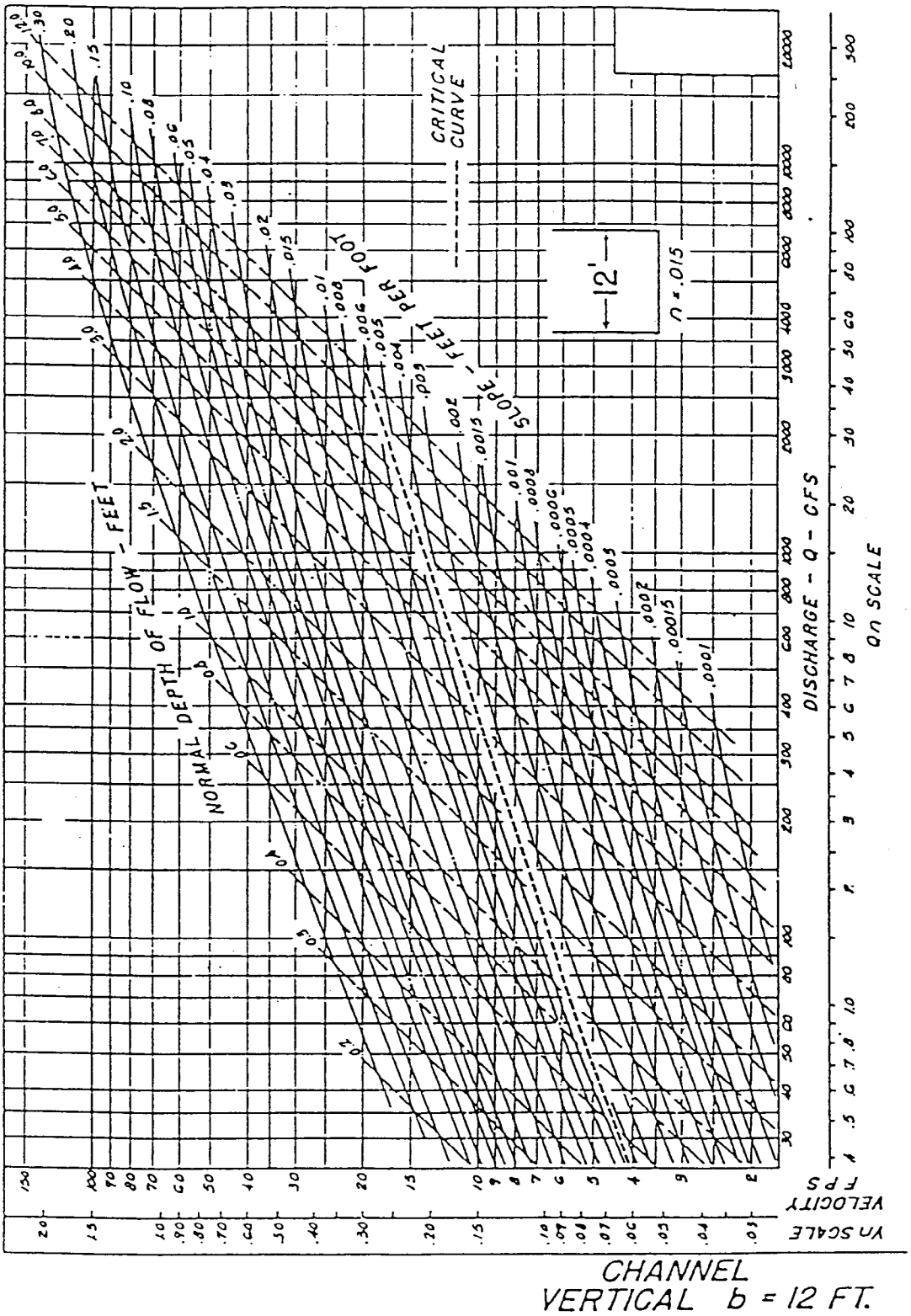


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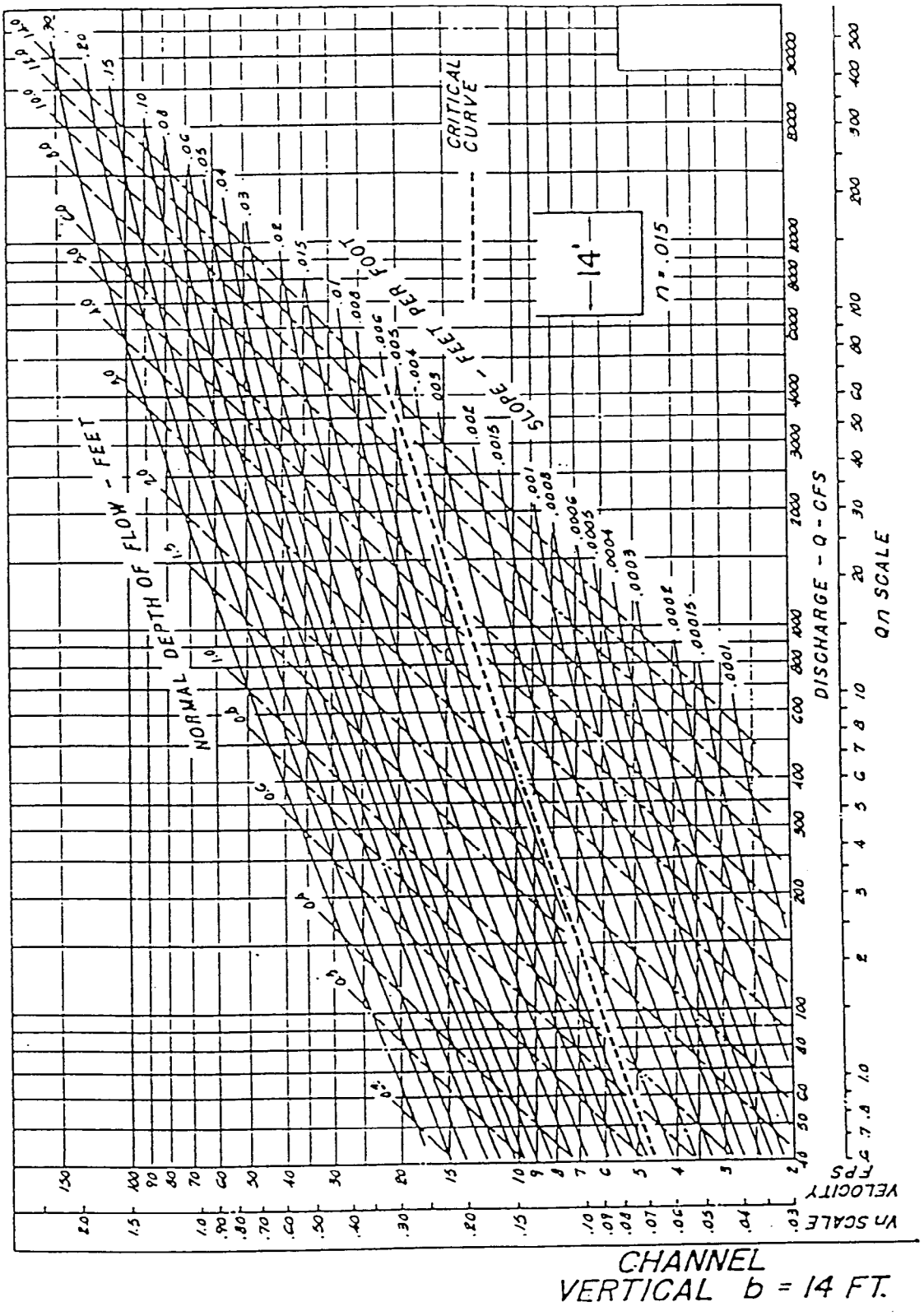
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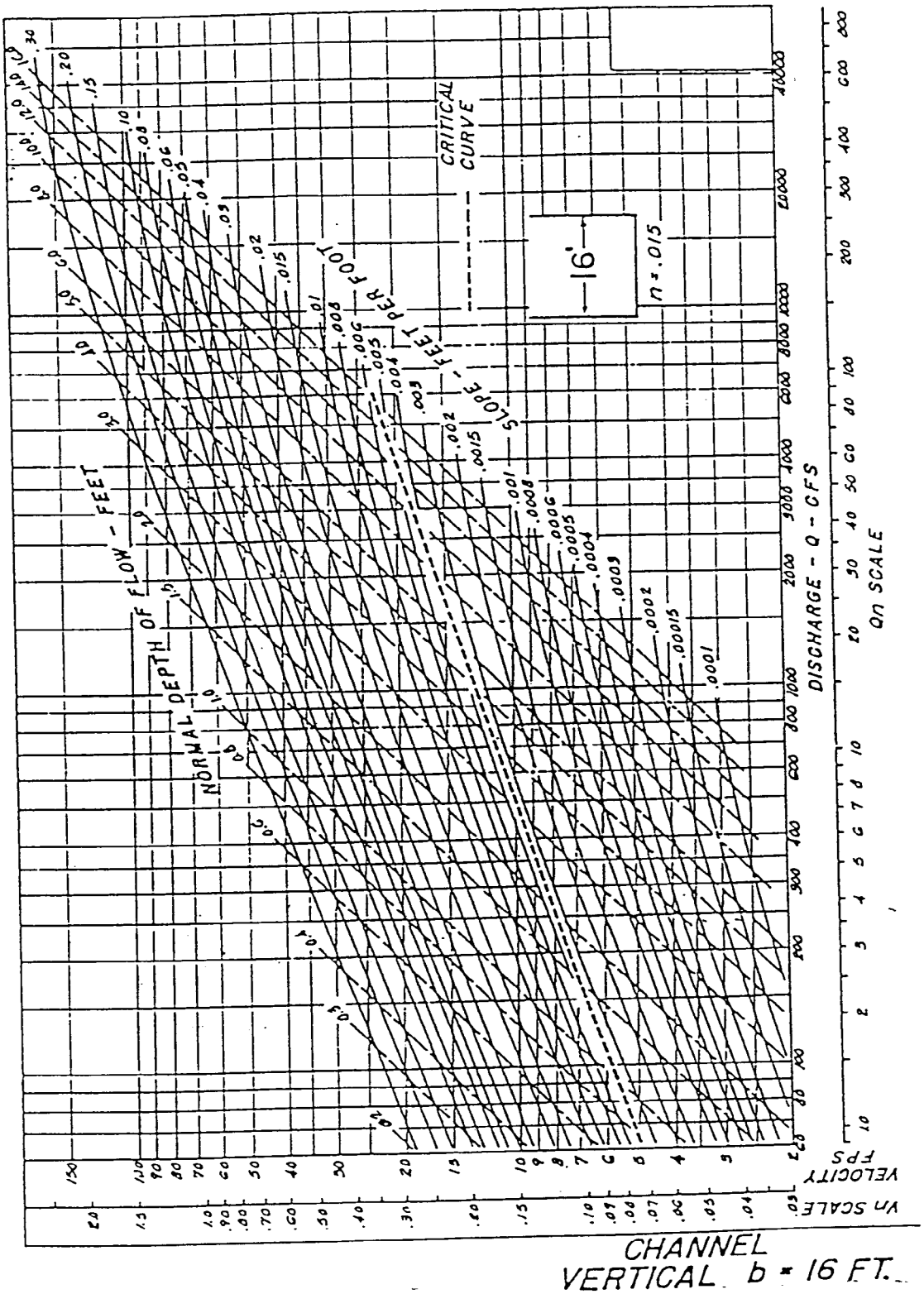
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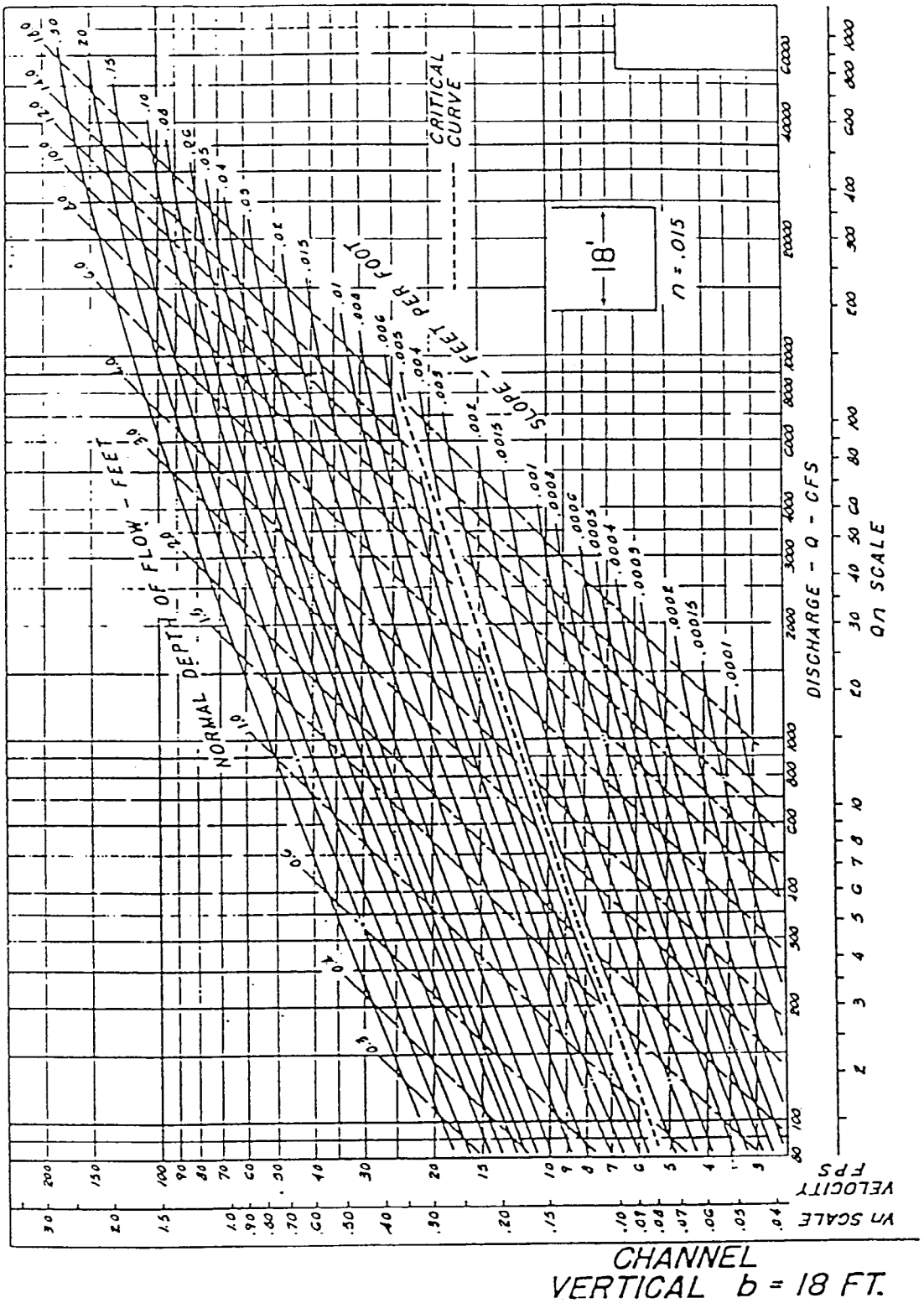


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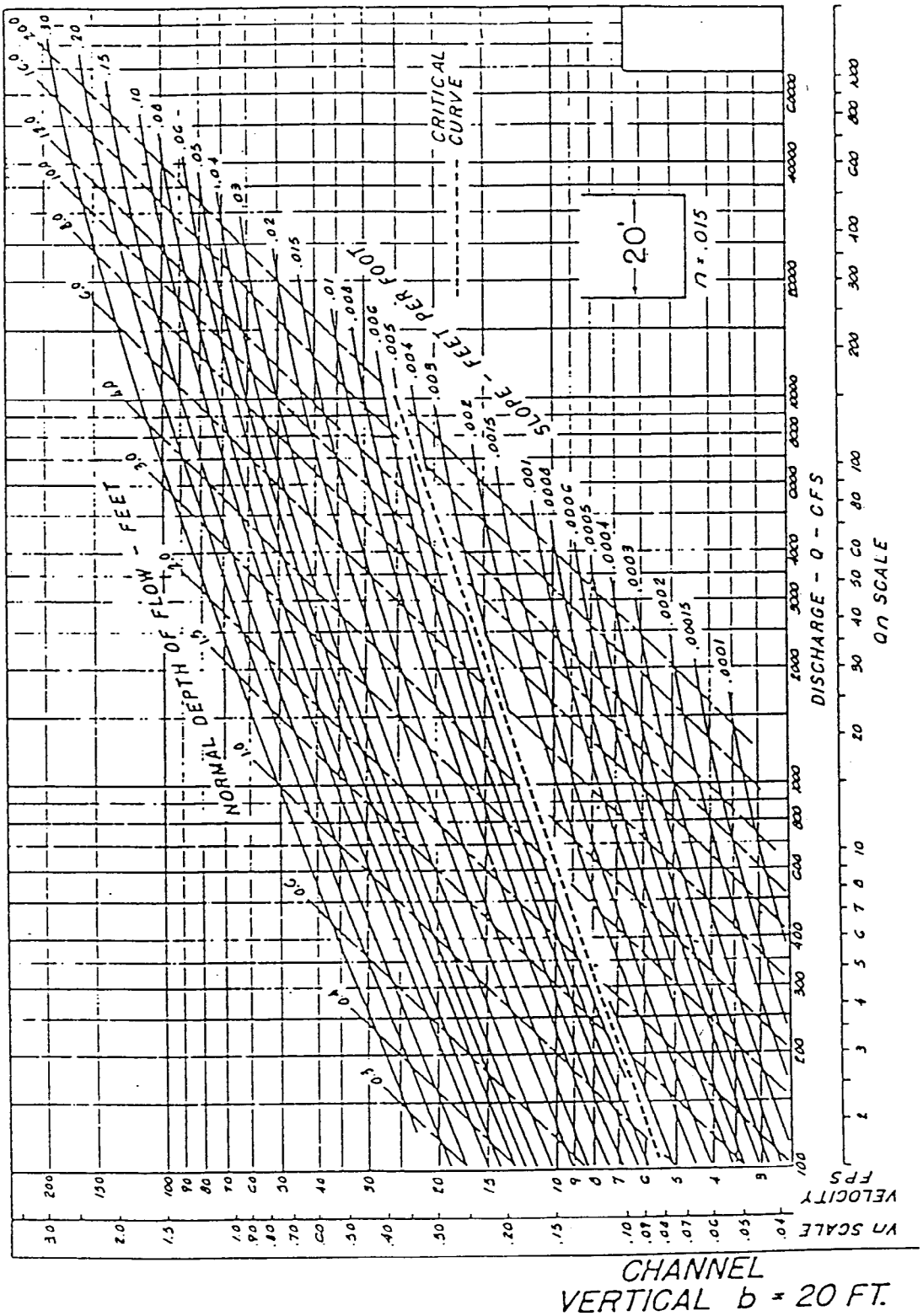


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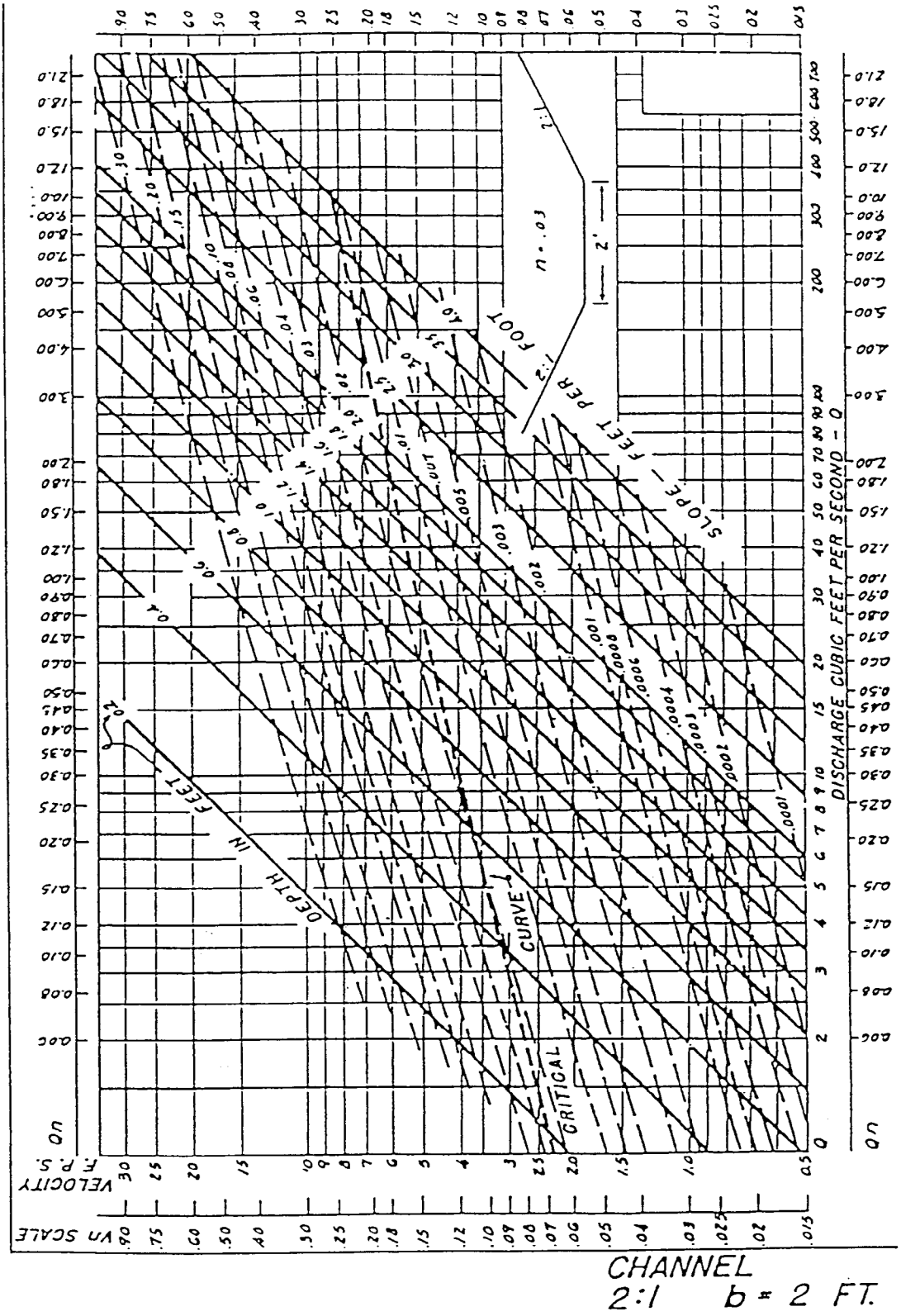


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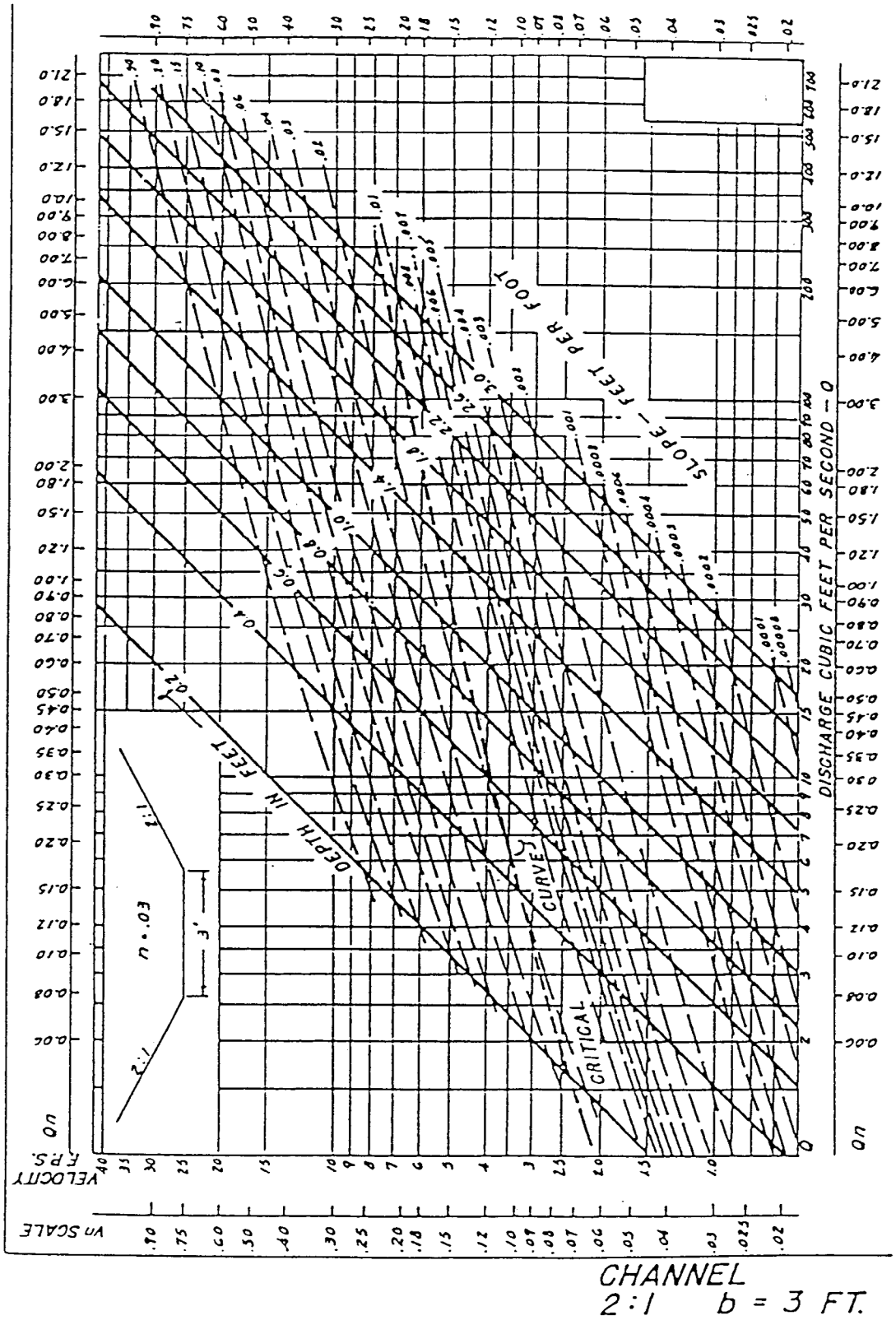


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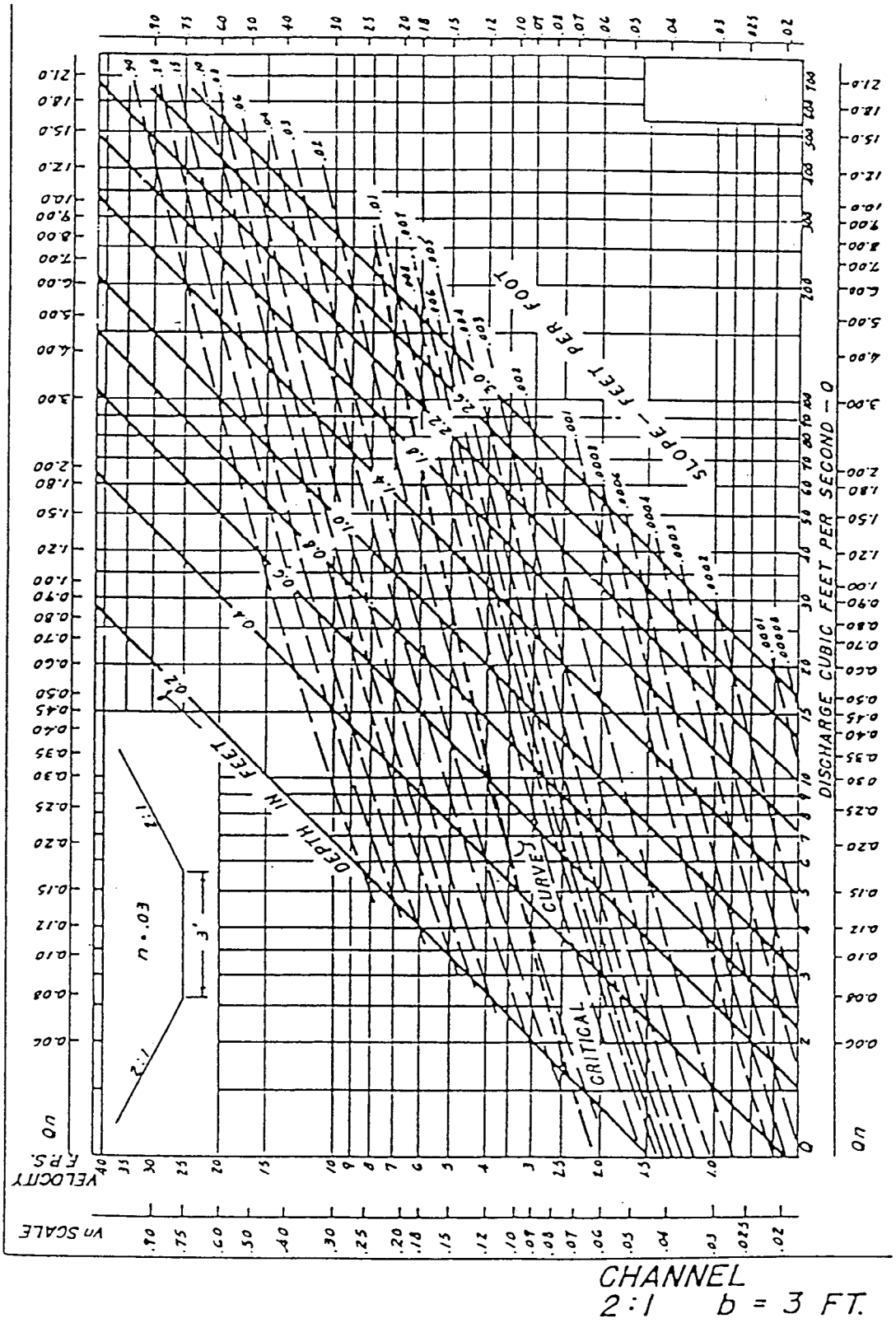


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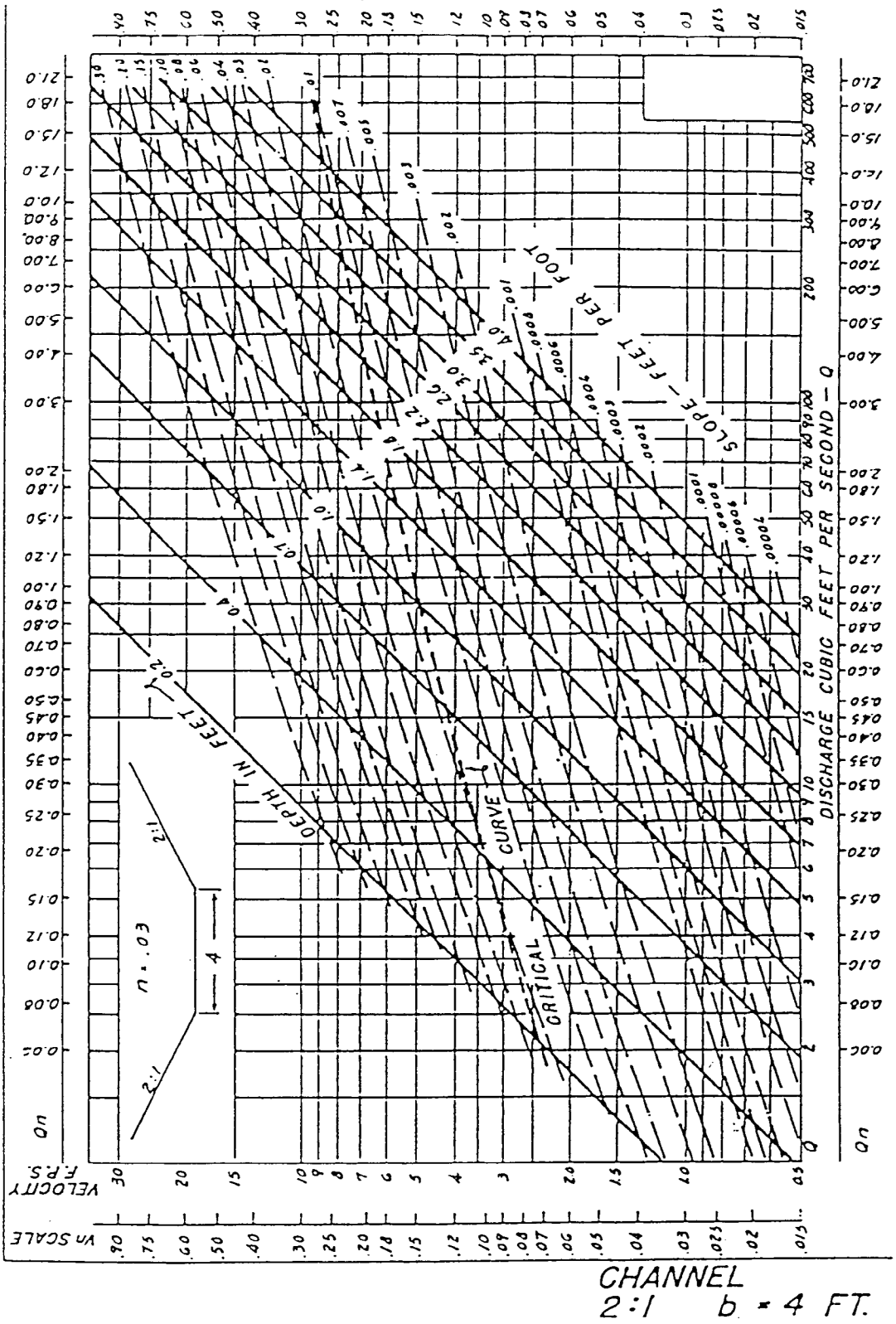


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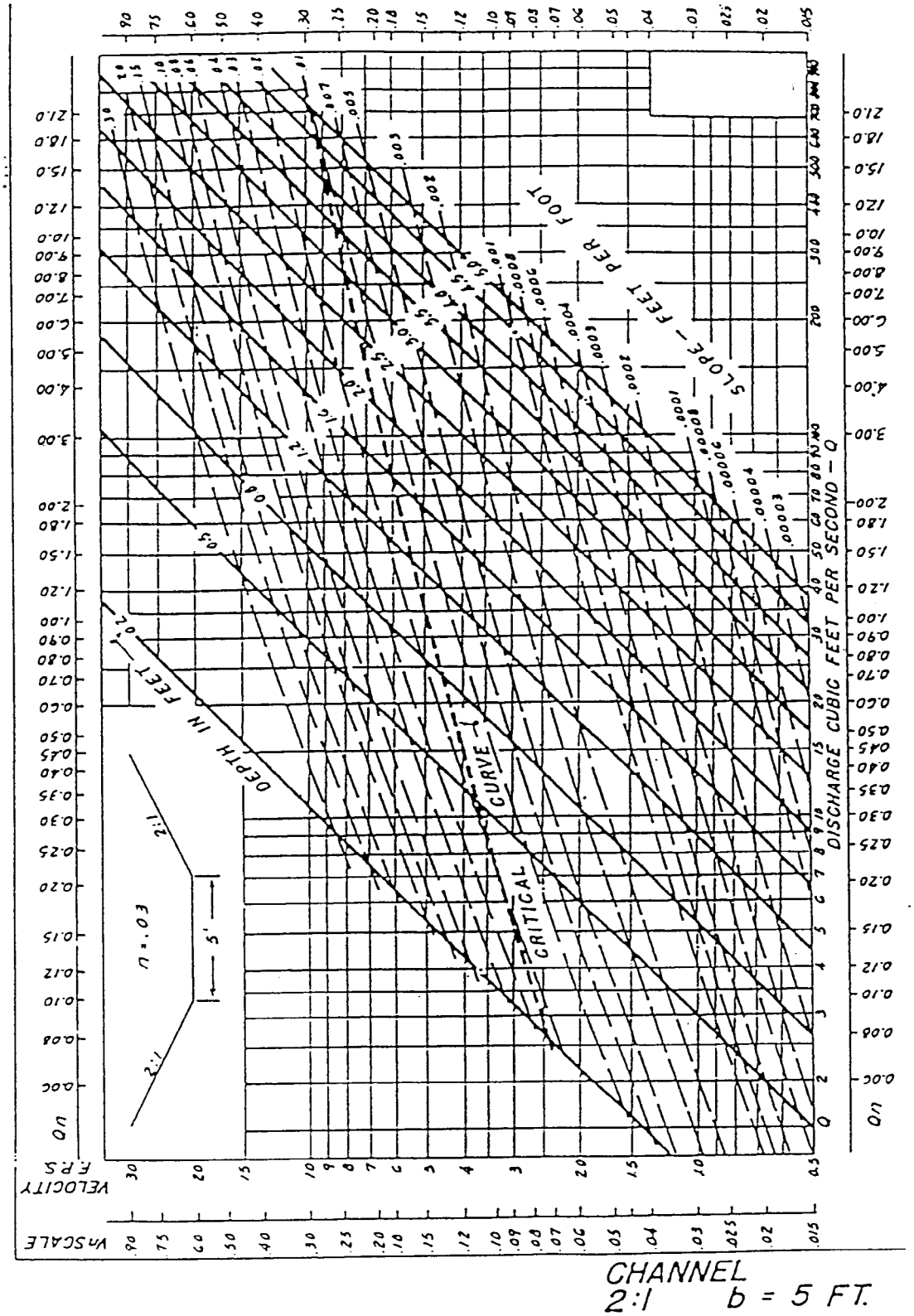


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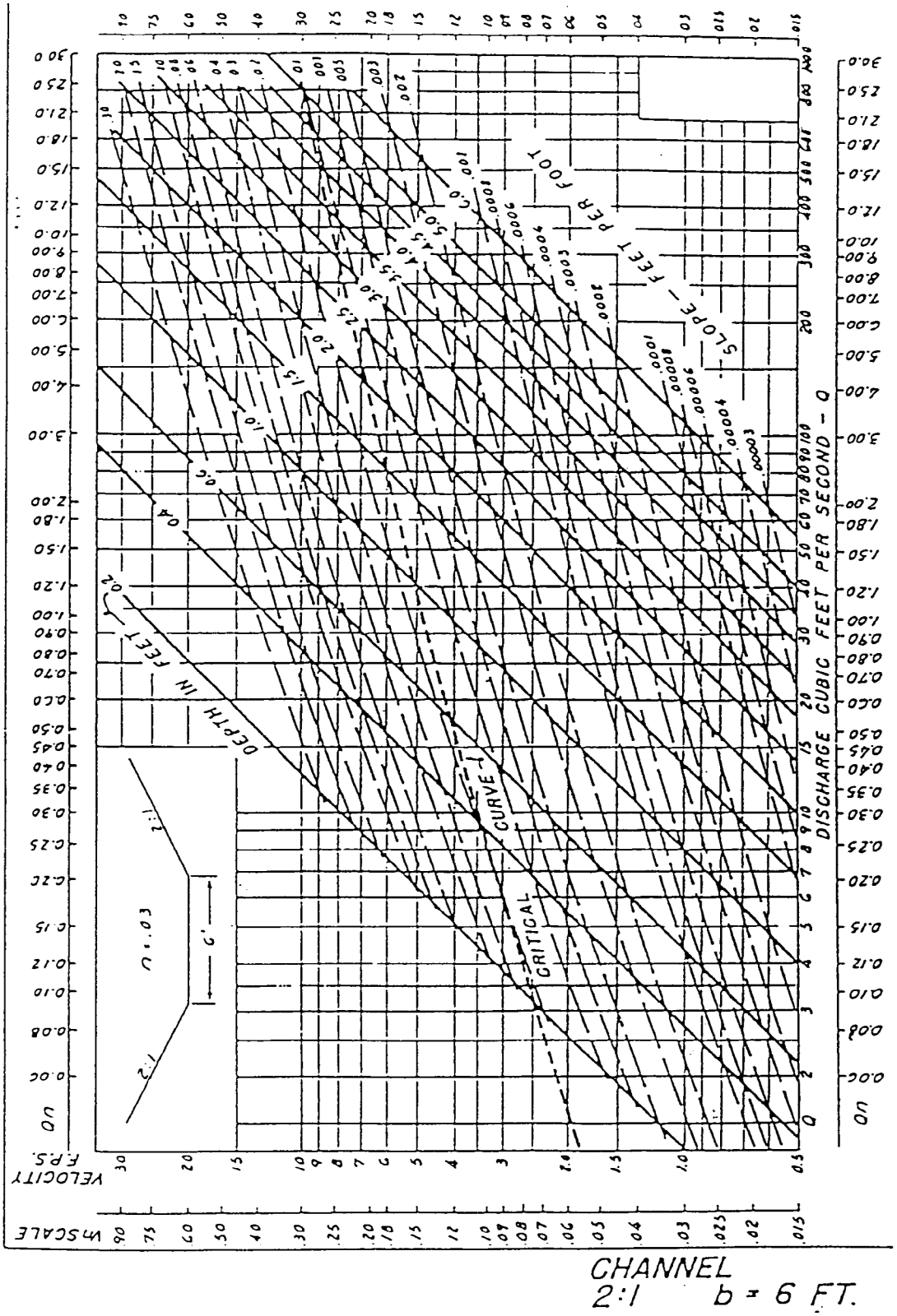


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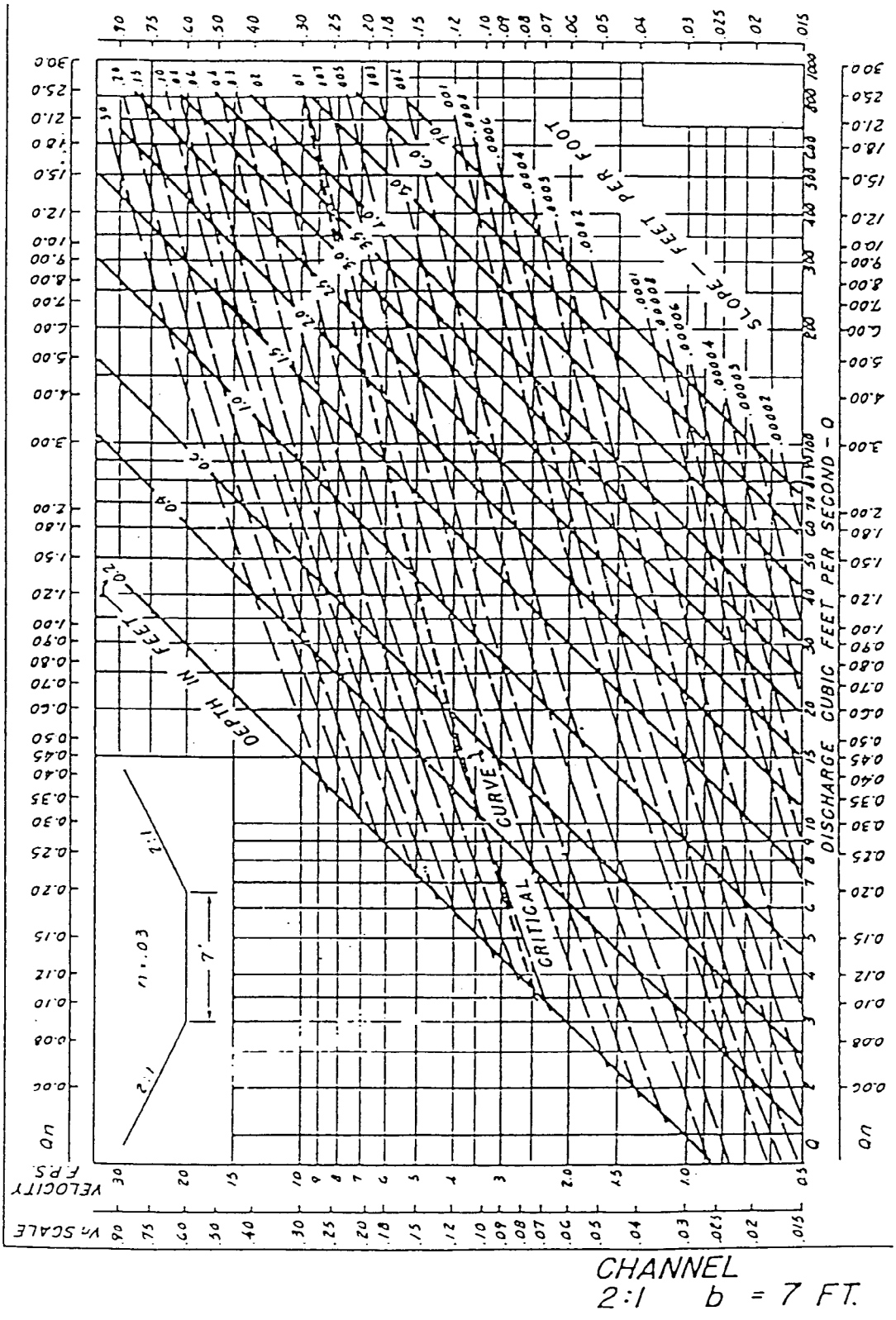


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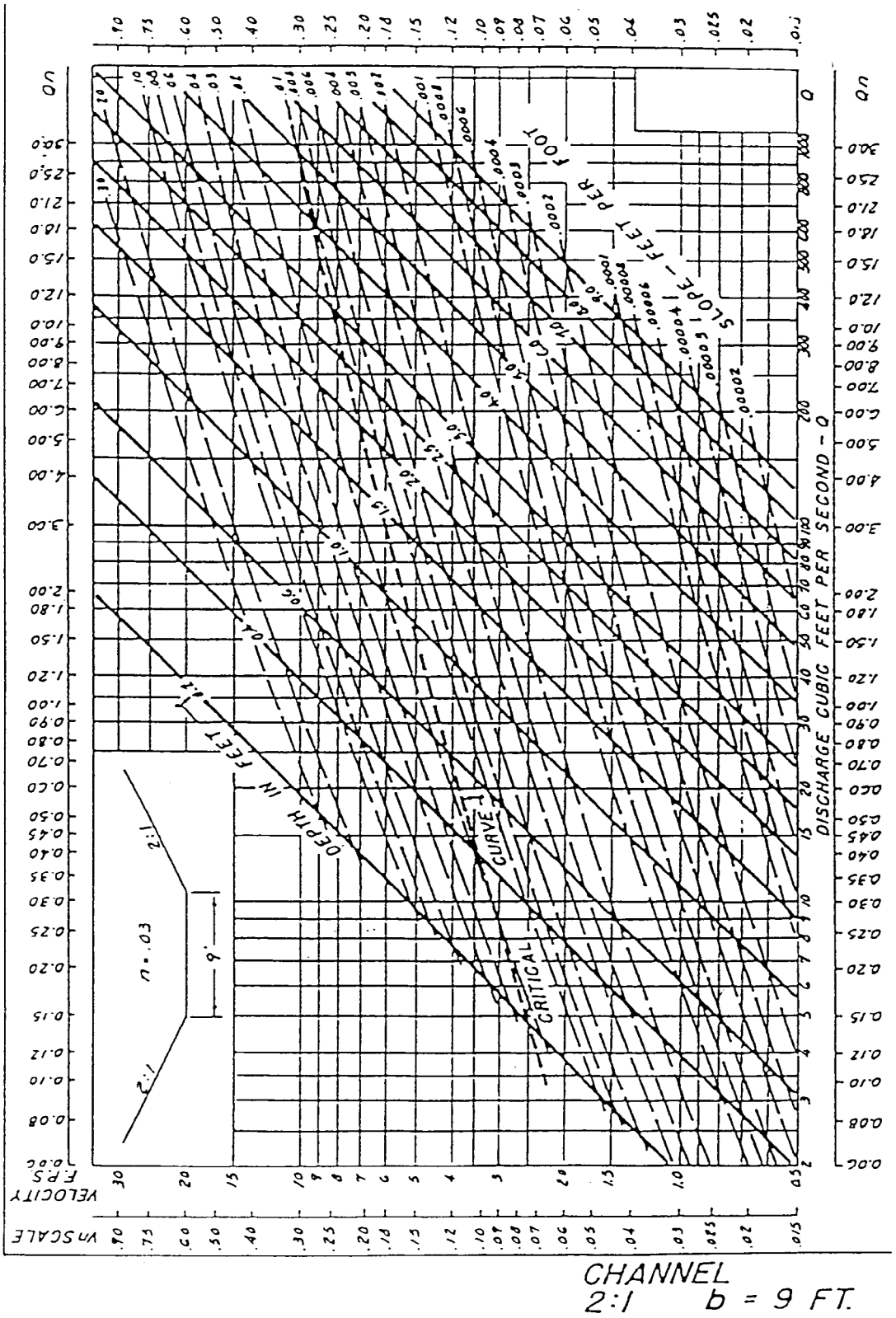


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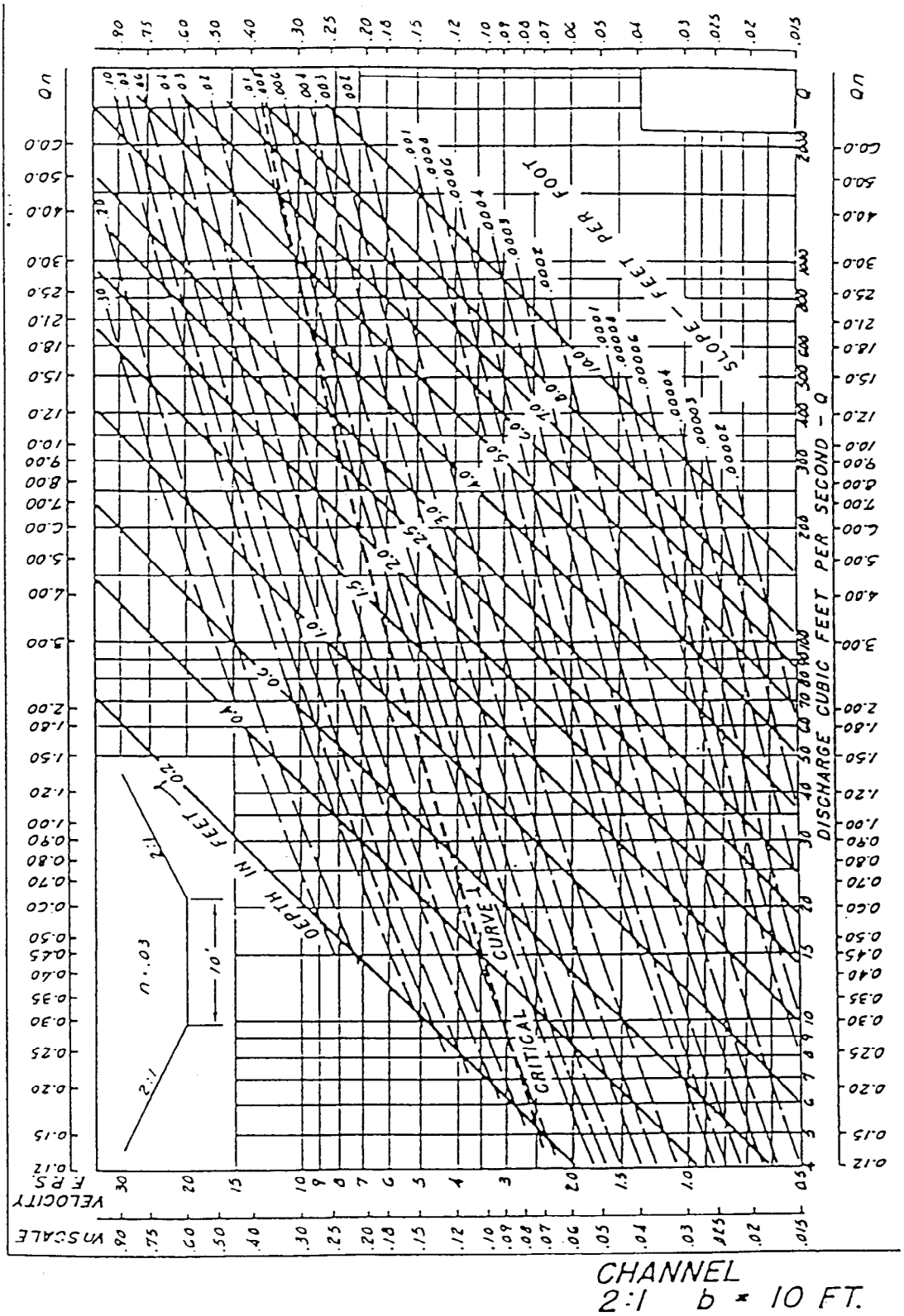
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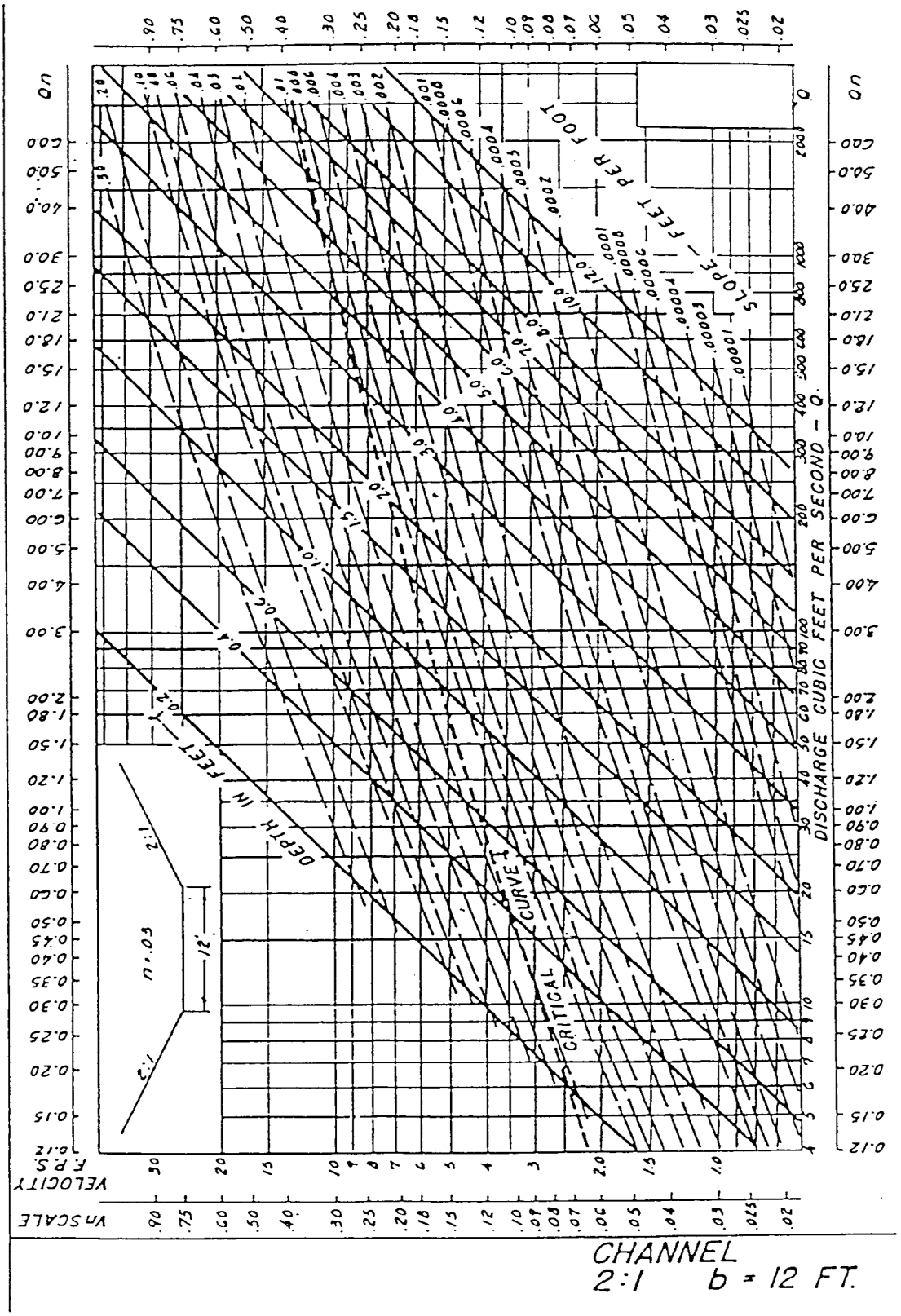
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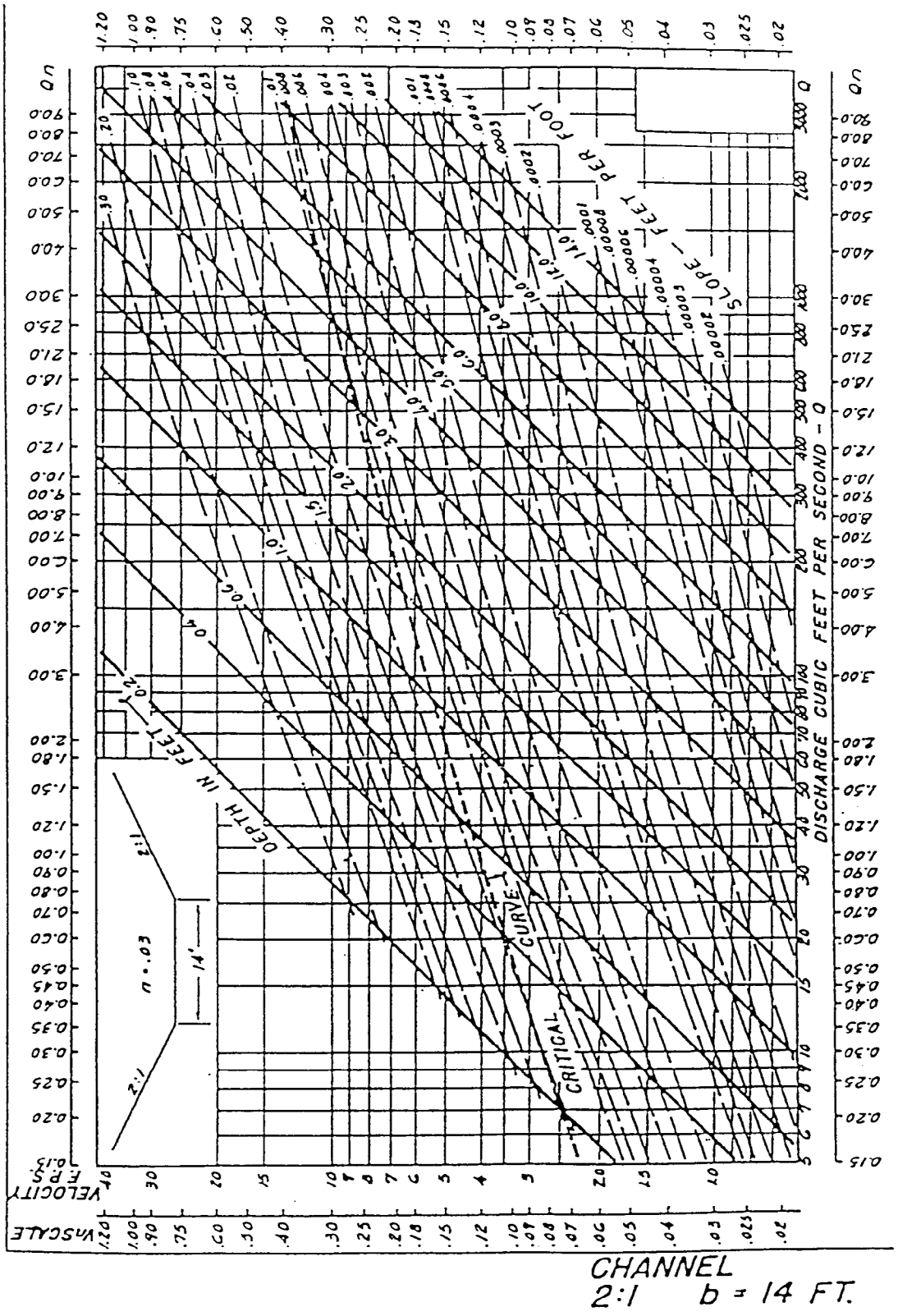
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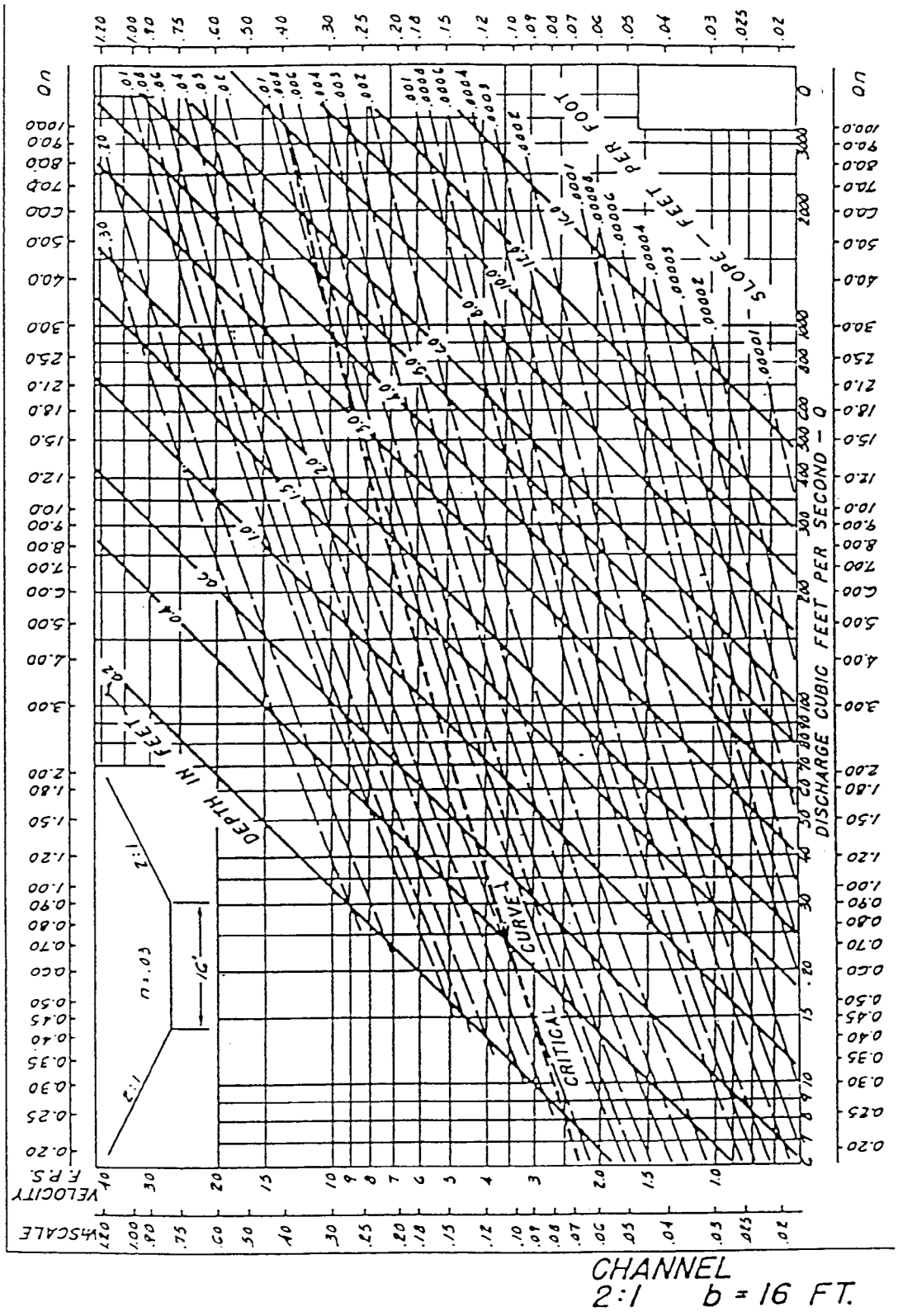
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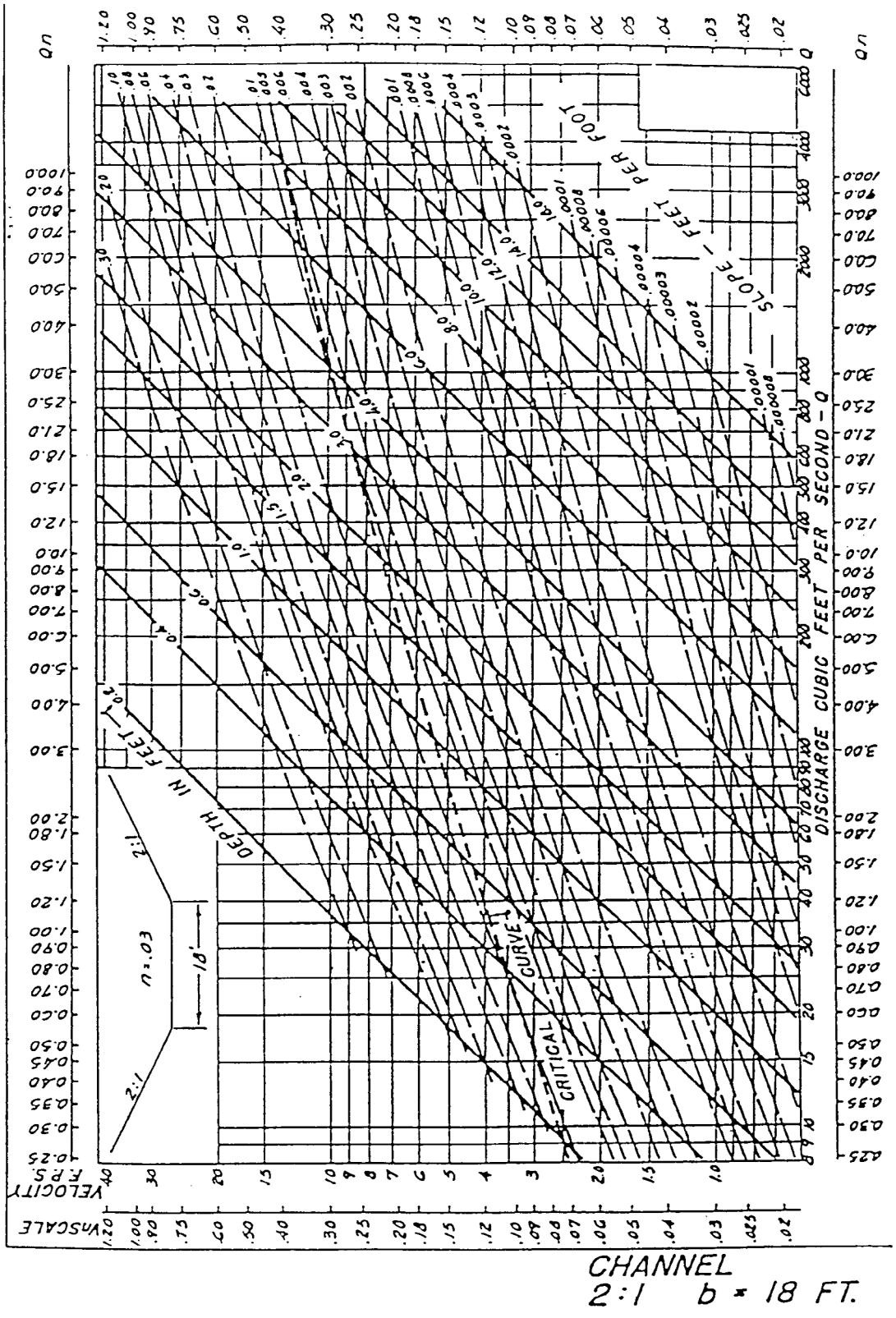
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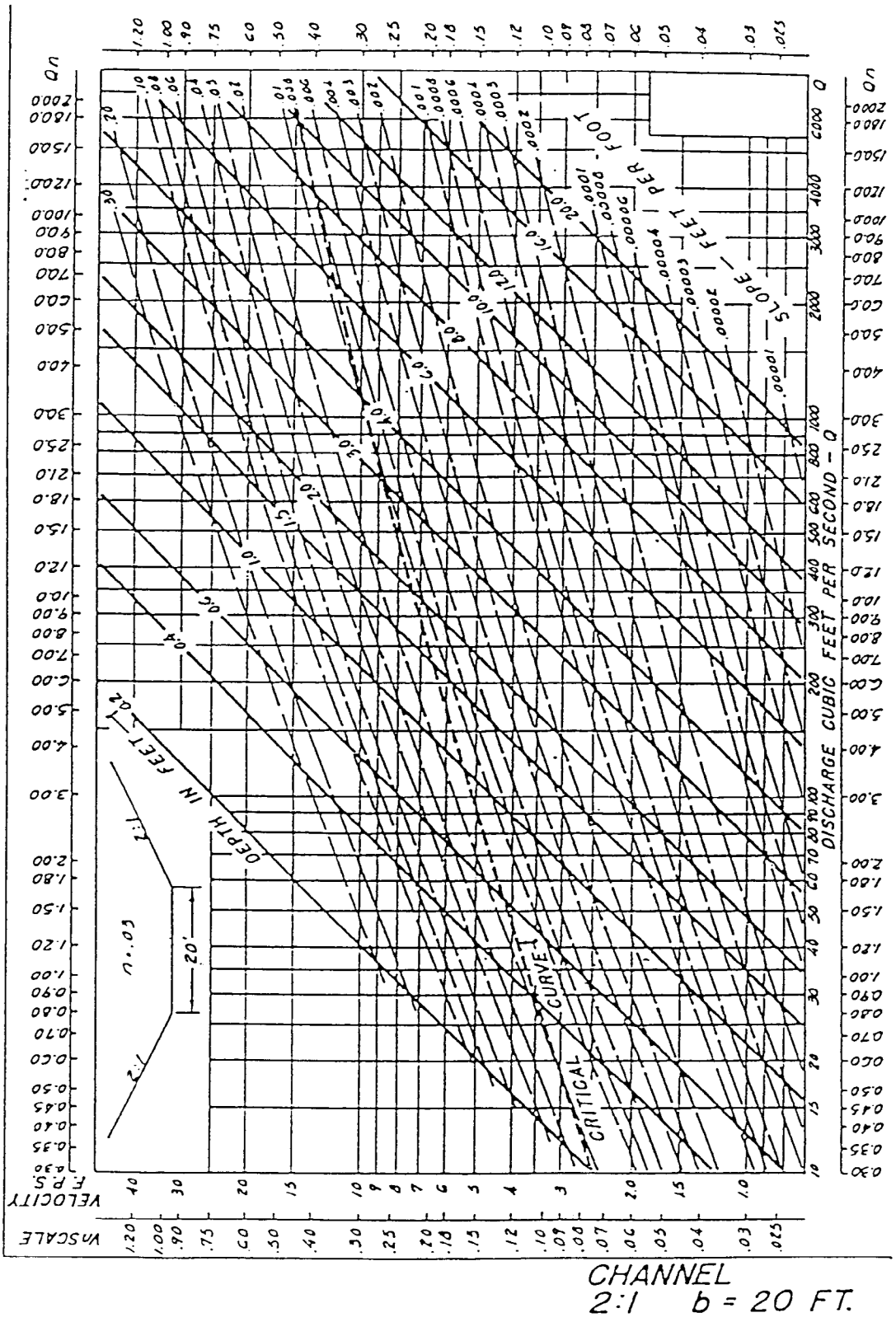
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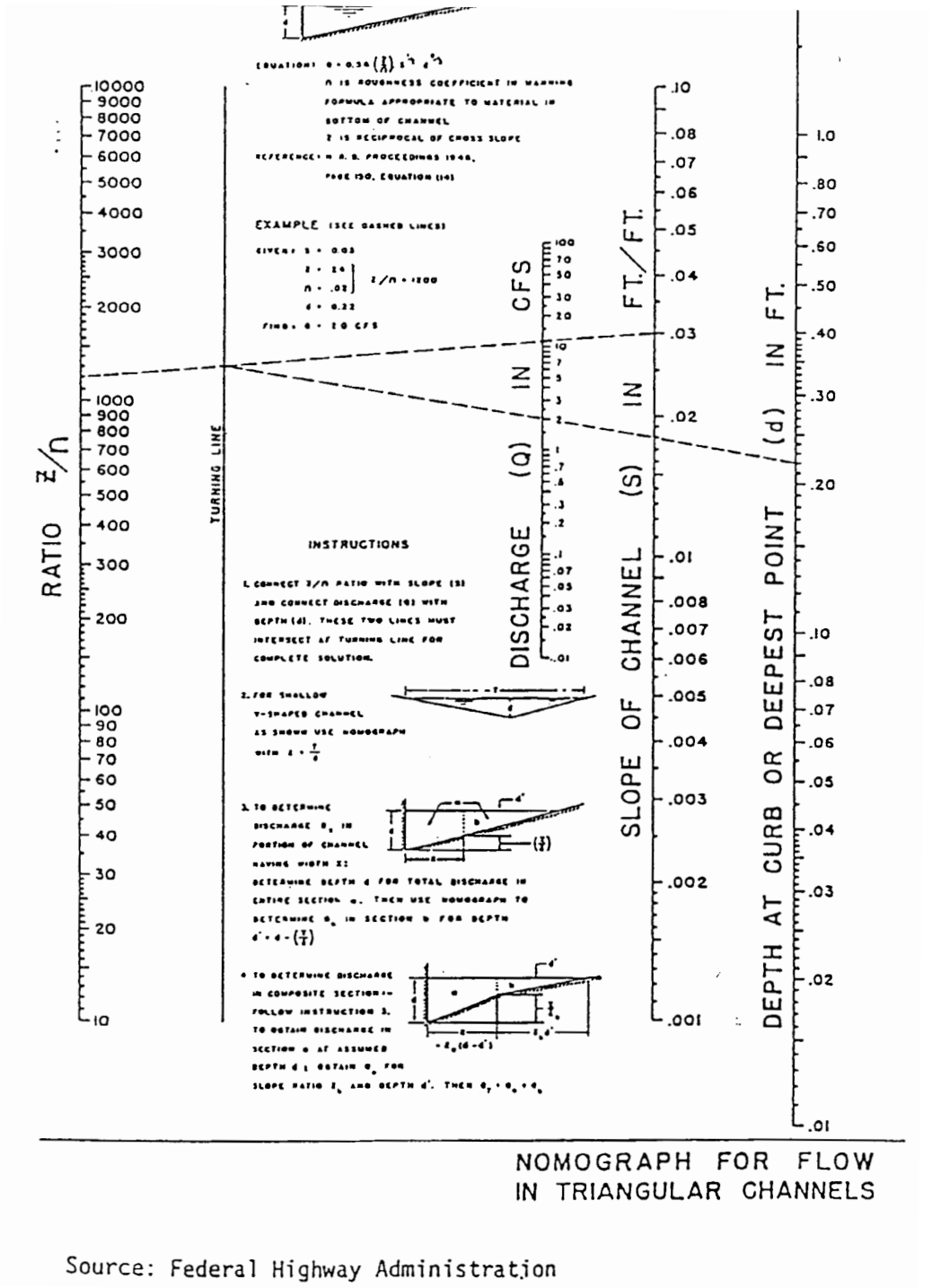
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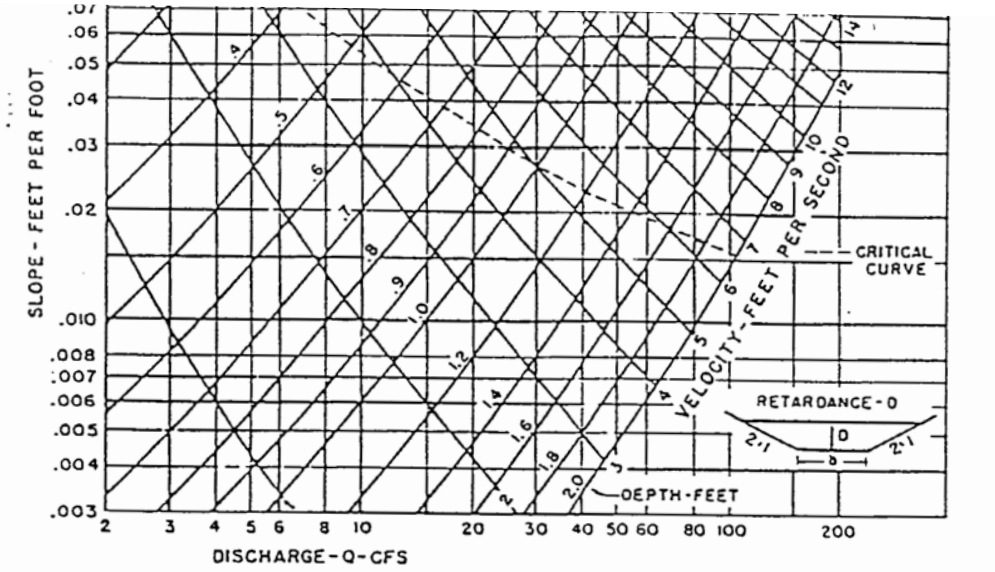
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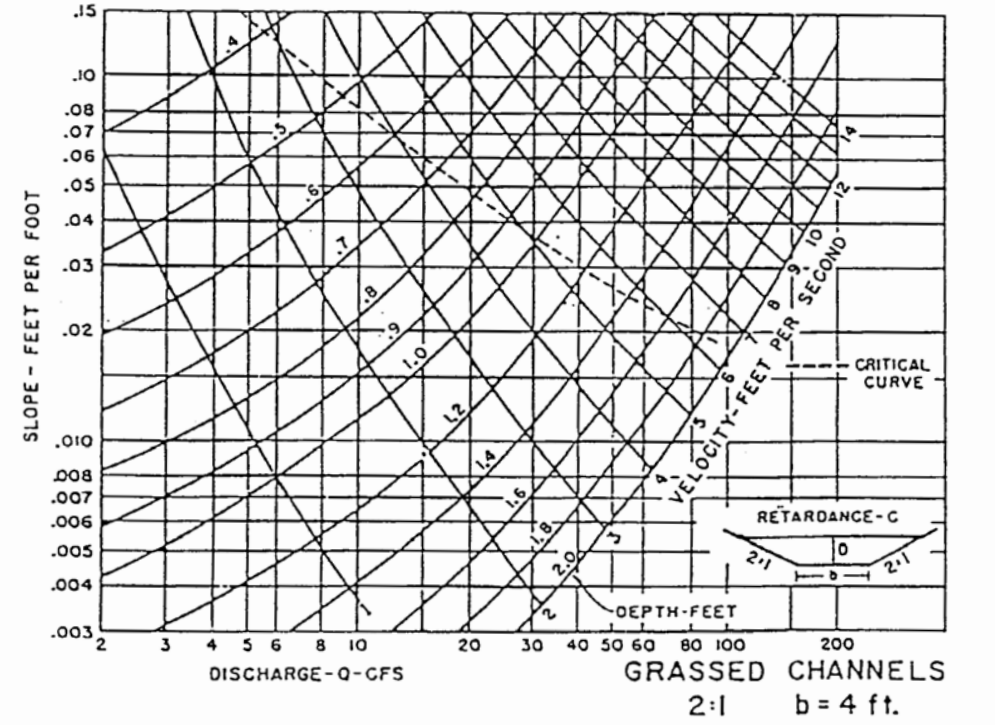
C-3 Triangular Channel Nomograph



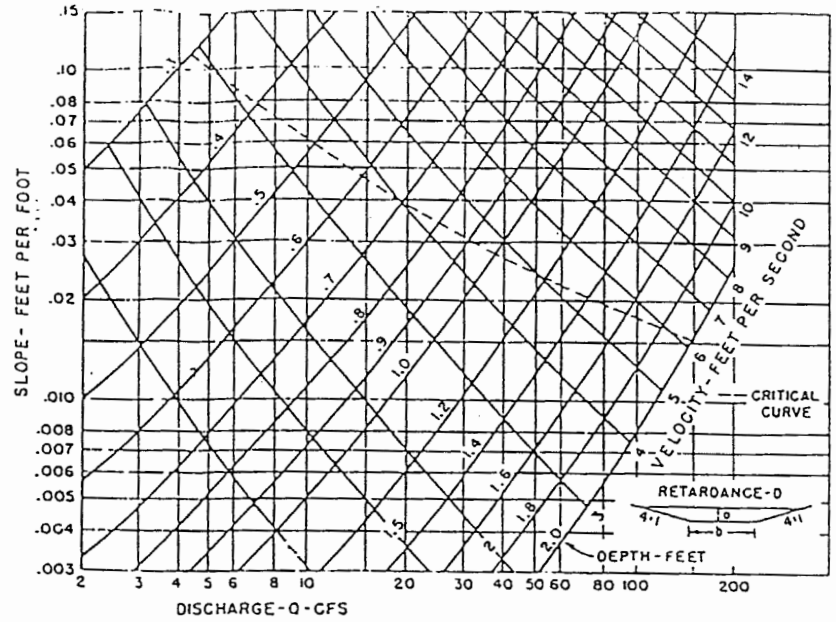
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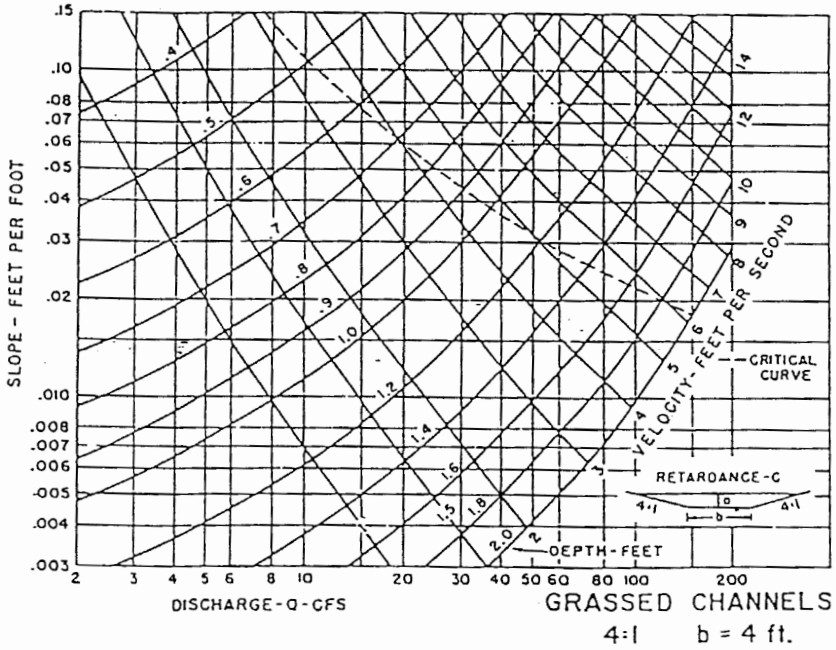
C-4 Grassed Channel Design Figures



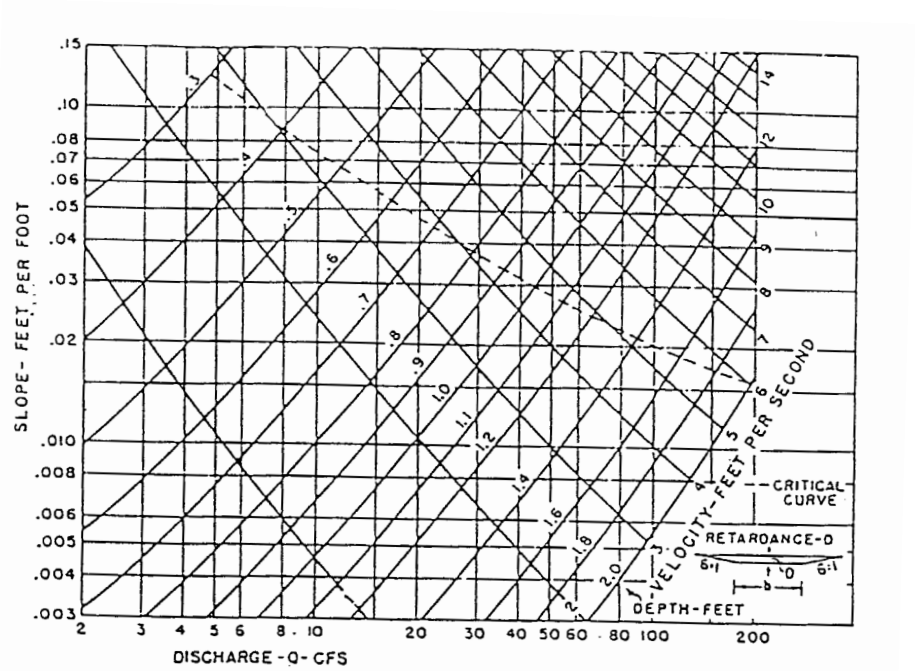


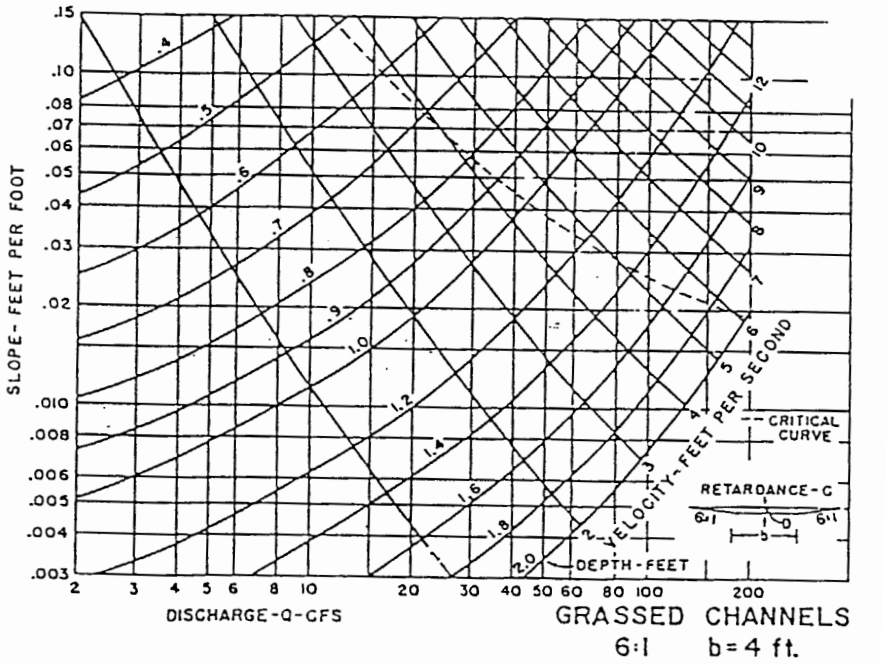
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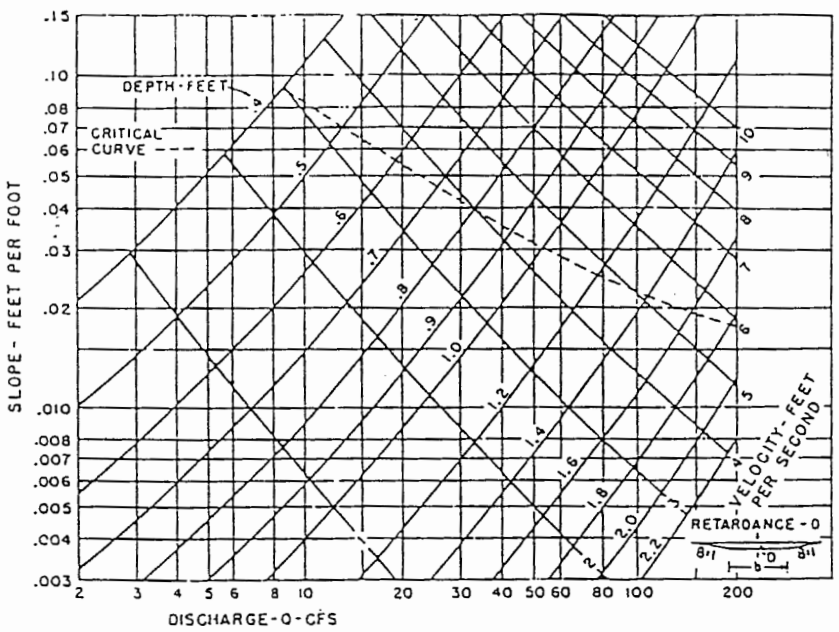


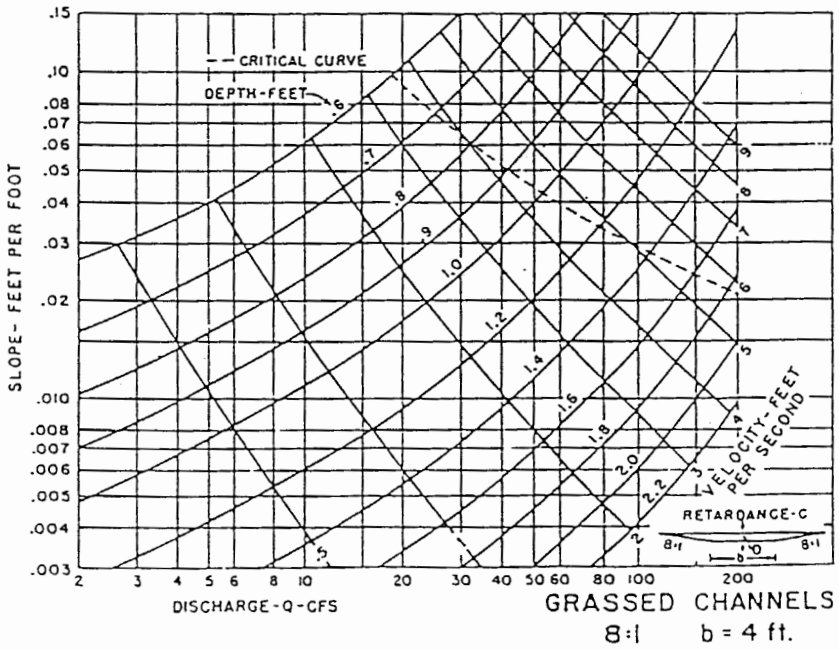
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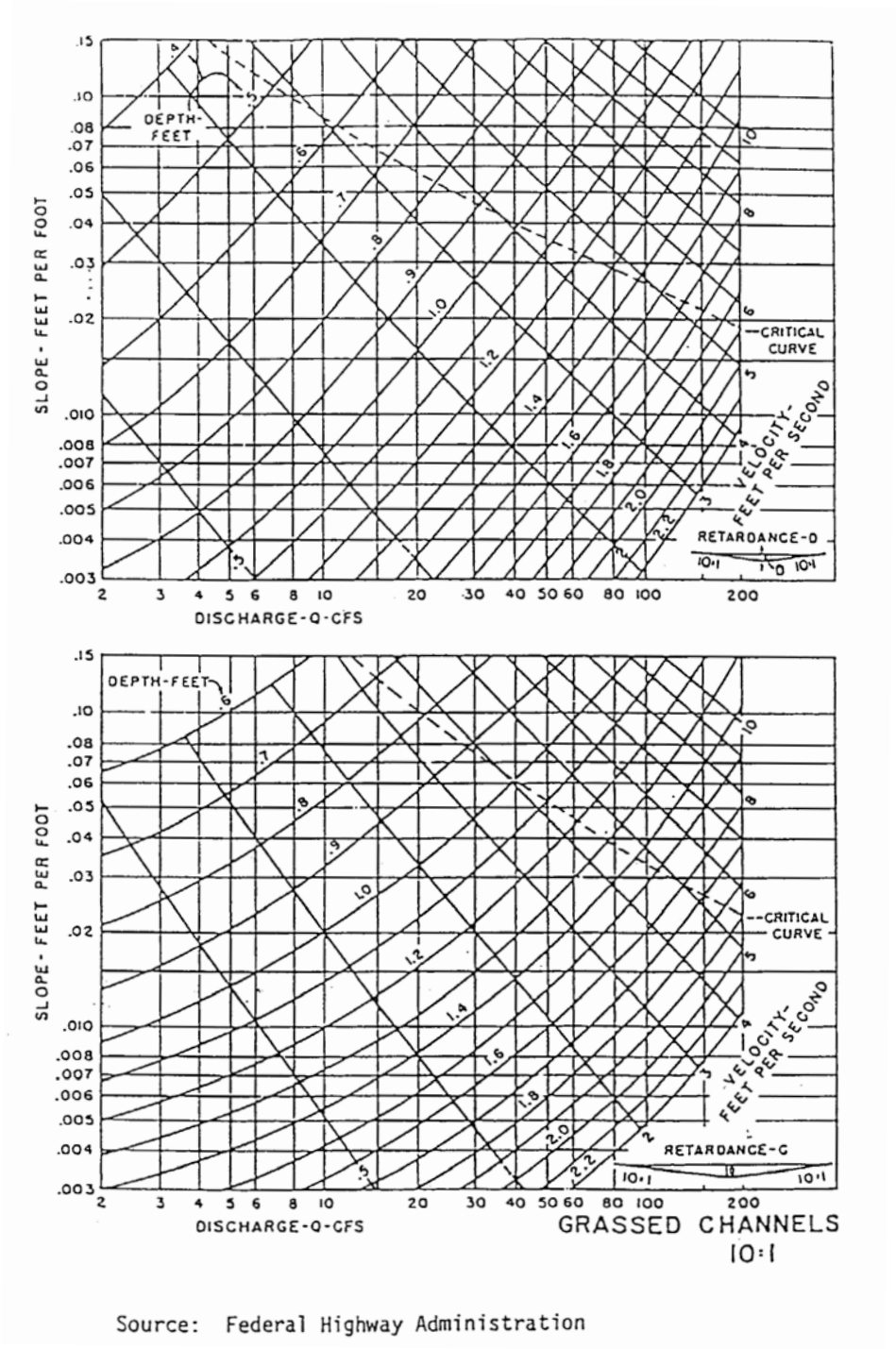


Source: Federal Highway Administration





Source: Federal Highway Administration



Source: Federal Highway Administration

Appendix D: Planting & Soil Guidance

Introduction

The proper selection of plants and soil composition specifications is a critical aspect to the function and success of many stormwater BMPs.

Plants*:* Plants reduce erosion, increase pollutant removal, reduce runoff velocity, enhance infiltration, control access and contribute to wildlife habitat. Plants can also improve the appearance of stormwater facilities.

Soil: The soil composition of many stormwater BMPs is vital to their relative success or failure. Properly specified, mixed and placed soil and/or planting media aids in infiltration and natural detention as well as plant health. The purpose of this Appendix is to provide guidance on plant selection and planting media for stormwater facilities. This appendix is divided into the following sections:

Section 1: General Planting Guidance

Section 2: Site Characteristics and Soil - discusses the physical site factors and considerations involved in selecting plant material for stormwater facility landscaping.

Section 3: Plant Selection for Stormwater Facilities - reviews key factors to consider in selecting plant material for stormwater landscaping, including hardiness, physiographic regions, inundation tolerance, and other factors.

Section 4: Specific Landscaping Criteria for BMPs

Section 5: Plant List for Stormwater BMPs

Section 6: Minimum Requirements for Landscape Plans

Section 7: Plant Establishment and Maintenance

Section 1: General Planting Guidance

Below are general guidelines that should be followed in the planting of any stormwater control or conveyance facility. Native plant species should be specified over exotic or foreign species because they are well adapted to local soil and climactic conditions.

- A variety of species should be utilized for the best performance of the stormwater BMP and for survivability of the plants.
- Trees, shrubs and grasses should be placed and spaced according to their mature size.
- Turf areas should be minimized or eliminated because of the maintenance (mowing, pesticides and fertilizers) required after installation. Recent research indicates that disturbed soils and managed turf also impact stormwater quality (Law et al, 2008). Groundcovers can be utilized as an alternative.
- Trees and shrubs should not be planted within 15 feet of the toe of the slope of a dam or from a non-clogging, low flow orifice.
- Tree species with tap roots that seek water (e.g., willow and poplar), should be avoided within 50 feet of sewer or water pipes or manmade drainage structures that continually hold water.
- Woody vegetation should not be planted on an embankment and herbaceous embankment plantings should be limited to 10" in height to allow inspectors to look for integrity compromising burrowing rodents.
- Evergreen trees and trees which produce relatively little leaf-fall (once per year) are preferred in areas draining to a detention practice.
- Site characteristics (e.g. views to be preserved, buffer, screens, slopes, existing soil) and plant characteristics, including plant maintenance should be considered when selecting plant material. Larger plant material should not block views at entrances, exits, or difficult road curves.
- Access for maintenance and blocking of access to pedestrians should both be considered.
- Drought tolerant species are recommended.
- Plants should be purchased from a source near the installation site for the best chance of survival.
- Existing vegetation should be considered before siting of stormwater BMP and preserved when possible.
- Water tolerances of existing vegetation should be analyzed.
- Water availability should be considered (see Section 7: Plant Establishment and Maintenance)
- Educational signage should be provided near stormwater BMPs to help educate the public and preserve/identify existing natural vegetation.

Section 2: Site Characteristics and Soil

A development site's characteristics often will help to determine which plant materials and planting methods the site designer should select and will help improve plant establishment. Primary site considerations include:

1. Soil Characteristics
2. Drainage
3. Slope
4. Orientation

Soils provide nutrients for plant growth, filtration of pollutants as well as the storage/release of storm flows which makes soils a critical piece of a successful stormwater BMP.

Soil Tests: To determine the characteristics of soil on your site, samples of on-site soils should be analyzed by experienced and qualified individuals who can explain the results and provide information on any soil amendments that are required for the intended stormwater BMP. For information about testing your own soil and to order a soil test kit you can contact your local extension service (UGA-Cooperative Extension Office here: http://extension.uga.edu/about/county/index.cfm or click here: http://aesl.ces.uga.edu/soiltest123/Georgia.htm to order a soil test kit). The test should indicate soil PH, content and texture. Where poor soils can't be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

Utilizing On-Site Soils: A soil test will help to determine if on-site soils can be utilized for your BMP. There are drawbacks to utilizing on-site soils which include the staging area required to mix soils, weather conditions making the blending process difficult, availability of clean organic content and control over the performance of the soil created which is particularly important for bioretention area soils. If it is decided that on-site soils can be utilized, recognize that both weight and volume of soil media components are routinely specified and stay consistent between the two.

Utilizing a Manufactured Soil Media: Several companies in Georgia are now manufacturing soil media for BMP's and can create mixes that meet the nutrient levels and textures that you require. The manufacturer should be able to provide a specification for their mix and to show the soil components, installation instructions, and infiltration rates (if applicable).

Soil Performance: Different planting media with different ratios of organic content, sand/clay content, permeability and pH will perform in different ways. Higher organic content is better for plants but can cause nutrient export. Higher sand content will increase permeability but can decrease the ability of the soil to hold proper nutrients to sustain plant life. Increasing or decreasing the clay in the planting media can slow or speed infiltration. An analysis of desired plant material, specific site conditions and desired function of the proposed BMP will need to be performed to determine the mix that is best suited. At this time there is no universal ASTM standard for planting media. Links are provided below for different planting media.

- See guidance for bioretention media composition: http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention
- http://www.lowimpactdevelopment.org/epa03/biospec_left.htm
- North Carolina State University Stormwater Engineering Group Soil Media Mix: https://www.bae.ncsu.edu/topic/bioretention/design-soil.html
- Page 367 / G1 http://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/susmppdf/lid_handbook_2014sm.pdf

D.2.1 Infiltration Testing

The purpose of green infrastructure (GI) or green management practices (GMPs) is to store, treat and infiltrate stormwater into the soil, mimicking natural systems. Subsurface conditions are key in assessing the feasibility of infiltration in the design of GI. Infiltration capacity testing and design of best management practices (BMPs) that rely on infiltration to treat the stormwater runoff shall follow the specifications summarized in this Section. While the Natural Resources Conservation Service (NRCS) soil classification of the site is encouraged as part of a desktop analysis to gain familiarity with potential native soil conditions, it is not adequate justification for infiltration testing results and cannot be substituted for infiltration testing using infiltrometers, test pits or other infiltration testing methods.

Background and Desktop Analysis

A desktop analysis of soils data, topography, the location of streams, waterbodies, existing/previous land uses, and structures is encouraged to identify potential BMP locations and types. Existing or previous soil investigation or lab data may also be used to support preliminary siting of BMPs and infiltration testing. While NRCS soil classification of the site is encouraged as part of a desktop analysis to gain familiarity with potential native soil conditions, it is not adequate justification for infiltration testing results and cannot be substituted for infiltration testing using infiltrometers or test pits.

Infiltration Testing Requirements

Infiltration tests shall not be conducted in the rain or within 48 hours of significant rainfall events (greater than 0.5 inches), or when the temperature is below freezing.

Infiltration testing performed; including testing procedures followed, shall be documented and submitted (as required) to the governing agency.

Infiltration testing shall be conducted by a qualified professional and plans including infiltration testing results must be certified by a professional engineer or professional geologist. However, homeowners may perform their own simple infiltration tests to site rain gardens in the proper location.

Portions of this Section present testing methods at the bottom of an excavation. It is the testing personnel's responsibility to be aware of and take proper health and safety precautions for activities in an excavation. See the U.S. Occupational Health and Safety Administration (OSHA) for guidelines and requirements (www.osha.gov).

Tiered Testing Approach

A tiered approach to infiltration testing recognizes the importance of accurate in situ conditions while screening out sites unsuitable for infiltration practices and thereby reducing soil investigation and testing costs. The following tiers include:

1. Feasibility Analysis
2. Conceptual Design Testing

Minimum testing recommendations for each tier are summarized in **Table D-1**, on the following page.

Tier 1: Feasibility Analysis

A minimum of one single-ring infiltrometer test must initially be performed on site.

Single-Ring Infiltrometer Infiltration Test

This test method utilizes perforated 200 mm to 250 mm (8-inch to 10-inch) plastic or metal canisters with bottom, set in coarse drainage sand, to minimize disturbance to in-place soils and to prevent siltation of the test hole during testing.

1. Holes in the test canister should be 3 mm (1/8 inch) diameter and spaced on 25 mm (1 inch) centers.
2. Excavate a test hole to the depth of the infiltration plane, or the bottom of the BMP and approximately 25 mm (1 inch) larger diameter and approximately 25 mm (1 inch deeper than the dimensions of a test canister. If the depth of testing is greater than 18", it may be necessary to excavate a shallow test pit to conduct testing.
3. Check that the sides of the test hole are not smooth, but scarified.
4. Place coarse drainage sand in the bottom of the hole and place the canister firmly into the hole. The bottom of the hole should be uncompacted.
5. Backfill the space around the canister with soil and tamp the soil into place.
6. Fill canister with water and allow to drain completely or to soak the surrounding soils for a minimum of one hour, whichever occurs first. Re-fill the canister and measure the rate at which the water level drops.
7. Record the infiltration rate as the decrease in depth of water per hour (inches/hour).

Where the feasibility analysis does not meet minimum infiltration criteria, the designer may prefer the use of an underdrain rather than continue with further testing.

Where the feasibility analysis meets the minimum infiltration criteria, the test pits are necessary for conducting infiltration testing per **Table D-1** to further verify site information characteristics.

Table D-1 Testing/Design Considerations

BMP Type	Tier 1: Feasibility Analysis	Tier 2: Conceptual Design Testing	
		For initial yields equal to or greater than 0.5"/hr	For initial yields less than 0.5"/hr
Linear practices (i.e., bioswales, interconnected tree boxes, infiltration trenches, etc.)	1 single-ring infiltrometer test per site	1 single-ring infiltrometer test and 1 test pit per 400 linear feet (minimum 1 infiltration test per test pit) of BMP practice	Underdrain required
Non-linear practices (rain gardens, basins, etc.)	1 single-ring infiltrometer test per site	1 single-ring infiltrometer test and 1 test pit per 400 square feet of practice area (minimum 1 infiltration test per test pit)	Underdrain required

Tier 2: Conceptual Design Testing

Test Pit Infiltration Test

This test method consists of a trench or pit that allows visual observation of the soil horizons and overall soil conditions at a particular location on the site. Multiple test pit observations can be made for a relatively low cost and in a short time period. The use of soil borings shall not be substituted for test pits. Test pits (see **Figure D-1**) allow in-situ visual observation of soil conditions, where soil borings do not. Soil borings are encouraged to supplement data collection, but cannot be substituted for infiltrometer or test pits.

1. Dig a backhoe-excavated trench/pit, 2-1/2 to 3 feet wide, to the proposed depth of the infiltration plane of the practice, or until bedrock or fully saturated conditions are encountered. Safe test pit entry should always be observed. A test pit should never be accessed if it is not safe to do so. OSHA regulations should always be observed.
2. Document soil profile (soil horizons, soil texture and color and depth below ground surface, depth to water table, depth to bedrock, etc).
3. Based on observed field conditions, the qualified professional should consider modifying the proposed infiltration plane of the practice and adjust infiltration testing locations as necessary.
4. Perform Single-Ring Infiltrometer test (above) at depth of infiltration plane of the proposed practice.
5. Soil samples may be collected at various horizons for additional analysis at the designer's discretion.
6. After testing is complete, re-fill test pit with original native soils and stake the location of the test pit.

Other Infiltration Testing and Verification Methods

Other infiltration testing standards that are acceptable include ASTM D3385—09 Standard Test Method for Infiltration Rate of Soils in Field Using Double Ring Infiltrometer.

Several simple infiltration tests do exist for homeowners and small sites to determine if a rain garden or small bioretention area can be sited in a specific place. One example of a simple test can be found here: http://www.phillywatersheds.org/whats_in_it_for_you/residents/infiltration-test.

Verification methods such as soil borings may be used to verify site conditions where final locations of BMPs are adjusted and do not fall within the original testing location. Test results must verify that the soil conditions are the same as those from the original test results.

Designers should also consider construction access and staging during the design process. Activities that could compact soils where BMPs are sited should be avoided. Where site constraints make this unavoidable, the designer shall compensate accordingly in the design of the BMP.

Construction Equipment and Minimizing Compaction

Soils should not be compromised by compaction from construction equipment. Care should be taken to minimize soil compaction throughout the BMP and especially at the plane of infiltration so that infiltration rates of native soils are not impacted. Acceptable excavation methods at infiltration practices include hand labor with shovels or the use of an excavator such as a backhoe or trackhoe (located outside the perimeter or footprint of the practice). Heavy equipment should never be used over the footprint of existing or planned infiltration practices. Prior to site disturbance, the perimeter of the practice should be partitioned off with temporary fencing/tape to keep heavy equipment from crossing the perimeter throughout time of active construction. In cases where the BMP is sufficiently large that equipment must enter it, methods proposed to limit and restore compacted soil must be approved in advance.

Long-term Infiltration Rates

Infiltration rates may decrease over time due to settlement of filter media, compaction, or accumulation of sediment in the practice. To sustain infiltration rates long-term, it is important that a maintenance plan is in place. Regular maintenance should be conducted to optimize operating infiltration rates.

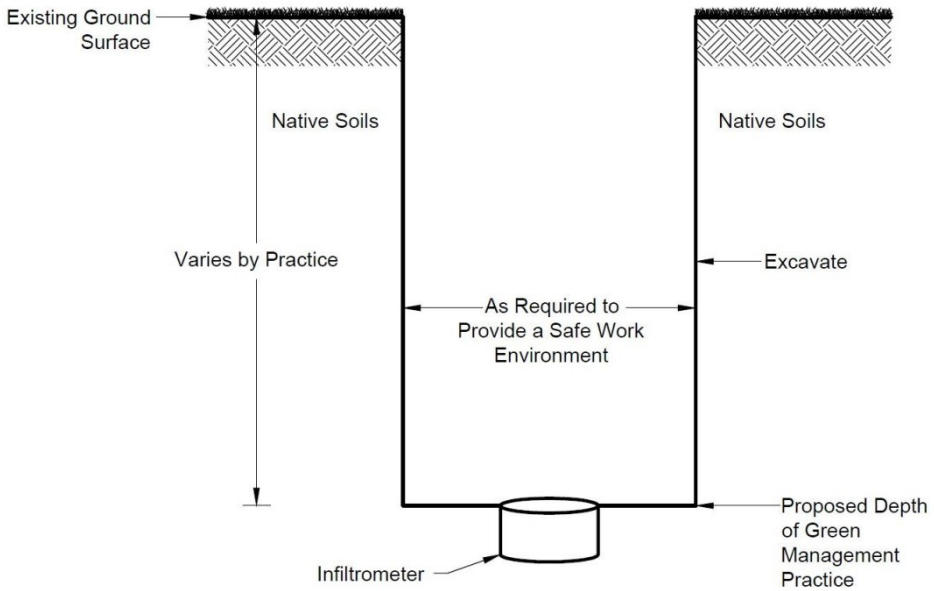


Figure D-1: Test Pit

D.2.2 Compaction, Construction and Soil

Areas that have recently been involved in construction as well as some native soils can become compacted so that plant roots cannot penetrate the soil. Seeds lying on the surface of compacted soils can be washed away or be eaten by birds. Soils should be loosened to a minimum depth of four inches, preferably to a six-inch depth. Hard soils may require a deeper depth. Loosening soils will improve seed contact with the soil, provide greater germination rates, and allow the roots to penetrate into the soil. Sod and other plantings will also benefit from loosened soil.

D.2.3 Soil Characteristics

The ability of the soil to store and release water and to provide plant establishment and plant growth can be limited by a number of different soil characteristics such as:

- Soil texture
- Soil Permeability
- pH -- whether acid, neutral, or alkali
- Nutrient levels -- nitrogen, phosphorus, potassium
- Minerals -- such as chelated iron, lime
- Salinity
- Toxicity

Soil texture: is determined by the percentage of sand, silt, and clay in the soil. The structure of a soil is influenced by soil texture and also by the combination of small soil particles into larger particles. The amount of aggregation in a soil is strongly influenced by the amount of organic matter present. Soils are made up of four basic ingredients: mineral elements, pore space, organic matter and other items consisting mainly of living organisms including fungi, bacteria, and nematodes. One classification of soils is based upon the mineral part of soil and consists of four sizes of particles. Clay particles are the smallest, followed by silt, sand, and gravel. The USDA has devised another system of classifying soil particles. In this system soil is divided into seven categories: clay, silt, and five sizes of sand.

Soil Permeability: Soil permeability is an important design factor in stormwater BMPs. It is advantageous and sometimes necessary to have high permeability in-situ soils for systems where infiltration may be desired (e.g. bioretention, infiltration practices, etc.). It is also advantageous and sometimes necessary to have low permeability in-situ soil for systems where permanent ponded water is required (e.g. stormwater wetlands, wet detention basins, etc.). In some BMP systems (e.g. sand filters, bioretention, etc.), high permeability media is required within the BMP, but since relatively small quantities are typically required, suitable soils can be imported to a site if necessary.

pH: Soil pH affects the acidity of a soil. A pH of 7 is considered to be neutral. A pH less than 7 is acidic and solutions with a pH greater than 7 are basic. Different trees, shrubs and grasses thrive in different pH levels and the availability of nutrients is optimal at a pH between 6.5 and 7.5.

Organic Content/Compost: Vegetation cannot survive without the proper amount of organic matter. Organic content requirements vary based on the site, the BMP and plants that are being selected. Organic content affects pollutant removal rates: higher organic content filters more pollutants than lower organic content but depending on the sources of the organic amendment, it can raise phosphorus levels which can become a contaminat. Compost utilized to meet the organic matter content within planting media should be a well-decomposed, stable, weed-free organic matter source derived from waste materials including yard debris, wood wastes or other organic materials, not including manure or biosolids. Compost shall have a dark brown color and a soil-like odor. Compost that is exhibiting a sour or putrid smell, contains recognizable grass or leaves, or is hot (120 degrees Fahrenheit) upon delivery is not acceptable. Examples of acceptable material include pine bark fines and leaf compost.

Topsoil: Topsoil provides organic matter, nutrients, and microbes beneficial to the plant material. This also allows the stabilizing plant materials to become established faster, while the roots are able to penetrate deeper and stabilize the soil, making it less likely that the plants will wash out during a heavy storm. It is important to understand the composition of the topsoil that is being utilized. For example, the clay content of topsoil affects the infiltration rate of the planting media. Also, the organic content in topsoil must be taken into consideration when calculating the total organic content in a bioretention planting media.

Whenever possible, the topsoil on a site should be stripped and stockpiled prior to any grading activities, After final grading, stockpiled topsoil should be spread to a depth of six inches (or more depending on the size of the plant material to be sustained) over the entire area to be planted. If stockpiled topsoil is insufficient, off-site soils and amendments may need to be brought in. If topsoil has been stockpiled in deep mounds for a long period of time, it is desirable to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, it may be necessary to inoculate the soil after application.

Topsoil should conform to ASTM D5268 – 13:

Total Sample Compositional Category:	Percentage by Mass
Deleterious materials (rock, gravel, slag, cinder, roots, sod)	5 max material passing the No. 10 (2 mm) sieve
Organic material	2 to 20
Sand content	20 to 60
Silt and clay content	35 to 70
pH	5 to 7

Source: (ASTM D5268-13, Standard Specification for Topsoil Used for Landscaping Purposes, ASTM International, West Conshohocken, PA, 2013, www.astm.org)

On or off-site topsoil should be obtained from sources that are naturally well-drained sites where topsoil occurs at least 4 inches (100 mm) deep, not from bogs, or marshes; and that do not contain undesirable organisms; disease-causing plant pathogens; or obnoxious weeds and invasive plants including, but not limited to, quackgrass, Johnsongrass, poison ivy, nutsedge, nimblewill, Canada thistle, bindweed, bentgrass, wild garlic, ground ivy, perennial sorrel, and bromegrass.

D.2.4 Drainage

Soil moisture and drainage have a direct bearing on the plant species and communities that can be supported on a site. Factors such as soil texture, topography, groundwater levels and climatic patterns all influence soil drainage and the amount of water in the soil. Identifying the topography and drainage of the site will help determine potential moisture gradients. The following categories can be used to describe the drainage properties of soils on a site:

- ❑ Flooded
  Areas where standing water is present most of the growing season.
- ❑ Wet
  Areas where standing water is present most of the growing season, except during times of drought. Wet areas are found at the edges of ponds, rivers, streams, ditches, and low spots. Wet conditions exist on poorly drained soils, often with a high clay content.
- ❑ Moist
  Areas where the soil is damp. Occasionally, the soil is saturated and drains slowly. These areas usually are at slightly higher elevations than wet sites. Moist conditions may exist in sheltered areas protected from sun and wind.
- ❑ Well-drained
  Areas where rain water drains readily, and puddles do not last long. Moisture is available to plants most of the growing season. Soils usually are medium textures with enough sand and silt particles to allow water to drain through the soil.
- ❑ Dry
  Areas where water drains rapidly through the soil. Soils are usually coarse, sandy, rocky or shallow. Slopes are often steep and exposed to sun and wind. Water runs off quickly and does not remain in the soil.

D.2.5 Slope

The degree of slope can also limit its suitability for certain types of plants. Plant establishment and growth requires stable substrates for anchoring root systems and preserving propagules such as seeds and plant fragments, and slope is a primary factor in determining substrate stability. Establishing plants directly on or below eroding slopes is not possible for most species. In such instances, plant species capable of rapid spread and anchoring soils should be selected or bioengineering techniques should be used to aid the establishment of a plant cover.

In addition, soils on steep slopes generally drain more rapidly than those on gradual slopes. This means that the soils may remain saturated longer on gradual slopes. If soils on gradual slopes are classified as poorly drained, care should be taken that plant species are selected that are tolerant of saturation.

Site topography also affects maintenance of plant species diversity. Small irregularities in the ground surface (e.g., depressions, etc.) are common in natural systems. More species are found in areas with many micro-topographic features than in areas without such features. Raised sites are particularly important in wetlands because they allow plants that would otherwise die while flooded to escape inundation.

In wetland plant establishment, ground surface slope interacts with the site hydrology to determine water depths for specific areas within the site. Depth and duration of inundation are principal factors in the zonation of wetland plant species. A given change in water levels will expose a relatively small area on a steep slope in comparison with a much larger area exposed on a gradual or flat slope. Narrow planting zones will be delineated on steep slopes for species tolerant of specific hydrologic conditions, whereas gradual slopes enable the use of wider planting zones.

D.2.6 Orientation

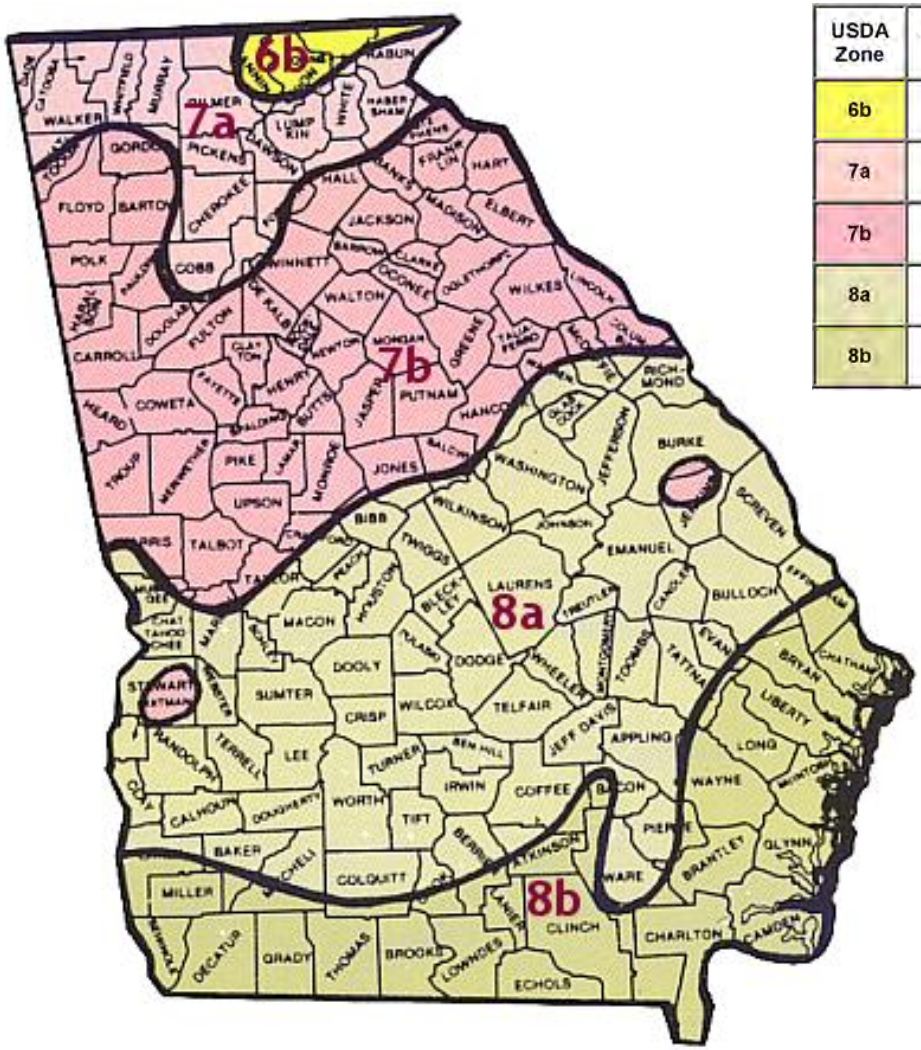
Slope exposure should be considered for its effect on plants. A southern-facing slope receives more sun and is warmer and drier, while the opposite is true of a northern slope. Eastern- and western-facing slopes are intermediate, receiving morning and afternoon sun, respectively. Western-facing slopes tending to be drier and receive more wind.

Section 3: Plant Selection for Stormwater Facilities

D.3.1 Hardiness Zones

Hardiness zones are based on historical average annual minimum temperatures recorded in an area. A site's location in relation to plant hardiness zones is important to consider first because plants differ in their ability to withstand very cold winters. This does not imply that plants are not affected by summer temperatures. Given that Georgia summers can be very hot, heat tolerance is also a characteristic that should be considered in plant selection.

It is best to recommend plants known to thrive in specific hardiness zones. The plant list included at the end of this appendix identifies the hardiness zones for each species listed as a general planting guide. It should be noted, however, that certain site factors can create microclimates or environmental conditions which permit the growth of plants not listed as hardy for that zone. By investigating numerous references and based on personal experience, a designer should be able to confidently recommend plants that will survive in microclimates.



USDA Zone	Average Annual Minimum Temperature Range
6b	-5 to 0 F (-17.8 to -20.5 C)
7a	0 to 5 F (-15.0 to -17.7 C)
7b	5 to 10 F (-12.3 to -14.9 C)
8a	10 to 15 F (-9.5 to -12.2 C)
8b	15 to 20 F (-6.7 to -9.4 C)

Figure D-2: USDA Plant Hardiness Zones in Georgia

D.3.2 Physiographic Provinces

There are five physiographic provinces in Georgia that describe distinct geographic regions in the state with similar physical and environmental conditions (**Figure F-2**). These physiographic provinces include, from northwest to southeast, Appalachian Plateau, Ridge and Valley, Blue Ridge, Piedmont and Coastal Plain (subdivided into upper and lower regions). Each physiographic region is defined by unique geological strata, soil type, drainage patterns, moisture content, temperature and degree of slope which often dictate the predominant vegetation. Because the predominant vegetation has evolved to live in these specific conditions it is important to understand the region in which your stormwater facility will reside. The five physiographic regions are described here: http://www.georgiawildlife.com/node/1704 with an associated map: http://www1.gadnr.org/cwcs/PDF/ga_eco_l3_pg.pdf.

D.3.3 Other Considerations in Plant Selection

The landscape planting design must include elements that ensure plant survival and overall stormwater BMP functional success. Plant selection is a complex task, involving matching the plant's physiological characteristics with a site's particular environmental conditions. The following factors should be considered:

- Full grown plant size and shape (e.g., limbs growing into power lines, maintenance access impediment).
- Growth rate.
- Site conditions (e.g., wind direction and intensity, street lighting, type and quantity of pollutants contained within stormwater runoff, etc.).
- Soil moisture and drought tolerance.
- Tolerance of periodic inundation.
- Sediment and organic matter build-up.
- Potential for outlet structure clogging (e.g., root structure).
- Maintenance requirements.
- Wildlife use

Plants need to provide aesthetics/ability to meet both landscape and stormwater BMP requirements. In urban or suburban settings, a plant's aesthetic interest may be of greater importance. Residents living next to a stormwater system may desire that the facility be appealing or interesting to look at throughout the year. Aesthetics is an important factor to consider in the design of these systems. Failure to consider the aesthetic appeal of a facility to the surrounding residents may result in reduced value to nearby lots. Careful attention to the design and planting of a BMP can result in maintained or increased values of a property.

Individual plants often have physiological characteristics difficult to convey in a general list. It is necessary to investigate specific information to ensure successful plant selection. There are many resources available to guide designers in the selection of plant material for stormwater BMPs. Knowledgeable landscape architects, wetland scientists, urban foresters, and nursery suppliers provide valuable information for considering specific conditions for successful plant establishment and accounting for the variable nature of stormwater hydrology.

D.3.3.1 AVAILABILITY AND COST

Often overlooked in plant selection is the availability from wholesalers and the cost of the plant material. There are many plants listed in landscape books that are not readily available from the nurseries. Without knowledge of what is available, time spent researching and finding the one plant that meets all the needs will be wasted, if it is not available from the growers. It may require shipping, therefore, making it more costly than the budget may allow. Some planting requirements, however, may require a special effort to find the specific plant that fulfills the needs of the site and the function of the plant in the landscape. Plants should be sourced from similar geographic regions to optimize survivability.

D.3.3.2 NATIVE VERSUS NONNATIVE SPECIES

This Manual encourages the use of native plants in stormwater management facilities since they are best suited to thrive and can provide benefits to pollinators and other native fauna. Unfortunately native plants may not always be available in quantity from local nurseries. Therefore, non-invasive naturalized plants that can survive under difficult conditions may be a useful alternative. Great care should be taken, however, when introducing plant species so as not to create a situation where they may become invasive and take over adjacent natural plant communities. The Georgia Exotic Pest Plant Council keeps a list of species that are invasive or could become invasive: http://www.gaeppc.org/list/.

D.3.3.3 MOISTURE STATUS

In landscaping stormwater management facilities, hydrology plays a large role in determining which species will survive in a given location.

For areas that are to be planted within a stormwater management facility it is necessary to determine what type of hydrologic zones will be created.

The six zones in the next section describe the different conditions encountered in stormwater management facilities. Every facility does not necessarily reflect all of these zones. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation by water. Each zone has its own set of plant selection criteria based on the hydrology of the zone, the stormwater functions required of the plant and the desired landscape effect.

Section 4: Specific Landscaping Criteria for Structural Stormwater Controls

D.4.1 Stormwater Ponds and Wetlands

Stormwater ponds and wetlands are engineered basins and wetland areas designed to control and treat stormwater runoff. Aquatic vegetation plays an important role in pollutant removal in both stormwater ponds and wetlands. In addition, vegetation can enhance the appearance of a pond or wetland, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris.

Within a stormwater pond or wetland, there are various hydrologic zones as shown in **Table D-2** that must be considered in plant selection. These hydrologic zones designate the degree of tolerance a plant must have to differing degrees of inundation by water. Hydrologic conditions in an area may fluctuate in unpredictable ways; thus the use of plants capable of tolerating wide varieties of hydrologic conditions greatly increases the successful establishment of a planting. Plants suited for specific hydrologic conditions may perish when those conditions change, exposing the soil, and therefore, increasing the chance for erosion. Each of the hydrologic zones is described in more detail below along with examples of appropriate plant species.

Table D-2 Hydrolic Zones

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep Water Pool	1-6 feet depth (permanent pool)
Zone 2	Shallow Water Bench	Normal pool elevation to 1 foot depth
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Zone 1: Deep Water Area (1- 6 Feet)

Ponds and wetlands both have deep pool areas that comprise Zone 1. These pools range from one to six feet in depth, and are best colonized by submergent plants, if at all.

This pondscaping zone is not routinely planted for several reasons. First, the availability of plant materials that can survive and grow in this zone is limited, and it is also feared that plants could clog the stormwater facility outlet structure. In many cases, these plants will gradually become established through natural recolonization (e.g., transport of plant fragments from other ponds via the feet and legs of waterfowl). If submerged plant material is commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

- ❏ Plant material must be able to withstand constant inundation of water of one foot or greater in depth.
- ❏ Plants may be submerged partially or entirely.
- ❏ Plants should be able to enhance pollutant uptake.
- ❏ Plants may provide food and cover for waterfowl, desirable insects, and other aquatic life.

Some suggested emergent or submergent species include, but are not limited to: Water Lily, Deepwater Duck Potato, Spatterdock, Wild Celery and Redhead Grass.

Zone 2: Shallow Water Bench (Normal Pool To 1 Foot)

Zone 2 includes all areas that are inundated below the normal pool to a depth of one foot, and is the primary area where emergent plants will grow in stormwater wetlands. Zone 2 also coincides with the aquatic bench found in stormwater ponds. This zone offers ideal conditions for the growth of many emergent wetland species. These areas may be located at the edge of the pond or on low mounds of earth located below the surface of the water within the pond. When planted, Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. This food chain includes predators, allowing a natural regulation of mosquito populations, thereby reducing the need for insecticidal applications.

- ❏ Plant material must be able to withstand constant inundation of water to depths between six inches and one foot deep.
- ❏ Plants will be partially submerged.
- ❏ Plants should be able to enhance pollutant uptake.
- ❏ Plants may provide food and cover for waterfowl, desirable insects and other aquatic life.

Common emergent wetland plant species used for stormwater wetlands and on the aquatic benches of stormwater ponds include, but are not limited to: Arrowhead/Duck Potato, Soft Rush, various Sedges, Softstem Bulrush, Cattail, Switchgrass, Southern Blue-Flag Iris, Swamp Hibiscus, Swamp Lily, Pickerelweed, Pond Cypress and various Asters.

Zone 3: Shoreline Fringe (Regularly Inundated)

Zone 3 encompasses the shoreline of a pond or wetland, and extends vertically about one foot in elevation from the normal pool. This zone includes the safety bench of a pond, and may also be periodically inundated if storm events are subject to extended detention. This zone occurs in a wet pond or shallow marsh and can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. In order to stabilize the soil in this zone, Zone 3 must have a vigorous cover.

- ❏ Plants should stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- ❏ Plant material must be able to withstand occasional inundation of water. Plants will be partially submerged partially at this time.
- ❏ Plant material should, whenever possible, shade the shoreline, especially the southern exposure. This will help to reduce the water temperature.
- ❏ Plants should be able to enhance pollutant uptake.
- ❏ Plants may provide food and cover for waterfowl, songbirds, and wildlife. Plants could also be selected and located to control overpopulation of waterfowl.
- ❏ Plants should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- ❏ Plants should have very low maintenance requirements, since they may be difficult or impossible to reach.
- ❏ Plants should be resistant to disease and other problems which require chemical applications (since chemical application is not advised in stormwater ponds).

Many of the emergent wetland plants that perform well in Zone 2 also thrive in Zone 3. Some other species that do well include Broom Grass, Upland Sea-Oats, Dwarf Tickseed, various Ferns, Hawthorns. If shading is needed along the shoreline, the following tree species are suggested: Boxelder, Ash, Willow, Red Maples and Willow Oak.

Zone 4: Riparian Fringe (Periodically Inundated)

Zone 4 extends from one to four feet in elevation above the normal pool. Plants in this zone are subject to periodic inundation after storms, and may experience saturated or partly saturated soil inundation. Nearly all of the temporary extended detention (ED) storage area is included within this zone.

- ❏ Plants must be able to withstand periodic inundation of water after storms, as well as occasional drought during the warm summer months.
- ❏ Plants should stabilize the ground from erosion caused by run-off.
- ❏ Plants should shade the low flow channel to reduce the pool warming whenever possible.
- ❏ Plants should be able to enhance pollutant uptake.
- ❏ Plant material should have very low maintenance, since they may be difficult or impossible to access.
- ❏ Plants may provide food and cover for waterfowl, songbirds and wildlife. Plants may also be selected and located to control overpopulation of waterfowl.
- ❏ Plants should be located to reduce pedestrian access to the deeper pools.

Some frequently used plant species in Zone 4 include Broom Grass, Yellow Indian Grass, Ironweed, Joe Pye Weed, Lilies, Flatsedge, Native Hollies, Forsythia, Lovegrass, Hawthorn and Sugar Maples.

Zone 5: Floodplain Terrace (Infrequently Inundated)

Zone 5 is periodically inundated by flood waters that quickly recede in a day or less. Operationally, Zone 5 extends from the maximum two year or CP_v water surface elevation up to the 25 or 100 year maximum water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone, and establish a low maintenance, natural vegetation.

- ❏ Plant material should be able to withstand occasional but brief inundation during storms, although typical moisture conditions may be moist, slightly wet, or even swing entirely to drought conditions during the dry weather periods.
- ❏ Plants should stabilize the basin slopes from erosion.
- ❏ Ground cover should be very low maintenance, since they may be difficult to access on steep slopes or if the frequency of mowing is limited. A dense tree cover may help reduce maintenance and discourage resident geese.
- ❏ Plants may provide food and cover for waterfowl, songbirds, and wildlife.
- ❏ Placement of plant material in Zone 5 is often critical, as it often creates a visual focal point and provides structure and shade for a greater variety of plants.

Some commonly planted species in Zone 5 include many wildflowers or native grasses, many Fescues, many Viburnums, Witch Hazel, Blueberry, American Holly, American Elderberry and Red Oak.

Zone 6: Upland Slopes (Seldom or Never Inundated)

The last zone extends above the maximum 100 year water surface elevation, and often includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe.

- ❏ Plant material is capable of surviving the particular conditions of the site. Thus, it is not necessary to select plant material that will tolerate any inundation. Rather, plant selections should be made based on soil condition, light, and function within the landscape.
- ❏ Ground covers should emphasize infrequent mowing to reduce the cost of maintaining this landscape.
- ❏ Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, serve as a buffer, or provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

Some frequently used plant species in Zone 6 include most ornamentals (as long as soils drain well, many wildflowers or native grasses, Linden, False Cypress, Magnolia, most Spruce, Mountain Ash and most Pine.

Specific plants appropriate for wetlands are listed in the Plant List in Section 5.

The figures below (**Figures D-3** to **D-6**) illustrate a sample design of plantings within a constructed wetland:

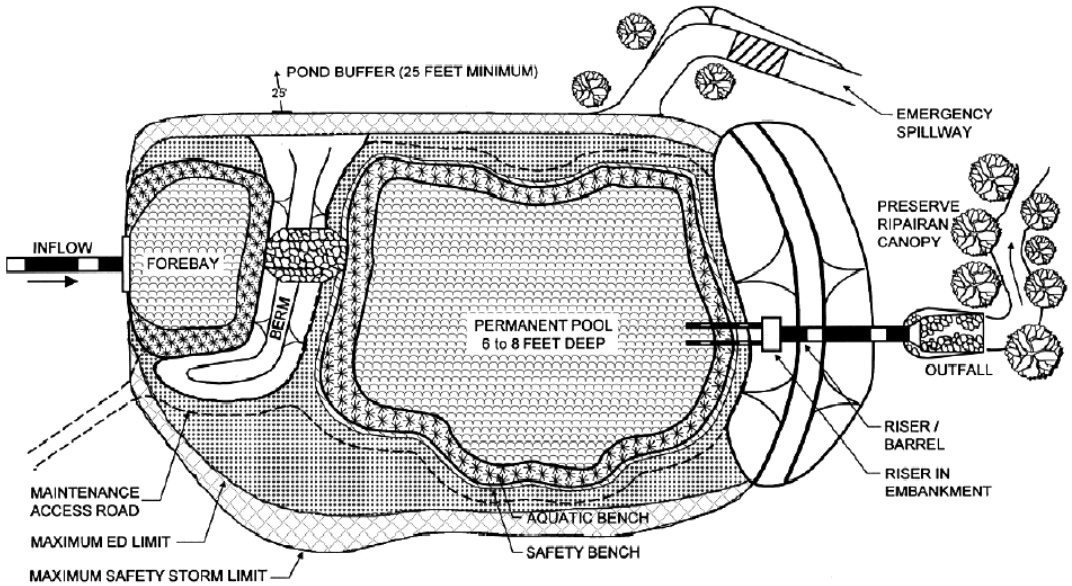


Figure D-3: Plan View of Hydrologic Zones around Stormwater Wet ED Pond

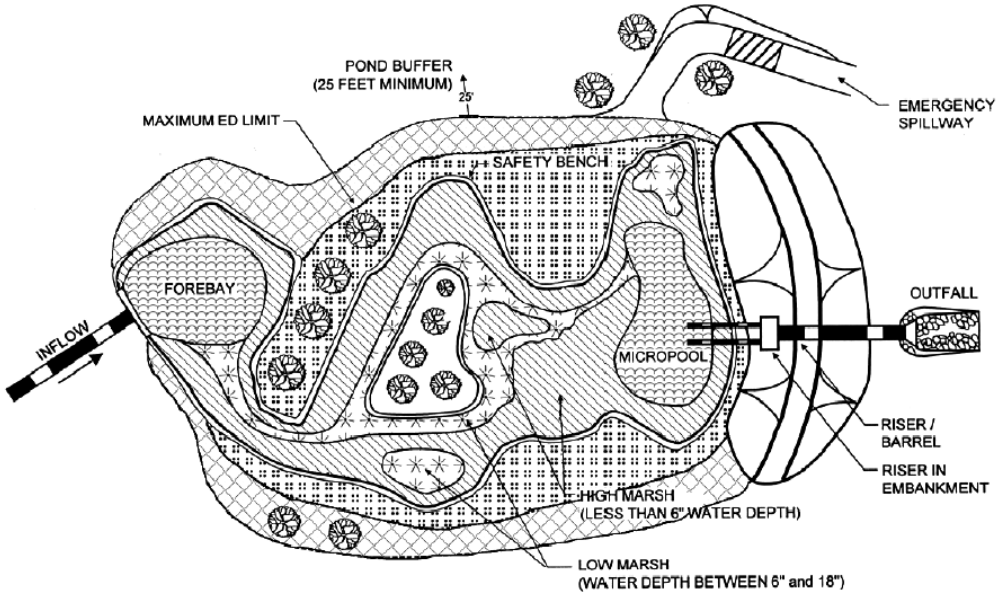


Figure D-4: Plan View of Hydrologic Zones around Stormwater ED Shallow Wetland

12 to 36 inch depth below normal pool elevation
Water Lily, Deep Water Duck Potato, Spatterdock, Wild Celery, Redhead Grass

0 to 12 inch depth below normal pool elevation
Arrowhead/Duck Potato, Soft Rush, various Sedges, Softstem Bulrush, Cattail, Switchgrass, Southern Blue Flag Iris, Swamp Hibiscus, Swamp Lily, Pickerelweed, Pond Cypress, various Asters

0 to 12 inch elevation above normal pool elevation
Various species from above, Broom Grass, Upland Sea-Oats, Dwarf Tickseed, various Ferns, Hawthorns, Boxelder, Ash, Willow, Red Maple, Willow Oak

1 to 4 foot elevation above normal pool elevation
Broom Grass, Yellow Indian Grass, Ironweed, Joe Pye Weed, various Lilies, Flatsedge, Hollies, Lovegrass, Hawthorn, Sugar Maple

CP_v to Qp_{25} or Q_f water surface elevation
Many wildflowers or native grasses, many Fescues, many Viburnums, Witch Hazel, Blueberry, American Holly, American Elderberry, Red Oak

Q_f water surface elevation and above
Many ornamentals as long as soils drain well, many wildflowers or native grasses, Linden, False Cypress, Magnolia, most Spruce, Mountain Ash, most Pine

Figure D-5 Legend of Hydrologic Zones Around Stormwater Facilities

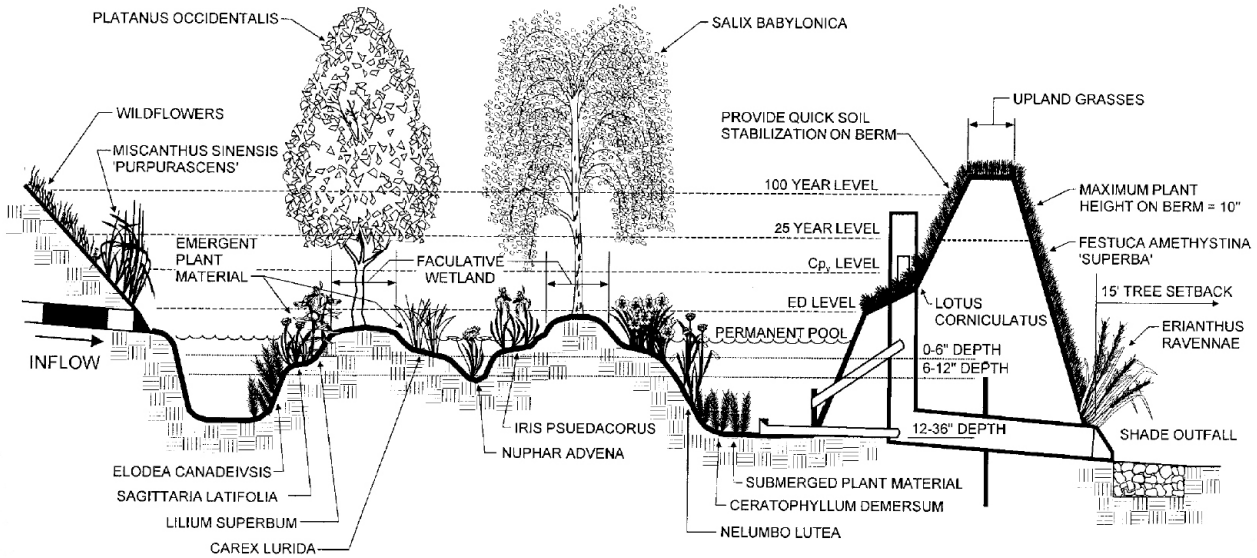


Figure D-6: Section of Typical Shallow ED Wetland

D.4.2 Bioretention Areas

Bioretention areas are structural stormwater controls that capture and treat runoff using soils and vegetation in shallow basins or landscaped areas. Landscaping is therefore critical to the performance and function of these facilities. Below are guidelines for soil characteristics, mulching, and plant selection for bioretention areas.

D.4.2.1 PLANTING MEDIA CHARACTERISTICS

Specifying the correct soils is critical in order to achieve stormwater objectives and plant health. Soils must balance three primary design objectives: 1) High enough infiltration rates to meet surface water draw down requirements, 2) infiltration rates that are not so high that they preclude pollutant removal function of soils and 3) soil composition that supports plant establishment and long-term health.

If the native soils cannot suffice for the planting media used within the bioretention area planting beds, then an engineered planting media should be provided that meets the specifications in the BMP write up. Keep in mind that increasing sand content increases permeability in the media but lowers phosphorus levels in the soil which hurts plant survivability.

D.4.2.2 MULCH LAYER

The mulch layer plays an important role in the performance of the bioretention system. The mulch layer helps maintain soil moisture and avoids surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. It also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment. The mulch layer should be standard landscape style, single or double, shredded hardwood mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least 12 months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat stormwater runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (**Figure D-7**). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. A sample of appropriate plant materials for bioretention facilities is included in Section 5.

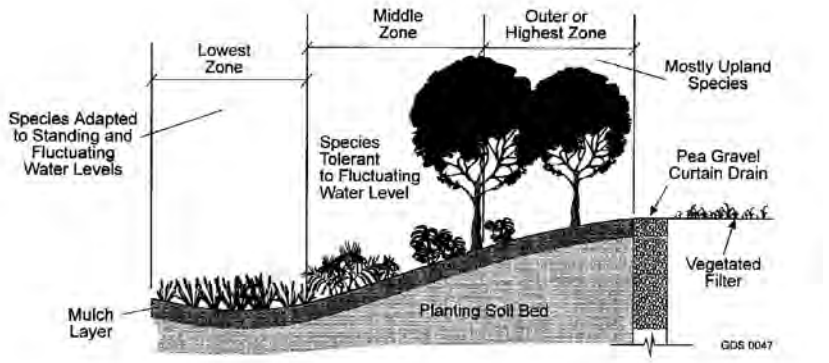


Figure D-7: Planting Zones for Bioretention Facilities

The layout of plant material should be flexible, but should follow the general principals described below. The objective is to have a system that resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth. A sample bioretention planting plan is presented in Figure D-8.

- ❏ Trees provide aesthetic and performance benefits in bioretention areas. When including trees, refer to the following guidelines:
  - Provide sufficient landscape width (a rule of thumb is 8' min.)
  - Locate trees on the side slopes, not in areas that pond
  - Select trees that will tolerate wet soils.
  - Locate trees with invasive roots away from perforated pipes.
  - Consider behavior and maintenance of plant material. Deciduous plant material that will drop leaves can impair the function of a bioretention area if not located properly or maintained.
- ❏ Native plant species should be specified.
- ❏ Appropriate vegetation should be selected based on the zone of hydric tolerance
- ❏ Species layout should generally be random and natural.
- ❏ The tree-to-shrub ratio should be 2:1 to 3:1.
- ❏ Plants should be placed at regular intervals based on their mature size to replicate a natural forest.
- ❏ Woody vegetation should not be specified at inflow locations.
- ❏ A canopy should be established with an understory of shrubs and herbaceous materials.
- ❏ Woody vegetation should not be specified in the vicinity of inflow locations.
- ❏ Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be considered when laying out the planting plan.
- ❏ Noxious weeds should not be specified.
- ❏ Aesthetics and visual characteristics should be a prime consideration.
- ❏ Traffic and safety issues must be considered.
- ❏ Existing and proposed utilities must be identified and considered.

See plant list in Section 5 for species appropriate to bioretention areas.

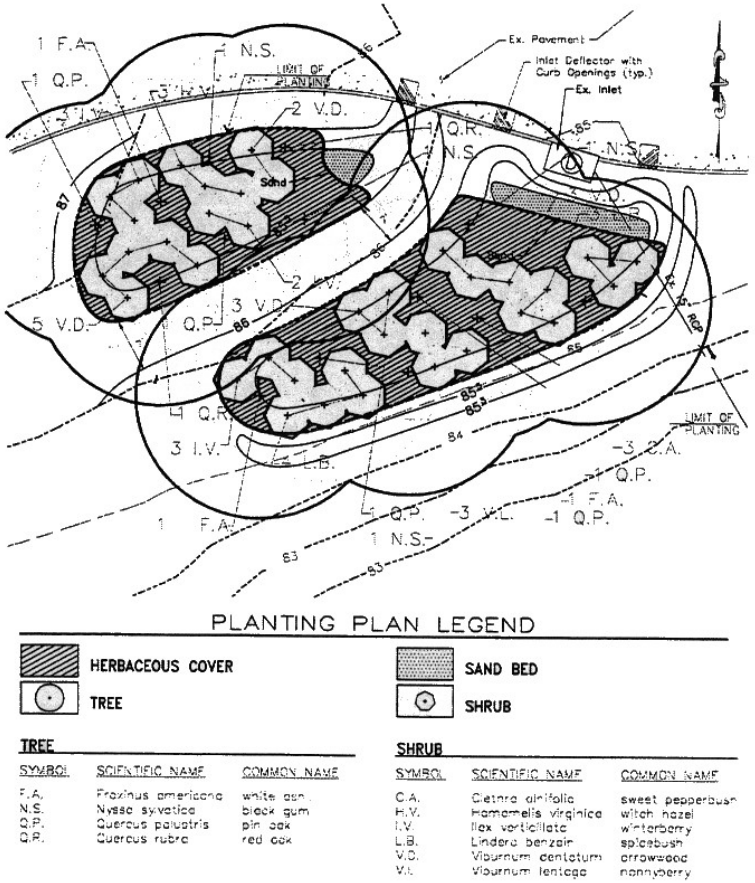


Figure D-8: Sample Bioretention Area Planting Plan
(Source: VDCR, 1999)

Section 5: Plant Selection for Stormwater Facilities

The following plant list is not representative of every plant that can be utilized in a stormwater bmp, but is meant as a starting point for native plant material. Many factors must be analyzed before selecting plant material types including sun/shade tolerance, flowering and/or fruiting habits, shape and full grown size of species, and local availability.

Many additional online and printed resources exist, including the following:

- Georgia Native Plant Society: http://gnps.org/indexes/Plant_Gallery_Index.php
- UGA Extension Native Plants for Georgia:
  - » Trees, Shrubs and Woody Vines: http://extension.uga.edu/publications/files/pdf/B%20987_8.PDF
  - » Grasses and Sedges: http://extension.uga.edu/publications/files/pdf/B%20987-4_1.PDF
  - » Ferns: http://extension.uga.edu/publications/detail.cfm?number=B987-2
  - » Wildflowers: http://extension.uga.edu/publications/files/pdf/B%20987-3_4.PDF

Georgia Native Plant List

TREES

Scientific Name	Common Name	Habit			H ZONE*	Hardiness
Acer negundo	Boxelder	Tree	Deciduous	Native	3,4,5	USDA Zone 2-10
Acer rubrum	Red Maple	Tree	Deciduous	Native	3,4,5	USDA Zone 3-9
Asimina triloba	Common Pawpaw	Tree	Deciduous	Native	3,4,5	USDA Zone 5-9
Betula nigra	River Birch	Tree	Deciduous	Native	2,3,4,5	USDA Zone 4-9
C Carya aquatica	Water Hickory	Tree	Deciduous	Native	3,4	USDA Zone 4-8
Carpinus caroliniana	American Hornbeam	Tree	Deciduous	Native	4,5	USDA Zone 3-9
Carya cordiformus	Bitternut Hickory	Tree	Deciduous	Native	3,4,5	USDA Zone 4-9
Carya illinoensis	Pecan	Tree	Deciduous	Native	3,4,5	USDA Zone 5b-9a
Carya laciniosa	Shellbark Hickory	Tree	Deciduous	Native	2,3,4,5	USDA Zone 5-8
Celtis laevigata	Sugarberry	Tree	Deciduous	Native	3,4,5	USDA Zone 6-9
Chemaecyparis thyoides	Atlantic White Cedar	Tree	Evergreen	Native	2,3,4,5	USDA Zone 4-8
Cornus drummondii	Rough-Leaf Dogwood	Tree	Deciduous	Native	3,4,5	USDA Zone 5-8
Crataegus spp.	Hawthornes	Tree	Deciduous	Native	4,5	USDA Zone 5-8
Diospyros virginiana	Common Persimmon	Tree	Deciduous	Native	4,5	USDA Zone 4-9
Fraxinus caroliniana	Carolina Ash	Tree	Deciduous	Native	3,4,5	USDA Zone 4-8
Fraxinus pennsylvanica	Green Ash	Tree	Deciduous	Native	3,4,5	USDA Zone 3-9a
Fraxinus profonda	Pumpkin Ash	Tree	Deciduous	Native	3,4,5	USDA Zone 5-9
Gordonia laisianthus	Loblolly Bay	Tree	Evergreen	Native	3,4	USDA Zone 6-9
Juniperus silicicola	Southern Red Cedar	Tree	Evergreen	Native	3,4,5	USDA Zone 8a-10b
Juniperus virginiana	Eastern Red Cedar	Tree	Evergreen	Native	3,4,5	USDA Zone 2-9
Liquidamber styraciflua	Sweetgum	Tree	Deciduous	Native	3,4,5	USDA Zone 5b-10a
Liriodendron tulipifera	Yellow Poplar	Tree	Deciduous	Native	3,4,5	USDA Zone 4-9
Magnolia virginiana	Sweetbay	Tree	Semi-Evergreen	Native	3,4,5	USDA Zone 5-10
Morus rubra	Red Mulberry	Tree	Deciduous	Native	4,5	USDA Zone 4-8
Myrica cerifera	Southern Bayberry	Tree	Evergreen	Native	3,4,5	USDA Zone 7-10
Nyssa aquatica	Water Tupelo	Tree	Deciduous	Native	3,4,5	USDA Zone 6-9
Nyssa ogeche	Ogeechee Tupelo	Tree	Deciduous	Native	3,4,5	USDA Zone 7a-9b
Nyssa sylvatica	Black Gum/ Swamp Tupelo	Tree	Deciduous	Native	3,4,5	USDA Zone 4b-9
Pinus elliottii	Slash Pine	Tree	Evergreen	Native	4,5	USDA Zone 7-11
Pinus glabra	Spruce Pine	Tree	Evergreen	Native	4,5	USDA Zone 8,9
Pinus serotina	Pond Pine	Tree	Evergreen	Native	4,5	USDA Zone 7-9
Pinus taeda	Loblolly Pine	Tree	Evergreen	Native	5	USDA Zone 6b-9
Platanus occidentalis	American Sycamore	Tree	Deciduous	Native	3,4,5	USDA Zone 4-9

**Hydrologic Zone for Stormwater Pond or Wetland*

Georgia Native Plant List (continued)

	Scientific Name	Common Name	Habit			H ZONE*	Hardiness
TREES	*Populus deltoides*	Eastern Cottonwood	Tree	Deciduous	Native	4,5	USDA Zone 3-9
	Populus heterophylla	Swamp Cottonwood	Tree	Deciduous	Native	3,4,5	USDA Zone 7-8
	Ptelea trifoliata	Wafer Ash	Tree	Deciduous	Native	5	USDA Zone 4-9
	Quercus bicolor	Swamp White Oak	Tree	Deciduous	Native	3,4,5	USDA Zone 3-8
	Quercus laurifolia	Laurel Oak	Tree	Deciduous	Native	4,5	USDA Zone 7-9
	Quercus lyrata	Overcup Oak	Tree	Deciduous	Native	3,4,5	USDA Zone 5-9
	Quercus michiauxii	Swamp Chestnut Oak	Tree	Deciduous	Native	4,5	USDA Zone 6-8
	Quercus nigra	Water Oak	Tree	Deciduous	Native	4,5	USDA Zone 5-9
	Quercus pagoda	Cherrybark Oak	Tree	Deciduous	Native	4,5	USDA Zone 4-8
	Quercus palustris	Pin Oak	Tree	Deciduous	Native	4,5	USDA Zone 4-8
	Quercus phellos	Willow Oak	Tree	Deciduous	Native	3,4,5	USDA Zone 5-9
	Quercus shumardii	Shumard Oak	Tree	Deciduous	Native	4,5	USDA Zone 5-9
	Salix caroliniana	Coastal Plain Willow	Tree	Deciduous	Native	3,4,5	USDA Zone 7-8
	Salix nigra	Black Willow	Tree	Deciduous	Native	3,4,5	USDA Zone 2-8
	Taxodium distichum *var. distichum*	Baldcypress	Tree	Deciduous	Native	2,3,4	USDA Zone 4-9
	Taxodium distichum *var. nutans*	Pondcypress	Tree	Deciduous	Native	2,3,4	USDA Zone 4-9
	Ulmus americana	American Elm	Tree	Deciduous	Native	3,4,5	USDA Zone 2-9
	Ulmus rubra	Slippery Elm	Tree	Deciduous	Native	3,4,5	USDA Zone 3-9
SHRUBS	*Aesculus pariviflora*	Bottlebrush Buckeye	Shrub	Deciduous	Native	3,4,5	USDA Zone 4-8
	Aesculus pavia	Red Buckeye	Shrub	Deciduous	Native	3,4,5	USDA Zone 4-8
	Alnus serrulata	Hazel Alder	Shrub	Deciduous	Native	3,4,5	USDA Zone 5-8
	Aronia arbutifolia	Red Chokeberry	Shrub	Deciduous	Native	3,4,5	USDA Zone 4-9
	Cephalanthus occidentalis	Common Buttonbush	Shrub	Deciduous	Native	2,3,4	USDA Zone 5-9
	Euonymus atropurpuresu	Eastern Burning Bush	Shrub	Deciduous	Native	4,5	USDA Zone 3-7
	Fothergilla gardenii	Fothergilla	Shrub	Deciduous	Native	4,5	USDA Zone 5-8
	Hamemelis virginiana	Witch Hazel	Shrub	Deciduous	Native	3,4,5	USDA Zone 3-8
	Hypericum densiflorum	Common St. Johns Wort	Shrub	Deciduous	Native	4,5	USDA Zone 5-9
	Ilex glabra	Inkberry	Shrub	Evergreen	Native	3,4,5	USDA Zone 4-9
	Ilex verticillata	Winterberry	Shrub	Deciduous	Native	2,3,4	USDA Zone 3-9
	Illex decidua	Decidious Holly	Shrub	Deciduous	Native	3,4,5	USDA Zone 5-9
	Juniperus horizontalis	Creeping Juniper	Shrub	Evergreen	Native	5	USDA Zone 3-9
	Lindera benzoin	Spicebush	Shrub	Deciduous	Native	3,4,5	USDA Zone 4-9

**Hydrologic Zone for Stormwater Pond or Wetland*

Georgia Native Plant List (continued)

GRASSES/HERBACEOUS

Scientific Name	Common Name	Habit			H ZONE*	Hardiness
Andropogon glomeratus	Bushy Broom Grass	Grass	Perennial	Native	3	USDA Zone 5-9
Andropogon virginicus	Broom Grass	Grass	Perennial	Native	4	USDA Zone 5-8
Chasmanthium latifolium	Upland Sea-Oats	Grass	Perennial	Native	3	USDA Zone 3-8
Leersia oryzoides	Rice Cut Grass	Grass	Perennial	Native	2	USDA Zone 3a-9b
Panicum virgatum	Switchgrass	Grass	Perennial	Native	2	USDA Zone 5-9
Sorghastrum nutans	Yellow Indian Grass	Grass	Perennial	Native	4	USDA Zone 5-9
Osmunda cinnamomea	Cinnamon Fern	Fern	Perennial	Native	3	USDA Zone 2-10
Osmunda regalis	Royal Fern	Fern	Perennial	Native	3	USDA Zone 3-9
Woodwardia virginica	Virginia Chain Fern	Fern	Perennial	Native	2	USDA Zone 3-10
Carex spp.	Carex Sedges	Sedge		Use only Native	2	Varies
Cyperus odoratus	Flat Sedge	Sedge		Native	2	USDA Zone 7-11
Juncus effusus	Soft Rush	Sedge		Native	2	USDA Zone 4-9
Scirpus californicus	Giant Bulrush	Sedge		Native	2	USDA Zone 6-9
Scirpus cyperinus	Woolgrass	Sedge		Native		USDA Zone 4-8
Scirpus validus	Softstem Bulrush	Sedge		Native	2	USDA Zone 3-9
Canna flaccida	Golden Canna	Perennial	Perennial	Native	2	USDA Zone 8-11
Coreopsis leavenworthii	Tickseed	Perennial	Perennial	Native	2	USDA Zone 8-11
Coreopsis tinctoria	Dwarf Tickseed	Perennial	Perennial	Native	3	USDA Zone 3-11
Crinum americanum	Swamp Lily	Perennial	Perennial	Native	2	USDA Zone 7-11
Eleocharis cellulosa	Coastal Spikerush	Perennial	Perennial	Native	2	USDA Zone 8-11
Eleocharis interstincta	Jonited Spikerush	Perennial	Perennial	Native	2	USDA Zone 8-10
Eupatorium fistolosum	Joe Pye Weed	Perennial	Perennial	Native	4	USDA Zone 4-8
Eupatorium perpurea	Joe Pye Weed	Perennial	Perennial	Native		USDA Zone 4-9
Helianthus angustifolius	Swamp Sunflower	Perennial	Perennial	Native	2	USDA Zone 6-9
Hibiscus coccinieus	Swamp Hibiscus	Perennial	Perennial	Native	2	USDA Zone 6-9
Iris louisiana	Louisiana Iris	Perennial	Perennial	Native	2	USDA Zone 5-9
Iris virginica	Southern Blue-Flag	Perennial	Perennial	Native	2	USDA Zone 5-9
Liatris spicata	Spiked Gayfeather	Perennial	Perennial	Native	3	USDA Zone 3-8
Lobelia cardinalis	Cardinal Flower	Perennial	Perennial	Native	3	USDA Zone 3-9
Peltandra virginica	Green Arum	Perennial	Perennial	Native	2	USDA Zone 5-9
Polygonum hydropiperoides	Smartweed	Perennial	Perennial	Native	2	USDA Zone 3-10
Pontederia cordata	Pickerelweed	Perennial	Perennial	Native	2	USDA Zone 3-10

**Hydrologic Zone for Stormwater Pond or Wetland*

Georgia Native Plant List (continued)

GRASSES/HERBACEOUS

Scientific Name	Common Name	Habit			H ZONE*	Hardiness
Pontederia lanceolata	Pickerelweed	Perennial	Perennial	Native	2	USDA Zone 3-10
Rudbeckia hirta	Black-eyed Susan	Perennial	Perennial	Native	4	USDA Zone 3-9
Rudbeckia laciniata	Greenhead Coneflower	Perennial	Perennial	Native	4	USDA Zone 3-9
Sagittaria lancifolia	Lance-leaf Arrowhead	Perennial	Perennial	Native	2	USDA Zone 5-10
Sagittaria latifolia	Duck Potato	Perennial	Perennial	Native	2	USDA Zone 5-10
Saururus cernuus	Lizard's Tail	Perennial	Perennial	Native	2	USDA Zone 3-9
Scirpus americanus	Three-square	Perennial	Perennial	Native	2	USDA Zone 3-9
Thalia geniculata	Alligator Flag	Perennial	Perennial	Native	2	USDA Zone 7-9
Typha latifolia	Broadleaf Cattail	Perennial	Perennial	Native	2	USDA Zone 3-10
Vernonia gigantea	Ironweed	Perennial	Perennial	Native	4	USDA Zone 5-8
Nuphar luteum	Water Lily	Water Lily	Perennial	Native	1	USDA Zone 4-10
Nymphaea mexicana	Yellow Water Lily	Water Lily	Perennial	Native	1	USDA Zone 3-11
Nymphaea odorata	Fragrant Water Lily	Water Lily	Perennial	Native	1	USDA Zone 3-11

**Hydrologic Zone for Stormwater Pond or Wetland*

Section 6: Minimum Requirements for Landscape Plans

Landscape plans must be prepared by a qualified design professional. They must include the following items, at a minimum:

1. Landscape plan sheet – A scaled construction drawing (typically at 1" = 20') to accurately locate and represent the plant material used within the BMP facility. Representation of plant material should be to scale and depicted at the mature width or spread.
2. A key that identifies all plant material used in the planting plan. The symbols used to identify the plants will correlate with the plant schedule. Plant groupings on the drawing are usually shown by an identifying symbol and the number of plants in that particular group.
3. List any other necessary information to communicate special construction requirements, materials, or methods such as specific plants that must be field located or approved by the designer and size or form matching of an important plant grouping.
4. Plant list/table – This must include scientific name, common name, quantity, nursery container size, container type (e.g., bare root, b&b, plug, container, etc.), appropriate planting season, and other information in accordance with the BMP facility-specific planting section and landscape industry standards.
5. Soil media specifications. If topsoil is specified, indicate the topsoil stockpile location, including source of the topsoil if imported to the site.
6. Construction notes with sequencing, soil and plant installation instructions, and initial maintenance requirements.
7. A description of the landscape contractor's responsibilities.
8. A minimum two-year warranty period stipulating requirements for plant survival/replacement.

Section 7: Plant Establishment and Maintenance

Establishment

Slope stabilization methods (such as planted erosion control mats or fiber rolls) should be utilized for slopes susceptible to washout. Erosion control mats and fabrics should also be utilized to protect channels that are susceptible to washing out. Flows should be diverted temporarily from seeded areas until they are stabilized. Aquatic and safety benches should be stabilized with emergent wetland plants and wet seed mixes

Irrigation

Planting design should minimize the need for a permanent irrigation system, however, irrigation is an important aspect of any landscape establishment. New plantings need two to three years of irrigation to become established but this varies by location and seasonal conditions. Temporary irrigation systems, hand watering or alternative methods of irrigation for landscape establishment should be specified. After that period, native plants will need little to no supplemental irrigation. Where permanent irrigation systems are utilized, they should include a weather-based controller to avoid watering during wet weather. Because bioretention soils are formulated to infiltrate, irrigation application rates must be properly designed to avoid overwatering and prevent potential discharges via underdrains.

Staking

Provide extra support to trees, especially in high wind areas. They should be securely staked during establishment and inspected once or twice a year and following storm events. Stakes should be removed as soon as they are no longer needed to stabilize the tree (between one and two years).

Weeding

Weeds compete with plants for nutrients, water and sunlight. They should be regularly removed, with their roots, by hand pulling or with manual pincer-type weeding tools. Care should be given to avoid unnecessary compaction of soils while weeding.

Leaf litter and trimmings present during maintenance should be removed from BMP rather than left to decompose because nitrogen levels can be affected and can change the function of the BMP.

Mulching

Compost Mulch (1" - 2") should be applied to specified areas to retain moisture, prevent erosion and suppress weed growth. Reapply annually as the mulch breaks down. Use a compost mulch and avoid bark mulches that can float during storm events.

Fertilization

The design for plantings shall minimize the need for herbicides, fertilizers, pesticides, or soil amendments at any time before, during, and after construction and on a long-term basis. Instead, a compost top dressing or application of compost tea can be used to introduce nutrients and beneficial microorganisms to the soil.
Apply compost mulch once per year in spring or fall or spray apply compost tea once per year between March and June.

Plant Replacement

At the end of the first year and again at the end of the two-year warranty period, all plants that do not survive must be replaced to avoid spreading disease, establishment of weeds in bare areas and reduced LID function. Before replacing with the same species, determine if another species may be better suited to the conditions.

References

Art, Henry W., 1986. *A Garden of Wildflowers, 101 Native Species and How to Grow Them*, Storey Communications, Inc., Pownal, VT.

Clausen, Ruth Rogers and Ekstrom, Nicolas, H., 1989. *Perennials for American Gardens*, Random House, New York, NY.

Dirr, Michael A., 1990. *Manual of Woody Landscape Plants, Their Identification, Ornamental Characteristics, Culture, Propagation, and Uses, 4th Edition*, Stipes Publishing Company, Champaign, IL.

Engineering Technology Associates Inc. and Biohabitats, Inc. (ETA&B), 1993. *Design Manual for Use of Bioretention in Stormwater Management,* Prince Georges County Dept. of Environmental Resources, Upper Marlboro, MD.

Garber, M.P. and Moorhead, D.J., 1999. *Selection, Production and Establishment of Wetland Trees and Shrubs*. University of Georgia, College of Agricultural & Environmental Sciences & Daniel B. Warnell School of Forest Resources Cooperative Extension Service.

Georgia Wildlife Web: http://fishesofgeorgia.uga.edu/gawildlife/index.php

Greenlee, John, (photographed by Derek Fell) 1992. *The Encyclopedia of Ornamental Grasses, How to Grow and Use Over 250 Beautiful and Versatile Plants*, Rodale Press, Emmas, PA.

Hodler, T.W. and H.A. Schretter. 1986. *The Atlas of Georgia*. University of Georgia Press, Athens.

Law, N.L., K. Cappiella and M.E. Novotney. 2008. "The Need to Address Both Impervious and Pervious Surfaces in Urban Watershed and Stormwater Management." Journal of Hydrologic Engineering. 14(4): 305-308.

Miles, Bebe, 1996. *Wildflower Perennials for Your Garden, A Detailed Guide to Years of Bloom from America's Native Heritage*, Stackpole Books, Mechanicsburg, PA.

Newcomb, Lawrence, 1977. *Newcomb's Wildflower Guide*, Little Brown and Company, Boston, MA.

Schueler, Thomas R., July 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMP's*, Department of Environmental Programs Metropolitan Washington Council of Governments, Metropolitan Information Center, Washington, DC.

Schueler, Thomas R., October 1996. *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetland Systems in the Mid-Atlantic Region*, Department of Environmental Programs Metropolitan Washington Council of Governments, Metropolitan Information Center, Washington, D.C.

Schueler, Thomas R. and Claytor, Richard A., 1997. *Design of Stormwater Filtering Systems: Appendix B and C*, Chesapeake Bay Consortium, Silver Spring, MD.

The Pennsylvania State University, College of Agriculture, Cooperative Extension Service, File No. IVC9 10M386, U. Ed. 85-439 and File No. IVC9 10M587 U.Ed. 86-356, *Weed Identification*, The Pennsylvania State University, College of Agriculture, Cooperative Extension Service, University Park, PA.

Tiner, Ralph W. Jr., April 1988. *Field Guide to Non-Tidal Wetland Identification*, U.S. Fish and Wildlife Service, Maryland Department of Natural Resources Maryland Geological

U.S. Army Corps of Engineers, Wetlands Research Program (WRP), 1993. *Baseline Site Assessments for Wetland Vegetation Establishment*. WRP Technical Note VN-EV-2.1, August 1993.

https://www.casqa.org/sites/default/files/downloads/central_coast_bioretention_plant_guidance_print.pdf

http://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/susmppdf/lid_appendix_g_bioretention_soil_specification.pdf

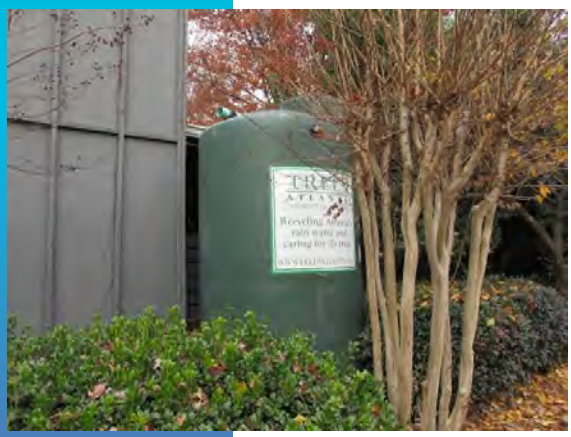
Special thanks to the N.C. Department of Environment and Natural Resources' Stormwater Permitting Program for assistance in developing content for this appendix.

Appendix E: Best Management Practice Operations & Maintenance

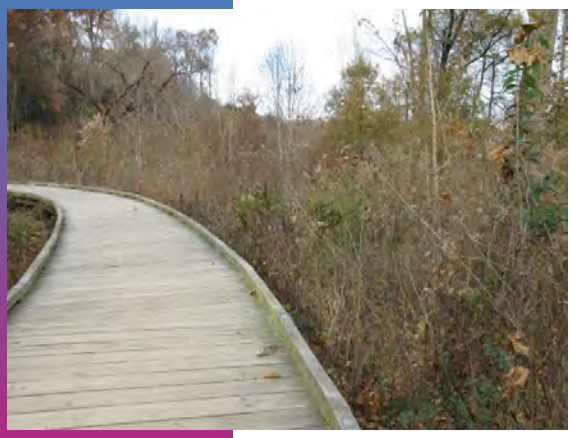
Operations & Maintenance Guidance Document











Georgia Stormwater Management Manual
Appendix E

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Introduction

The purpose of this Operation and Maintenance (O&M) Guidance Document is to define a Stormwater Best Management Practice (also called a BMP or a practice), explain the importance of BMPs, show the components of a typical BMP, and offer direction and information to keep the practice operational.

BMPs are structural practices designed to store or treat stormwater runoff to prevent or reduce pollution from entering surface waters in the State of Georgia. They improve water quality by treating, detaining, and retaining stormwater runoff. Detaining water is accomplished by creating a basin that holds the water for a short period of time to allow some of the water to exfiltrate into the ground and the remainder of the water to release slowly over a period of time. Retaining stormwater is similar to detaining stormwater; however, the difference is the length of time the water is held. Retaining the water extends the period of time the water is held.

In order for a BMP to work properly, it must be maintained. BMPs generally require annual inspections, but more frequent routine inspections, such as after major storm events, may be required based on the site conditions, past maintenance issues, or risk associated with safety due to non-performance of a structure. The key to the long-term success of a BMP is routine inspection and maintenance.

Why are BMPs important?

When an area is being developed, the property or portions of the property often change from grassed or wooded areas to paved areas. Grassed or wooded areas are pervious, which means that rainwater can infiltrate into the ground. Paved areas, on the other hand, are impervious, which means that rainwater cannot infiltrate into the ground. Because impervious areas cannot infiltrate water, increasing the amount of impervious area during development results in higher volumes of stormwater runoff. This can cause flooding and stormwater pollution, if not controlled through BMPs or other stormwater control measures. BMPs designed to retain or infiltrate stormwater help recharge the ground water and create a pervious area for the stormwater to infiltrate in the ground that has otherwise been altered by development. BMPs can also help reduce erosion and habitat loss in streams caused by excessive runoff and can reduce flooding and potentially make areas that are prone to flooding safer.

In addition, BMPs improve the quality of stormwater runoff from developed areas by removing pollutants that can contaminate the surrounding streams, rivers, lakes, etc. which, in turn, may contaminate our drinking water and food. Building BMPs in new developments, small business parks, or an individual residential lot or residential subdivisions, provides opportunities to remove the pollutants generated by the development. Example stormwater pollutants include sediment, excess nutrients, trash, fecal coliform, and metals.

An operational BMP will include some variation of the following components as shown in Figure 1.

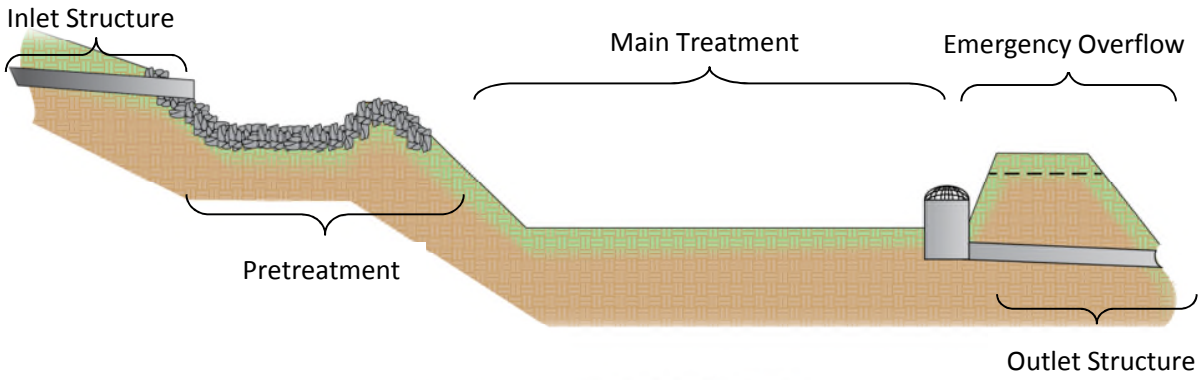


Figure 1 – Components of a BMP

The purpose and function of the main components of a BMP are described below:



- **Inlet structure** – This component brings water into the practice. The picture to the right shows an example of an inlet structure. Another example of an inlet structure would be a catch basin.
- **Pretreatment** – Pretreatment is designed to act as the first layer of protection for the main treatment area. Protection is provided by removing debris and coarse sediment, which reduces the frequency of clogging in the main treatment area. The pretreatment area is designed to be somewhat sacrificial so that it can be cleaned (or even replaced) before the main treatment area of the practice. This provides two maintenance benefits: ease of maintenance and less cost to maintain. Because of this, maintenance on this section is critical. The picture to the left shows a forebay, a type of pretreatment device. Other types of pretreatment devices include filter strips or grassy areas, grass channels, or rock lined plunge pools.





- **Main treatment** – The main treatment area is where the majority of the stormwater treatment takes place by removing sediment, nutrients, pollutants, etc. It is also the area where stormwater is contained, either through detention or retention, so that the water can be discharged at a controlled rate. Therefore, it is important that this section is routinely inspected and maintained to ensure the practice is functioning properly. The picture to the right shows an example of the main treatment area of a dry enhanced swale. Main treatment areas treat stormwater runoff through different methods including vegetated conveyance, infiltration, filtration, and settling. For example, the main treatment area of a pond treats stormwater runoff primarily through settling, and the main treatment area of a sand filter treats runoff through filtration. Specific maintenance concerns within a treatment area are

based on the method of treatment in a BMP. Examples of specific maintenance concerns for each treatment method include the following:

- Vegetated Conveyance – Erosion
- Infiltration – Media clogging and clogging the underdrain
- Filtration – Media clogging and clogging the underdrain
- Settling – Excessive sediment, embankment failure, and debris or other issues at the outlet structure.



- **Emergency overflow** – An emergency overflow is necessary for rain events that are larger than the practice was designed to treat. This component will keep the area surrounding the practice from flooding by allowing water to continue to flow into a nearby drainage system or water body. Usually an emergency overflow is an elevated grass or paved channel that provides a way for stormwater to leave the BMP in an extreme rain event. It should be noted that other types of emergency overflow exist, and sometimes the emergency overflow and outflow structure can be combined.



- **Outlet structure** –The outlet structure allows treated water to exit the practice. It is important that this component has regular maintenance because if the outlet structure is clogged, flooding will occur within the practice. The picture on the right shows an example of an outlet structure. Other examples of outlet structures include open pipes and underdrains.

Importance of Inspection

Once the BMP is built, routine inspection is very important to keep the practice working properly and catch potential problems before they become major problems (such as financial problems, legal problems, or both). Another benefit of routine inspection is it allows you to see the area surrounding the site and observe possible pollutants. For example, inspecting a BMP provides the opportunity to discover an unstable or eroding area upstream of the BMP that may be providing excessive sediment to the BMP, which could clog the practice quickly.

Items to check during routine inspections include, but are not limited to, the following:

- Structural problems
- Excessive ponding
- Unhealthy or undesirable vegetation
- Erosion
- Stability of the surrounding ground
- Clogging in the inlet or outlet structures or practice (from sediment, debris, or animals)
- Deterioration of pipes (or observation wells)

- New pollutant sources
- Infiltration rate by completing soil testing
- Monitoring water levels in observation wells

Some BMPs require an underground system, making inspection difficult to conduct. Generally these underground systems can be inspected by looking in the observation well. Sometimes, however, maintenance requires an individual who is certified in Occupational Safety and Health Administration (OSHA) confined space entry. Should there be a situation where a safety concern arises, the inspection should stop and the safety concern addressed. Once the concern is addressed, the inspection can continue. Signs indicating a potential maintenance problem with the underground system include the following:

- Ponding water or water remaining in the observation well longer than the design time
- Excessive sediment built up
- Damage to the structure through compaction or settling

Maintenance Agreements

Oftentimes BMPs are covered by a maintenance agreement between the owner and local city or county or other jurisdiction. Be sure to follow these maintenance requirements for the practice. This guidance document provides helpful maintenance tips; however, the maintenance performed on the practice has to meet the written standards and specifications in the maintenance agreement.

General Maintenance

Proper maintenance of each BMP is important to make sure the components of the BMP are operating and functioning the way the practice was designed to work. In other words, if the structure is not properly working, this could lead to the release of sediment, debris, and potential pollutants to a receiving water. Generally, maintenance for each practice includes:



- Removing built up sediment, debris, or trash within the practice
- Removing debris from the inflow and outflow structure of the practice
- Implementing erosion and sediment control practices on portions of the BMP where vegetation is missing or in poor condition, replace vegetation
- Inspecting the BMPs regularly to ensure the structural integrity and functionality of the BMP
- Replacing the filter media (as needed)

Before and after photos are recommended as proof that maintenance has been performed.

Vegetation Maintenance



Many BMPs include vegetation within or around the practice. Vegetation is an important part of the practice and aids infiltration and filtration. In addition, vegetation keeps the soil from eroding and washing into nearby drainage systems and water bodies. Finally, planting vegetation gives the area an additional aesthetic value. General vegetation maintenance includes:

- Irrigating and weeding during the first few months to establish the vegetation
- Maintaining the vegetation to ensure the health and abundance of native species and plantings
- Mowing, trimming, or pruning annually to prevent unwanted plants from growing in the practice
- Removing grass clippings or dead leaves from the practice to prevent clogging
- Minimize use of fertilizers and herbicides

When to Call a Professional

It is unlikely that a lawn care (or similar) company will know how to properly inspect or maintain a BMP. Therefore, a qualified licensed professional is recommended to perform inspections and maintain the practice. Sources for potential assistance include the following:

- Local stormwater authority
- Professional Engineer
- Landscape architect
- Extension service office

If it is decided that a licensed professional is not required to perform routine inspection and maintenance, there are times where one will be necessary for major problems. Examples of when to call a licensed professional include, but are not limited to, the following:

- Significant damage to the structure
- Significant sediment build-up
- Excessive ponding of water
- Abnormal odor
- Signs of water seepage on the downstream side of a dam
- Excessive erosion
- Signs of pollutants other than sediment, such as chemical spills

Additional Resources

Although most BMPs are similar in that they improve water quality or control quantity, they differ through site conditions, purpose, and function. Even two of the same type of BMP may require different maintenance due to site conditions. BMPS are designed to remove pollutants from stormwater which means they must be cleaned out periodically or they will cease to function. Since each BMP is unique there

is no “one size fits all” approach to maintaining them. Some BMPs may also have more complicated maintenance requirements that require special skills, tools, or equipment. When in doubt about the proper way to test and maintain a BMP the owner should seek additional assistance.

The following is a list of suggested resources for inspection and maintenance of a BMP:

- Georgia Stormwater Management Manual, Volumes 1 and 2
- Georgia Department of Transportation Stormwater System Inspection and Maintenance Manual
- Louisville Kentucky Metropolitan Sewer District Design Manual (Chapter 18.7)
- City of Philadelphia Green Stormwater Infrastructure Maintenance Manual
- North Carolina Division of Energy, Mineral and Land Resources Stormwater BMP Manual and BMP Forms
- West Virginia Stormwater Manual
- Post Construction Manual Managing Stormwater in Your Community
- Local stormwater authority
- Local Cooperative Extension Service office
- Manufacturer’s Guidelines (if applicable)

Within individual sections of this document, there may be references to certain tests such as soil infiltration and pH testing. It is recommended that testing for infiltration or pH be performed periodically on certain BMPs. In those cases it is recommended that a professional is consulted to ensure that the proper test is being performed in accordance with accepted procedures. The following is a list of suggestions for finding a professional:

- Local stormwater authority
- Local Cooperative Extension Service office
- Local Professional Engineer
- US Department of Agriculture Natural Resources Conservation Service

Bioretention Areas



A bioretention area is a shallow stormwater basin or landscaped area with well-draining soils, generally composed of sand, fines, and organic matter, and vegetation to capture and treat stormwater runoff. The basin or main treatment area of the bioretention area includes plants to aid in the filtration and infiltration of the stormwater flowing through the practice. An underdrain may be placed in the bioretention area to collect runoff that has filtered through the soil layers and pipe it to the storm sewer system or a nearby water body.

There are some common problems to be aware of when maintaining a bioretention area. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Establishing vegetation within the bioretention area
- Clogging the underdrain (if applicable)
- Mosquitoes breeding in the practice
- Ant mounds
- Maintaining the proper pH levels for plants
- Pruning and weeding to maintain appearance

Routine maintenance should be performed on the bioretention areas to ensure that the structure is functioning properly. Note that during the first year the bioretention area is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice.

In addition to routine maintenance, bioretention areas have seasonal and intermittent maintenance requirements. For example, the following are maintenance activities and concerns specific to winter months. Planting material should be trimmed during the winter, when the plants are dormant. In the event of snow, ensure that snow does not pile up in the bioretention area. Accumulated snow adds additional weight and may compact the bioretention area soil, which would reduce its infiltration capacity. In addition, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution.

Bioretention areas should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate into the ground. Note that it might take longer for the water to infiltrate into the ground during the winter months and early spring. Mulch the practice

as needed to keep a thickness of 3-4 inches. Shredded hardwood mulch is preferred, and care should be taken to keep the mulch from piling on the stems of the plants. For more information on vegetation in bioretention areas, see Appendix D: Planting and Soil Guidance.

If the bioretention area is not draining properly, check for clogging of the inflow and outflow structures as well as the infiltration rate of the soil media. If the soil is not draining properly, it could be clogged or over-compacted. In a bioretention area, the media is likely to become clogged at the mulch or upper layer of the soil first. If the media is clogged or over-compacted, then the media should be replaced. Potential sources of excessive sediment that could clog the media include ant mounds and unstable soil upstream of the practice. Possible sources of compaction are vehicles, such as tractors, traveling through the practice. If the practice includes an underdrain, a structural repair or cleanout to unclog the underdrain may be necessary.

In order to keep the water that exits the bioretention area clean, fertilizers should only be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the bioretention area is important, the primary purpose of a bioretention area is to act as a water quality device and introducing fertilizers into the bioretention area introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, bioretention areas should already be a nutrient rich environment that does not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

If designed correctly, there is no danger of bioretention areas becoming a breeding ground for mosquitoes. A mosquito egg requires 24-48 hours to hatch. In addition, it takes 10-14 more days for the larvae to develop and become an adult. By having a bioretention area that drains properly, it is unlikely that a bioretention area would provide a habitat that could become a breeding area for mosquitoes. Should the bioretention area become a breeding ground for mosquitoes, the problem is likely with the soil media or the overflow structure which may need to be addressed.

The table below shows a schedule for when different maintenance activities should be performed on the bioretention area.

Bioretention Area Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Prune and weed to maintain appearance. • Dissipate flow when erosion is evident. • Remove trash and debris. • Remove sediment and debris from inlets and outlets. • Remove and replace dead or damaged plants. • Mow around the bioretention area as necessary, ensuring grass clippings are not placed in the practice. • Observe infiltration rates after rain events. Bioretention areas should have no standing water within 24 hours of a storm event. • Inspect for evidence of animal activity.	As needed or 4 times during growing season

Activity	Schedule
• Inspect for erosion, rills, or gullies and repair. • Inspect filter strip/grass channel for erosion or gullying, if applicable. Re-seed or sod as necessary. • Inspect trees and shrubs to evaluate their health, and remove and replace any dead or severely diseased vegetation. • Obtain a mulch depth of at least 3 to 4 inches should be inspected and obtained. Additional mulch should be added as necessary.	Semi-annually in spring and fall
• Trim planting material. • Inspect for snow accumulation.	As needed or during winter months
• Test the planting soils for pH levels. Consult with a qualified licensed Professional to determine and maintain the proper pH levels.	Annually
• Replace/repair inlets, outlets, scour protection or other structures as needed. • Implement plant maintenance plan to trim and divide perennials to prevent overcrowding and stress. • Check soil infiltration rates to ensure the bioretention area soil is draining the water at a proper rate. Re-aerate or replace soil and mulch layers as needed to achieve infiltration rate of at least 0.5 inches per hour.	2 to 3 years

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Bioretention Area					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment.					
Weir – area is free of trash, debris, and sediment is less than 25% of the total depth of the weir.					
Filter Strip or Grass Channels – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Rock Lined Plunge Pools – area is free of trash debris and sediment. Rock thickness in pool is adequate.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					

Bioretention Area					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Mulching depth of 3-4 inches is maintained. Comment on mulch depth.					
Native plants were used in the practice according to the planting plan.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Results					
Overall condition of Bioretention Area:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Bioslopes



Bioslopes are linear BMPs with a permeable media that allows stormwater runoff to infiltrate and filter through the practice before exiting through an underdrain. High flows bypass the bioslope in the form of sheet flow running over the bioslope. Generally, a filter strip is placed before the bioslope for pretreatment where it captures sediment and debris and prevents premature clogging of the bioslope. If the space available for the bioslope is limited, a grass shoulder or pea gravel diaphragm may be used as an alternate method of pretreatment.

There are some common problems to be aware of when maintaining a bioslope. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure as well as the underdrain
- Undesirable vegetation
- Erosion
- Mowing the grass filter strip
- Compaction

Typically bioslopes are indistinguishable from the surrounding areas, so it is recommended that GPS co-ordinates of the bioslope location be obtained and the BMP be staked with markers. If markers are used, they should be placed at both ends at the toe of the slope and every 50 feet.

Routine inspection and maintenance should be performed on the bioslope to ensure that the practice is functioning properly. Generally maintenance will consist of removing debris and trash that could accumulate on the practice and cause clogging. Other routine maintenance includes mowing the bioslope and removing grass clippings. Mowing and landscaping crews should be alerted not to access the bioslope during wet conditions to avoid damaging or rutting the area.

Inspect the bioslope after a large rainstorm. Keep drainage paths (both to and from the BMP) clean to promote sheet flow and allow stormwater runoff to be routed in the intended direction.

In addition to routine maintenance, bioslopes have seasonal and intermittent maintenance requirements. For example, during the winter months, the bioslope should be inspected after a snow event (this is specific to northern areas of Georgia). Accumulated snow adds additional weight and may compact the media, which would reduce its infiltration capacity. In addition, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further

pollution. Also, note that it might take longer for the water to infiltrate into the ground during the winter months and early spring.

If the bioslope is not draining properly, it may be necessary to repair or unclog the underdrain as well as the inflow and outflow structures. Another possible reason the bioslope is not draining properly could be due to clogged or over-compacted bioslope media. If the mix becomes clogged or over-compacted, then it should be replaced. The degree of required media removal and replacement can vary depending on the characteristics of the contributing drainage area and the consistency of regular maintenance. For example, it is likely that removal and replacement of the top two to five inches of media will be necessary every three to five years for low sediment applications. Media replacement may be needed more often for areas of high sediment yield or high oil and grease.

The table below shows a schedule for when different maintenance activities should be performed on the bioslopes.

Bioslope Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Clear debris in inlets and outlets. • Mow and stabilize the area surrounding the bioslope. Remove grass clippings. • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • Remove trash and debris.	As needed or 4 times during growing season
• Stabilize eroded areas on the bioslope. • Ensure that flow is not bypassing the facility. • Ensure that no noticeable odors are detected outside the facility. • Mow the bioslope grass using a retractable arm mower to avoid compaction. Grass height should be mowed to a height of 6 to 15 inches. Remove grass clippings.	Monthly
• Ensure that gravel spreader or other structural elements of the bioslope are in good condition and free of debris. • Test the permeability of the bioslope media using a hydraulic conductivity test. Replace the media as needed. • Flow test the cleanouts to look for signs indicating the underdrain system is clogged. • Evaluate sediment accumulation and remove once it reaches or exceeds a depth of 3 inches.	Annually

Bioslope					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet.					
Water is going through the bioslope (i.e. no evidence of water going around the BMP).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment					
Area is free of trash debris and sediment.					
Area has been mowed and grass clippings are removed. Grass seems healthy and there are no bare areas or dying grass.					
No evidence of erosion or gullies.					
Area is free of undesirable vegetation.					
No standing water in the practice.					
No sediment accumulation within in the pretreatment area.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
No evidence of erosion of gullies within the bioslope.					
No evidence of long-term ponding or standing water in the practice (examples include: stains, odors, mosquito larvae, etc).					
Practice seems to be working properly. No settling around the structure. Comment on overall condition of practice.					

Bioslope					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
No undesirable vegetation within the bioslope.					
Area has been mowed at a height of 6-15 inches. Grass clippings are removed.					
Cleanout caps for underdrain are not damaged or missing.					
Flow testing has been performed on bioslope to determine if underdrain is clogged.					
Observation well has no signs of standing water.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet pipe is not damaged or clogged and is in good condition.					
Results					
Overall condition of Bioslope:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Downspout Disconnects



A downspout disconnect is a method to spread rooftop runoff from individual downspouts across lawns and other pervious areas, where it is slowed, filtered and allowed to infiltrate into the native soils. Downspout disconnects can be used in conjunction with other BMPs such as bioretention areas, enhanced swales, and vegetated filter strips. If the downspout disconnect is used in conjunction with another BMP, then that BMP will need to be inspected and maintained as well.

Common problems that can occur when maintaining a downspout disconnect include, but are not limited to, the following:

- Clogged gutters or downspouts
- Loose gutters or downspouts
- Water not draining away from buildings
- Poorly draining soils
- Poorly functioning splash blocks
- Cracks within the downspout extension

Routine maintenance should be performed on the downspout disconnects to ensure that the practice is properly functioning to ensure that a water problem is not created for neighbors. Ensure that there is no erosion occurring at the base of the downspout. Other specific maintenance items depend on where the downspout has been disconnected from the storm or sanitary sewer and where the flow has been redirected.

Inspect the downspout disconnect after a large rainstorm. Make sure that there is no evidence of a leak in the gutters or downspouts, and ensure that rooftop runoff is directed through the system. During the winter months, downspouts should be inspected for cracks caused by water freezing in the downspout.

The table below shows a schedule for when different maintenance activities should be performed routine maintenance activities typically associated with downspout disconnects.

Downspout Disconnect Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Pervious areas located below simple downspout disconnections should be watered to promote plant growth and survival. • Inspect the pervious areas located below simple downspout disconnections following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)

Activity	Schedule
• Inspect pervious area located below simple downspout disconnection. Maintain vegetation (e.g., mow, prune, trim) as needed. • Remove accumulated trash and debris in pervious area located below the simple downspout disconnection.	Regularly (Monthly)
• Inspect gutters and downspouts. Remove any accumulated leaves or debris. • Inspect the pervious areas located below simple downspout disconnections for erosion and the formation of rills and gullies. Plant replacement vegetation in any eroded areas. • Inspect the pervious areas located below simple downspout disconnections for dead or dying vegetation. Plant replacement vegetation as needed.	Annually (Semi-Annually During First Year)

Downspout Disconnects					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Access to the site is adequately maintained for inspection and maintenance.					
Gutters are clean. No sediment, debris, or trash to clog the system.					
Downspouts are properly fastened to convey water from the roof.					
Downspouts are free of trash, debris, and sediment and conveying water properly.					
No evidence of leaks at joints or other components of downspouts.					
Erosion control mats are present on site to prevent erosion on pervious area below downspout disconnects.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Vegetation is in place and is healthy. No bare or dying areas.					
Unwanted vegetation is trimmed and removed.					
No evidence of erosion, scour, or flooding.					
Results					
Overall condition of Downspout Disconnects:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

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Dry Detention Basins



A dry detention basin is a storage basin designed to provide water quantity control through detention of stormwater runoff. The purpose of detention is to allow some of the water to exfiltrate into the ground and the remainder of the water to release slowly over a period of time to reduce downstream water quantity impacts. Dry detention basins are designed to completely drain following a storm event and are normally dry between rain events. They provide limited pollutant removal benefits and are not intended for water quality treatment alone.

There are some common problems to be aware of when maintaining a dry detention basin. They include, but are not limited to, the following:

- Sediment build-up
- Trash, litter, and debris accumulation
- Clogging and structural repairs in the inlet and outlet structures
- Establishing vegetation within the dry detention basin
- Erosion
- Mowers compacting and rutting the basin bottom
- Mosquitoes breeding in the practice
- Ant mounds

Routine maintenance should be performed on the dry detention basins to ensure that the structure is properly functioning. Note that during the first year the dry detention basin is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice. In the event of snow, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution.

Dry detention basins should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate into the ground. Note that it might take longer for the water to infiltrate into the ground during the winter months and early spring. If the dry detention basin is not draining properly, check for clogging of the inflow and outflow structures.

If the forebay or dry detention basin has received a significant amount of sediment over a period of time, then the sediment at the bottom of the forebay or dry detention basin may need to be removed. Accumulated sediment in the practice decreases the available storage volume and affects the basin's ability to function as it was designed.

If designed and maintained correctly, dry detention basins should not become a breeding ground for mosquitoes. A mosquito egg requires 24-48 hours to hatch. In addition, it takes 10-14 more days for the egg to develop and become an adult. By having a dry detention basin that drains properly, it is unlikely that a dry detention basin would provide a habitat that could become a breeding area for mosquitoes. Should the dry detention basin become a breeding ground for mosquitoes, the problem is likely with the overflow structure which may need to be addressed.

The table below shows a schedule for when different maintenance activities should be performed on the dry detention basins.

Dry Detention Basin Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Remove debris from basin surface to minimize outlet clogging and improve aesthetics. • Note erosion of detention basin banks or bottom • Inspect for damage to the embankment. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annually and following significant storm events
• Remove sediment buildup. • Repair and revegetate undercut and/or eroded areas. • Perform structural repairs to inlet and outlets. • Repair undercut or eroded areas. • Mow side slopes. • Seed or sod to restore dead or damaged ground cover.	As needed based on inspection
• Mow to limit unwanted vegetation. • Litter/ Debris Removal.	Routine

Dry Detention Basin					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Inlet pipe is in good condition and is not clogged.					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (forebay)					
Area is free of trash, debris, and sediment.					
Sediment accumulation is less than 50% of the forebay volume.					
No undesirable vegetation within the forebay. Weeds are removed to prevent clogging.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc.).					

Dry Detention Basin					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Basin seems to be working properly. No settling around the basin. Comment on overall condition of basin.					
Vegetation within and around practice is maintained. Grass clippings are removed.					
Sediment accumulation within dry detention basin is less than 3 inches.					
No standing water within the basin.					
No evidence of use of fertilizer on grass (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
No shrubs or trees growing on embankment.					
No signs of seepage on the downstream face.					
No signs of animal activity.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
All moveable components are operational.					
Results					
Overall condition of Dry Detention Basin:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Dry Enhanced Swales/Wet Enhanced Swales



An enhanced swale is a vegetated open channel designed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means. Enhanced swales are generally shallow, wide, and vegetated to help slow and filter stormwater runoff.

There are two different types of enhanced swales. The first is a dry swale which includes a filter bed of prepared soil that overlays an underdrain system. They are designed to let stormwater be filtered or infiltrated through the bottom of the swale. Because they are dry most of the time, they are often the preferred option in residential settings. The second type of enhanced swale is a wet swale. Wet swales are designed to retain water or marshy conditions that support wetland vegetation. Because this practice is meant to retain water, they are generally used in areas with a high water table or poorly drained soils. Wet swales achieve pollutant removal both from sediment accumulation and biological removal.

There are some common problems to be aware of when maintaining an enhanced swale. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Establishing vegetation
- Clogging in the underdrain (if applicable)
- Mosquitoes breeding in the practice
- Ant mounds
- Maintaining the proper pH levels for plants
- Pruning and weeding to maintain appearance

Routine inspection and maintenance should be performed on the dry or wet enhanced swale to ensure that the practice is properly functioning. Note that during the first year the enhanced swale is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice. For more information on vegetation within a swale, see Appendix D: Planting and Soil Guidance. Enhanced swales should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly flow in and out of the practice.

In addition to routine maintenance, dry or wet enhanced swales have seasonal and intermittent maintenance requirements. For example, during the winter months, the enhanced swale should be inspected after a snow event (this is specific to northern areas of Georgia). Accumulated snow adds

additional weight and may compact the dry enhanced swale soil, which would reduce its infiltration capacity. In addition, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution. Note that it might take longer for the water to infiltrate into the ground during the winter months and early spring.

If the dry enhanced swale is not draining properly, check for clogging in the inflow and outflow structures. Another consideration would be the permeable soil layer, which could be clogged or over-compacted. In a dry enhanced swale, the media is likely to become clogged at the upper layer of the soil first. Potential sources of excessive sediment that could clog the media include ant mounds and unstable soil upstream of the practice. Possible sources of compaction are vehicles, such as tractors, traveling through the practice. If the media is clogged or over-compacted, then the media should be replaced. If the practice includes an underdrain, a structural repair or cleanout to unclog the underdrain may be necessary.

In order to keep the water that exits the dry or wet enhanced swale clean, fertilizers should only be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the enhanced swale is important, the primary purpose of an enhanced swale is to act as a water quality device, and introducing fertilizers into the enhanced swale introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, enhanced swales should already be nutrient rich environments that do not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

If designed and maintained correctly, there is no danger of dry enhanced swales becoming a breeding ground for mosquitoes. A mosquito egg requires 24-48 hours to hatch. In addition, it takes 10-14 more days for the egg to develop and become an adult. By having a dry enhanced swale that drains properly (within 24-48 hours), it is unlikely that a dry enhanced swale would provide a habitat that could become a breeding area for mosquitoes. Should the dry enhanced swale become a breeding ground for mosquitoes, the problem is likely with the soil media or the overflow structure which may need to be addressed.

The table below shows a schedule for when different maintenance activities should be performed on an enhanced swale.

Enhanced Swale Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Prune and weed to maintain appearance. • Dissipate flow when erosion is evident. • Remove trash and debris. • Remove sediment and debris from inlets and outlets. • Remove sediment build-up within the bottom of the swale once it has accumulated to 25% of the original design volume. • Remove and replace dead or damaged plants.	As needed or 4 times during growing season

Activity	Schedule
• Mow the dry enhanced swale as necessary to maintain a grass height of 4-6 inches, ensuring grass clippings are not placed in the practice. • Observe infiltration rates after rain events. Dry enhanced swales should have no standing water within 48 hours of a storm event (though 24 hours is more desirable). • Inspect for evidence of animal activity.	
• Inspect for erosion, rills, or gullies and repair. • Replant wetland species (for wet swale) if not sufficiently established. • Test the planting soils for pH levels. Consult with a qualified licensed Professional to determine and maintain the proper pH levels. • Inspect pea gravel diaphragm for clogging.	Annually (Semi-annually the first year)
• Trim planting material. • Inspect for snow accumulation.	As needed or during winter months
• Replace/repair inlets, outlets, scour protection or other structures as needed. • Implement plant maintenance plan to trim and divide perennials to prevent overcrowding and stress. • Check soil infiltration rates to ensure the dry enhanced swale soil is draining the water at a proper rate. Roto-till or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours.	2 to 3 years

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Dry Enhanced Swale/Wet Enhanced Swale					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed (for dry enhanced swale).					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment.					
Weir – area is free of trash, debris, and sediment is less than 25% of the total depth of the weir.					
Filter Strip or Grass Channels – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Rock Lined Plunge Pools – area is free of trash debris and sediment. Rock thickness in pool is adequate.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
For dry enhanced swale, no evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
Plants were used in the practice according to the planting plan.					

Dry Enhanced Swale/Wet Enhanced Swale					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
No evidence of undesirable vegetation.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
No evidence of erosion around the sides of the check dam.					
Cleanout caps are in place and in good condition (for dry enhanced swale).					
The underdrain appears to be unclogged evidenced by water exiting the practice freely (for dry enhanced swale).					
Pea gravel diaphragm or other flow spreader is clean and working properly.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Results					
Overall condition of Enhanced Swale:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

Dry Extended Detention Basins



A dry extended detention basin provides temporary storage of stormwater runoff to control the peak rate of runoff by allowing the stored water to release slowly over a period of time. This practice is mostly used to control water quantity, although some water quality benefits can be obtained by the settling of floatables and sediment. This extended version of a dry detention basin is designed to maximize water quality benefits.

There are some common problems to be aware of when maintaining a dry extended detention basin. They include, but are not limited to, the following:

- Sediment build-up
- Trash, litter, and debris accumulation
- Clogging in the inlet and outlet structures
- Erosion
- Structural repairs to inlets and outlets
- Mowers compacting and rutting the basin bottom
- Clogging in the emergency spillway
- Mosquitoes breeding in the practice

Routine maintenance should be performed on dry extended detention basins to ensure that the structure is properly functioning. Note that during the first year the dry extended detention basin is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice. In the event of snow, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution.

Inspect the dry extended detention basin after a large rainstorm. Keep drainage paths (both to and from the BMP) clean so that the water can properly flow into the basin. If the dry extended detention basin is not draining properly, check for clogging of the inflow and outflow structures.

If the forebay or dry detention basin has received a significant amount of sediment over a period of time, then the sediment at the bottom of the forebay or dry detention basin may need to be removed. Accumulated sediment in the practice decreases the available storage volume and affects the basin's ability to function as it was designed.

The table on the next page shows a schedule for when different maintenance activities should be performed on the dry extended detention basin.

Dry Extended Detention Basin Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Remove trash, sediment, and debris from forebay and inlet and outlet structures. • Mow the embankment and maintenance access. Periodically mow along maintenance rights-of-ways and the embankment. Remove grass clippings.	Monthly or as needed
• Repair and re-vegetate eroded areas. • Remove and dispose of vegetation that may hinder the operation of the pond. • Perform structural repairs to pond, outlet structures, embankments, control gates, valves, or other mechanical devices.	As needed
• Remove sediment when volume of pond is significantly reduced.	As needed (roughly every 20-50 years, but will vary based on the characteristics of the drainage area and amount of sediment entering the practice)

Dry Extended Detention Basin					
Inspection Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet/Outlet Structure					
Drainage ways to and from the practice is free of trash, debris, large branches, etc.					
Area around the inlet/outlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet/outlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
No signs of significant sediment accumulation.					
Concrete is in good condition. No signs of cracks.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Vegetation seems healthy. No signs of bare spots or dead vegetation.					
No signs of undesirable vegetation growth.					
No signs of excessive sedimentation.					
No signs of pollution draining into the practice (oil sheens, discolored or unnatural water, odor, etc.).					
Embankment and Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No signs of animal activity in embankment.					
No signs of seepage on downstream side of embankment.					

Dry Extended Detention Basin					
Inspection Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
No signs structural deformation of embankment.					
No obstructions in spillway.					
Results					
Overall condition of Dry Extended Detention Basin:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

Dry Wells



Dry wells are located below the surface of development sites, and consist of shallow excavations, typically filled with stone, that are designed to intercept and temporarily store post-construction stormwater runoff until it infiltrates into the underlying and surrounding soils. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites.

There are some common problems to be aware of when maintaining a dry well. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the gutters, pipes, and downspouts

Routine inspection and maintenance should be performed on the dry wells to ensure that the structure is functioning properly. Dry wells should be inspected after a large rainstorm. Keep gutters, pipes, and downspouts draining to the dry well clean and free of trash and debris. Every dry well should include an observation well to observe the draw down time of the dry well following a storm event. This is important to determine if clogging is occurring within the dry well.

If water is not draining to the dry well properly, check for clogging in the gutters, pipes, and downspouts. If the dry well is not draining properly the filter fabric may be clogged. The filter fabric lines the top and sides of the dry well. In addition, if the soil is not draining properly, the soil may be over-compacted. In a dry well, the media is likely to become clogged at the upper layer of the soil first. If the media is clogged or over-compacted, then the filter fabric and media should be replaced.

The table below shows a schedule for when different maintenance activities should be performed on the dry well.

Dry Well Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• If applicable, water to promote plant growth and survival within landscaped area over the top of the dry well. • If applicable, inspect vegetative cover on the surface of the dry well following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed
• If applicable, inspect gutters and downspouts. Remove any accumulated leaves or debris. • Inspect dry well following rainfall events. Check observation well to	Annually (Semi-Annually During First Year)

Activity	Schedule
ensure that complete drawdown has occurred within 24 hours after the end of a rainfall event. Failure to drawdown within this timeframe may indicate dry well failure. • If applicable, inspect pretreatment devices for sediment accumulation. Remove accumulated trash and debris. • Inspect top layer of filter fabric for sediment accumulation. Remove and replace if clogged.	
• Perform total rehabilitation of the dry well, removing dry well stone and excavating to expose clean soil on the sides and bottom of the well.	Upon Failure

Dry Well					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean around the practice (trash, debris, grass clippings, etc. removed).					
Gutters, pipes, and downspouts to the dry well are free of trash, debris, leaves, etc.					
No evidence of structural deficiencies or settling around the structure.					
Main treatment area is free of trash, debris, and sediment.					
Sediment has not accumulated and clogged filter fabric.					
Preatreatment is in place if dry well does not receive roof top runoff. Pretreatment is in good condition.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
The observation well is capped and locked when not in use.					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Results					
Overall condition of Dry Well:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

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Grass Channel



Grass channels are vegetated open channels designed to enhance water quality by settling suspended solids through filtration, infiltration, and biofiltration. This practice offers a method to manage pollution while also conveying stormwater runoff. Grass channels are well suited to a number of applications and land uses, including treating runoff from roads and highways and pervious surfaces. Grass channels are broad and shallow channels that are generally positioned parallel to roadways or other impervious areas. They can also be used as a single BMP, a pretreatment to another BMP, or as a link between other BMPs.

There are some common problems to be aware of when maintaining a grass channel. They include, but are not limited to, the following:

- Trash, litter, and debris accumulation
- Watering the practice during dry periods
- Establishing vegetation within the grass channel
- Clogging in the inlet and outlet pipes
- Ant mounds
- Erosion

Routine inspection and maintenance should be performed on the grass channels to ensure that the practice is functioning properly. Routine maintenance tasks include removing trash from the grass channel and ensuring that grass clippings and other debris are removed from the channel.

In order to keep the water that exits the grass channel clean, fertilizers should only be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the grass channel is important, a primary purpose of a grass channel is to act as a water quality device and introducing fertilizers into the grass channel introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

The table on the following page show routine maintenance activities typically associated with grass channels.

Grass Channel Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Mow grass to maintain a height of 3 to 4 inches. Remove grass clippings. • Repair eroded or bare spots. • Remove accumulated sediment, trash, and debris. • Water the practice during dry condition while vegetation is establishing.	As needed
• Inspect grass alongside slopes for erosion and formation of rills or gullies and correct. • Remove sediment from bottom of channel once sediment is 25% of the original design volume. • Remove trash and debris accumulated in the inflow forebay. • Inspect and correct erosion problems in the sand/soil bed of dry swales. • Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established. • Inspect pea gravel diaphragm for clogging and correct the problem.	Annually (Semi-annually the first year and then annually thereafter)

Grass Channel					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet.					
No signs of clogging or damage around the inlet.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment.					
Filter Strip or Grass Channels – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
No evidence of erosion in the practice.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
No undesirable vegetation located within the practice.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, blackened roots, etc.).					
Grass within and around practice is maintained at the proper height (3-4 inches). Grass clippings are removed.					
Grass cover seems healthy with no bare spots or dying grass.					

Grass Channel					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
No accumulating sediment within the grass channel.					
Outlet					
Outlet is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding.					
Results					
Overall condition of Grass Channel:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Gravity (Oil-Grit) Separators



Gravity (oil-grit) separators are designed to treat stormwater runoff by removing settleable solids, oil and grease, debris and floatables from stormwater runoff through gravitational settling and trapping of pollutants. Typically these systems are underground and installed at inlet structures. Gravity (oil-grit) separators come in different shapes and sizes ranging from small to large systems that have multiple chambers that use gravity to separate sediment, floatables, and oil/grease from stormwater runoff.

There are some common problems to be aware of when maintaining gravity (oil-grit) separators. They include, but are not limited to, the following:

- Clogging in the inlet and outlet structure
- Sediment and oil/grease build-up
- Inability to remove dissolved or emulsified oils and pollutants such as coolants, soluble lubricants, glycols and alcohols

Routine inspection and maintenance should be performed on the gravity separator to ensure that the structure is functioning properly. Typical maintenance will include removing accumulated sediment and pressure washing the system to remove blockage. Additional maintenance may be necessary if a spill occurs upstream of the system and drains into the practice. The contributing drainage areas should be maintained to limit the amount of trash and debris that enter the practice.

Gravity (oil-grit) separators should be inspected after a large rainstorm. It may be necessary to make repairs to the inlets, outlets, and other structural components. Check with the manufacturer's guidelines for recommended maintenance on the system. In addition, it is required that a maintenance plan be developed and implemented.

The table below shows a schedule for when different maintenance activities should be performed on gravity (oil-grit) separators.

Gravity (Oil-Grit) Separators Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Keep contributing drainage area free of trash, chunks of sediment, and debris. • Cleanout if spill occurs and enters the system. • Repair structural components. • Check to make sure practice is draining properly.	As needed (quarterly or after a large rain storm event)

Activity	Schedule
• Check maintenance plan and/or manufacturer's guidelines for additional maintenance needs. • Check system to make sure no blockage or significant sediment accumulation is occurring in the system.	Quarterly
• Cleanout system with vacuum or boom trucks. • Remove sediment and oil from chambers	Annually

Gravity (Oil-Grit) Separator					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Contributing drainage area is clean (trash, debris, grass clippings, etc. removed).					
Inlet and outlet pipes are clean; stormwater can enter and exit the practice without being blocked.					
Overflow structure is in good condition and clean.					
Maintenance is being performed according to manufacturer's guidelines.					
Maintenance is being performed according to maintenance plan.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Results					
Overall condition of Gravity (Oil-Grit) Separator:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

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Green Roofs



Green roofs represent an alternative to traditional impervious roof surfaces. They typically consist of underlying waterproofing and drainage materials and an overlying engineered growing media that is designed to support plant growth. Stormwater runoff is captured and temporarily stored in the engineered growing media, where it is subjected to evaporation and transpiration before being conveyed back into the storm drain system. This allows green roofs to provide measurable reductions in post-construction stormwater runoff rates, volumes and pollutant loads on development sites. There are two different types of green roof systems, intensive and extensive. Intensive green roofs have a thick layer of soil, can support a diverse plant community, and may include trees. Extensive green roofs have a much thinner layer of soil that is comprised primarily of drought tolerant vegetation. Plants chosen for a green roof should be compatible for warmer temperatures found on rooftops.

There are some common problems to be aware of when maintaining a green roof. They include, but are not limited to, the following:

- Clogging in the outlet structure
- Establishing vegetation within the green roof
- Clogging the drainage layer
- Maintaining the proper pH levels for plants
- Pruning and weeding to maintain appearance and prevent roots from potentially compromising the waterproof membrane

Routine inspection maintenance should be performed on green roofs to ensure that the system is functioning properly. Note that during the first year the green roof is built, inspection and maintenance will be required at a higher frequency to ensure the proper establishment of vegetation in the practice. Frequent watering and weed germination during establishment is key to maintaining a healthy green roof and preventing more long-term maintenance problems. For more information on green roof vegetation, see Appendix D: Planting and Soil Guidance.

Green roofs should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly flow to the plants and keep the vegetation healthy. Impaired drainage can cause damage to the roofing system and add structural loads beyond the building's design limits; this could lead to structural failure. Note that it might take longer for the water to infiltrate into the system during the winter months and early spring.

In order to keep the water that exits the green roof clean, fertilizers should be used only be used sparingly and during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the green roof is important, the primary purpose of a green roof is to act as a water quality device and introducing fertilizers into the green roof introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, after initial vegetation establishment, green roofs should already be a nutrient rich environment that does not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

The table below shows a schedule for when different maintenance activities should be performed on a green roof.

Green Roofs Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Water to promote plant growth and survival. • Inspect green roof for dead or dying vegetation. Dead vegetation should be removed along with any woody vegetation. Plant replacement vegetation as needed. • Mow and remove grass clippings. • Remove trash, debris, and other pollutants from the rooftop • Observe infiltration rates after rain events, the roof should drain in 24 hours of rain event.	As Needed
• Inspect waterproof membrane for leaks. Repair as needed. • Inspect outflow and overflow areas for trash, debris, and sediment accumulation. Remove any accumulated sediment or debris. • Inspect vegetation for signs of stress. If vegetation begins showing signs of stress, including drought, flooding, disease, nutrient deficiency or insect attack, treat the problem or replace the vegetation. • Weed and prune vegetation.	Semi-Annually (Quarterly During First Year)
• Test the planting soils for pH levels. Consult with a qualified licensed Professional to determine and maintain the proper pH levels.	Annually

Green Roof					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet and outlet pipes are free of trash, debris, etc.					
Inspect waterproof membrane.					
No signs of structural deficiency or settling. Comment on overall condition of roof.					
Water can flow freely in the drainage routes, no obstructions.					
Native plants were used in the practice according to the landscaping plan. Plants seem to be in good condition. Comment on condition of plants.					
No unwanted vegetation in the practice.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
No evidence of long-term ponding or standing water (examples include: stains, odors, mosquito larvae, etc).					
Results					
Overall condition of Green Roof:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

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Infiltration Practice



An infiltration practice is a shallow excavation, typically filled with stone or an engineered soil mix, which is designed to temporarily hold stormwater runoff until it infiltrates into the surrounding soils. Infiltration practices are able to reduce stormwater quantity, recharge the groundwater, and reduce pollutant loads.

There are some common problems to be aware of when maintaining infiltration practices. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Clogging the underdrain (if applicable)
- Mosquitoes breeding in the practice

Routine maintenance should be performed on infiltration practices to ensure that the practice is functioning properly. Infiltration practices should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate into the ground. Note that it might take longer for the water to infiltrate into the ground during the winter months and early spring.

In order to limit the sediment that enters the infiltration practice, infiltration practices should always be designed with adequate pretreatment (e.g., vegetated filter strip, sediment forebay). Routine maintenance of the pretreatment device, such as removing accumulated sediment, trash, and debris, decreases the amount of maintenance required on the infiltration practice as well as its likelihood of clogging and failing. Infiltration trenches can have either exposed aggregate at the surface of the practice which provides sediment removal and additional pretreatment upstream of the infiltration trench and can be easily removed and replaced when it becomes clogged.

If the infiltration practice is not draining properly, check for clogging of the inflow structure or underdrain. To help ensure that larger storm events are able to safely bypass the infiltration practice a perforated pipe (e.g., underdrain) is sometimes placed near the top of the stone reservoir or planting bed. This provides additional conveyance of stormwater runoff after the infiltration trench or basin has filled. Another consideration is the infiltration rate of the soil media. If the soil is not draining properly, the filter fabric could be clogged or the soil could be clogged or over-compacted. In an infiltration practice, the filter fabric is likely to be clogged along the top and sides of the infiltration practice. If the filter fabric becomes clogged, the practices will need to be dug up, cleaned, and the fabric replaced. The media is likely to become clogged at the upper layer of the soil first. If the media is clogged or over-compacted, then the media should be replaced. Potential sources of excessive sediment that could clog the media include ant mounds and unstable soil upstream of the practice. Possible sources of

compaction are tractors or maintenance vehicles traveling through the practice. If the practice includes an underdrain, a structural repair or cleanout to unclog the underdrain may be necessary.

If designed and maintained correctly, there is no danger of infiltration practices becoming a breeding ground for mosquitoes. A mosquito egg requires 24-48 hours to hatch. In addition, it takes 10-14 more days for the egg to develop and become an adult. By having an infiltration practice that drains properly, it is unlikely that it would provide a habitat that could become a breeding area for mosquitoes. Should the infiltration practices become a breeding ground for mosquitoes, the problem is likely with the soil media or the overflow structure which may need to be addressed.

The table below shows a schedule for when different maintenance activities should be performed on the infiltration practice.

Infiltration Practice Typical Routine Maintenance Activities and Schedule

Maintenance Activity	Schedule
• Inspect to ensure that contributing drainage area and infiltration practice are clear of sediment, trash and debris. Remove any accumulated sediment and debris. • Ensure that the contributing drainage area is stabilized. Plant replacement vegetation as needed. • Check observation well to ensure that infiltration practice is properly dewatering after storm events.	Monthly
• Inspect pretreatment devices for sediment accumulation. Remove accumulated sediment, trash and debris. • Inspect top layer of filter fabric and pea gravel or landscaping for sediment accumulation. Remove and replace if clogged. • Inspect the practice for damage, paying particular attention to inlets, outlets and overflow spillways. Repair or replace any damaged components as needed. • Inspect the practice following rainfall events (specifically large rainfall events). Check observation well to ensure that complete drawdown has occurred within 72 hours after the end of a rainfall event. Failure to drawdown within this timeframe may indicate infiltration practice failure.	Semi-Annually during first year and Annually thereafter
• Remove aggregate and install clean, washed trench aggregate • It may be necessary to replace piping, filter fabric, etc.	Upon Failure

Infiltration Practice					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc. Drainage ways are in good condition.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or underdrain) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment.					
Forebay – No undesirable vegetation.					
Forebay – No signs of erosion, rills, or gullies. Erosion protection is present on site.					
Forebay – No signs of standing water.					
Filter Strip– area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion or sediment accumulation.					
Filter Strip – No signs of unhealthy grass, bare or dying grass. Grass height is maintained to a height of 6 – 15 inches.					
Filter Strip– No signs of erosion, rills, or gullies. Erosion protection is present on site.					
Filter Strip – No undesirable vegetation.					
Filter Strip – No signs of standing water (examples include: stains, odors, mosquito larvae, etc).					

Infiltration Practice					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
No signs of ponding water more than 48 hours after a rain storm event (examples include: stains, odors, mosquito larvae, etc).					
No undesirable vegetation growing within the practice.					
Native plants were used in the practice according to the landscaping plan.					
Observation well is capped and locked when not in use					
Flow testing has been performed on infiltration practice to determine if underdrain is clogged.					
Emergency Overflow and Outlet Structure					
Area is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
No signs of sediment accumulation.					
Grass height of 6 – 15 inches is maintained.					
Results					
Overall condition of Infiltration Practice:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Multi-Purpose Detention Basins



Multi-purpose detention basins are facilities designed primarily for another purpose, such as a parking lot or roof top, that also provide water quantity control through detention of stormwater runoff. The temporary storage provided by multi-purpose detention basins reduces downstream water quantity impacts. Multi-purpose detention areas are normally dry between rain events, and by their very nature must be useable for their primary function the majority of the time.

There are some common problems to be aware of when maintaining a multi-purpose detention basin. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structures
- Establishing vegetation within the multi-purpose detention basin
- Erosion
- Structural repairs to inlets and outlets
- Clogging in the emergency spillway

Routine inspection and maintenance should be performed on a multi-purpose detention basin to ensure that the structure is properly functioning. In addition to routine maintenance, multi-purpose detention basins may have seasonal and intermittent maintenance requirements. For example, if vegetation is included in the practice, trim the planting material during the winter, when the plants are dormant.

The table below shows routine maintenance activities typically associated with multi-purpose detention basins.

Multi-Purpose Detention Basin Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Remove debris from ponding area to minimize outlet clogging and improve aesthetics.	Annually and following significant storm events
• Remove sediment buildup. • Repair and revegetate eroded areas. • Perform structural repairs to inlet and outlets.	As needed based on inspection
• Perform additional maintenance activities specific to the type of facility.	As required

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Multi-Purpose Detention Basin					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure and Pretreatment					
Drainage ways (overland flow, pipes or preteatment) to the practice are free of trash, debris, large branches, etc.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Emergency Overflow and Outlet Structure					
Area is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					

Multi-Purpose Detention Basin					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Results					
Overall condition of Multi-Purpose Detention Basin:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

Organic Filter



Organic filters, a design variant of the surface sand filter with organic materials as the filter media, are multi-chamber structures designed to treat stormwater runoff through filtration. An organic filter consists of a pretreatment chamber, and one or more filter cells. Each filter bed contains a layer of leaf compost or a peat/sand mixture, followed by an underdrain system. Maintenance frequency on organic filters is typically high due to clogging.

Common problems to be aware of when maintaining an organic filter include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Clogging the underdrain
- Mosquitoes breeding in the practice
- Ant mounds

Routine inspection and maintenance should be performed on the organic filters to ensure that the structure is functioning properly. Note that if the organic filter includes topsoil and vegetation, maintenance may be required at a higher frequency during the first year the organic filter is built to ensure the proper establishment of vegetation in the practice.

Inspect the organic filter after a large rainstorm. Keep drainage paths (both to and from the BMP) clean so that the water can properly infiltrate into the ground. If the organic filter is not draining properly, check for clogging at the inflow and outflow structures as well as the infiltration rate of the filter bed. In an organic filter, the filter bed is likely to become clogged at the upper layer of the filter (top 2-3 inches) and will need to be removed and replaced. If the filter becomes clogged or over-compacted, then the media should be replaced. In order to determine if maintenance is necessary, a record should be kept of the dewatering time for an organic filter. Typically the filter bed is designed to drain in 40 hours or less, if it the practice takes longer to drain, maintenance may be required for the practice.

For organic filters with vegetation, to keep the water that exits the organic filter clean, fertilizers should only be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the organic filter is important, the primary purpose of an organic filter is to act as a water quality device and introducing fertilizers into the organic filter introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, organic filters should already be a nutrient rich environment that does not require

fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

Potential sources of excessive sediment that could clog the media include ant mounds and unstable soil upstream of the practice. Possible sources of compaction are maintenance vehicles traveling through the practice. If the underdrain does not work properly, a structural repair or cleanout to unclog the underdrain may be necessary.

In the event of snow, ensure that the snow does not pile up in the organic filter. Accumulated snow adds additional weight and may compact the organic filter soil, which would reduce its infiltration capacity. In addition, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution.

If designed and maintained correctly, there is no danger of organic filters becoming a breeding ground for mosquitoes. A mosquito egg requires 24-48 hours to hatch. In addition, it takes 10-14 more days for the egg to develop and become an adult. By having an organic filter that drains properly, it is unlikely that an organic filter would provide a habitat that could become a breeding area for mosquitoes. Should the organic filter become a breeding ground for mosquitoes, the problem is likely with the soil media or the overflow structure which may need to be addressed. This is not applicable to the perimeter organic filter which has a permanent pool.

The table below shows a schedule for when different maintenance activities should be performed on the organic filter.

Organic Filter Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Check to see that the filter bed is clean of sediment, and the sediment chamber is not more than 50% full or 6 inches, whichever is less, of sediment (also check after moderate and major storms). Remove sediment as necessary. • Make sure that there is no evidence of deterioration, spalling or cracking of concrete. • Inspect grates (perimeter Organic Filter). • Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damaged structural parts. • Stabilize any eroded areas. • Ensure that flow is not bypassing the practice. • Ensure that no noticeable odors are detected outside the BMP.	Monthly
• Ensure that contributing area, organic filter, inlets and outlets are clear of trash and debris. • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Prune and weed to maintain appearance, if applicable. • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • If permanent water level is present (perimeter Organic Filter), ensure that the chamber does not leak, and normal pool level is retained.	As needed or 4 times during growing season

Activity	Schedule
• If filter bed is clogged or partially clogged, manual manipulation of the surface layer of sand may be required. Remove the top few inches of sand, roto-till, or otherwise cultivate the surface, and replace media with sand meeting the design specifications. • Replace any filter fabric that has become clogged.	Annually
• Remove and replace the top 2-3 inches of sand in the filter.	Every 3-5 years or as needed

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Organic Filter					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Area is free of signs of erosion.					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment. Area is free of undesirable vegetation.					
Sedimentation Chamber – area is free of trash, debris, and sediment.					
Perforated stand-pipe is free of trash, debris, and sediment. Surrounding vegetation is trimmed back so that there is no potential to restrict flow. Pipe is in good working order.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					

Organic Filter					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Undesirable vegetation within and around practice is trimmed and removed.					
Significant sediment accumulation is not occurring within the filter bed.					
Grass cover is healthy and there are no bare areas or dying grass.					
No evidence of leaks at joints or other components of the practice.					
Underdrain cleanout caps are not missing or damaged.					
Observation well does not have standing water.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
No evidence of animal activity.					
No evidence of seepage on the downstream face of the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet structure does not appear to be blocked.					
Results					
Overall condition of Organic Filter:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Permeable Bricks/Blocks



Permeable bricks/blocks are pavers with void areas areas between the bricks or blocks that are generally filled with pervious materials such as small pieces of gravel, or top soil if a grid is used. Beneath the bricks/blocks is a base layer of aggregate that acts as a holding area for stormwater runoff while still providing structural support for the road. This practice provides enough structural support so that cars can drive over them or they can be used in parking lots. Permeable brick/blocks are not recommended in areas with high traffic volume or heavy trucks. These systems provide water quality benefits in addition to groundwater recharge and a reduction in stormwater volume.

There are some common problems to be aware of when maintaining permeable bricks/blocks. They include, but are not limited to, the following:

- Sediment build-up and clogging between bricks/blocks
- Settling
- Bricks/blocks cracking or splitting

There are four basic types of permeable bricks/blocks that are used. They are bricks, concrete blocks, concrete grid, and articulated concrete block. The concrete grid can be filled with grass or gravel. Routine maintenance should be performed on the permeable bricks/blocks to ensure that the structure is functioning properly. Permeable bricks/blocks should be cleaned with a street vacuum or low pressure washer to remove debris and sediment monthly, or as needed, and all vegetation between bricks/blocks should be mowed and clippings removed to reduce clogging. Cleaning the bricks will help keep the water permeating through the pavers. After cleaning, the bricks/blocks may need to be filled in with additional aggregate or top soil to replace anything that may have been removed during cleaning.

In addition to routine maintenance, permeable bricks/blocks have seasonal and intermittent maintenance requirements. In the winter months permeable bricks/blocks can be plowed similarly to any other unpaved road by lifting the blade a few inches above the road or by using a beveled plow. Deicing materials such as sand, ash, or salt should be avoided if possible. They can potentially harm the bricks/blocks and may cause clogging. Non-toxic, organic deicers are recommended.

Permeable bricks/blocks should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate into the ground. Note that it might take longer for the water to permeate into the ground during the winter months and early spring.

If the permeable bricks/blocks are not draining properly, check for clogging between the bricks or blocks or at the upper layer of the aggregate, directly below the bricks/blocks. If clogging occurs, then the stones between the blocks/bricks should be replaced. In addition, the top layer of soil under the bricks/blocks may also need to be cleaned and replaced. Some areas of the blocks/bricks may need additional maintenance due to potential sources of clogging which include unstable soil upstream of the practice, leaves from trees, low points in blocks/bricks, trash, and debris from vehicle traffic. Another reason for the bricks/blocks not draining properly is settling. If major settling occurs, then the bricks/blocks should be removed, cleaned, and replaced.

Permeable bricks/blocks may also include an underdrain. If the practice includes an underdrain, additional maintenance will be required. Periodic testing will need to be done on the system to make sure that the underdrain is not clogged. This is done by pouring water into cleanout and observing how the water exits the practice. The observation well should be checked to make sure water is draining out of the practice.

The table below shows a schedule for when different maintenance activities should be performed on the permeable bricks/blocks.

Permeable Bricks/Blocks Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Keep the permeable bricks/blocks free of trash, debris, and sediment. • Make sure that there is no standing water in the bricks/blocks between storms. • Remove weeds and grass growing between the bricks/blocks (unless concrete grid pavers are being used). • Mow grass within the bricks/blocks (only for concrete grid with grass) • Mow / trim grass or vegetation near the bricks/blocks and remove clippings from area. • Visually inspect the bricks/blocks after large storms to ensure the overflow drainage system is working. • Inspect the bricks/blocks for damage and repair. • Vacuum sweep permeable brick/block surface to keep free of sediment. • After cleaning, additional aggregate may need to be added between the pavers. Replace aggregate between pavers as necessary.	Monthly during warm weather
• Keep the contributing drainage area and surface of the bricks/blocks clear of debris, trash, and sediment. • Ensure that the areas surrounding the practice are stabilized and mowed, remove grass clippings.	As needed, based on inspection

Activity	Schedule
• If the pavers are installed in an area that is subject to high amounts of sediment, leaves, or low point (i.e. large trucks traveling on the bricks/blocks daily) additional cleaning may be necessary. • Replace any joint material that has eroded or washed away. • Observe the system during a rain event. • Areas should be routinely inspected for settling and loss of water flow through the system.	Semi-annually in Spring and Fall
• Organic deicers may be used to melt ice and snow. • Snow plows may be used when necessary under the following conditions: o The edges of the plows are beveled. o The blade of the snow plow is raised 1-2 inches. o The snow plow is equipped with snow shoes which allow the blade to glide across uneven surfaces.	As needed in winter
• Inspect the surface for deterioration or breaking into fragments. • Flush the underdrain system to check for clogging (if applicable).	Annually
• Remove the permeable bricks/blocks; include the top and base layers of the practice. Clean bricks/blocks and base aggregate, and replace as needed.	Upon failure

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Permeable Bricks/Blocks					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, leaves, etc. removed).					
Area around the practice is mowed and grass clippings are removed. No signs of bare or dead grass.					
No evidence of gullies, rills, or erosion around the practice.					
Water is permeating the bricks/blocks (i.e. no evidence of water going around the practice).					
Bricks/blocks are structurally sound. No signs of cracks or splitting.					
Aggregate between the bricks/blocks is reasonable.					
No evidence of long-term ponding or standing water in the practice.					
Grass in the concrete grid is healthy, no dead grass or bare spots.					
Grass in the concrete grid is mowed and grass clippings are removed.					
Structure seems to be working properly. No signs of the bricks/blocks settling. Comment on overall condition of bricks/blocks.					
Vegetation within and around practice is maintained. Grass clippings are removed.					
No exposed soil near the bricks/blocks that could cause sediment accumulation within the practice.					
Cleanout caps are present and not missing (if applicable).					
The underdrain system has been flushed properly and there is no sign of clogging (if applicable).					
Results					
Overall condition of Permeable Bricks/Blocks:					

Permeable Bricks/Blocks					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Additional Comments					

Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.

Pervious Concrete



Pervious concrete is a special mixture with a high void space that allows water to infiltrate into the subsoil through the pavement surface and base layers. This aggregate base layer acts as both a structural layer and a container to temporarily hold stormwater runoff until it can infiltrate into the subsoil or drainage system.

There are some common problems to be aware of when maintaining pervious concrete. They include, but are not limited to, the following:

- Sediment build-up on surface
- Settling
- Cracking

Routine maintenance should be performed on pervious concrete to ensure that the area is functioning properly. Pervious concrete should be observed monthly to ensure the practice is functioning properly. Maintenance activities including street vacuum or low pressure washer to remove debris and sediment should be conducted at least annually, or as needed.

In addition to routine maintenance, pervious concrete has seasonal and intermittent maintenance requirements. In the winter months pervious concrete can be plowed, however, the snow plow should be equipped with snow shoes which can allow the blade to glide across uneven surfaces. Deicing materials such as sand, ash, salt, or other products should be avoided if possible. They will harm the concrete and other materials and may cause clogging. Organic deicers are recommended.

Pervious concrete should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate through the concrete and into the ground. Note that it might take longer for the water to infiltrate into the ground during the winter months and early spring.

If the pervious concrete is not draining properly, check for clogging at the top of the concrete. If clogging occurs, then the concrete should be cleaned by vacuuming or jet washing the area. Potential sources of clogging include unstable soil, leaves from trees, trash, and debris from vehicle traffic. The concrete could also not be draining properly due to settling or structural failure. If this happens, then the concrete should be removed and replaced. Settling or structural failure is most likely to occur in areas with high volumes of traffic or in areas with heavy traffic, such as large trucks.

The surface of the concrete should be inspected for deterioration. If the concrete fails, then the concrete should be resurfaced. Pervious concrete is intended for areas of low traffic; constant traffic and heavy equipment will cause the pavement to deteriorate more quickly.

Pervious concrete may also include an underdrain or a trench outlet. If the practice includes an underdrain or a trench, additional maintenance will be required. Periodic testing may be necessary to make sure that the underdrain or trench is not clogged. The underdrain or trench can be tested by pouring water into cleanout and observing how the water exits the practice. The observation well for the underdrain should be checked to make sure water is draining out of the practice.

The table below shows routine maintenance activities typically associated with pervious concrete.

Pervious Concrete Typical Routine Maintenance Activities and Schedule

Maintenance Activity	Schedule
• Ensure that contributing area, facility, inlets and outlets are clear of debris. • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Remove trash and debris. • Check to ensure that the pavement surface is not clogging (also check after moderate and major storms). • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system.	As needed
• Make sure that there is no evidence of deterioration or cracking of the concrete. • Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damage to the asphalt. • Ensure that flow is not bypassing the facility.	Monthly
• Vacuum sweep pervious concrete surface followed by high pressure hosing to keep pores free of sediment. • Flush the underdrain system and check for signs of clogging.	Annually or based on inspection
• Utilize organic de-icers on the pavement surface	During temperatures below freezing

Pervious Concrete					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance. No signs of bare or dead grass.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
No evidence of long-term ponding or standing water in the practice (examples include: stains, odors, etc).					
Structure seems to be working properly. No signs of concrete settling or cracking. Comment on overall condition of concrete.					
Vegetation around practice is maintained. Grass clippings are removed.					
No exposed soil near the concrete.					
Cleanout caps are present and not missing (if applicable).					
The underdrain system or trench has been flushed properly and there is no sign of clogging.					
Results					
Overall condition of Pervious Concrete:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

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Porous Asphalt



In general, porous asphalt is asphalt with reduced sands or fines and larger void spaces to allow water to drain through it. Porous asphalt allows water to infiltrate into the subsoil through the paved surface and base layer. This base, aggregate layer acts as both a structural layer and container to temporarily hold water. Porous asphalt is generally used instead on sidewalks or bicycle paths or roads with low traffic volumes.

There are some common problems to be aware of when maintaining porous asphalt. They include, but are not limited to, the following:

- Sediment build-up on surface
- Settling
- Cracking

Routine maintenance should be performed on porous asphalt to ensure that the area is functioning properly. Porous asphalt should be observed monthly to ensure the practice is functioning properly. Maintenance activities including vacuuming and jet washing should be conducted at least annually, or as needed.

In addition to routine maintenance, porous asphalt has seasonal and intermittent maintenance requirements. In the winter months porous asphalt can be plowed, however, the snow plow should be equipped with snow shoes which allow the blade to glide across uneven surfaces. Deicing materials such as sand, ash, or salt should be avoided if possible because they may harm the asphalt and aggregate and may cause clogging. Non-toxic, organic deicers are recommended.

Porous asphalt should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate into the ground. Note that it might take longer for the water to infiltrate into the ground during the winter months and early spring.

If the porous asphalt is not draining properly, check for clogging at the top of the asphalt. If clogging occurs, then the asphalt should be cleaned by vacuuming or low pressure washer the area. Potential sources of clogging include upstream unstable soil, leaves from trees, trash, and debris from vehicle traffic. Asphalt could also not be draining properly due to settling or structural failure. If this happens, then the asphalt should be removed and replaced. Settling or structural failure is most likely to occur in areas with high volumes of traffic or in areas with heavy traffic, such as large trucks.

The surface of both types of porous asphalt should be inspected for deterioration. If the pavement fails, the asphalt should be resurfaced. Potholes, though uncommon, can be patched using standard measures. If the damaged area is 10% or more of the total area, consult a qualified licensed Professional Engineer for repair.

Porous asphalt may also include an underdrain. If the practice includes an underdrain, additional maintenance will be required. Periodic testing will be necessary to make sure that the underdrain is not clogged. This is done by pouring water into cleanout and observing how the water exits the practice. The observation well should be checked to make sure water is draining out of the practice.

The table below shows routine maintenance activities typically associated with porous asphalt.

Porous Asphalt Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Ensure that contributing area, facility, inlets and outlets are clear of debris. • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Remove trash and debris. • Check to ensure that the pavement surface is not clogging (also check after moderate and major storms). • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system.	As needed
• Make sure that there is no evidence of deterioration, spalling or cracking of asphalt. • Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damage to the asphalt. • Ensure that flow is not bypassing the facility.	Monthly
• Vacuum sweep pervious concrete surface followed by high pressure hosing to keep pores free of sediment. • Flush the underdrain system and check for signs of clogging.	Annually or based on inspection
• Utilize organic de-icers on the pavement surface	During temperatures below freezing

Porous Asphalt					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Filter Strip (if applicable) – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Asphalt is structurally sound. No signs of cracks or raveling (disintegration of material from surface down).					
No evidence of long-term ponding or standing water in the practice.					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Vegetation around practice is maintained. Grass clippings are removed.					
No exposed soil near the asphalt.					
Cleanout caps are present and not missing.					
The underdrain system has been flushed properly and there is no sign of clogging (if applicable).					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Results					
Overall condition of Porous Asphalt:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain what and why in the appropriate comment box.					

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Proprietary Systems

Proprietary systems are control systems available from commercial vendors designed to treat stormwater runoff and/or provide water quantity control. Typically these systems are underground and installed at inlet structures. There are many types of proprietary stormwater structural controls to provide water quality treatment and quantity control. These systems come in different shapes and sizes ranging from small systems that use a swirling vortex to a large system that has multiple chambers to separate sediment, floatables, and oil/grease from the stormwater runoff.

There are some common problems to be aware of when maintaining propriety systems. They include, but are not limited to, the following:

- Sediment and oil/grease build-up
- Clogging in the inlet and outlet structure
- Inability to remove dissolved pollutants
- Must be maintained routinely so that system does not become a potential source of pollutants

Routine inspection and maintenance should be performed on the proprietary systems to ensure that the structure is functioning properly. Typical maintenance will include removing accumulated sediment and pressure washing the system to remove blockage. It is important that the accumulated sediment and water from cleaning the proprietary system be collected and disposed of properly. This is important to keep the ground surrounding the system clean to avoid clogging.

Additional maintenance may be necessary if a spill occurs upstream of the system and drains into the practice. The contributing drainage area should be maintained to limit the amount of trash and debris that enters the practice.

Proprietary systems should be inspected after a large rainstorm. It may be necessary to make repairs to the inlets, outlets, and other structural components. Check the manufacturer's guidelines for recommended maintenance on the system. In addition, it is required that a maintenance plan is developed and implemented.

The table below shows a schedule for when different maintenance activities should be performed on proprietary systems.

Proprietary Systems Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Check to make sure practice is draining properly.	After a large rain storm event or as needed
• Keep contributing drainage area free of trash, chunks of sediment, and debris. • Cleanout if spill occurs and enters the system. • Repair structural components.	As needed

Activity	Schedule
• Check maintenance plan and/or manufacturer's guidelines for additional maintenance needs. • Check system to make sure no blockage or significant sediment accumulation is occurring in the system.	Quarterly
• Cleanout system with vacuum or boom trucks. • Remove sediment and oil from chambers	Annually

Proprietary System					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Contributing drainage area is clean (trash, debris, grass clippings, etc. removed).					
Inlet and outlet pipes are clean; stormwater can enter and exit the practice without being blocked.					
Overflow structure is in good condition and clean.					
Maintenance is being performed according to manufacturer's guidelines.					
Maintenance is being performed according to the maintenance plan.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Results					
Overall condition of Proprietary System:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

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Rainwater Harvesting



Rainwater harvesting is a common stormwater management practice used to catch rainfall and store it to be used later. Gutters and downspout systems are typically used to collect the water from roof tops. Rainwater harvesting systems can be either above or below the ground. Once captured in the storage tank, the water may be used for non-potable indoor and outdoor uses. If properly designed, rainwater harvesting systems can significantly reduce post-construction stormwater runoff rates, volumes and pollutant loads on development sites. Rainwater harvesting also helps reduce the demand on public water supplies, which in turn helps protect aquatic resources, such as groundwater aquifers, from drawdown and seawater intrusion.

There are some common problems to be aware of when maintaining a rainwater harvesting system. They include, but are not limited to, the following:

- Sediment build-up in the system
- Wear and tear on pumping equipment (if applicable)
- Clogging in the gutters or downspout connections
- Algae growing in the rainwater system

Routine maintenance should be performed on the rainwater harvesting system. A well-designed rainwater harvesting system typically consists of five major components, including the collection and conveyance system (e.g., gutter and downspout system), pretreatment devices (e.g., leaf screens, first flush diverters, roof washers), the storage tank or cistern, the overflow pipe (which allows excess stormwater runoff to bypass the storage tank or cistern) and the distribution system (which may or may not require a pump, depending on site characteristics). Each of these components should be inspected and maintained.

Generally, maintenance should be performed in the spring and fall. Before the first significant freeze, downspouts should be disconnected, and the rainwater harvesting system should be completely drained. Other maintenance includes checking the system to make sure algae is not growing in the system. Check the elements of the unit and make repairs or replace broken parts as necessary. Any vegetation that receives accumulated water from the system should be checked for signs of stress. Replace the plants as necessary.

The table below shows a schedule for when different maintenance activities should be performed on the rainwater harvesting system.

Rainwater Harvesting System Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Disconnect rainwater harvesting system from roof downspouts (this may not be necessary for all areas of the state of Georgia). • Drain aboveground cisterns and clean for winter.	Late Fall (Before major freeze)
• Connect rainwater harvesting system to roof downspouts.	Early Spring (After last major freeze)
• Empty harvesting rainwater system periodically by watering vegetation. • Examine vegetation for health/distress and determine if additional watering needs are necessary. • Inspect storage tank screens and pretreatment devices. Clean as needed.	Regularly during above freezing temperatures
• Inspect gutters and downspouts. Remove any accumulated leaves or debris. • Clean storage tank screens. • Inspect pretreatment devices for sediment accumulation. Remove accumulated trash and debris. • Inspect for tight connection at inlet and drain valve. • Verify pumping system is properly working. • Keep pipe clear of obstructions. • Inspect storage tank for algal blooms. Treat as necessary. • Inspect overflow areas for erosion and the formation of rills and gullies. Plant replacement vegetation in any eroded areas.	Semi-annually in spring and fall
• Check system for sediment. Clean out the tank when the sediment is more than 5% of the volume in the cistern.	Annually

Rainwater Harvesting

Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Gutters and downspouts are free of trash, debris, etc.					
Leaf screens are clean and in good condition.					
First flush diverter is working properly and in good condition (if applicable).					
Roof washer is working properly and in good condition (if applicable).					
Cistern inlet and downspout fits tightly.					
Cistern tank is clean and free of sediment.					
Cistern is free of indication of algal blooms.					
Plants being watered from the rainwater harvesting system seem to be healthy and in good condition. Comment on condition of plants.					
No signs of the overflow valve leaking (stains, dampness).					
Cistern is in good condition structurally, no signs of cracking or leaking.					
Performance of pump matches pumping details (if applicable).					
Results					
Overall condition of Rainwater Harvesting:					
Additional Comments					

Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.

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Regenerative Stormwater Conveyance



A regenerative stormwater conveyance (RSC) is a practice that provides treatment, infiltration, and conveyance to stormwater runoff through a combination of pools, riffles (with either cobble rocks or boulders), native vegetation, an underlying sand layer, and wood chips.

There are some common problems to be aware of when maintaining a RSC. They include, but are not limited to, the following:

- Establishing vegetation within the RSC area
- Ant mounds
- Pruning and weeding to maintain appearance
- Deterioration of riprap

Routine maintenance should be performed on RSC to ensure that the system is functioning properly. Note that during the first year the RSC is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice.

A RSC should be inspected after a large rainstorm, especially during the first six months after establishment. Keep drainage paths, both to and from the BMP, clean so that the water can properly infiltrate into the ground.

Spot fertilization may be required during the first two months to establish vegetation. After that period, however, fertilizers should not be used. While vegetation in the RSC is important, a primary purpose of a RSC is to act as a water quality device, and introducing fertilizers into the RSC introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

The table on the following page shows a schedule for when different maintenance activities should be performed on the RSC area.

Regenerative Storm Conveyance Typical Maintenance Activities and Schedule

Activity	Schedule
• Inspect two times after establishment for first 6 months after storms that exceed ½ inch of rain. • Repair any erosion, rills, or gullies that may form in the practice • Conduct any needed repairs or stabilization • Repair areas with bare or dead grass in the contributing drainage area or around the RSC. • Watering and spot fertilization may be necessary during first 2 months to establish vegetation. • Remove and replace dead, damaged, or diseased plants.	Upon establishment
• Prune and weed vegetation. • Remove trash, sediment, and debris.	Four times per year
• Add additional plants to maintain needed vegetation density. • Remove and replace any dead, damaged, or diseased plants. • Repair any eroded areas.	As Needed
• Make sure weirs, riffles, and pools are in structurally good condition and that the practice has stable water levels. • Prune trees and shrubs (when they are dormant). • Remove any invasive species. • Remove any sediment accumulation in pretreatment area and inflow points.	Annually
• Remove accumulated sediment in pools • Repair damage to weirs, riffles, pools, or other structural components.	Once every 2 to 3 years

Regenerative Stormwater Conveyance					
Inspection Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Native plants were used in the practice according to the planning plan.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					

Regenerative Stormwater Conveyance					
Inspection Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Results					
Overall condition of RSC:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

Sand Filters



Sand filters are multi-chamber structures designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media, and typically an underdrain system. Sand filters can be designed in many ways; however, there are three primary sand filter system designs, surface sand filter, perimeter sand filter, and underground sand filter. A surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a filter bed chamber. A perimeter sand filter is an enclosed system typically just below the ground in a vault along the edge of an impervious area such as a parking lot. Finally, an underground sand filter is for areas with limited space and high density areas and should only be considered where local communities allow this practice. Because underground sand filters require additional planning, maintenance and incorporation with the stormwater management plan, coordinate with the local community for specific maintenance concerns. Maintenance frequency on sand filters is typically high due to clogging.

There are some common problems to be aware of when maintaining a sand filter. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Clogging the underdrain
- Mosquitoes breeding in the practice
- Ant mounds

Routine inspection and maintenance should be performed on the sand filters to ensure that the structure is functioning properly. Note that if the sand filter include a grass cover or vegetation, maintenance may be required at a higher frequency during the first year the sand filter is built to ensure the proper establishment of grass cover or vegetation in the practice. For more information on vegetation in a sand filter, see Appendix D: Planting and Soil Guidance.

Inspect the sand filter after a large rainstorm. Keep drainage paths (both to and from the BMP) clean so that the water can properly infiltrate into the ground. If the sand filter is not draining properly, check for clogging at the inflow and outflow structures as well as the infiltration rate of the filter bed. In a sand filter, the filter bed is likely to become clogged at the upper layer of the filter (top 2-3 inches) and will need to be removed and replaced. If the filter becomes clogged or over-compacted, then the media should be replaced. In order to determine if maintenance is necessary, a record should be kept of the dewatering time for a sand filter. Note that sand filters are typically designed to completely drain over 40 hours.

Potential sources of excessive sediment that could clog the media include ant mounds and unstable soil upstream of the practice. Possible sources of compaction are maintenance vehicles traveling through the practice. If the underdrain does not work properly, a structural repair or cleanout to unclog the underdrain may be necessary.

In the event of snow, ensure that the snow does not pile up in the sand filter. Accumulated snow adds additional weight and may compact the sand filter, which would reduce its infiltration capacity. In addition, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution.

If designed and maintained correctly, there is no danger of sand filters becoming a breeding ground for mosquitoes. A mosquito egg requires 24-48 hours to hatch. In addition, it takes 10-14 more days for the larvae to develop and become an adult. By having a sand filter that drains properly, it is unlikely that a sand filter would provide a habitat that could become a breeding area for mosquitoes. Should the sand filter become a breeding ground for mosquitoes, the problem is likely with the sand media or the overflow structure which may need to be addressed. This is for surface sand filters, where there is open water.

The table below shows a schedule for when different maintenance activities should be performed on the sand filter.

Sand Filter Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Check to see that the filter bed is clean of sediment, and the sediment chamber is not more than 50% full or 6 inches, whichever is less, of sediment. Remove sediment as necessary. • Make sure that there is no evidence of deterioration, spalling or cracking of concrete. • Inspect grates (perimeter sand filter). • Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damaged structural parts. • Stabilize any eroded areas. • Ensure that flow is not bypassing the BMP. • Ensure that no noticeable odors are detected outside the practice.	Monthly
• Ensure that contributing area, sand filter, inlets and outlets are clear of debris. • Prune and weed to maintain appearance (if applicable). • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • If permanent water level is present (perimeter sand filter), ensure that the chamber does not leak, and normal pool level is retained.	As needed or 4 times during growing season

Activity	Schedule
• If filter bed is clogged or partially clogged, manual manipulation of the surface layer of sand may be required. Remove the top few inches of sand, roto-till or otherwise cultivate the surface, and replace media with sand meeting the design specifications. • Replace any filter fabric that has become clogged.	Annually
• Remove and replace the top 2-3 inches of sand in the filter.	Every 3-5 years or as needed

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Sand Filter					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Area is free of signs of erosion.					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment. Area is free of undesirable vegetation.					
Sedimentation Chamber – area is free of trash, debris, and sediment.					
Perforated stand-pipe is free of trash, debris, and sediment. Surrounding vegetation is trimmed back so that there is no potential to restrict flow. Pipe is in good working order.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples: stains, odors, mosquito larvae, etc).					

Sand Filter					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Sand Filter seems to be working properly. No settling around the practice. Comment on overall condition of structure.					
Undesirable vegetation within and around practice is trimmed and removed.					
Significant sediment accumulation is not occurring within the filter bed.					
Grass cover is healthy and there are no bare areas or dying grass.					
No evidence of leaks at joints or other components of the practice.					
Underdrain cleanout caps are not missing or damaged.					
Observation well does not have standing water.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
No evidence of animal activity.					
No evidence of seepage on the downstream face of the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet structure does not appear to be blocked.					
Results					
Overall condition of Sand Filter:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Site Reforestation/Revegetation



Site reforestation/revegetation is a process of planting trees, shrubs and other native vegetation in disturbed pervious areas to restore the area to pre-development or better conditions. The process can be used to establish mature native plant communities, such as forests, in pervious areas that have been disturbed by clearing, grading and other land disturbing activities. These plant communities intercept rainfall and slow and filter the stormwater runoff to improve infiltration in the ground. This in turn can reduce the total amount of stormwater runoff and pollutant loads leaving the site. Areas that have been reforested or revegetated should be maintained in an undisturbed, natural state over time. These areas must be designated as conservation areas and protected in perpetuity through a legally enforceable conservation instrument (e.g., conservation easement, deed restriction).

There are some common problems to be aware of when maintaining a site reforestation/revegetation area. They include, but are not limited to, the following:

- Establishing vegetation within the area
- Watering the practice
- Erosion

Routine inspection and maintenance should be performed on the reforestation/revegetation site to ensure that the practice is functioning properly. Note that during the first year this process is implemented, maintenance may be required at a higher frequency to ensure the vegetation is properly established. Once the vegetation is established, very little maintenance is typically needed. For more information on vegetation, see Appendix D: Planting and Soil Guidance.

In order to keep the stormwater runoff that exits the site reforestation/revegetation area clean, fertilizers should only be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation growth in the site reforestation/revegetation area is important, the primary purpose of this process is to act as both a way to filter and infiltrate stormwater. Introducing fertilizers into the site reforestation/revegetation area introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

The table on the following page shows routine maintenance activities typically associated with site reforestation/revegetation areas.

Site Reforestation/Revegetation Routine Maintenance Activities and Schedule

Activity	Schedule
• Water to promote plant establishment, growth, and survival. • Inspect reforested/revegetated area following rainfall events. Plant replacement vegetation in any eroded areas. • Remove sediment from practice. • Revegetate if eroded.	As needed (Following Construction)
• Inspect reforested/revegetated area for erosion. Plant replacement vegetation in any eroded areas. • Inspect reforested/revegetated area for dead or dying vegetation. Plant replacement vegetation as needed. • Prune and care for individual trees and shrubs as needed.	Annually (Semi-Annually During First Year)

Site Reforestation/Revegetation					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
No evidence of gullies, rills, or excessive erosion.					
Area is free of trash, debris, and sediment.					
No evidence of long-term ponding or standing water (examples include: stains, odors, mosquito larvae, etc).					
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Native plants were used in the practice according to the planting plan.					
No evidence of excessive use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Results					
Overall condition of Site Reforestation/Revegetation area:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

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Soil Restoration



Soil restoration is the process of tilling and adding compost and other amendments to soils to restore them to their pre-development conditions. This improves the soil's ability to reduce post-construction stormwater runoff rates, volumes and pollutant loads. This process is ideal for areas that have been disturbed by clearing, grading and other land disturbing activities. This process is generally used in conjunction with other practices including, but not limited to, vegetated filter strips, grass channels, and simple downspout disconnections.

Restored pervious areas require some maintenance during the first few months following construction, but typically require very little maintenance after that.

In order to keep the water that exits the soil restoration area clean, fertilizers should be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation growth in the soil restoration area is important, introducing fertilizers into the soil restoration area introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

The table below shows routine maintenance activities typically associated with soil restoration areas.

Soil Restoration Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Water to promote plant growth and survival. • Inspect restored pervious area following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)
• Inspect restored pervious area for erosion. Plant replacement vegetation in any eroded areas. • Inspect restored pervious area for dead or dying vegetation. Plant replacement vegetation as needed.	Annually (Semi-Annually During First Year)

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Soil Restoration					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
No evidence of gullies, rills, or excessive erosion.					
No evidence of long-term ponding or standing water (examples include: stains, odors, mosquito larvae, etc).					
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Native plants were used in the practice according to the landscaping plan.					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Results					
Overall condition of Soil Restoration:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

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Stormwater Planters/Tree Boxes



Stormwater planters are similar to bioretention areas in their design purpose to detain, filter, and infiltrate stormwater. In addition stormwater planters utilize native or non-invasive flowers, shrubs, and trees to provide aesthetic qualities to the site. Planters and tree boxes receive stormwater from a variety of sources such as, roof tops and downspouts and runoff from streets.

There are some common problems when maintaining a stormwater planter. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the downspouts (only applicable of stormwater planters receive water from downspouts)
- Establishing vegetation within the stormwater planter
- Clogging the underdrain
- Maintaining the proper pH levels for plants

Routine maintenance should be performed on stormwater planters to ensure that the structure is functioning properly. Note that during the first year the stormwater planter is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice.

In addition to routine maintenance, stormwater planters have seasonal and intermittent maintenance requirements. For example, the following are maintenance activities and concerns specific to winter months. Planting material should be trimmed during the winter, when the plants are dormant. In the event of snow, ensure that snow does not pile up in the stormwater planter. Accumulated snow adds additional weight and may compact the stormwater planter soil, which would reduce its infiltration capacity. In addition, check to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid clogging and further pollution.

Stormwater planters should be inspected after a large rainstorm. Mulch the practice as needed to keep a thickness of 2-4 inches. Shredded hardwood mulch is preferred, and care should be taken to keep the mulch from piling on the stems of the plants. For more information on vegetation in stormwater planters, see Appendix D: Planting and Soil Guidance.

In order to keep the water that exits the stormwater planter clean, fertilizers should only be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the stormwater planter is important, the primary purpose of a stormwater planter is to act as a water quality device and introducing fertilizers into the stormwater planter introduces nutrients such as phosphorus and nitrogen that can pollute

downstream waters. In addition, stormwater planters should already be a nutrient rich environment that does not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

Invasive species should be kept out of the stormwater planters and the overall health of the plants should be maintained. If periodic observations indicate the presence of contaminants, the soil and mulch in the plants should be tested to avoid the build-up of pollutants that may harm the vegetation.

The table below shows a schedule for when different maintenance activities should be performed on a stormwater planter.

Stormwater Planters/Tree Boxes Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Water to promote plant growth and survival. • Inspect stormwater planter following rainfall events to ensure the planter is working properly.	As Needed (Following Construction)
• Prune and weed stormwater planter. • Remove accumulated trash and debris. • Remove and replace dead or damaged plants. Plant replacement vegetation as needed. • Observe infiltration rates after rain events. Planters should have no standing water within 24 hours.	As needed, or 4 times during growing season
• Inspect inflow and outflow areas for sediment accumulation. Remove any accumulated sediment or debris. • Inspect stormwater planter for erosion and the formation of rills and gullies. Plant replacement vegetation in any eroded areas. • Replace mulch. • Test the planting soils for pH levels. Consult with a qualified licensed Professional to determine and maintain the proper pH levels.	Semi-annually in spring and fall
• Implement plant maintenance plan to trim and divide perennials to prevent overcrowding and stress. • Check soil infiltration rates to ensure the soil is draining the water at a proper rate. Re-aerate or replace soil and mulch layers as needed to achieve infiltration rate of at least 0.25 inches per hour (1-2 in/hr preferred).	2 to 3 years

Stormwater Planter (Tree Box)					
Maintenance Item	Condition				Comments
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Pipes to the practice are free of trash, debris, large branches, etc.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Level spreader is in good condition with no trash, debris, or sediment accumulation (applicable if planters do not receive rooftop runoff).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
Structure seems to be working properly. No settling around the structure. Comment on overall condition of structure.					
Vegetation within the practice is maintained per landscaping plan.					
Mulching depth of 2-4 inches is maintained. Comment on mulch depth.					
Plants used in the practice are consistent with the requirements in the landscaping plan.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					

Stormwater Planter (Tree Box)					
Maintenance Item	Condition				Comments
	Good	Marginal	Poor	N/A*	
Plants seem to be healthy and in good condition. Comment on condition of plants.					
The underdrain has been flushed and there is no indication the underdrain system is clogged.					
Cleanout caps for underdrain is present and in good condition.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Results					
Overall condition of Stormwater Planter:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

Stormwater Ponds



A stormwater pond is a constructed, shallow stormwater retention basin or landscaped area with a permanent pool of water. Stormwater runoff collected in the pool is treated through settling. In addition, the aquatic bench (fringe wetlands), safety bench, side slopes, and shallow areas of the pond include plants to aid in the filtration and infiltration of the stormwater runoff flowing through the practice.

There are some common problems to be aware of when maintaining a stormwater pond. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Establishing vegetation within the stormwater pond
- Pruning and weeding to maintain appearance
- Eutrophic conditions indicated by excessive algae growth or fish kills
- Creating a mosquito habitat

Routine inspection and maintenance should be performed on stormwater ponds to ensure that the structure is functioning properly. Note that during the first year the stormwater pond is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice. For more information on vegetation in stormwater ponds, see Appendix D: Planting and Soil Guidance.

In addition to routine maintenance, stormwater ponds have seasonal and intermittent maintenance requirements. During the winter months, the stormwater pond should be inspected after a snow event (this is specific to northern areas of Georgia) to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid further pollution. In addition, planting material should be trimmed during the winter, when the plants are dormant.

Inspect the stormwater pond after a large rainstorm. Keep drainage paths (both to and from the BMP) clean so that the water can properly flow into the stormwater pond. If the stormwater pond is not draining properly, check for clogging in the inflow and outflow structures.

If the forebay or stormwater pond has received a significant amount of sediment over a period of time, then the sediment at the bottom of the forebay or pond may need to be removed. Accumulated sediment in the practice decreases the available storage volume and affects the pond's ability to function as it was designed. A sediment marker should be placed in the forebay to determine when sediment removal is required. It important to note that sediment excavated from stormwater ponds

that does not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Stormwater hotspots are areas that produce higher concentrations of metals, hydrocarbons, or other pollutants than normally found in urban runoff. Examples of operations performed in potential stormwater hotspots include vehicle maintenance and repair, vehicle washing, landscaping/grounds care, and outdoor material and product storage. Check with the local development review authority to identify any additional constraints on the disposal of sediments excavated from stormwater ponds.

Periodic mowing of the pond buffer is only required along maintenance right-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or a forest.

In order to keep the water that exits the stormwater pond clean, fertilizers should be used sparingly during establishment. Once the vegetation in the practice has been established, fertlizers should not be used. While vegetation in the stormwater pond is important, the primary purpose of a stormwater pond is to act as a water quantity and quality device, and introducing fertilizers into the stormwater pond introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, stormwater ponds should already be nutrient rich environments that do not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

Stormwater ponds create a challenge for controlling mosquitos, because some types of vegetation, such as cattails, can create an environment that allows mosquitoes to breed both in the pond and along the shoreline. Keeping the practice free of trash will help the practice from becoming a mosquito habitat. Another method to control mosquitoes is to place fish, such as the mosquitofish (Gambusia affinis), in the pond to help with controlling the mosquitoes. Animals such as dragonflies, diving beetles, birds, and bats may aid on controlling mosquitoes, however it is likely that additional measures, such as chemicals, may be required to control the mosquitoes (using chemicals should be a last resort). Keeping the pond at a depth of four feet or greater can aid in mosquito control by limiting vegetation growing around the pond. If mosquitoes begin to pose a problem, consult a qualified professional.

Pond dam inspection and maintenance is also very important. The pond dam should be inspected for seepage and structural integrity. Look for saturated soil, sediment deposits, and flowing water at the base of an earthen dam and on the rear face of the dam. On concrete dams, look for seepage, cracks, leaks and rust stains, or bulges. If any signs of seepage are found, consult a Professional Engineer. Pests such as burrowing animals and fire ants can pose a major threat to dam safety. Fire ant tunnels and animal burrows can weaken the dam structure and create an undesired water pathway through the dam. In addition, tree roots are another source of potential damage and failure. Woody vegetation may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure. If you have a large dam that is subject to regulations by the state, other maintenance items may be required. Please consult a Professional Engineer for additional guidance.

Ponds can be an attractive nuisance, so security and safety should be taken into consideration. Fencing requirements are at the discretion of the local government. If security measures such as a fence and gate are present, ensure that they are functional and locked.

It is important that the embankment for a pond be inspected regularly for trees and animal activity. Trees growing on the top or sides of the embankment should be removed. The roots of trees grow into the embankment and will weaken the structure of the embankment by creating passage ways that allow water to flow through the embankment. Trees that are blown over or damaged by storms can loosen or remove soil which weakens the strength of the embankment. In the same way animals can burrow holes weakening the structure of the embankment. These holes act as a passage way for the water to travel through the embankment, increasing the potential for the embankment to fail.

Geese are attracted to open water, clean lines of sight, and grass. They can become a nuisance to stormwater ponds if they are causing damage to plants or the banks, or if they are 'loading' the pond with nutrients and bacteria. Geese can be discouraged from using a stormwater pond by planting the buffer with shrubs and native ground covers or installing an aquatic shelf, but ensure that access points are maintained.

The table below shows a schedule for when different maintenance activities should be performed on a stormwater pond.

Stormwater Ponds Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Clean and remove debris from inlet and outlet structures. • Mow side slopes. • Inspect pond dam for structural integrity. • Remove trash from the area around the pond.	Monthly
• If wetland components are included, inspect for invasive vegetation.	Semiannual Inspection
• Inspect for damage, paying particular attention to the control structure. • Check for signs of eutrophic conditions (e.g., algal blooms and fish kills). • Note signs of hydrocarbon build-up (e.g., an oil sheen), and remove appropriately. • Monitor for sediment accumulation in the facility and forebay. • Check all control gates, valves, or other mechanical devices.	Annual Inspection
• Repair undercut or eroded areas.	As Needed
• Perform wetland plant management and harvesting.	Annually (if needed)
• Remove sediment from the forebay.	5 to 7 years or after 50% of the total forebay capacity has been lost

Activity	Schedule
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, or the pond becomes eutrophic.	10 to 20 years or after 25% of the permanent pool volume has been lost

(Source: WMI, 1997)

Stormwater Pond					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Inlet pipe is in good condition, and water is going through the structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment.					
Filter Strip or Grass Channels – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Rock Lined Plunge Pools – area is free of trash debris and sediment. Rock thickness in pool is adequate.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No algal growth along or within the pond.					
Native plants were used in the practice according to the planting plan. No undesirable vegetation.					
Practice seems to be working properly. No settling around the stormwater pond.					

Stormwater Pond					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Comment on overall condition of stormwater pond.					
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
No significant sediment accumulation within the practice.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, flooding, or animal activity around the structure.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet structure does not appear to be blocked.					
No evidence of animal activity.					
No evidence of seepage on the downstream face.					
Results					
Overall condition of Stormwater Pond:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Stormwater Wetland



Stormwater wetlands are constructed wetland systems built for stormwater management purposes. They typically consist of a combination of open water, shallow marsh and semi-wet areas that are located just above the permanent water surface. As stormwater runoff flows through a wetland, it is treated, primarily through gravitational settling and biological uptake.

There are some common problems to be aware of when maintaining a stormwater wetland. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Establishing vegetation within the wetland area
- Maintaining the proper pH levels for plants
- Pruning and weeding to maintain appearance
- Mosquitoes breeding in the practice

Routine maintenance should be performed on the stormwater wetlands to ensure that the structure is properly functioning. Note that during the first year the stormwater wetland is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice. For more information on stormwater wetland vegetation, see Appendix D: Planting and Soil Guidance. Regular inspection and maintenance is crucial to the success of the wetland as an effective stormwater management practice.

In addition to routine maintenance, stormwater wetlands have seasonal and intermittent maintenance requirements. During the winter months, the stormwater pond should be inspected after a snow event (this is specific to northern areas of Georgia) to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid further pollution. In addition, planting material should be trimmed during the winter, when the plants are dormant.

Inspect the stormwater wetland after large rainstorm events. Keep drainage paths (both to and from the BMP) clean so that the water can properly flow into the stormwater wetland. If the stormwater wetland is not draining properly, check for clogging in the inflow and outflow structures.

If the forebay or stormwater wetland has received a significant amount of sediment over a period of time, then the sediment at the bottom of the forebay or wetland may need to be removed. Accumulated sediment in the practice decreases the available storage volume and affects the wetland's ability to function as it was designed. It important to note that sediment excavated from stormwater wetlands that do not receive stormwater runoff from stormwater hotspots are typically not considered to be toxic and can be safely disposed through either land application or landfilling. Stormwater

hotspots are areas that produce higher concentrations of metals, hydrocarbons, or other pollutants than normally found in urban runoff. Examples of operations performed in potential stormwater hotspots include vehicle maintenance and repair, vehicle washing, landscaping/grounds care, and outdoor material and product storage. Check with the local development review authority to identify any additional constraints on the disposal of sediments excavated from stormwater wetlands.

In order to keep the water that exits the stormwater wetland clean, fertilizers should be used sparingly around the wetland. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the stormwater wetland is important, the primary purpose of a stormwater wetland is to act as a water quantity and quality device and introducing fertilizers into the stormwater wetland introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, stormwater wetlands should already be a nutrient rich environment that does not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

It is important that the embankment for a wetland be inspected regularly for trees and animal activity. Trees growing on the top or sides of the embankment should be removed. The roots of trees grow into the embankment and will weaken the structure of the embankment by creating passage ways that allow water to flow through the embankment. Trees that are blown over or damaged by storms can loosen or remove soil which weakens the strength of the embankment. In the same way animals can burrow holes weakening the structure of the embankment. These holes act as a passage way for the water to travel through the embankment, increasing the potential for the embankment to fail.

Stormwater wetlands create a challenge for controlling mosquitos, because some types of vegetation, such as cattails, can create an environment that allows mosquitoes to breed both in the pond and along the shoreline. Keeping the practice free of trash will help the practice from becoming a mosquito habitat. Another method to control mosquitoes is to place fish, such as the mosquitofish (Gambusia affinis), in the wetland to help with controlling the mosquitoes. Animals such as dragonflies, diving beetles, birds, and bats may aid on controlling mosquitoes, however it is likely that additional measures, such as chemicals, may be required to control the mosquitoes (using chemicals should be a last resort). Keeping the wetland at a depth of four feet or greater can aid in controlling mosquitoes by limiting vegetation growing around the wetland. If mosquitoes begin to pose a problem, consult a qualified professional.

The table below shows a schedule for when different maintenance activities should be performed on a stormwater wetland.

Stormwater Wetland Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Water side slopes and buffers to promote plant growth and survival. • Inspect wetland, side slopes and buffers following major storm events. Plant replacement vegetation in any eroded areas.	As Needed (Following Construction)

Activity	Schedule
• Examine to ensure that inlet and outlet devices are free of sediment and debris and are operational. • Inspect wetland, side slopes and buffers for dead or dying vegetation. Plant replacement vegetation as needed. • Inspect wetland, side slopes and buffers for invasive vegetation and remove as needed.	Monthly
• Inspect wetland, side slopes and buffers for erosion. Plant replacement vegetation in any eroded areas. • Monitor wetland vegetation and perform replacement planting as necessary. • Harvest wetland plants that have been “choked out” by sediment build-up.	Semi-Annually (Quarterly During First Year)
• Inspect for damage, paying particular attention to the control structure and side slopes. Repair as necessary. • Examine stability of the original depth zones and microtopographical features (i.e., shallow areas with minor ridges that increase water quality, provide flood storage, and enhance the development of a more diverse vegetative community). • Inspect side slopes for erosion and undercutting and repair as needed. • Check for signs of eutrophic conditions (e.g., excessive algal growth). • Check for signs of hydrocarbon accumulation (e.g., oil sheens) and remove appropriately. • Monitor sediment markers for sediment accumulation in forebays and permanent pools. • Check all control gates, valves and other mechanical devices.	Annually
• Remove sediment, trash, and debris from inlets/forebay.	5 years or after 50% of the total forebay storage capacity has been lost
• Monitor sediment accumulation in the wetland and remove sediment when the permanent pool volume has become reduced significantly, plants are “choked” with sediment, or the wetland becomes eutrophic.	10 plus years or after 25% of the wetland storage volume has been lost

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Stormwater Wetland					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Inlet pipe is in good condition, and water is going through the structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment. Sediment accumulation in forebay is less than 50% of the storage capacity.					
Filter Strip or Grass Channels – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Rock Lined Plunge Pools – area is free of trash debris and sediment. Rock thickness in pool is adequate.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No algal growth along or within the wetland.					
Native plants were used in the practice according to the planting plan. No undesirable vegetation.					

Stormwater Wetland					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Wetland seems to be working properly. No settling around the practice. Comment on overall condition.					
No significant sediment accumulation within the practice.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, flooding, or animal activity around the structure. No evidence of seepage on the downstream face.					
No evidence of unwanted vegetation and vegetation is in good condition.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet structure does not appear to be blocked.					
Results					
Overall condition of Stormwater Wetland:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Submerged Gravel Wetlands



The submerged gravel wetland system is similar to a regular stormwater wetland; however, it is filled with crushed rock or gravel and designed to allow stormwater to flow through the root zone of the constructed wetland. The outlet from each cell is set at an elevation to keep the rock or gravel submerged. Wetland plants are rooted in the media, where they can directly take up pollutants. In addition, algae and microbes thrive on the surface area of the rocks. Mimicking the pollutant removal ability of nature, this structural control relies on the pollutant-stripping ability of plants and soils to remove pollutants from runoff.

There are some common problems to be aware of when maintaining a submerged gravel wetland. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Establishing vegetation within the wetland area
- Maintaining the proper pH levels for plants
- Pruning and weeding to maintain appearance
- Mosquitoes breeding in the practice

Routine maintenance should be performed on the submerged gravel wetlands to ensure that the structure is properly functioning. Note that during the first year the submerged gravel wetland is built, maintenance may be required at a higher frequency to ensure the proper establishment of vegetation in the practice. For more information on vegetation in submerged gravel wetlands, see Appendix D: Planting and Soil Guidance. Regular inspection and maintenance is crucial to the success of the wetland as an effective stormwater management practice.

In addition to routine maintenance, submerged gravel wetlands have seasonal and intermittent maintenance requirements. During the winter months, the stormwater pond should be inspected after a snow event (this is specific to northern areas of Georgia) to make sure that the materials used to de-ice the surrounding areas stay out of the practice to avoid further pollution. In addition, planting material should be trimmed during the winter, when the plants are dormant.

Inspect the submerged gravel wetland after large rainstorm events. Keep drainage paths (both to and from the BMP) clean so that the water can properly flow into the submerged gravel wetland. If the submerged gravel wetland is not draining properly, check for clogging in the inflow and outflow

structures. If sediment buildup is preventing flow through the wetland, remove gravel and sediment from cell. Replace with clean gravel and replant vegetation.

If the forebay or submerged gravel wetland has received a significant amount of sediment over a period of time, then the sediment at the bottom of the forebay or gravel wetland may need to be removed. It is important to note that sediment excavated from submerged gravel wetlands that do not receive stormwater runoff from stormwater hotspots are typically not considered toxic and can be safely disposed through either land application or landfilling. Stormwater hotspots are areas that produce higher concentrations of metals, hydrocarbons, or other pollutants than normally found in urban runoff. Examples of operations performed in potential stormwater hotspots include vehicle maintenance and repair, vehicle washing, landscaping/grounds care, and outdoor material and product storage. Check with the local development review authority to identify any additional constraints on the disposal of sediments excavated from submerged gravel wetlands.

In order to keep the water that exits the submerged gravel wetland clean, fertilizers should be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizer should not be used. While vegetation in the submerged gravel wetland is important, the primary purpose of a submerged gravel wetland is to act as a water quantity and quality device and introducing fertilizers into the submerged gravel wetland introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. In addition, submerged gravel wetlands should already be a nutrient rich environment that does not require fertilization. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

It is important that the embankment of a submerged gravel wetland be inspected regularly for trees and animal activity. Trees growing on the top or sides of the embankment should be removed. The roots of trees grow into the embankment and will weaken the structure of the embankment by creating passage ways that allow water to flow through the embankment. Trees that are blown over or damaged by storms can loosen or remove soil which weakens the strength of the embankment. In the same way animals can burrow holes weakening the structure of the embankment. These holes act as a passage way for the water to travel through the embankment, increasing the potential for the embankment to fail.

The table below shows a schedule for when different maintenance activities should be performed on a submerged gravel wetland.

Submerged Gravel Wetlands Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Ensure that inlets and outlets to each submerged gravel wetland cell are free from debris and not clogged. • Remove any accumulated sediment and debris from inlet and outlet structures.	Monthly

Activity	Schedule
• Inspect wetland, side slopes and buffers for erosion. Replace vegetation in eroded areas. • Inspect wetland, side slopes and buffers for dead or dying vegetation. Replace vegetation as needed. • Inspect wetland, side slopes and buffers for invasive vegetation and remove as needed.	Semi-Annually (Quarterly During First Year)
• Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. • Monitor for sediment accumulation in the facility. • Examine to ensure that inlet and outlet devices are free of sediment and debris and operational. • Inspect side slopes for erosion and undercutting and repair as needed. • Check for signs of eutrophic conditions (e.g., excessive algal growth). • Check for signs of hydrocarbon accumulation and remove appropriately. • Monitor sediment markers for sediment accumulation in forebays and permanent pools. • Check all control gates, valves and other mechanical devices.	Annually
• Water side slopes and buffers to promote plant growth and survival. • Inspect wetland, side slopes, strucutres, and buffers following rainfall events. Plant replacement vegetation in any eroded areas.	As Needed
• Remove sediment, trash, and debris from inlets/forebay.	5 years or after 50% of the total forebay storage capacity has been lost
• Monitor sediment accumulation in the wetland and remove sediment when the permanent pool volume has become reduced significantly, plants are “choked” with sediment, sediment buildup is preventing flow through the wetland, or the wetland becomes eutrophic. Replace with clean gravel and replant vegetation.	10 plus years or after 25% of the wetland storage volume has been lost

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Submerged Gravel Wetlands					
Inspection Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet structure is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet structure.					
Water is going through structure (i.e. no evidence of water going around the structure).					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Forebay – area is free of trash, debris, and sediment.					
Filter Strip or Grass Channels – area is free of trash debris and sediment. Area has been mowed and grass clippings are removed. No evidence of erosion.					
Rock Lined Plunge Pools – area is free of trash debris and sediment. Rock thickness in pool is adequate.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Erosion protection is present on site (i.e. turf reinforcement mats). Comment on types of erosion protection and evaluate condition.					
No algal growth along or within the wetland.					
Native plants were used in the practice according to the landscaping plan. No undesirable vegetation.					

Submerged Gravel Wetlands					
Inspection Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Vegetation within and around practice is maintained per landscaping plan. Grass clippings are removed.					
Wetland seems to be working properly. No settling around the practice. Comment on overall condition.					
No significant sediment accumulation within the practice.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					
Plants seem to be healthy and in good condition. Comment on condition of plants.					
Emergency Overflow					
Emergency overflow is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet Structure					
Outlet structure is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding around the structure.					
Outlet structure does not appear to be blocked.					
Results					
Overall condition of Submerged Gravel Wetland:					
Additional Comments					
Notes: * If a specific maintenance item was not checked, please check N/A and explain why in the appropriate comment box.					

Underground Detention



Underground detention is detention storage located in underground tanks or vaults designed to provide water quantity control through temporary storage of stormwater runoff. In addition they can improve water quality by removing heavy amounts of sediment.

There are some common problems to be aware of when maintaining an underground detention area. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the inlet and outlet structure
- Requirement to have Occupational Safety and Health Administration (OSHA) confined space entry training

Routine maintenance should be performed on the underground detention areas to ensure that the structure is properly functioning. Routine maintenance includes the removal of debris from inlet and outlet structures and cleaning sediment built up inside the structure. Because this is an underground system, inspection and maintenance may be difficult to conduct. Generally these underground systems can be inspected by looking in an access opening. Sometimes, however, maintenance requires an individual who is certified in OSHA confined space entry. Should there be a situation where a safety concern arises, the inspection should stop and the safety concern addressed. Once the concern is addressed, the inspection can continue.

Inspect the underground detention area after a large rainstorm. If the underground detention area is not draining properly, check the inlet and outlet structures to make sure they are not clogged.

Sediment should be removed from the practice by either a vacuum or boom. If the system is accepting water that flowed from a hazardous facility, the sediment may need to be disposed of by other means. Check with the local government to identify any additional constraints on the disposal of sediments excavated from underground detention.

The table on the following page shows a schedule for when different maintenance activities should be performed on a submerged gravel wetland.

Underground Detention Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Remove any trash/debris and sediment buildup in the underground trash racks, vaults or tanks. • Check drainage areas for trash, erosion, and debris. • Clean underground detention if hazardous or foreign substances are spilled in the contributing drainage area. • Perform structural repairs to inlet and outlets.	As needed
• Follow manufacturer's guidelines and develop/adjust plan for the underground detention. • Clean out underground detentions with vacuum or boom trucks. • Clean sediment or oil chambers	Annually

Underground Detention

Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet Structure and Pretreatment					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Inlet structure is in good condition. No signs of cracks or leaks.					
Diversion structure (high flow bypass structure or other) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Inlet pipe fits tightly to the underground detention.					
Inlet has protection to prevent clogging with leaves or other debris and has fine mesh for mosquito control.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
Structure seems to be working properly. No signs of settling, leaking, or cracking. Comment on overall condition of structure.					
Emergency Overflow and Outlet Structure					
Area is free of trash, debris, and sediment.					
Overflow valve appears to be in good condition and show no signs of leaking.					
Results					
Overall condition of Underground Detention:					
Additional Comments					

Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.

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Vegetated Filter Strips



Vegetated filter strips are uniformly graded and densely vegetated sections of land, designed to treat runoff and remove pollutants through vegetative filtering and infiltration. Vegetated filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. These filter strips may be constructed with turf, meadow grasses, or other dense vegetation. They are also ideal components of the "outer zone" of a stream buffer, or as pretreatment for another structural stormwater control. Filter strips can serve as a buffer between incompatible land uses, be landscaped to be aesthetically pleasing, and provide groundwater recharge in areas with pervious soils.

There are some common problems to be aware of when maintaining a vegetated filter strip. They include, but are not limited to, the following:

- Sediment build-up
- Clogging in the pea gravel diaphragm or other flow spreader
- Establishing vegetation within the vegetated filter strip
- Ant mounds
- Erosion
- Concentrated flow

Routine maintenance should be performed on the vegetated filter strips to ensure that the practice is functioning properly. Note that during the first year the vegetated filter strip is built, maintenance may be required at a higher frequency to ensure the proper establishment of grass and vegetation in the practice. Upon establishment, grass should be routinely cut and vegetation trimmed, as necessary, to maintain a grass height of 3-12 inches or 6-15 inches along a roadway. Other routine maintenance includes removing trash from the vegetated filter strip and ensuring that grass clippings and other debris are removed from the filter strip.

Vegetated filter strips should be inspected after a large rainstorm. Keep drainage paths, both to and from the BMP, clean to promote sheet flow so that the water can be filtered by the BMP.

If the vegetated filter strip is not draining properly, check for clogging in the inlet and outlet structures. Also, consider if the filter strip has a sufficient slope or if there are obstructions within the filter strip that may cause inhibit the flow of water. If the practice includes a permeable berm, a structural repair or cleanout to unclog the outlet pipe may be necessary.

In order to keep the water that exits the vegetated filter strip clean, fertilizers should be used sparingly during the establishment of the practice. Once the vegetation in the practice has been established, fertilizers should not be used. While vegetation in the vegetated filter strip is important, a primary purpose of a vegetated filter strip is to act as a water quality device and introducing fertilizers into the vegetated filter strip introduces nutrients such as phosphorus and nitrogen that can pollute downstream waters. To control animal nuisances and invasive species, pesticides (including herbicides, fungicides, insecticides, or nematode control agents) should be used sparingly and only if necessary.

The table below shows a schedule for when different maintenance activities should be performed on a vegetated filter strip.

Vegetated Filter Strips Typical Routine Maintenance Activities and Schedule

Activity	Schedule
• Mow grass to a height to maintain a dense vegetative cover. It is recommended that the height of grass is 3-12 inches and 6-15 inches along a roadway. Remove any grass clippings • Keep the practice clean and remove all trash, sediment, and debris. • Reseed any eroded or bare spots. • Water the practice during dry conditions of vegetation establishment.	As needed
• Inspect vegetated filter strip for signs of erosion, and repair the strip as needed. • Inspect for invasive species and remove as needed. • Inspect pea gravel diaphragm for clogging and remove built-up sediment. • Inspect vegetation for rills and gullies. Seed or sod bare areas. • Inspect to ensure that grass has established. If not, replace with an alternative species.	Annual Inspection

Vegetated Filter Strip					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
General Inspection					
Access to the site is adequately maintained for inspection and maintenance.					
Area is clean (trash, debris, grass clippings, etc. removed).					
Inlet					
Drainage ways (overland flow or pipes) to the practice are free of trash, debris, large branches, etc.					
Area around the inlet is mowed and grass clippings are removed.					
No evidence of gullies, rills, or excessive erosion around the inlet.					
Water is going through the filter (i.e. no evidence of water going around the filter).					
Diversion structure (high flow bypass channel or overflow spillway) is free of trash, debris, or sediment. Comment on overall condition of diversion structure and list type.					
Pretreatment (choose one)					
Area is free of trash, debris, and sediment.					
No signs of erosion, rills, or gullies.					
Pea gravel diaphragm or other level or flow spreader – No cracks or structural damage in concrete trough.					
Main Treatment					
Main treatment area is free of trash, debris, and sediment.					
No signs of erosion, rills, or gullies.					
No evidence of long-term ponding or standing water in the ponding area of the practice (examples include: stains, odors, mosquito larvae, etc).					
Practice seems to be working properly.					
No areas of unhealthy grass or bare areas.					
No unwanted or invasive vegetation.					
No evidence of use of fertilizer on plants (fertilizer crusting on the surface of the soil, tips of leaves turning brown or yellow, blackened roots, etc.).					

Vegetated Filter Strip					
Maintenance Item	Condition				Comment
	Good	Marginal	Poor	N/A*	
Grass is kept at the proper mowing height, 3-12 inches and 6-15 inches along the roadway. Grass clippings are removed.					
No signs of accumulated sediment.					
Outlet Structure					
Outlet is free of trash, debris, and sediment.					
No evidence of erosion, scour, or flooding.					
Results					
Overall condition of Vegetated Filter Strip:					
Additional Comments					
Notes: *If a specific maintenance item was not checked, please explain why in the appropriate comment box.					

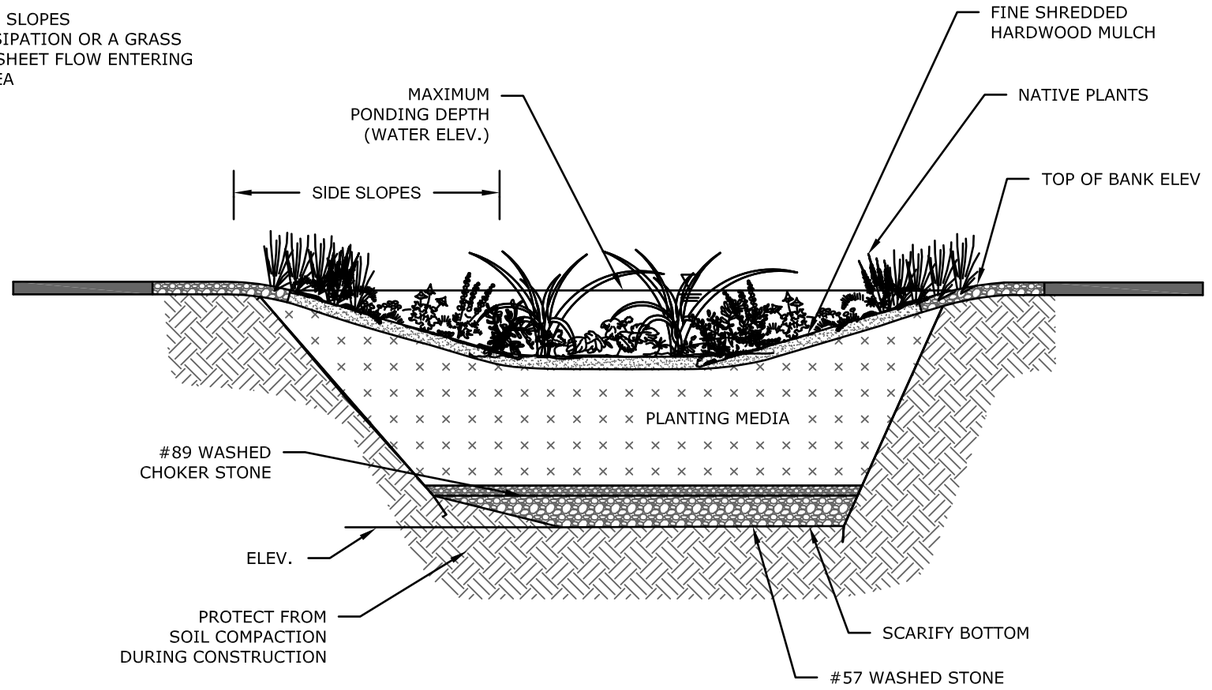
Appendix F: Standard Drawings

NOTES TO DESIGNERS:

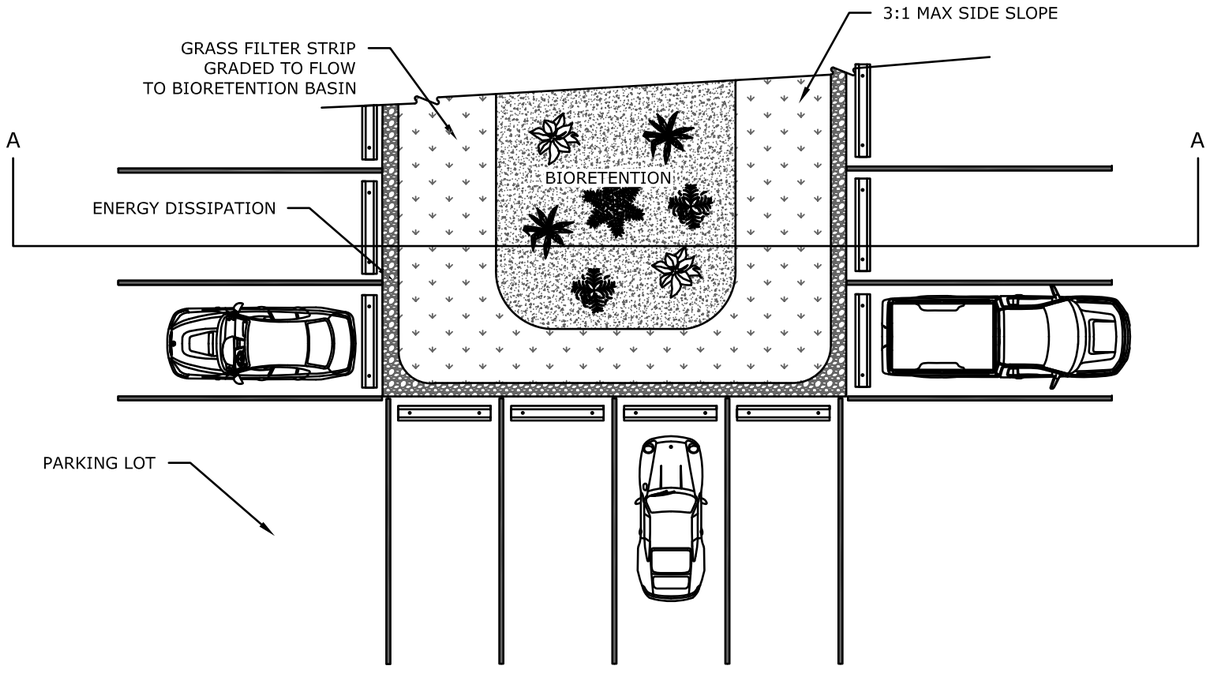
1. MAXIMUM 3:1 SIDE SLOPES
2. HAVE ENERGY DISSIPATION OR A GRASS FILTER STRIP FOR SHEET FLOW ENTERING BIORETENTION AREA

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



BIORETENTION WITHOUT UNDERDRAIN
SECTION A-A



PLAN VIEW

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

BIORETENTION WITHOUT UNDERDRAIN

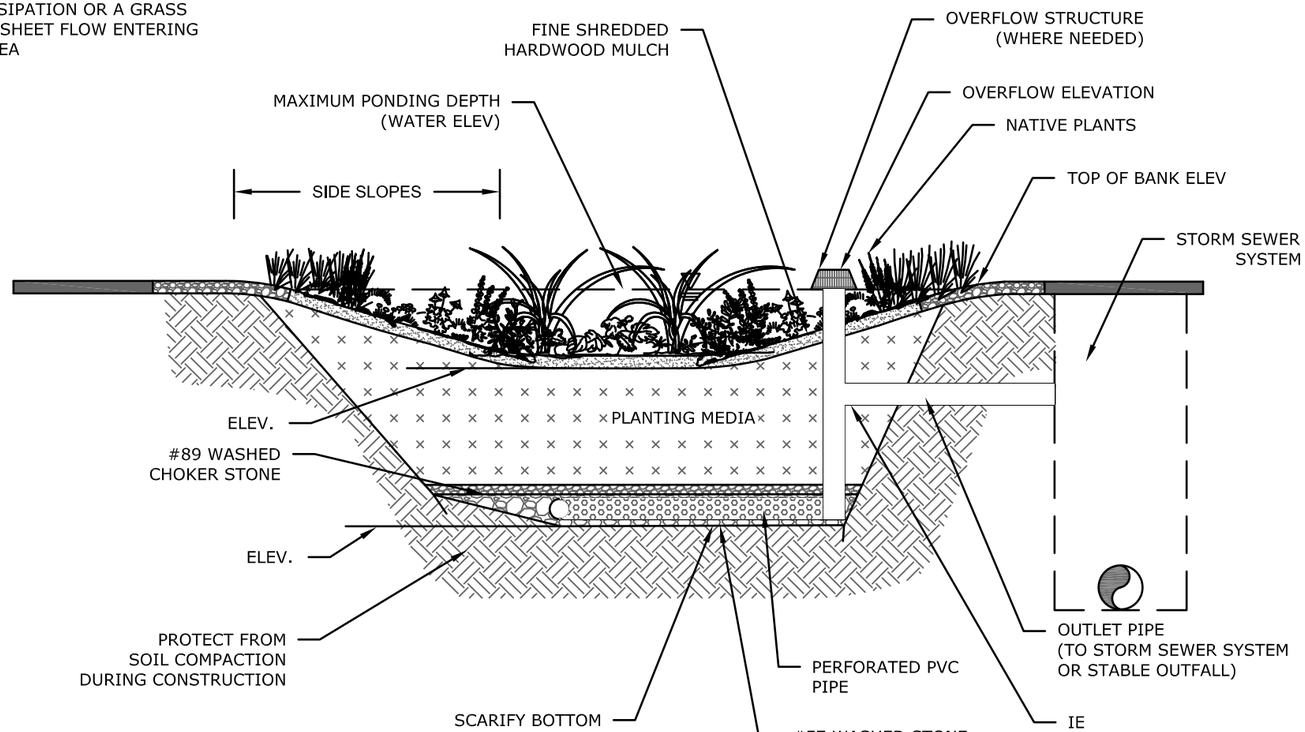
DATE: DECEMBER 2017 SHEET: BMP 4.2.1

NOTES TO DESIGNERS:

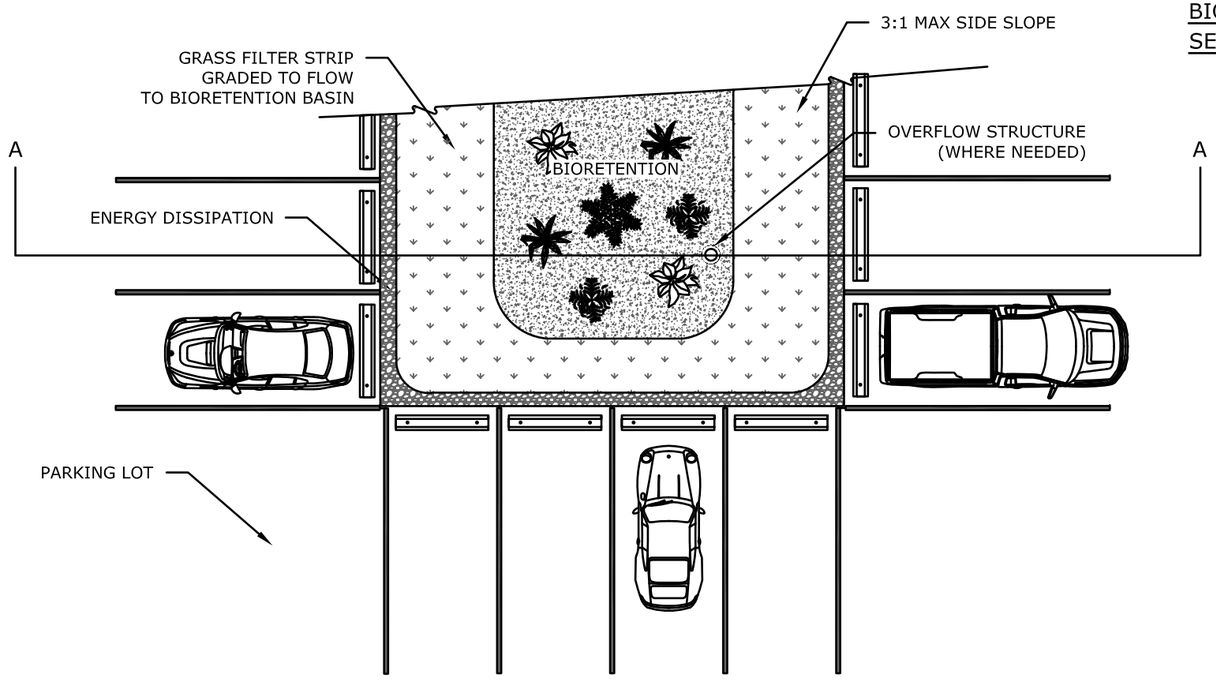
1. MAXIMUM 3:1 SIDE SLOPES
2. HAVE ENERGY DISSIPATION OR A GRASS FILTER STRIP FOR SHEET FLOW ENTERING BIORETENTION AREA

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



BIORETENTION WITH UPTURNED UNDERDRAIN
SECTION A-A



PLAN VIEW

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

BIORETENTION WITH UPTURNED UNDERDRAIN

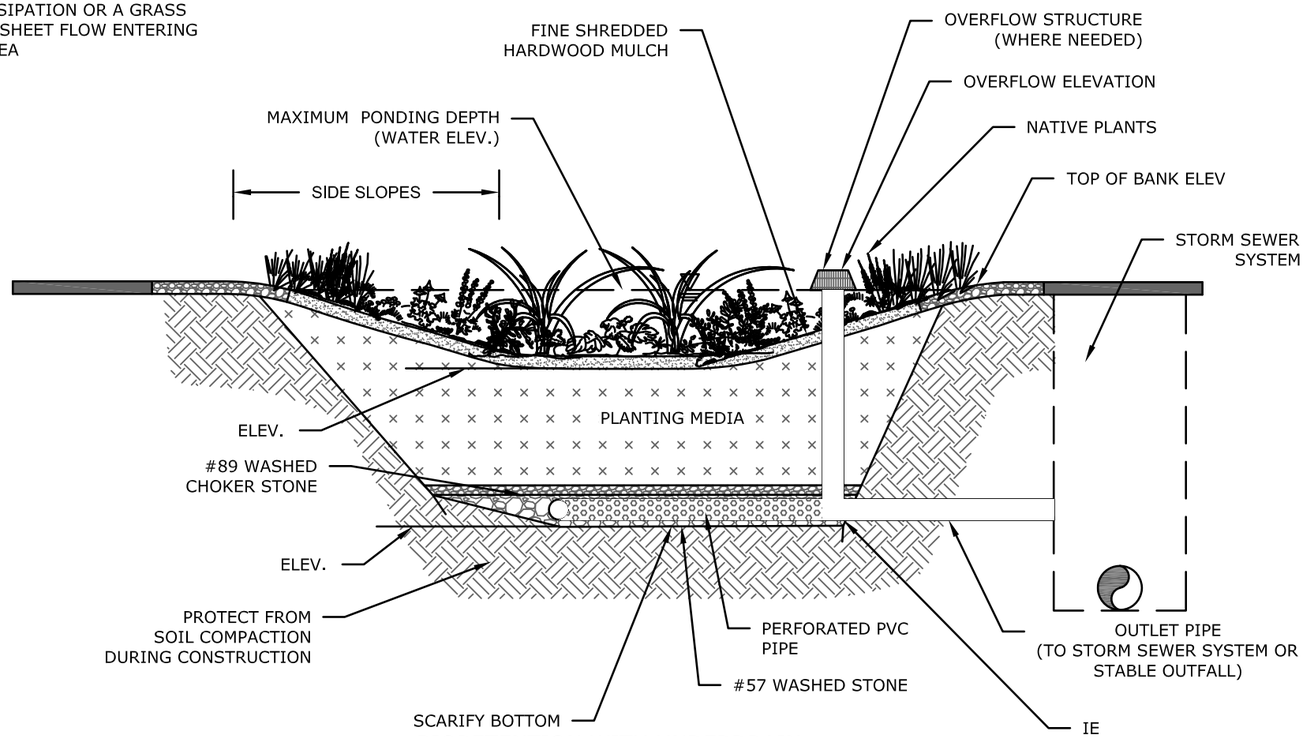
DATE: DECEMBER 2017 SHEET: BMP 4.2.2

NOTES TO DESIGNERS:

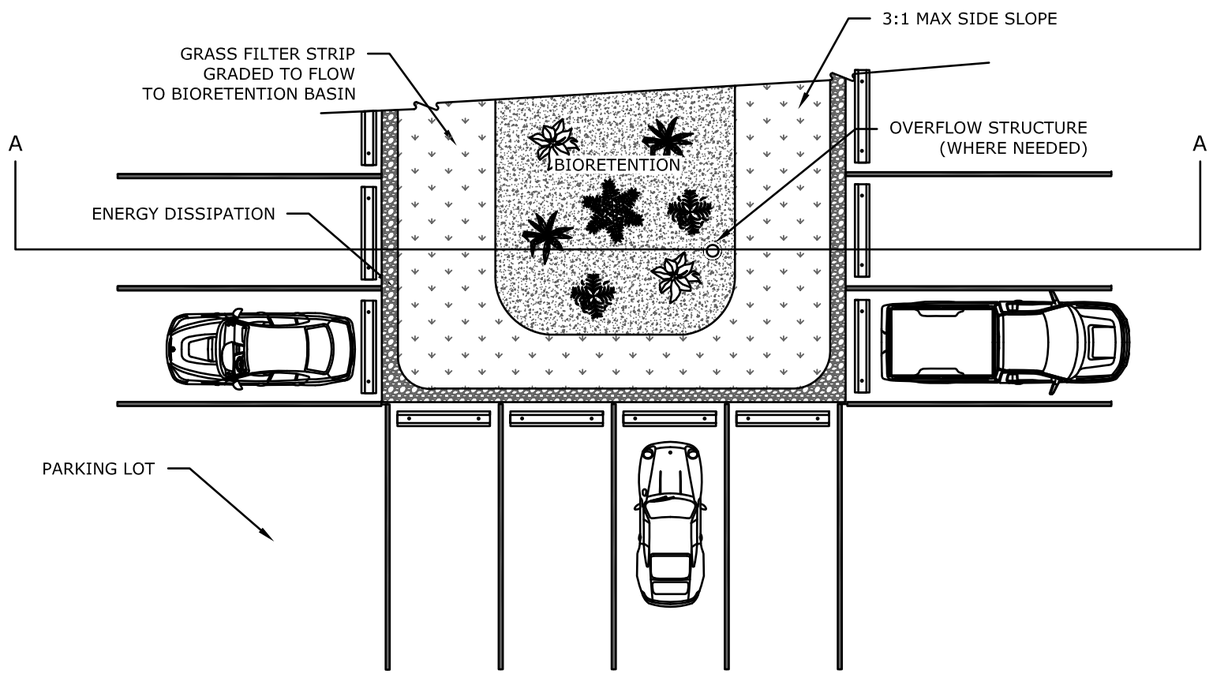
1. MAXIMUM 3:1 SIDE SLOPES
2. HAVE ENERGY DISSIPATION OR A GRASS FILTER STRIP FOR SHEET FLOW ENTERING BIORETENTION AREA

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



BIORETENTION WITH UNDERDRAIN
SECTION A-A



PLAN VIEW

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

BIORETENTION WITH UNDERDRAIN

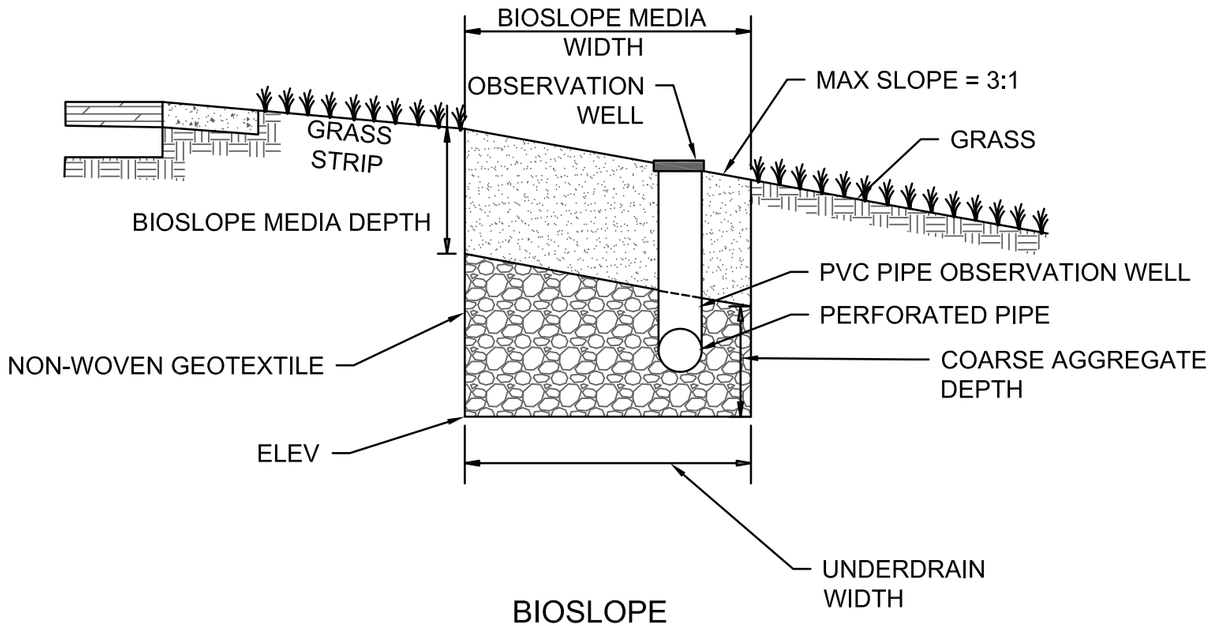
DATE: DECEMBER 2017 SHEET: BMP 4.2.3

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS:

1. MAXIMUM SLOPE IS 3:1.
2. MINIMUM BIOSLOPE WIDTH IS 2'.
3. MINIMUM BIOSLOPE MEDIUM DEPTH IS 1',
4. MINIMUM WIDTH OF BOTTOM OF BIOSLOPE IS 2'.
5. MINIMUM DEPTH OF COARSE AGGREGATE IS 18".
6. MINIMUM DIAMETER OF PERFORATED UNDERDRAIN IS 6".
7. MINIMUM DISTANCE BETWEEN BOTTOM OF PRACTICE AND INVERT OF UNDERDRAIN PIPE IS 6".
8. MAXIMUM LONGITUDINAL SLOPE IS 5%.



BIOSLOPE
TYPICAL SECTION
N.T.S.

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

BIOSLOPE

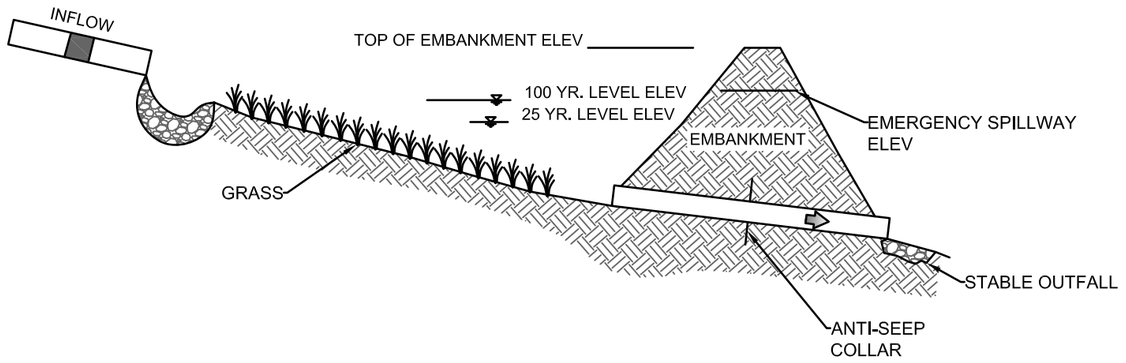
DATE: DECEMBER 2017 SHEET: BMP 4.3.1

NOTES TO DESIGNERS

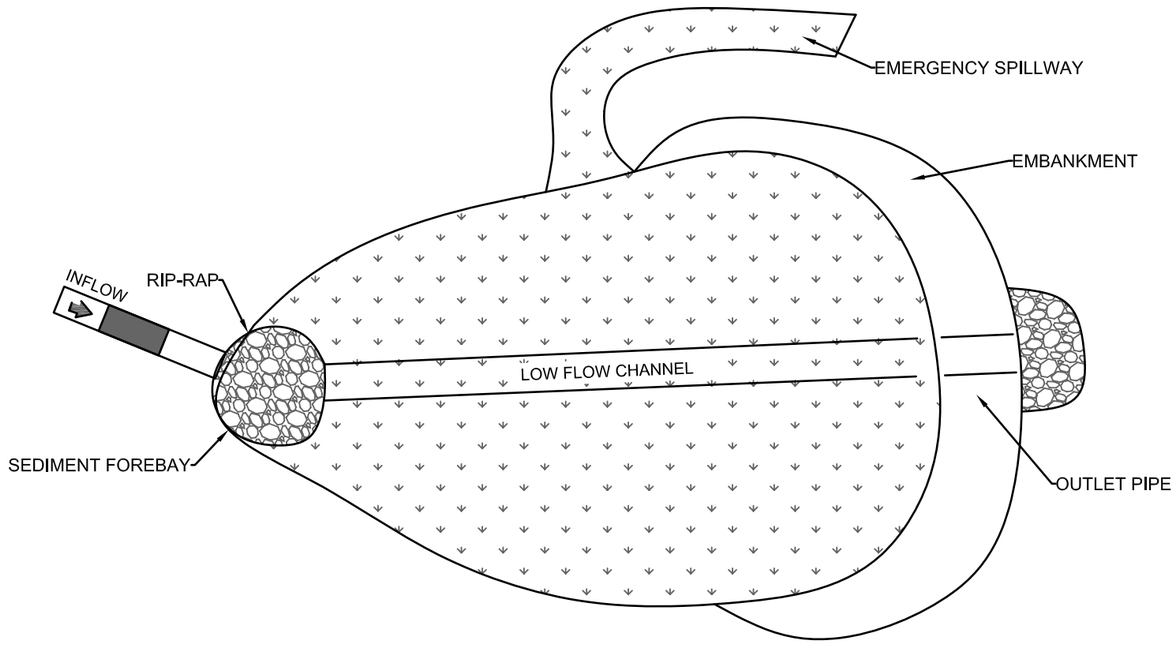
1. PROVIDE A MINIMUM OF 18" OF FREEBOARD BETWEEN EMERGENCY SPILLWAY AND TOP OF EMBANKMENT.
2. PROVIDE A MINIMUM OF 0.1' BETWEEN 100 YR. LEVEL AND EMERGENCY SPILLWAY.

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



PROFILE



DRY DETENTION BASIN

PLAN

GWINNETT COUNTY GOVERNMENT

CONCEPTUAL DRAWING

DRY DETENTION BASIN

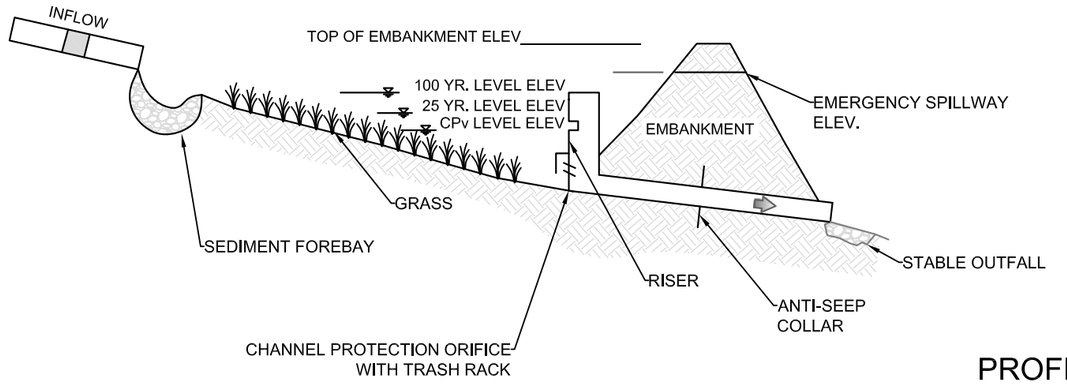
DATE: DECEMBER 2017 SHEET: BMP 4.5.1

NOTES TO DESIGNERS

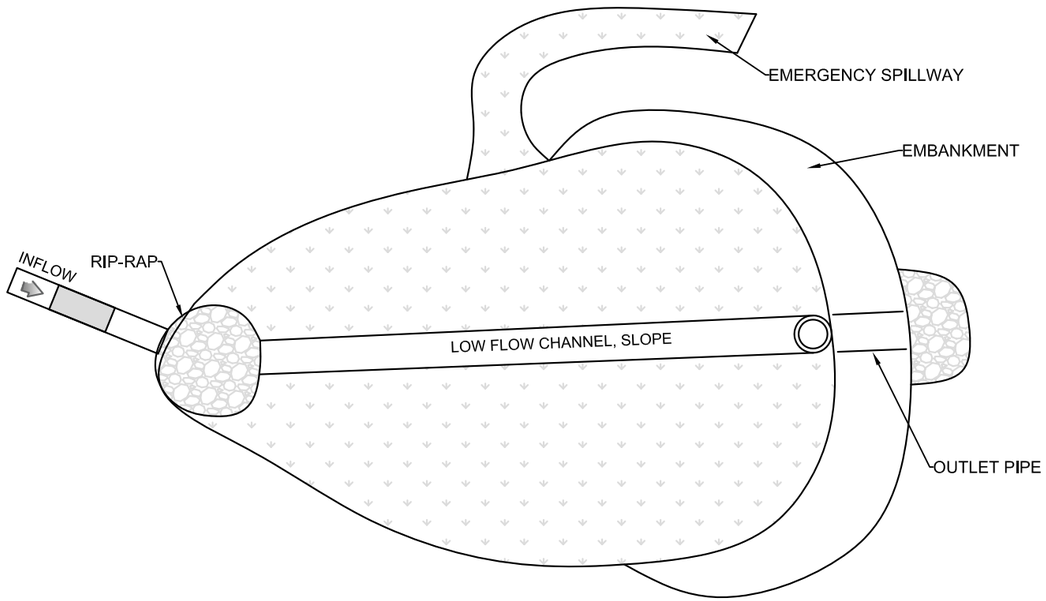
1. PROVIDE A MINIMUM OF 18" OF FREEBOARD BETWEEN EMERGENCY SPILLWAY AND TOP OF EMBANKMENT.
2. PROVIDE A MINIMUM OF 0.1' BETWEEN 100 YR. LEVEL AND EMERGENCY SPILLWAY

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



PROFILE



DRY EXTENDED DETENTION (ED) BASIN

PLAN

GWINNETT COUNTY GOVERNMENT

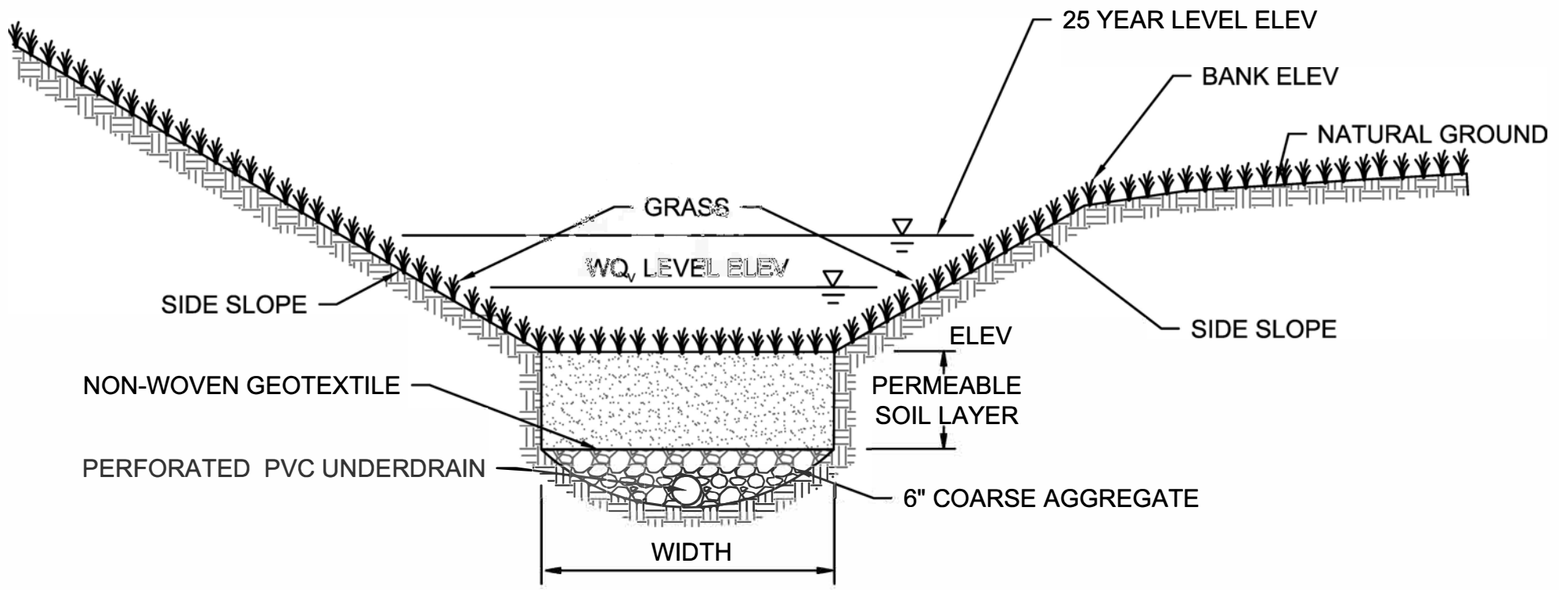
CONCEPTUAL DRAWING

DRY EXTENDED DETENTION BASIN

DATE: DECEMBER 2017 SHEET: BMP 4.6.1

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



DRY ENHANCED SWALE
TYPICAL SECTION

N.T.S.

NOTES TO DESIGNERS:

1. LONGITUDINAL SLOPE MUST BE <4%.
2. MIN. 6" FREEBOARD ABOVE 25-YR STORM WATER SURFACE ELEVATION
3. MAXIMUM SIDE SLOPE IS 2:1.
4. WIDTH SHOULD BE BETWEEN 2' AND 8'.
5. MAXIMUM WQ_V PONDING DEPTH IS 18".

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

DRY ENHANCED SWALE

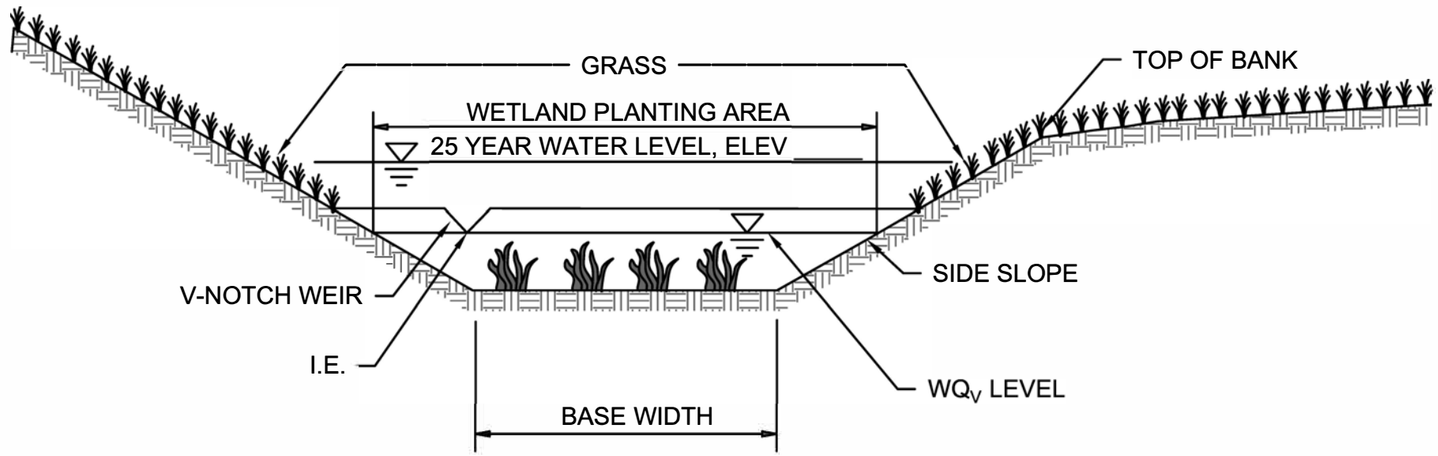
DATE: DECEMBER 2017 SHEET: BMP 4.8.1

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS:

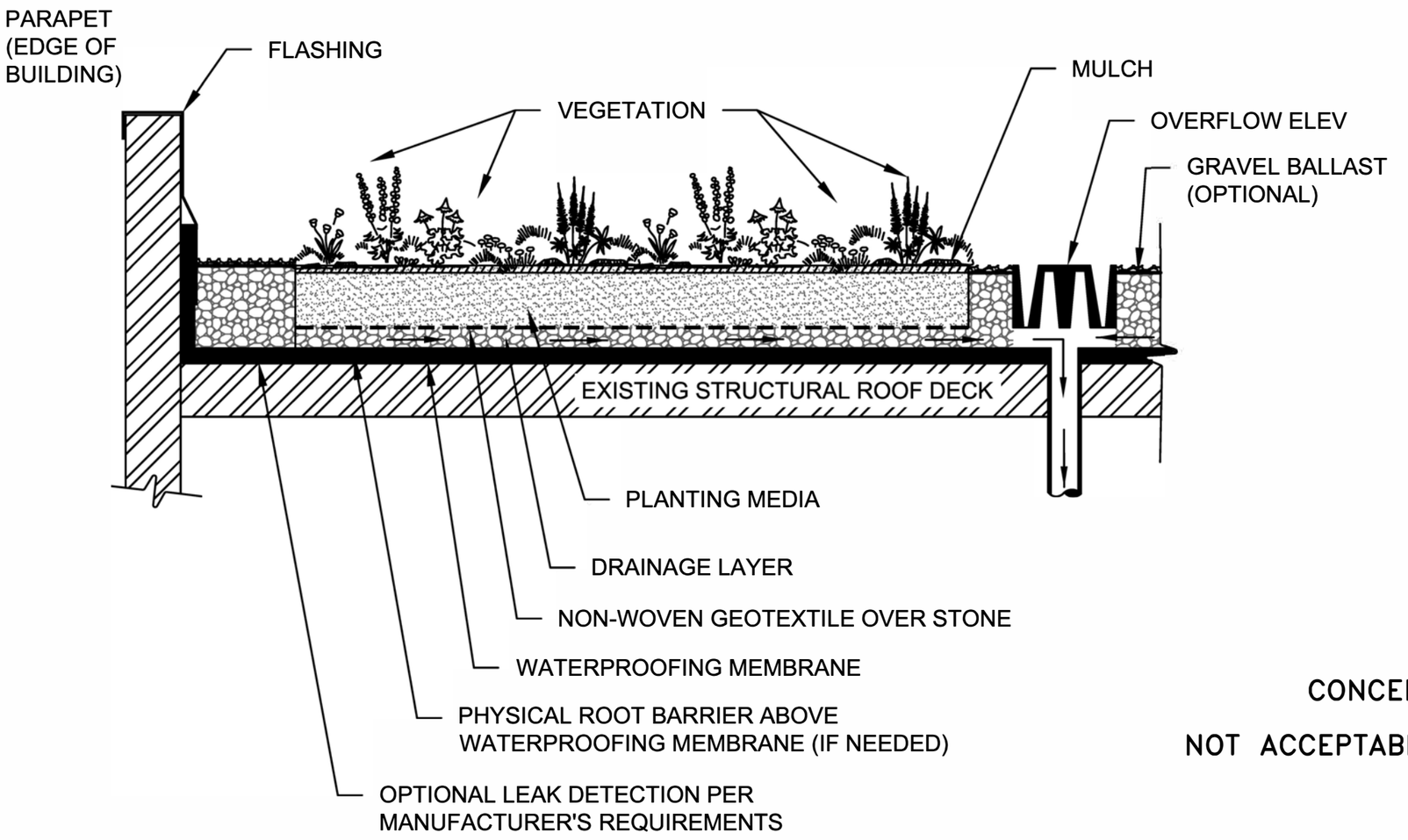
1. MIN. 6" FREEBOARD ABOVE 25-YR STORM WATER SURFACE ELEVATION.
2. MAXIMUM SIDE SLOPE IS 2:1.
3. BASE WIDTH SHOULD BE BETWEEN 2' AND 8'.
4. MAX WQ_V PONDING DEPTH IS 18".



WET ENHANCED SWALE
TYPICAL SECTION
N.T.S.

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING
WET ENHANCED SWALE

DATE: DECEMBER 2017 SHEET: BMP 4.8.2



GREEN ROOF WITH DRAINAGE LAYER

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS:

1. SYSTEM COMPONENTS, LEAK DETECTION, TYPES OF PRODUCTS AND CONFIGURATION WILL DEPEND ON DESIGN CRITERIA AND EXISTING CONDITIONS. SYSTEM LAYERS AND INSTALLATION REQUIREMENTS WILL VARY DEPENDING ON MANUFACTURER REQUIREMENTS. REFER TO SPECIFICATIONS.
2. MINIMUM PLANTING MEDIA DEPTH IS 2" FOR EXTENSIVE ROOF SYSTEMS AND 12" FOR INTENSIVE ROOF SYSTEMS.

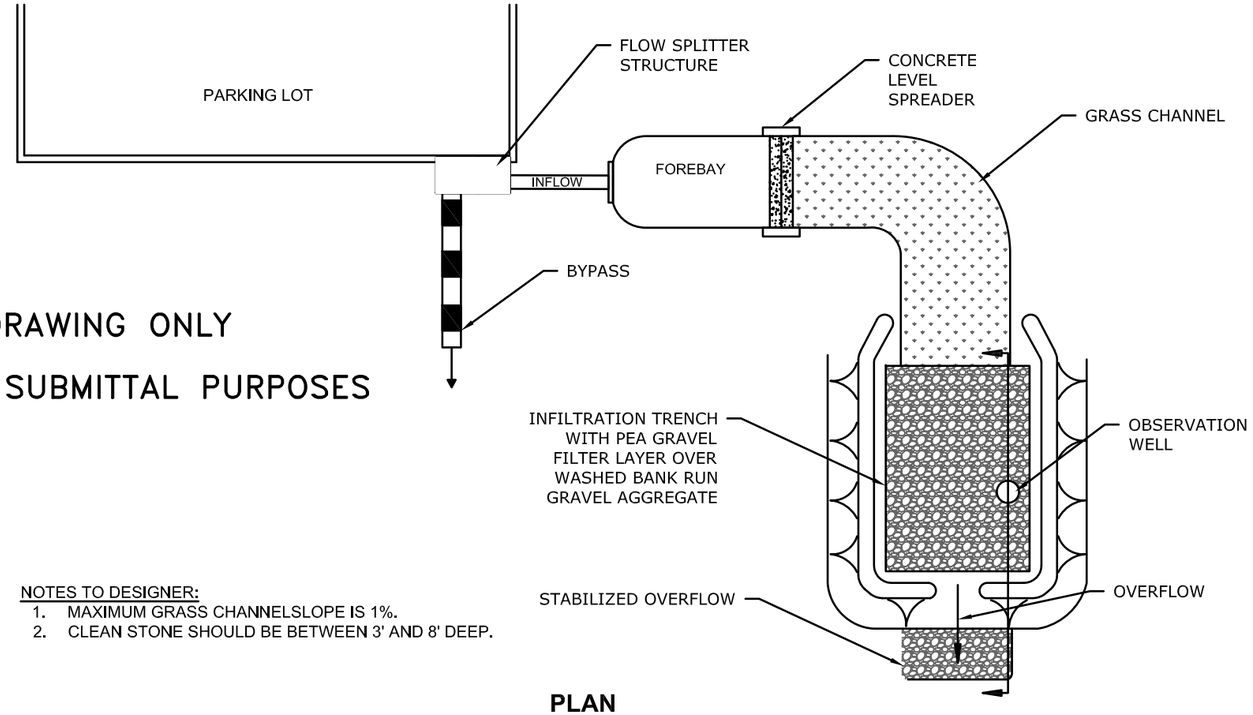
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

GREEN ROOF WITH DRAINAGE LAYER

DATE: DECEMBER 2017 SHEET: BMP 4.11.1

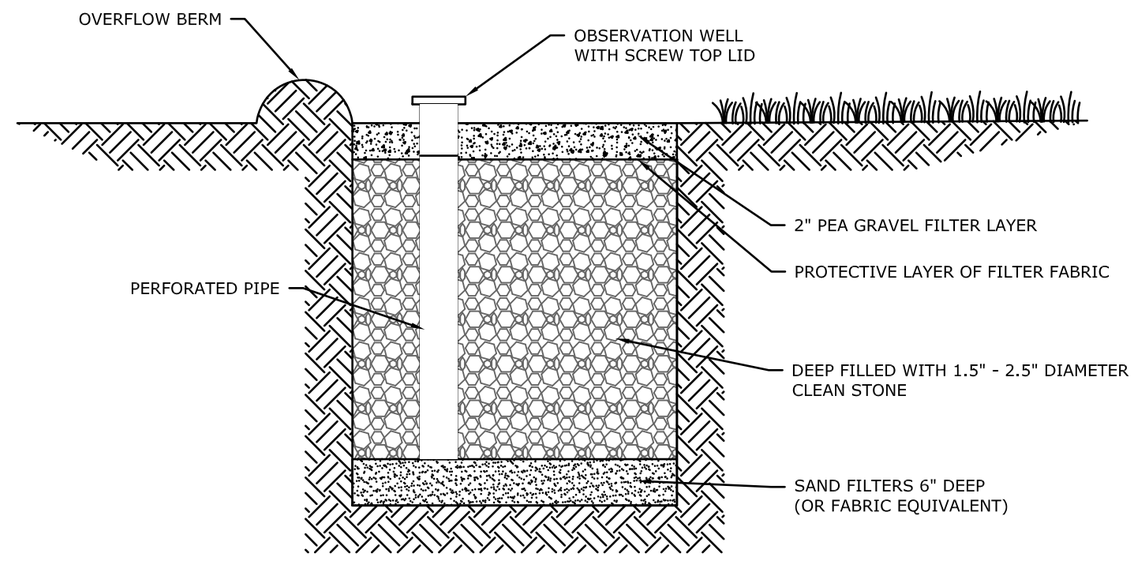
CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



NOTES TO DESIGNER:
1. MAXIMUM GRASS CHANNELSLOPE IS 1%.
2. CLEAN STONE SHOULD BE BETWEEN 3' AND 8' DEEP.

PLAN



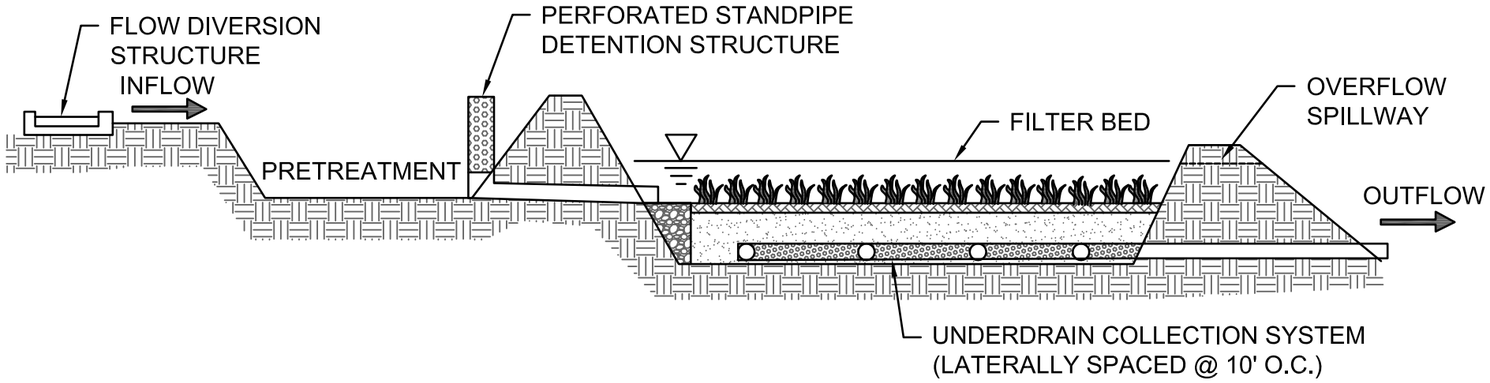
SECTION

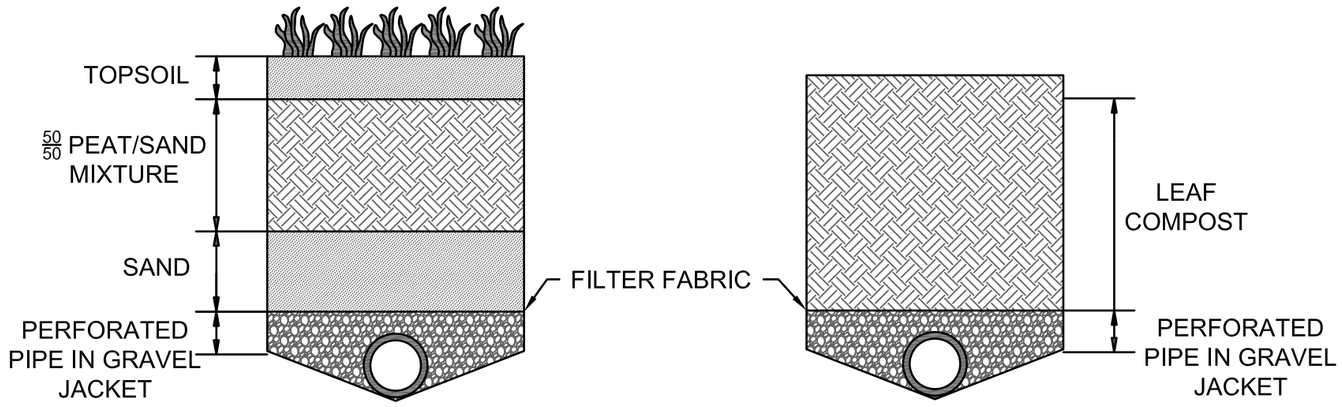
INFILTRATION PRACTICE

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

INFILTRATION PRACTICES

DATE: DECEMBER 2017 SHEET: BMP 4.12.1





ORGANIC FILTER
TYPICAL SECTION
N.T.S.

PROFILE

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

ORGANIC FILTER

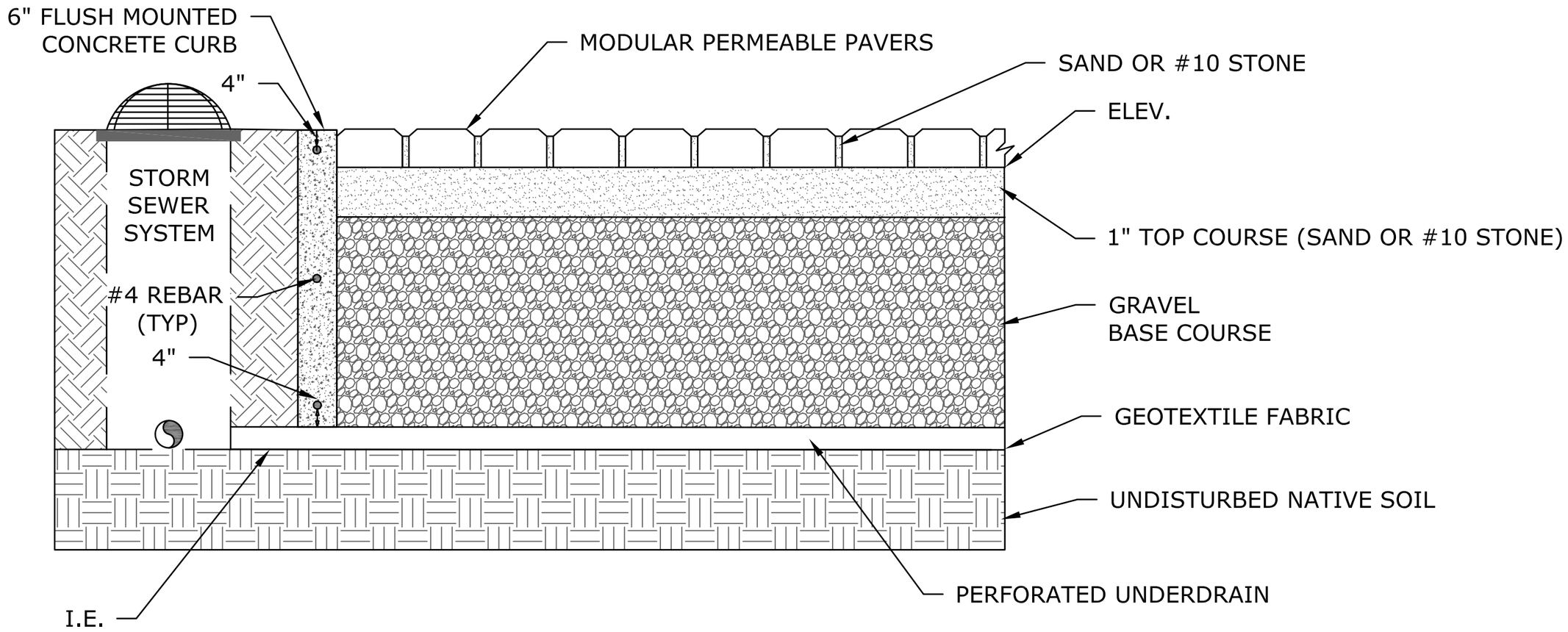
DATE: DECEMBER 2017 SHEET: BMP 4.14.1

NOTES TO DESIGNERS

1. MINIMUM GRAVEL BASE COURSE DEPTH IS 12".
2. FOLLOW PAVER MANUFACTURER'S DESIGN RECOMMENDATIONS.

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



PERMEABLE PAVERS WITH AN UNDERDRAIN

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

PERMEABLE PAVERS WITH AN UNDERDRAIN

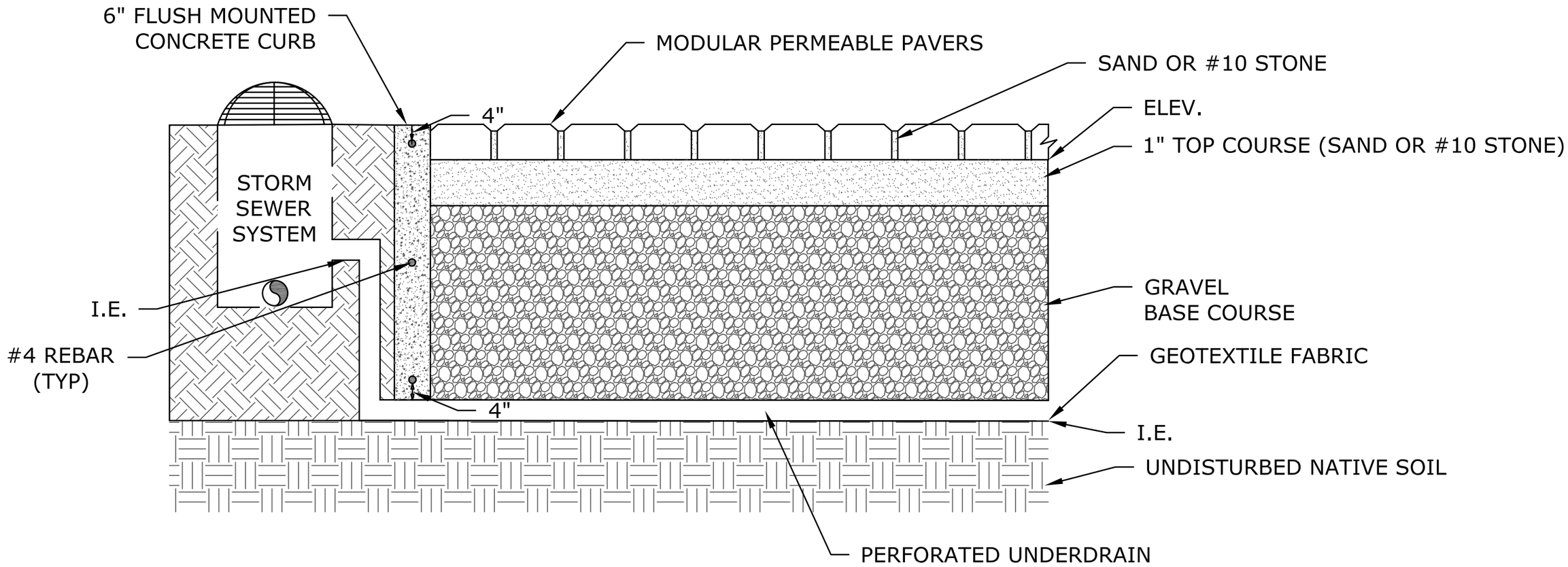
DATE: DECEMBER 2017 SHEET: BMP 4.15.1

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS

1. MINIMUM GRAVEL BASE COURSE DEPTH IS 12".
2. FOLLOW PAVER MANUFACTURER'S DESIGN RECOMMENDATIONS.



PERMEABLE PAVERS WITH AN UPTURNED UNDERDRAIN

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

PERMEABLE PAVERS WITH AN UPTURNED UNDERDRAIN

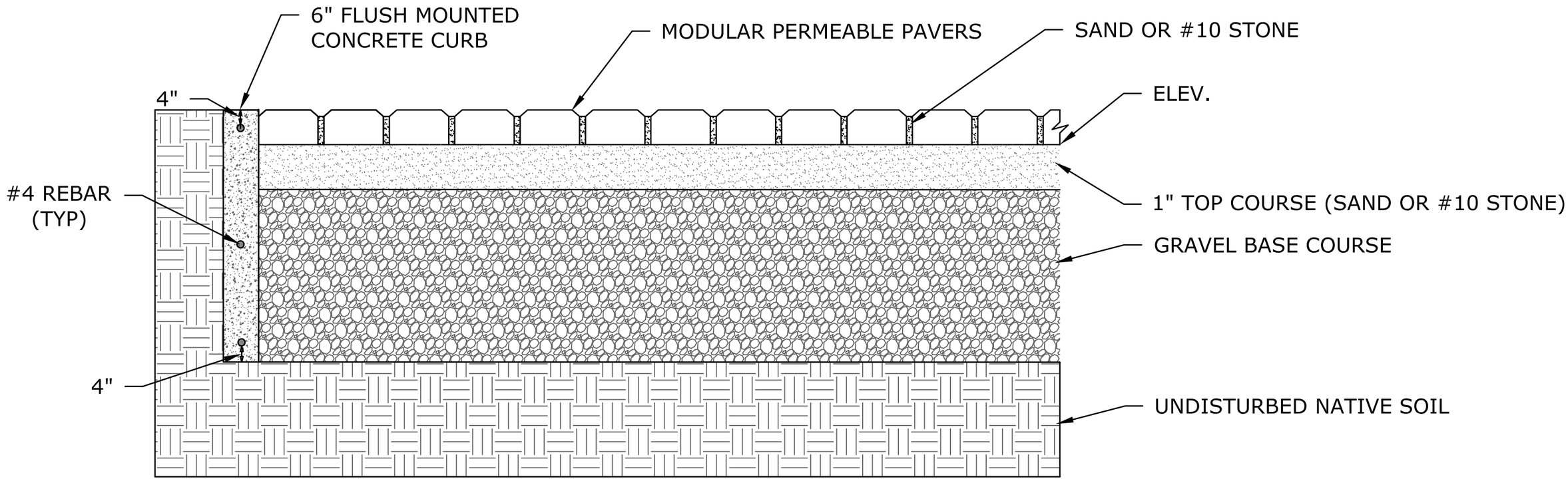
DATE: DECEMBER 2017 SHEET: BMP 4.15.2

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS

1. MINIMUM GRAVEL BASE COURSE DEPTH IS 12".
2. FOLLOW PAVER MANUFACTURER'S DESIGN RECOMMENDATIONS.



PERMEABLE PAVERS WITHOUT AN UNDERDRAIN

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

PERMEABLE PAVERS
WITHOUT AN UNDERDRAIN

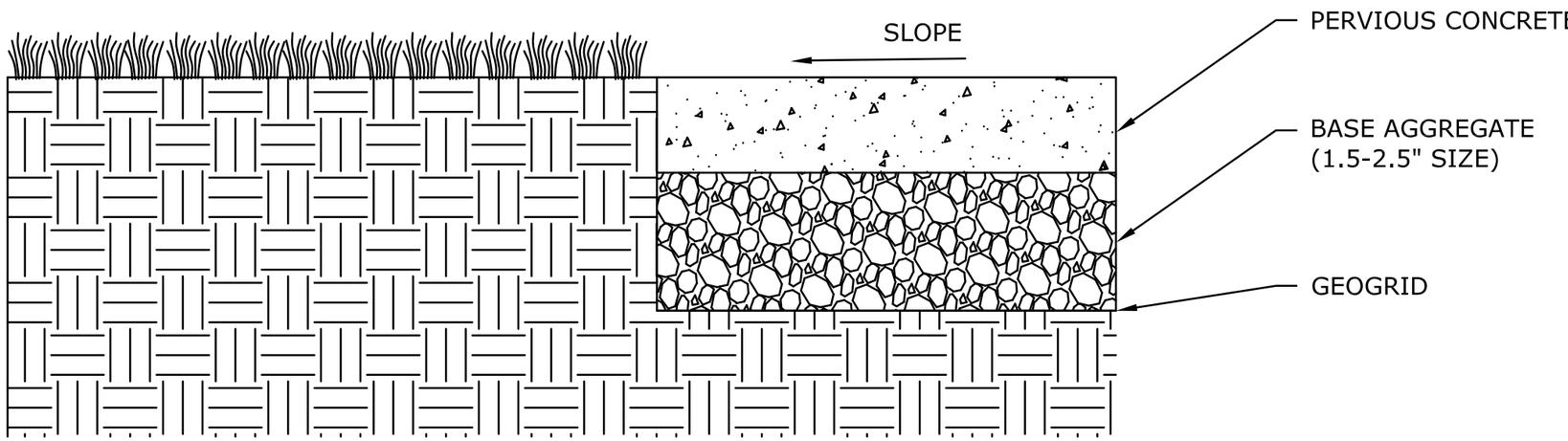
DATE: DECEMBER 2017 SHEET: BMP 4.15.3

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS

1. MINIMUM BASE THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. PERVIOUS CONCRETE SHOULD BE BETWEEN 6 AND 15 INCHES.
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



PERVIOUS CONCRETE TYPICAL INSTALLATION

GWINNETT COUNTY GOVERNMENT

CONCEPTUAL DRAWING

PERVIOUS CONCRETE
TYPICAL INSTALLATION

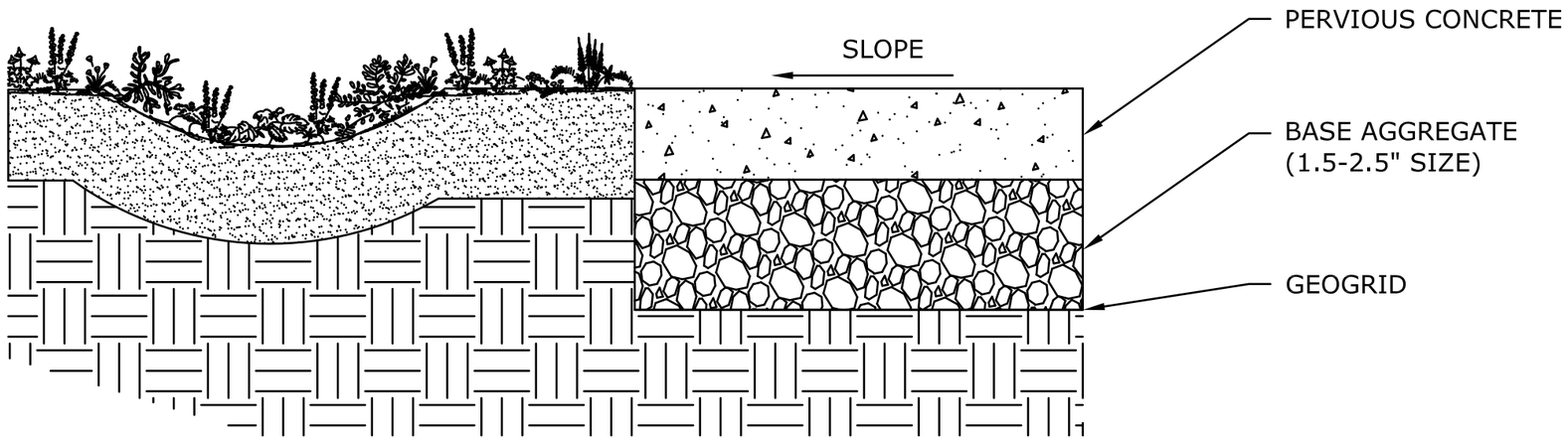
DATE: DECEMBER 2017 SHEET: BMP 4.16.1

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS

1. MINIMUM BASE THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. PERVIOUS CONCRETE SHOULD BE BETWEEN 6 AND 15 INCHES.
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



PERVIOUS CONCRETE WITH BIOSWALE OUTLET

GWINNETT COUNTY GOVERNMENT

CONCEPTUAL DRAWING

PERVIOUS CONCRETE WITH BIOSWALE OUTLET

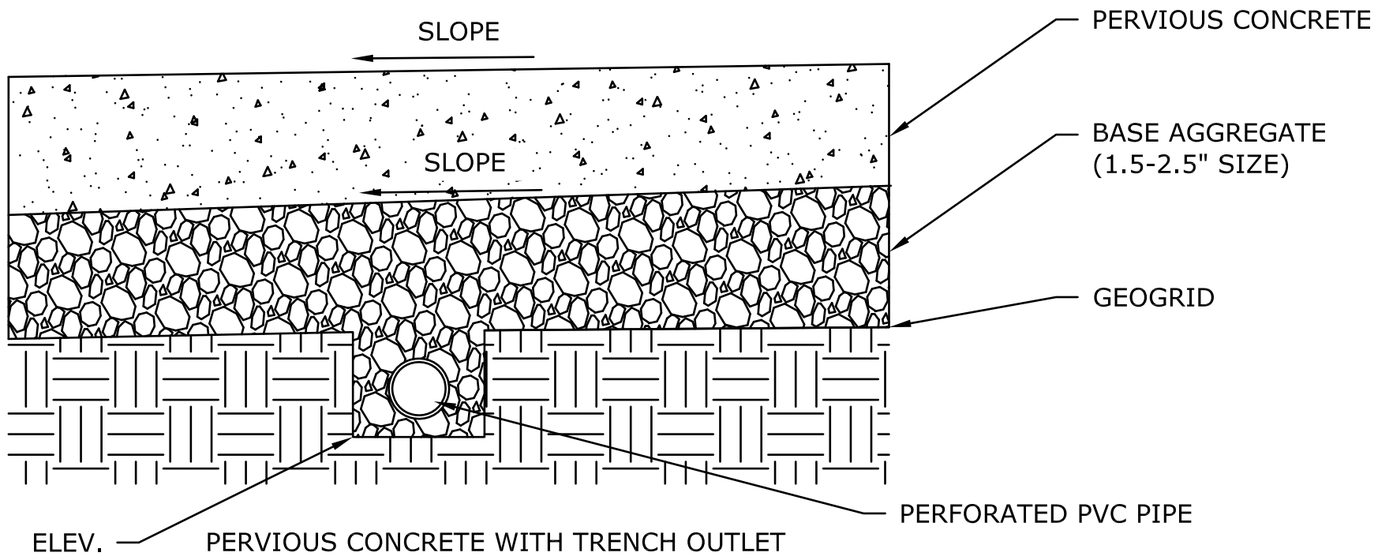
DATE: DECEMBER 2017 SHEET: BMP 4.16.2

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS

1. MINIMUM BASE THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. PERVIOUS CONCRETE SHOULD BE BETWEEN 6 AND 15 INCHES.
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



GWINNETT COUNTY GOVERNMENT

CONCEPTUAL DRAWING

PERVIOUS CONCRETE WITH TRENCH OUTLET

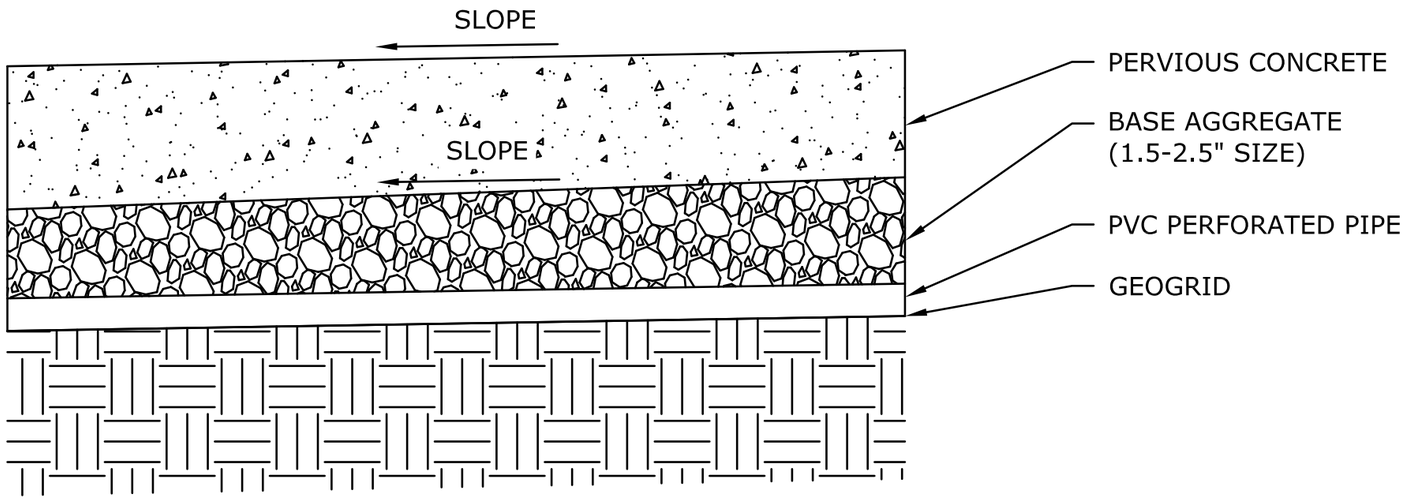
DATE: DECEMBER 2017 SHEET: BMP 4.16.3

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

NOTES TO DESIGNERS

1. MINIMUM BASE THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. PERVIOUS CONCRETE SHOULD BE BETWEEN 6 AND 15 INCHES.
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



PERVIOUS CONCRETE WITH UNDERDRAIN SYSTEM

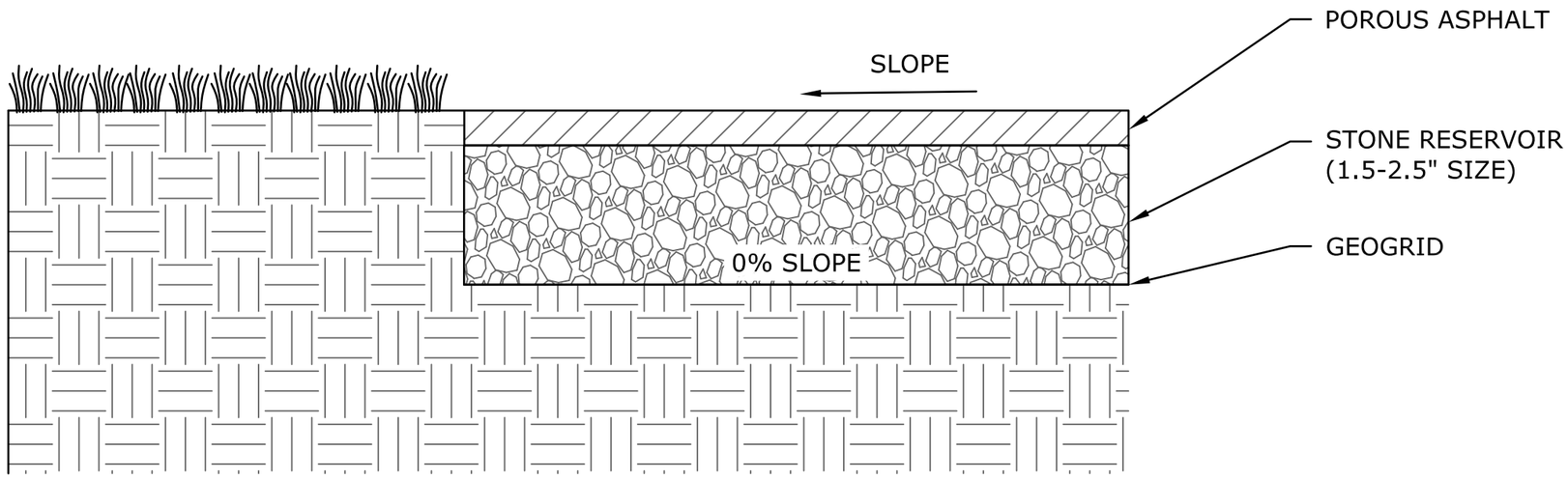
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

PERVIOUS CONCRETE WITH UNDERDRAIN SYSTEM

DATE: DECEMBER 2017 SHEET: BMP 4.16.4

NOTES TO DESIGNERS

1. MINIMUM STONE RESERVOIR THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. POROUS ASPHALT THICKNESS SHOULD BE BETWEEN 2" AND 4".
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



POROUS ASPHALT TYPICAL INSTALLATION

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

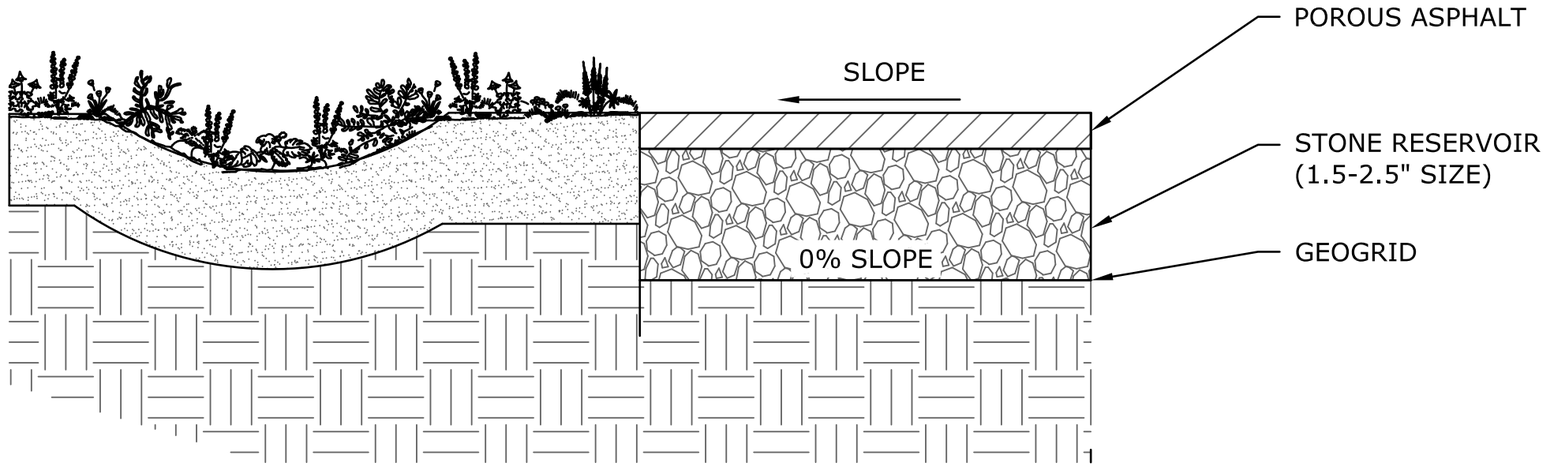
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

POROUS ASPHALT TYPICAL INSTALLATION

DATE: DECEMBER 2017 SHEET: BMP 4.17.1

NOTES TO DESIGNERS

1. MINIMUM STONE RESERVOIR THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. POROUS ASPHALT THICKNESS SHOULD BE BETWEEN 2" AND 4".
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



POROUS ASPHALT WITH BIOSWALE OUTLET

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

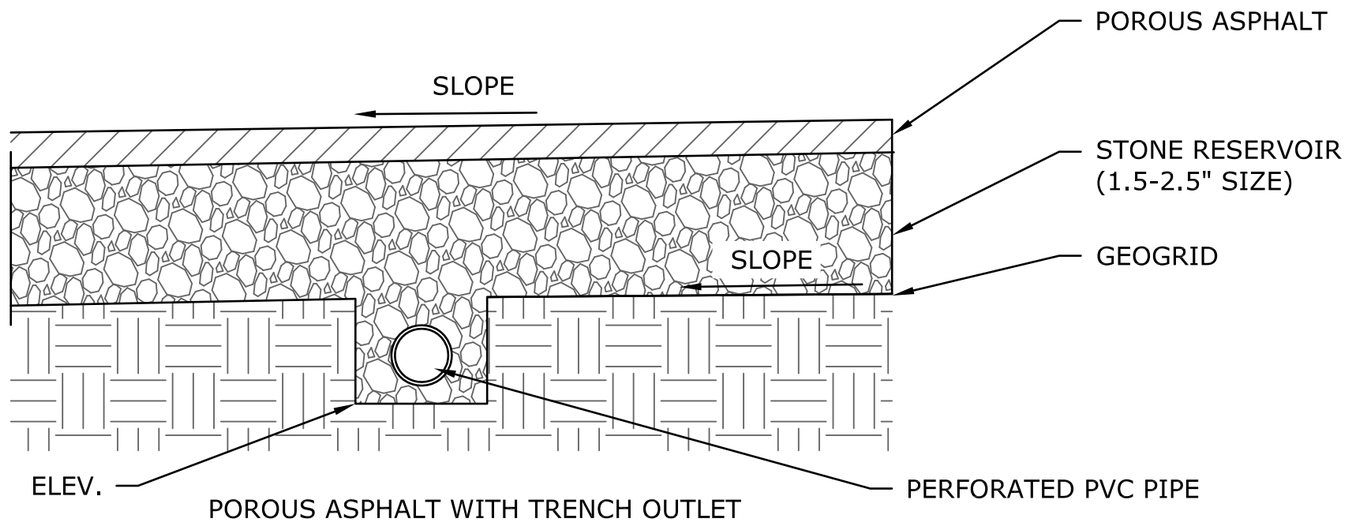
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

POROUS ASPHALT WITH BIOSWALE OUTLET

DATE: DECEMBER 2017 SHEET: BMP 4.17.2

NOTES TO DESIGNERS

1. MINIMUM STONE RESERVOIR THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. POROUS ASPHALT THICKNESS SHOULD BE BETWEEN 2" AND 4".
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



POROUS ASPHALT WITH TRENCH OUTLET

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

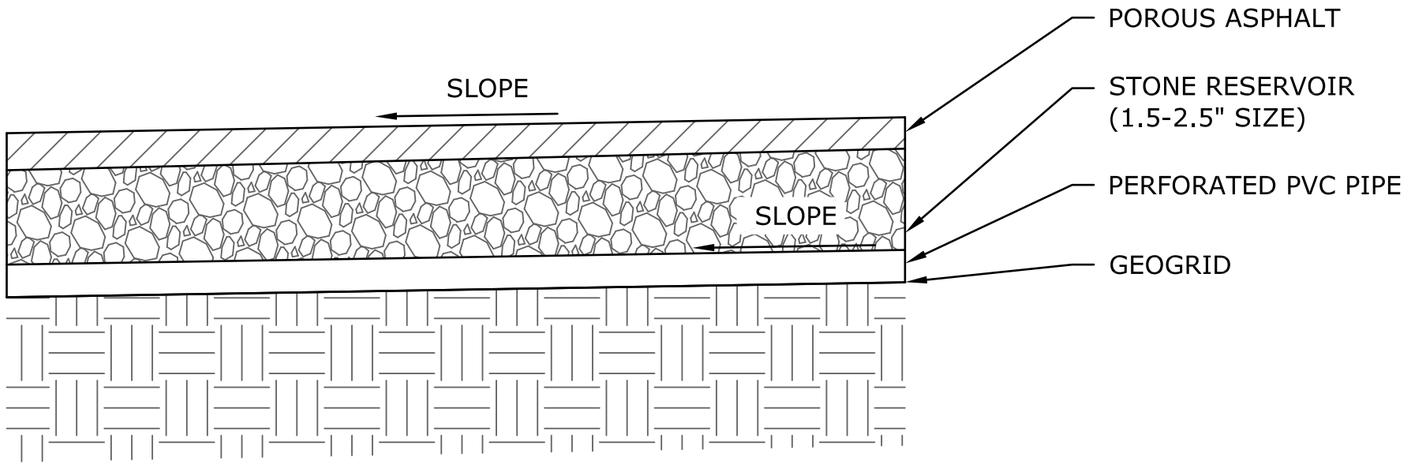
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

POROUS ASPHALT WITH TRENCH OUTLET

DATE: DECEMBER 2017 SHEET: BMP 4.17.3

NOTES TO DESIGNERS

1. MINIMUM STONE RESERVOIR THICKNESS IS 12".
2. USE GEOGRID AS NEEDED FOR DESIGN.
3. POROUS ASPHALT THICKNESS SHOULD BE BETWEEN 2" AND 4".
4. MAXIMUM SLOPE IS 5%.
5. MIN. TRENCH WIDTH IS 18".
6. MIN. 4" DIAMETER FOR PERFORATED PVC PIPE.



POROUS ASPHALT WITH UNDERDRAIN SYSTEM

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

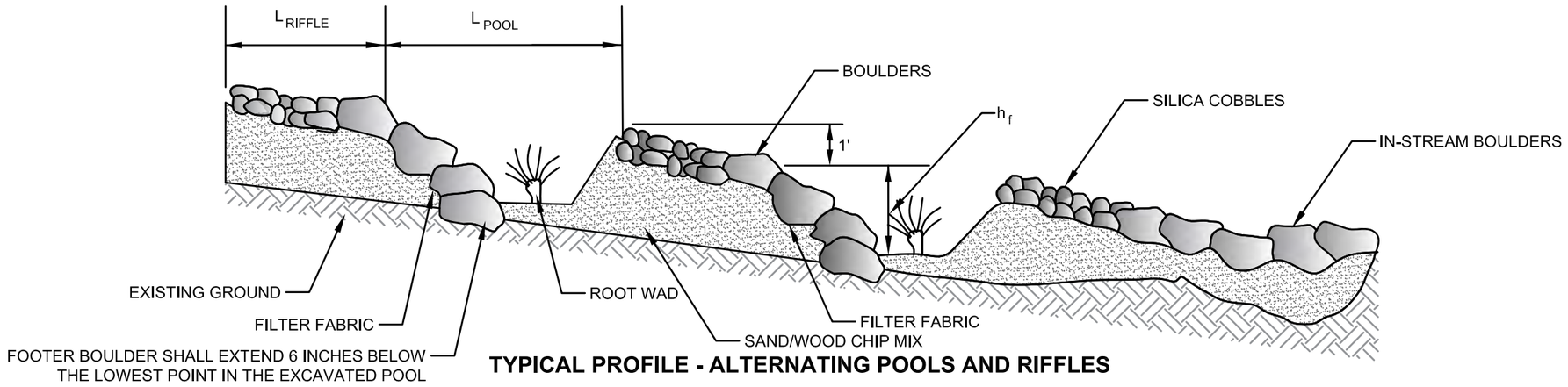
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

POROUS ASPHALT WITH UNDERDRAIN SYSTEM

DATE: DECEMBER 2017 SHEET: BMP 4.17.4

NOTES TO DESIGNERS:

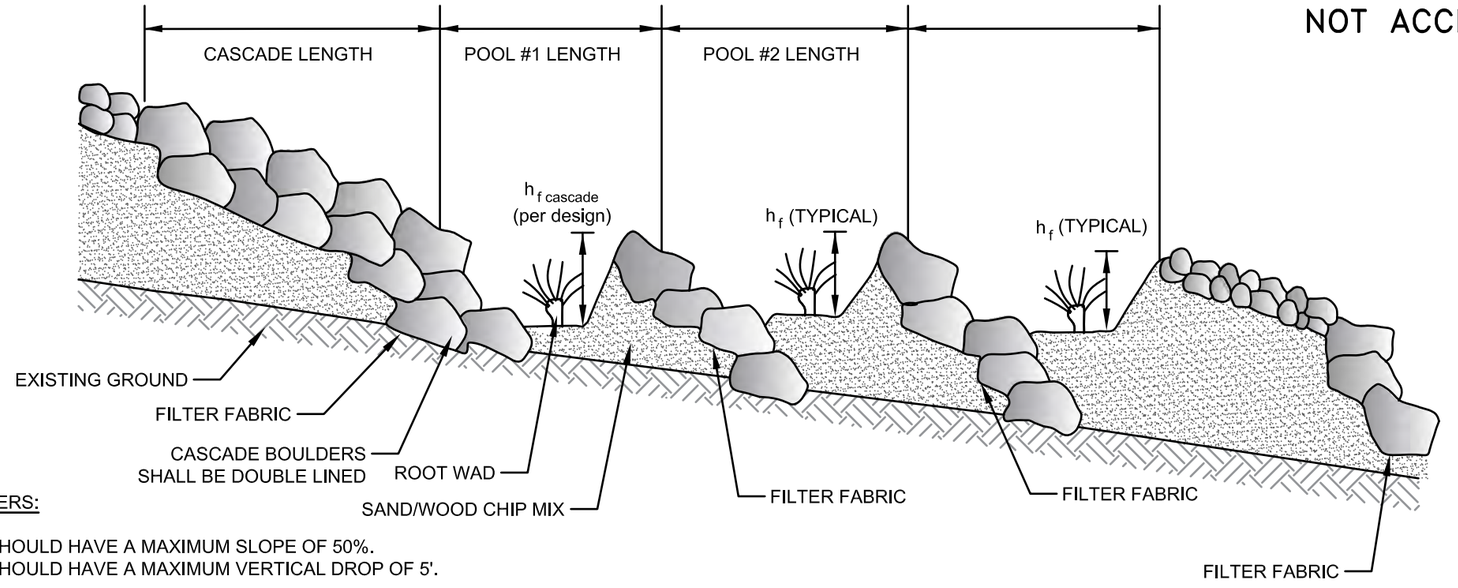
1. THE LENGTH OF THE RIFFLE SHOULD NOT EXCEED 10'.
2. THE LENGTH OF THE POOL SHOULD BE 10' MINIMUM.
3. THE DEPTH OF THE POOL SHOULD BE 18" MINIMUM.



TYPICAL PROFILE - ALTERNATING POOLS AND RIFFLES

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



NOTES TO DESIGNERS:

1. CASCADES SHOULD HAVE A MAXIMUM SLOPE OF 50%.
2. CASCADES SHOULD HAVE A MAXIMUM VERTICAL DROP OF 5'.

CASCADE PROFILE - THREE POOLS FOLLOWING CASCADE

REGENERATIVE STORMWATER CONVEYANCE - PROFILE

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

REGENERATIVE STORMWATER CONVEYANCE – PROFILE

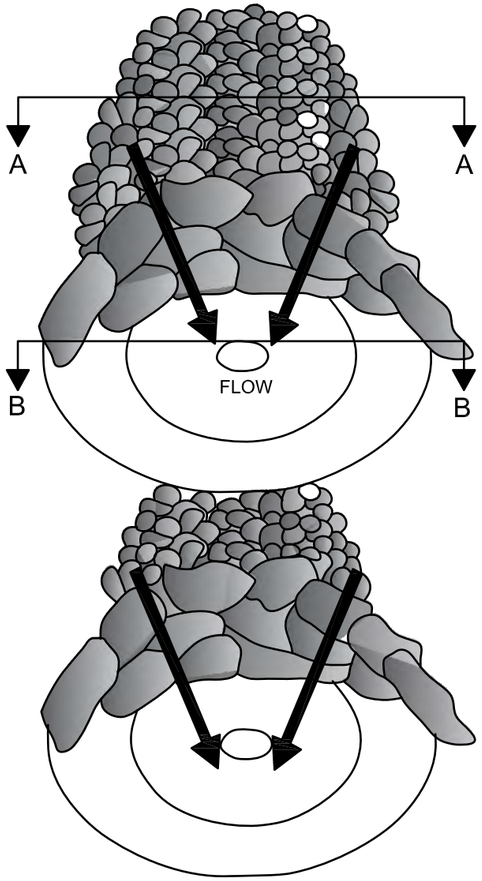
DATE: DECEMBER 2017 SHEET: BMP 4.20.1

NOTES TO DESIGNERS:

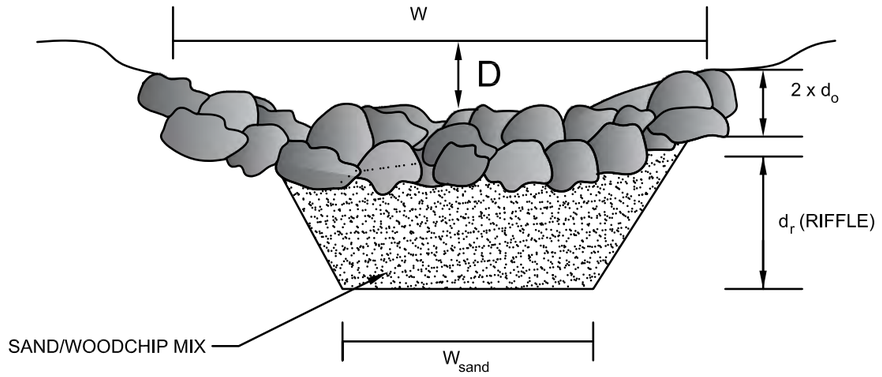
1. W≥8'
2. WIDTH OF THE SAND ≥ 4'
3. SAND DEPTH IN POOL ≥18"
4. WATER DEPTH IN POOL ≥18"

CONCEPTUAL DRAWING ONLY

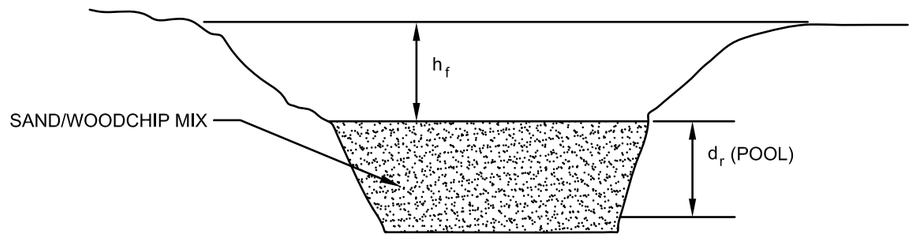
NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



RIFFLE - POOL SEQUENCE (TYPICAL)

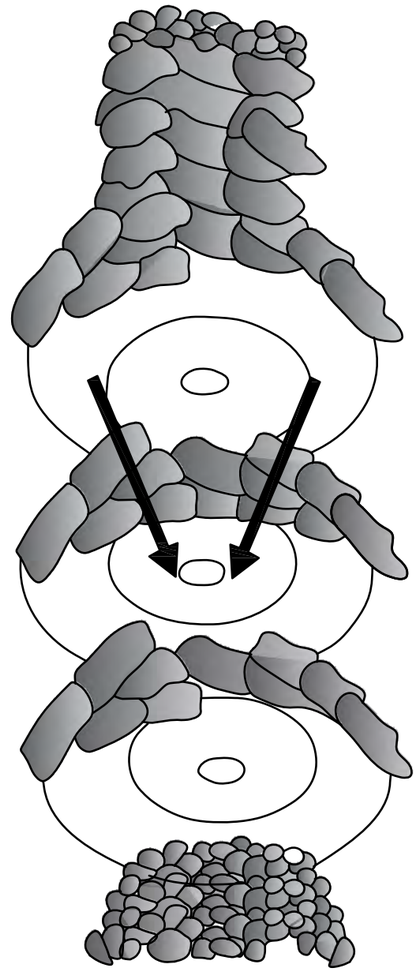


SECTION A-A
RIFFLE POOL CROSS SECTION THROUGH COBBLE



SECTION B-B
RIFFLE POOL CROSS SECTION THROUGH POOL

REGENERATIVE STORMWATER CONVEYANCE - PLAN AND SECTIONS

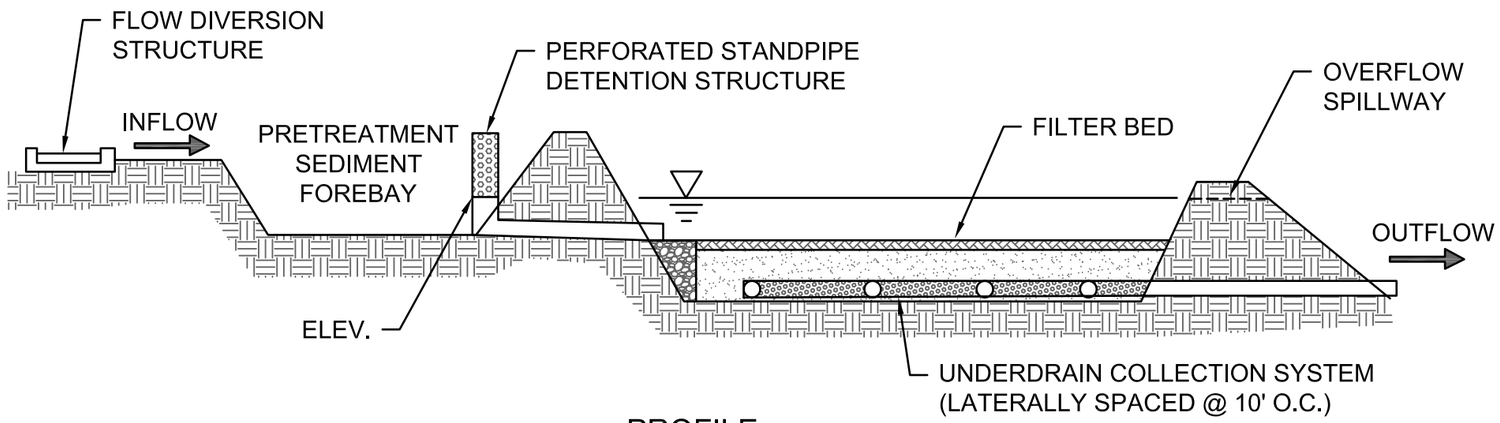


CASCADE SEQUENCE

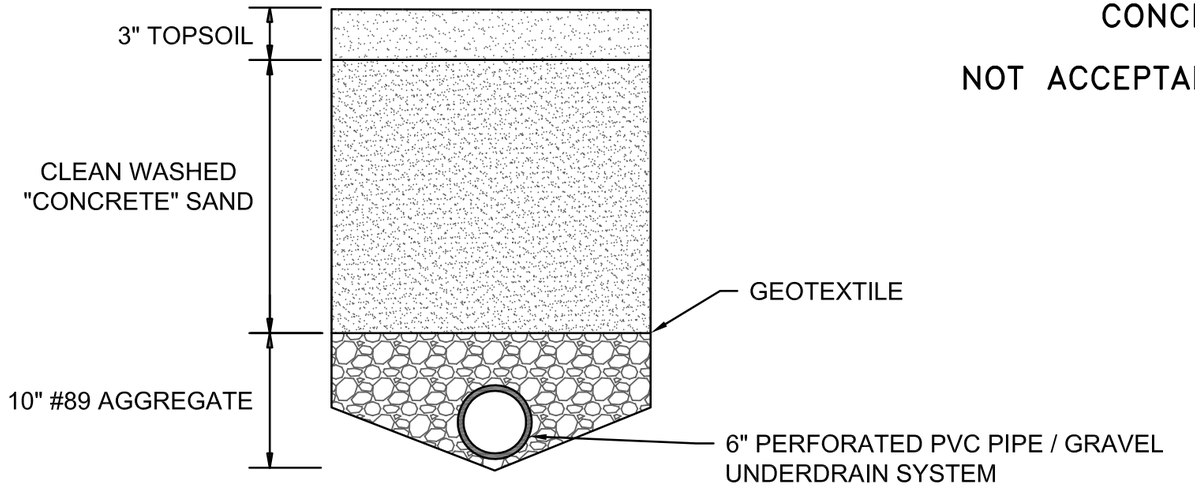
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING
REGENERATIVE STORMWATER CONVEYANCE – PLAN & SECTIONS
DATE: DECEMBER 2017 SHEET: BMP 4.20.2

NOTES TO DESIGNERS:

1. SAND DEPTH SHOULD BE MINIMUM OF 18".



PROFILE



SECTION

SAND FILTER

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

SAND FILTER

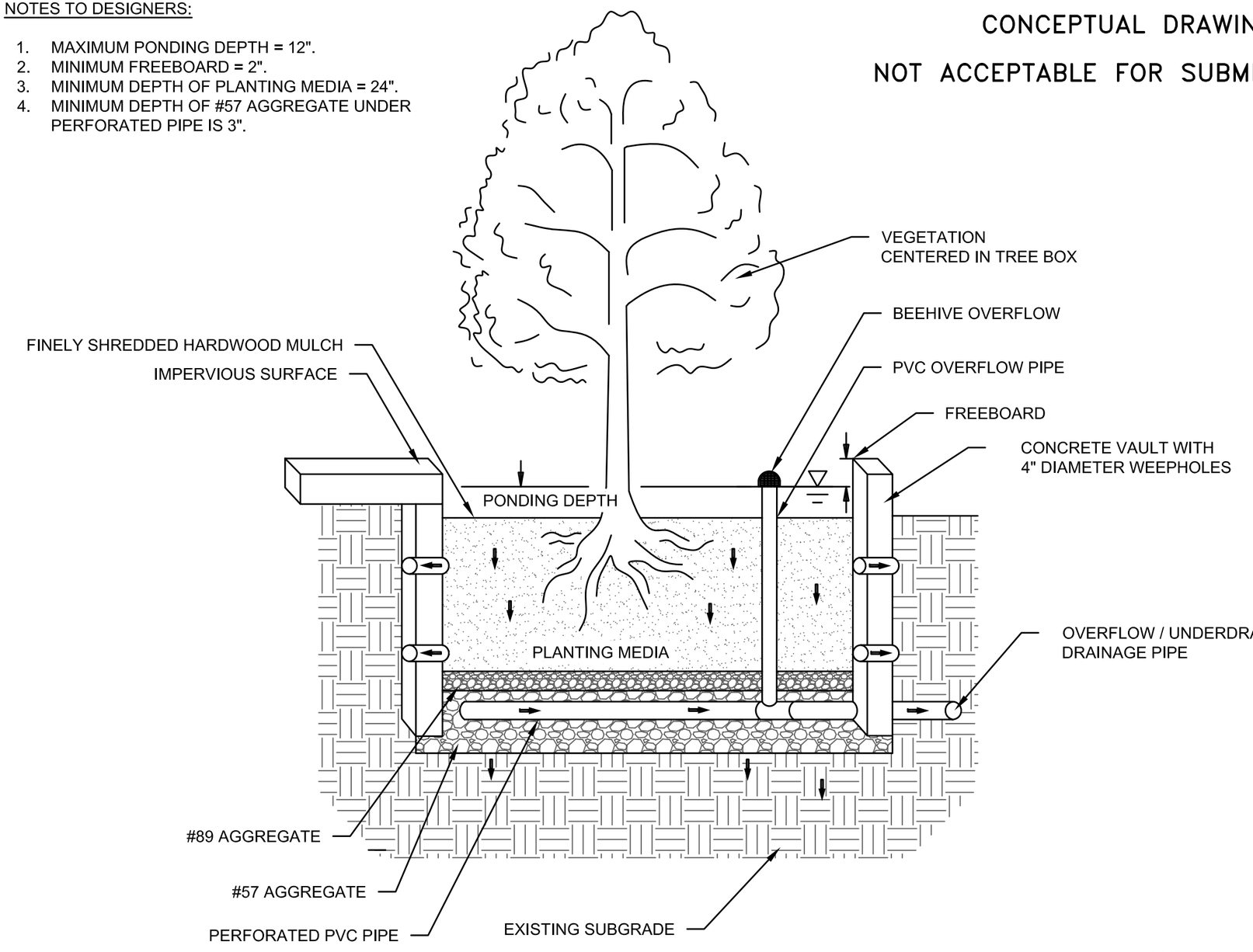
DATE: DECEMBER 2017 SHEET: BMP 4.21.1

NOTES TO DESIGNERS:

1. MAXIMUM PONDING DEPTH = 12".
2. MINIMUM FREEBOARD = 2".
3. MINIMUM DEPTH OF PLANTING MEDIA = 24".
4. MINIMUM DEPTH OF #57 AGGREGATE UNDER PERFORATED PIPE IS 3".

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



TREE BOX WITH UNDERDRAIN

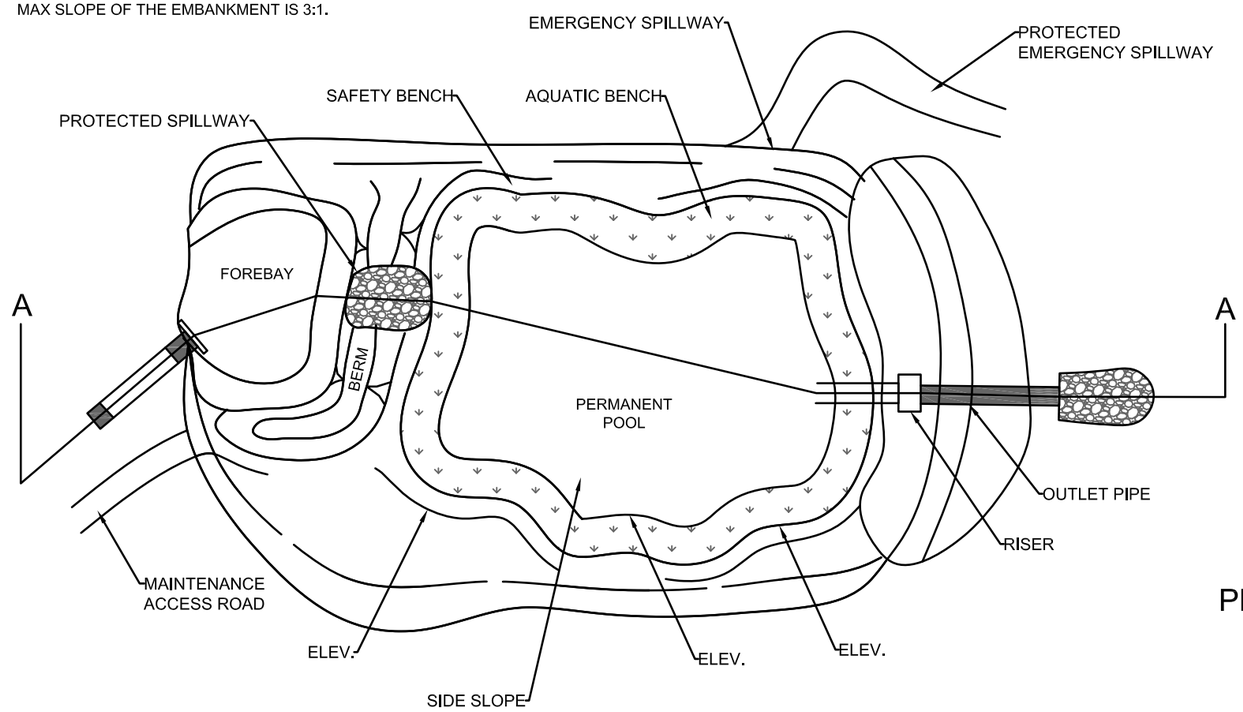
GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING

TREE BOX WITH UNDERDRAIN

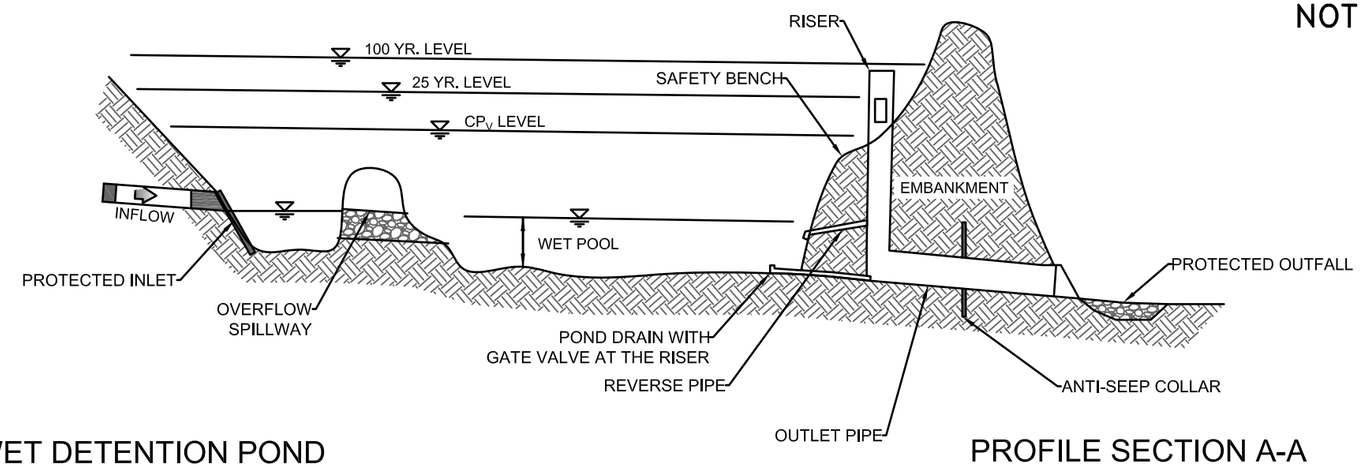
DATE: DECEMBER 2017 SHEET: BMP 4.24.1

NOTES TO DESIGNERS:

1. PROVIDE A MINIMUM OF 18" OF FREEBOARD BETWEEN EMERGENCY SPILLWAY AND TOP OF EMBANKMENT.
2. PROVIDE A MINIMUM OF 0.1' BETWEEN 100 YR. LEVEL AND EMERGENCY SPILLWAY.
3. MIN. LENGTH-TO-WIDTH RATIO FOR PERMANENT POOL IS 1.5:1.
4. MIN. PERMANENT POND DEPTH IS 3' AND MAX IS 8'.
5. MAX. SIDE SLOPE IS 3:1.
6. MAX. SLOPE OF SAFETY BENCH IS 6%.
7. FOREBAY SHOULD BE 4-6' DEEP.
8. MAX SLOPE OF THE EMBANKMENT IS 3:1.



PLAN



WET DETENTION POND

PROFILE SECTION A-A

CONCEPTUAL DRAWING ONLY

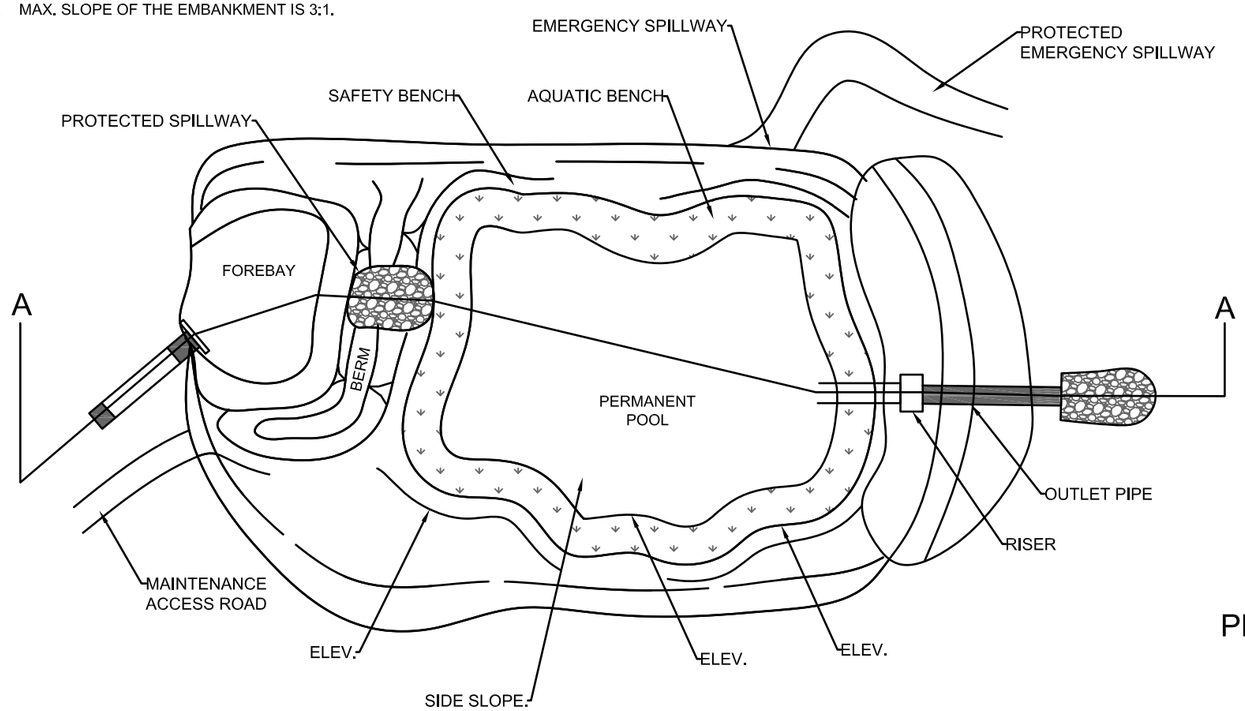
NOT ACCEPTABLE FOR SUBMITTAL PURPOSES

GWINNETT COUNTY GOVERNMENT
CONCEPTUAL DRAWING
WET DETENTION POND

DATE: DECEMBER 2017 SHEET: BMP 4.25.1

NOTES TO DESIGNERS:

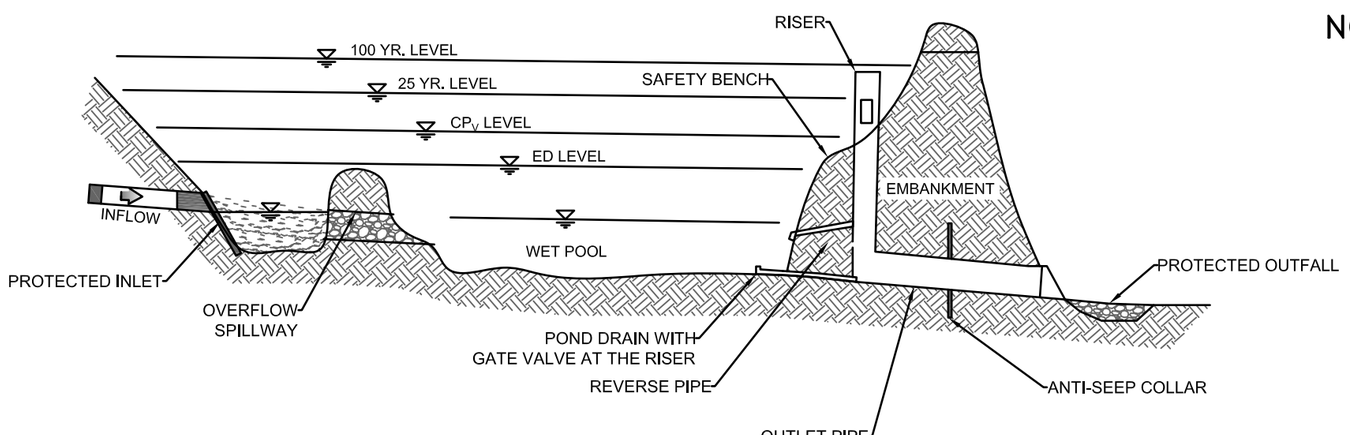
1. PROVIDE A MINIMUM OF 18" OF FREEBOARD BETWEEN EMERGENCY SPILLWAY AND TOP OF EMBANKMENT.
2. PROVIDE A MINIMUM OF 0.1' BETWEEN 100 YR. LEVEL AND EMERGENCY SPILLWAY.
3. MIN. LENGTH-TO-WIDTH RATIO FOR PERMANENT POOL IS 1.5:1.
4. MIN. PERMANENT POND DEPTH IS 3' AND MAX IS 8'.
5. MAX. SIDE SLOPE IS 3:1.
6. MAX. SLOPE OF SAFETY BENCH IS 6%.
7. FOREBAY SHOULD BE 4-6' DEEP.
8. MAX. SLOPE OF THE EMBANKMENT IS 3:1.



PLAN

CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



WET EXTENDED DETENTION (ED) POND

PROFILE SECTION A-A

GWINNETT COUNTY GOVERNMENT

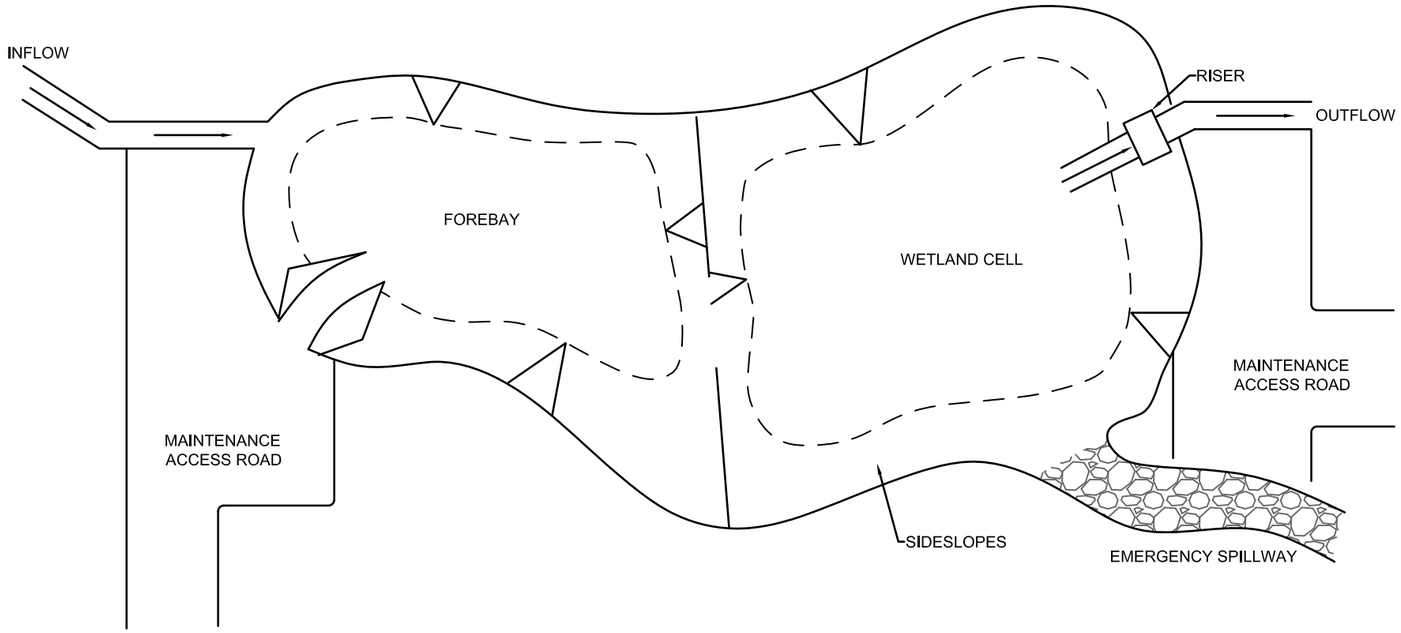
CONCEPTUAL DRAWING

WET EXTENDED DETENTION (ED) POND

DATE: DECEMBER 2017 SHEET: BMP 4.25.2

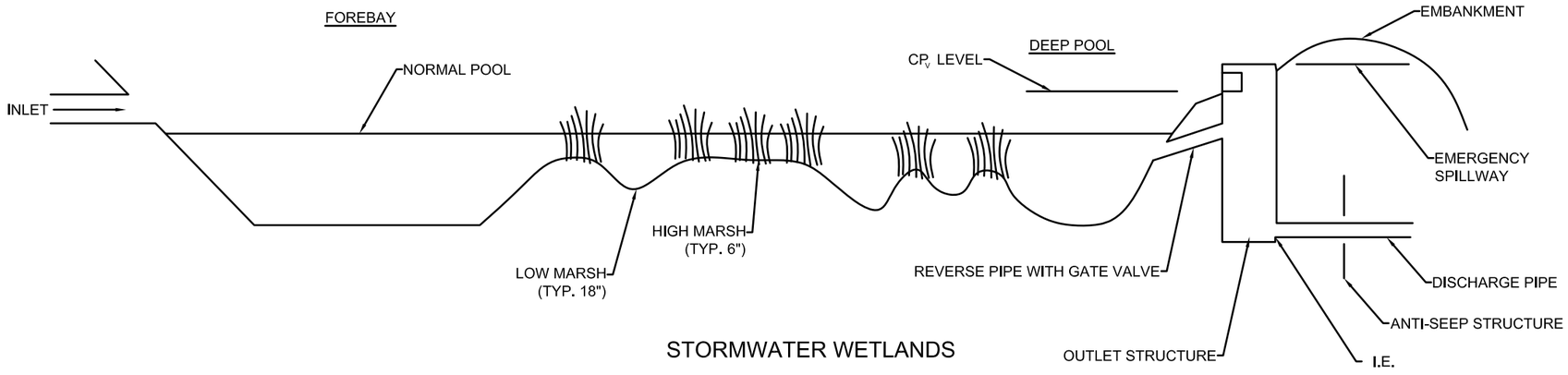
NOTES TO DESIGNERS

1. FOREBAY SHOULD BE AT LEAST 10% OF THE WQ_v.
2. PROVIDE A MINIMUM OF 18" OF FREEBOARD BETWEEN EMERGENCY SPILLWAY AND TOP OF EMBANKMENT.
3. PROVIDE A MINIMUM OF 0.1' BETWEEN 100 YR. LEVEL AND EMERGENCY SPILLWAY.



CONCEPTUAL DRAWING ONLY

NOT ACCEPTABLE FOR SUBMITTAL PURPOSES



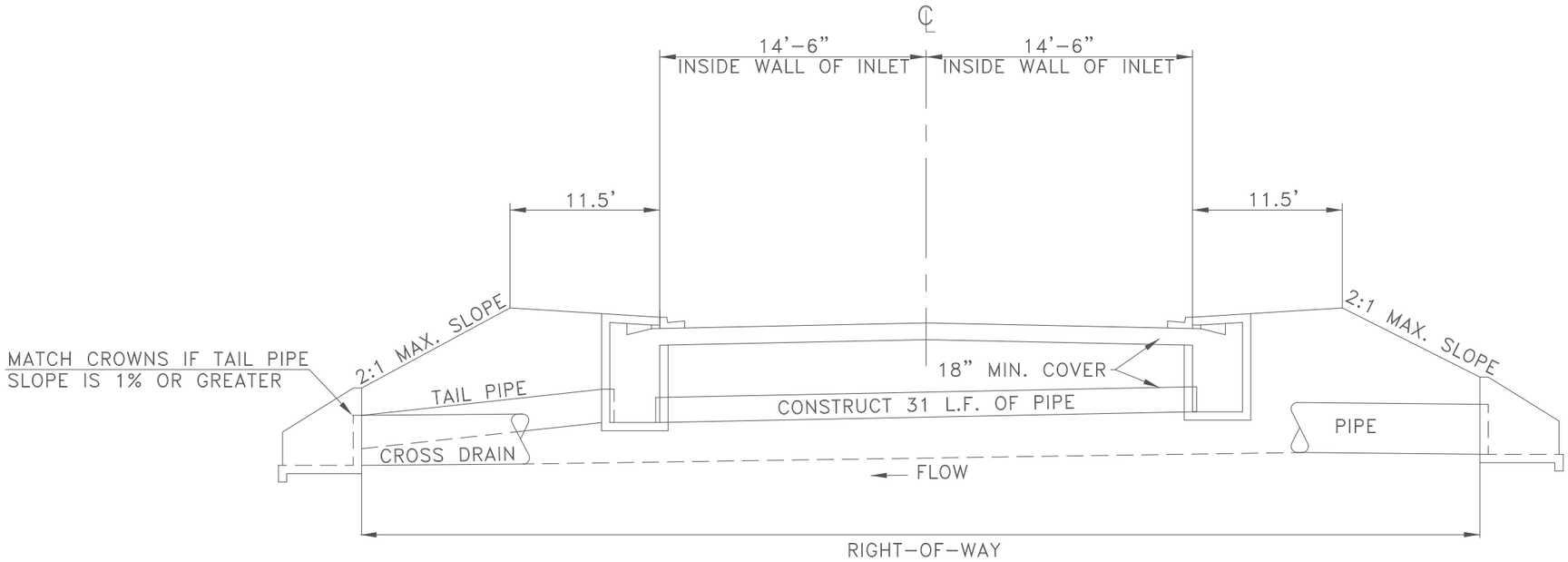
STORMWATER WETLANDS

GWINNETT COUNTY GOVERNMENT

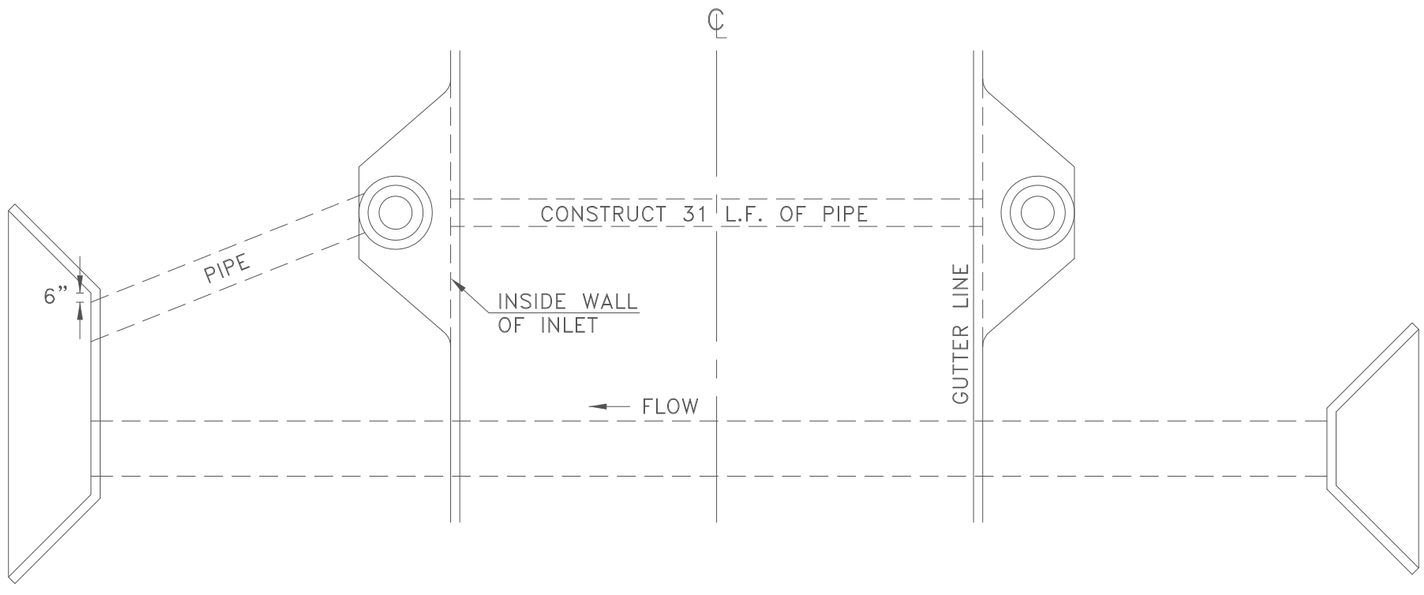
CONCEPTUAL DRAWING

STORMWATER WETLANDS

DATE: DECEMBER 2017 SHEET: BMP 4.26.1



SECTION



PLAN

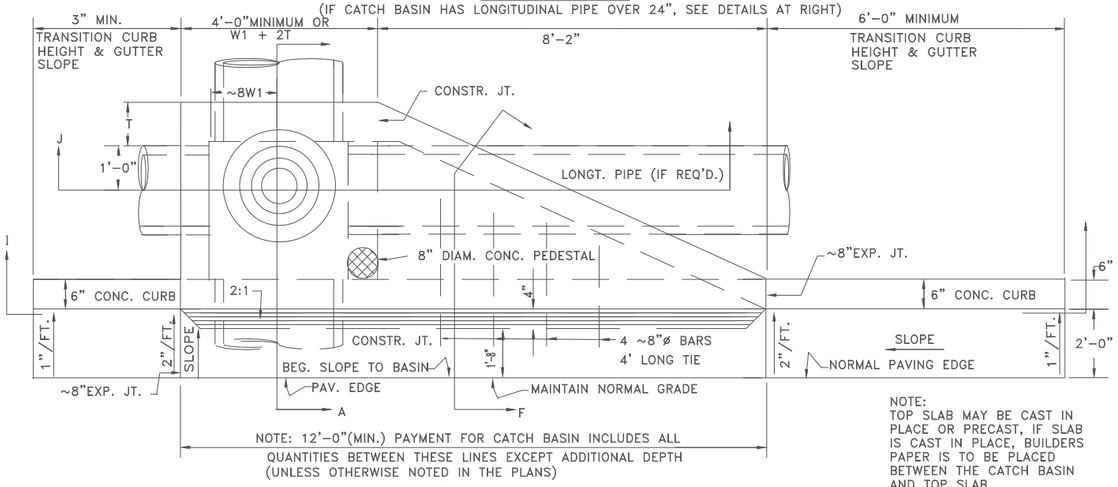
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

LOCATION OF CATCH BASINS 27' WIDE RESIDENTIAL STREETS

DATE: JANUARY 1985 SHEET: 601
REVISED: DECEMBER 2017

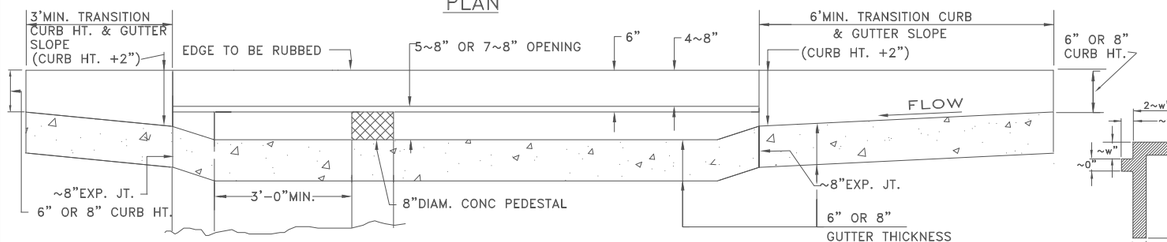
CATCH BASIN

(IF CATCH BASIN HAS LONGITUDINAL PIPE OVER 24", SEE DETAILS AT RIGHT)



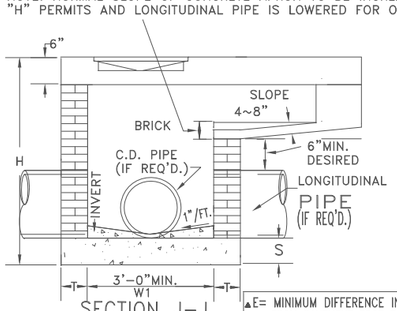
PLAN

NOTE:
TOP SLAB MAY BE CAST IN PLACE OR PRECAST, IF SLAB IS CAST IN PLACE, BUILDERS PAPER IS TO BE PLACED BETWEEN THE CATCH BASIN AND TOP SLAB.



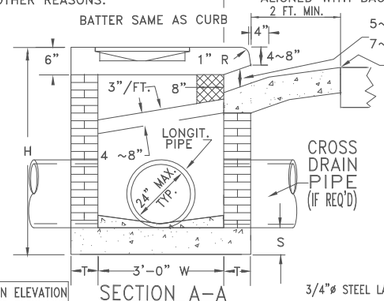
SECTION I–I

NOTE: NORMAL SLOPE OF CONCRETE APRON TO BE INCREASED BY 4" TO 8" WHERE "H" PERMITS AND LONGITUDINAL PIPE IS LOWERED FOR OTHER REASONS.

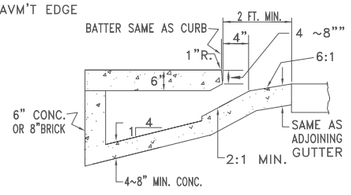


SECTION J–J

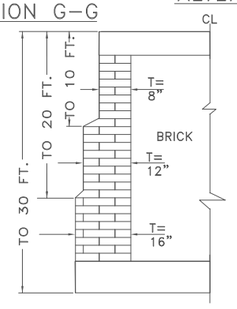
▲E= MINIMUM DIFFERENCE IN ELEVATION FROM PAVEMENT EDGE TO FLOW LINE OF OUTLET PIPE.



SECTION A–A

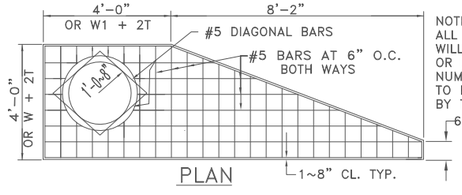


SECTION F–F



DEPTH LIMITS FOR INCREASING "T"

DETAIL OF TOP REINFORCED CONCRETE SLAB

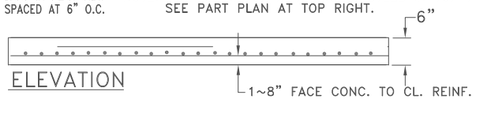


PLAN

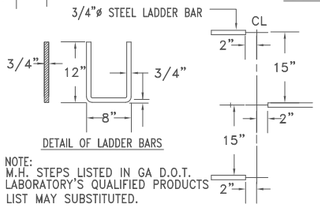
NOTE:
ALL CATCH BASINS WILL HAVE STEPS OR LADDER BARS NUMBER & LOCATION TO BE AS DIRECTED BY THE ENGINEER.

NOTE: ALL BARS IN PLAN VIEW ARE SPACED AT 6" O.C.

NOTE: FOR DETAIL OF REINFORCING STEEL IN TOP PORTION OF SLAB, SEE PART PLAN AT TOP RIGHT.



ELEVATION



DETAIL OF LADDER BARS

NOTE:
M.H. STEPS LISTED IN GA D.O.T. LABORATORY'S QUALIFIED PRODUCTS LIST MAY SUBSTITUTED.

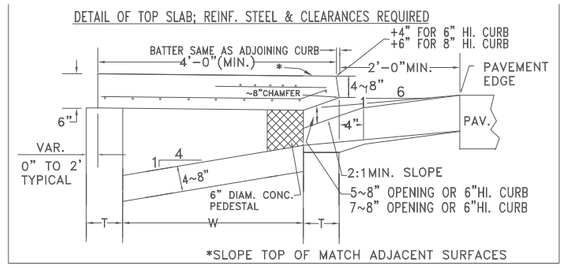
ARRANGEMENT OF LADDER BARS

W OR W1 (MAX.)	BOTTOM SLAB MATERIALS	S
TO 4'–6"	NON–REINF. CONCRETE	6"
	OR BRICK	8"
OVER 4'–6"	CONC. REINF. W1 #4 BARS 12" O.C. BOTH WAYS 2" CL. FROM SLAB TOP	8"

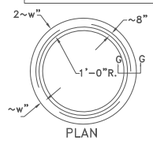
TYPICAL MIN. DIMENSIONS			
PIPE DIA	MIN. H	W OR W1	▲E (MIN.)
12"	4'–4"	3'–0"	3'–3"
15"	4'–7"	3'–0"	3'–6"
18"	4'–10"	3'–0"	3'–9"
24"	5'–6"	3'–0"	4'–4"
30"	6'–2"	3'–7"	5'–0"
36"	6'–10"	4'–6"	5'–7"
42"	7'–4"	5'–3"	5'–11"
48"	8'–0"	6'–0"	6'–6"
54"	8'–6"	6'–8"	7'–0"
60"	9'–2"	7'–4"	7'–7"

NOTE:
THE MIN. H & MIN. E GIVEN IN ABOVE TABLE ARE BASED UPON TYPICAL OUTSIDE DIAMETERS OF CONC. PIPE AND MAY BE VARIED IF CONDITIONS PERMIT WITH VARIED DIMENSIONS SPECIFIED IN THE PLANS OR DIRECTED BY THE ENGINEER. W. & W. DIMENSIONS DO NOT HAVE BE EQUAL.

DETAIL OF TOP SLAB; REINF. STEEL & CLEARANCES REQUIRED



*SLOPE TOP OF MATCH ADJACENT SURFACES



PLAN

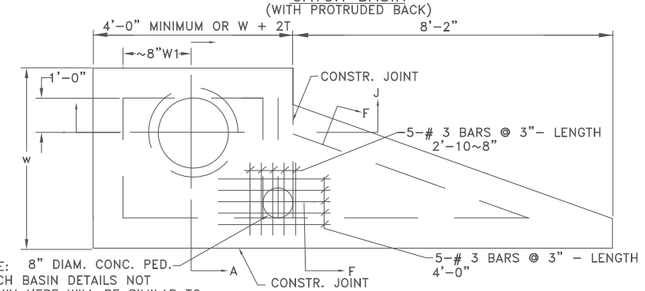
ELEVATION
C.I. RING
APPROX. WT. = 78 LBS.

CASTING DETAILS

FOR CAST IRON LID DETAILS SEE STANDARD DWG. #611

(TYPICAL FOR CATCH BASIN WITH LARGE LONGITUDINAL PIPE OR RECESSED BOX)

CATCH BASIN
(WITH PROTRUDED BACK)

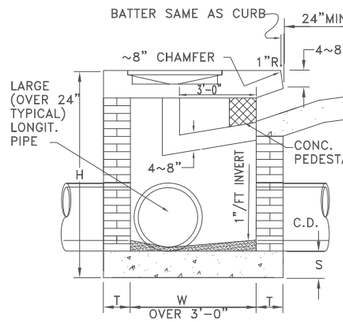


NOTE: 8" DIAM. CONC. PED. CATCH BASIN DETAILS NOT SHOWN HERE WILL BE SIMILAR TO THOSE AT LEFT FOR NORMAL CATCH BASIN.

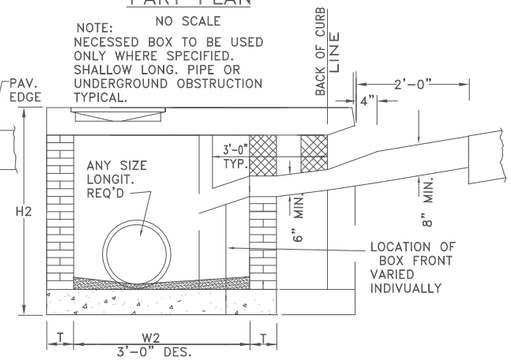
PART PLAN

NO SCALE

NOTE:
NECESSED BOX TO BE USED ONLY WHERE SPECIFIED. SHALLOW LONG. PIPE OR UNDERGROUND OBSTRUCTION TYPICAL.

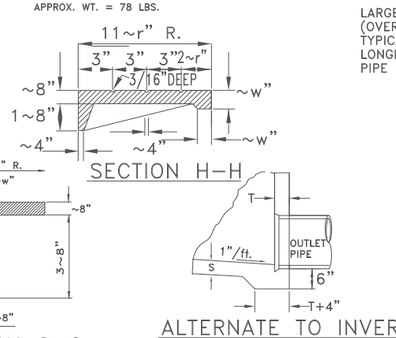


SECTION A–A
(WITH LARGE LONGITUDINAL PIPE)

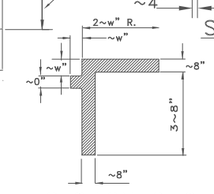


NOTE: H2 & W2 TO BE SHOWN IN THE PLANS

SECTION A–A
(WITH RECESSED BOX)

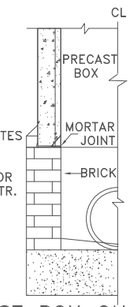


SECTION H–H



SECTION G–G

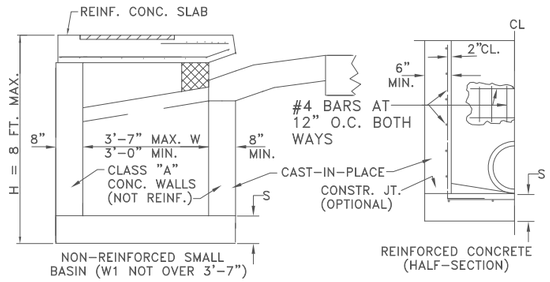
ALTERNATE TO INVERT



NOTE:
SEE SEPARATE STD. FOR PRECAST ALTERNATES ADAPTERS (STD. 606) WILL BE REQUIRED WITH CIRCULAR, AND/OR BUILT–IN–PLACE CONSTR. MAY BE USED IN COMBINATIONS.

PRECAST BOX ON BRICK
(HALF–SECTION)

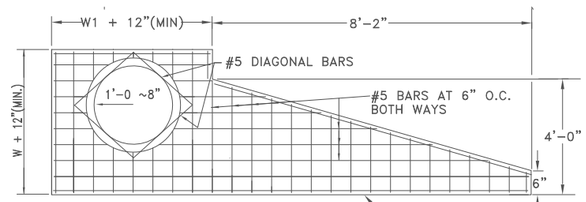
TYPICAL TREATMENT FOR SKEWED PIPE ARE: CIRCULAR PRECAST SWIVEL SECTIONS; PIPE ELBOWS OR INCREASED BOX SIZE



CONSTRUCTION ALTERNATES

NOTE: DETAILS NOT SHOWN ABOVE FOR CONSTRUCTION ALTERNATES WILL BE SIMILAR TO BRICK CATCH BASIN DETAILS.

DETAIL OF REINFORCED CONCRETE SLAB



PLAN



ELEVATION

NOTE: PIPE SIZES, NUMBER, ALIGNMENT, AND INVERT SHOWN ARE ILLUSTRATIVE, SEE PLANS FOR SPECIFICS. INVERTS TO BE FORMED WITH GROUT OR CONCRETE AS DIRECTED BY THE ENGINEER OR AS SHOWN IN THE PLANS.

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

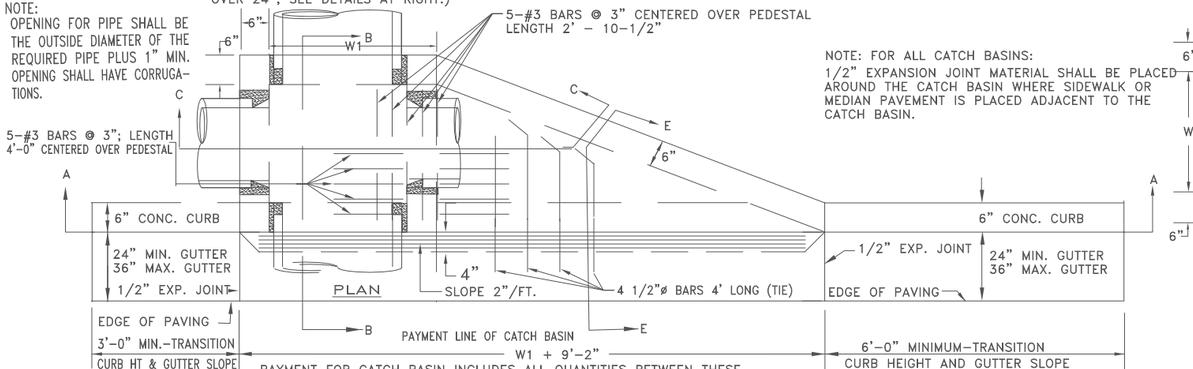
STANDARD CATCH BASINS (MOUNTABLE CURB USE)

DATE: JANUARY 1988 SHEET: 602
REVISED: DECEMBER 2017

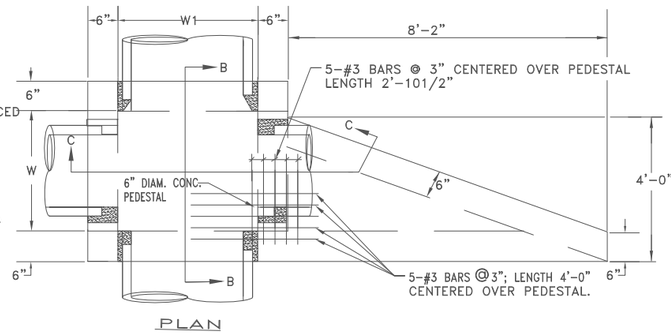
CATCH BASIN

(IF CATCH BASIN HAS LONGITUDINAL PIPE OVER 24", SEE DETAILS AT RIGHT.)

NOTE:
OPENING FOR PIPE SHALL BE THE OUTSIDE DIAMETER OF THE REQUIRED PIPE PLUS 1" MIN. OPENING SHALL HAVE CORRUGATIONS.

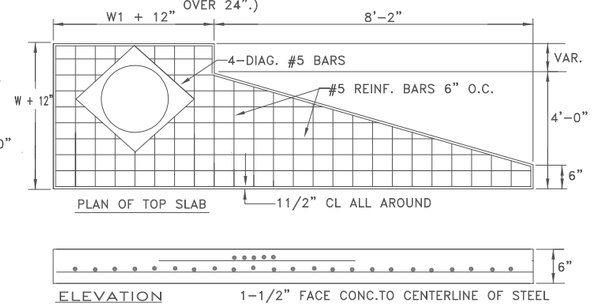


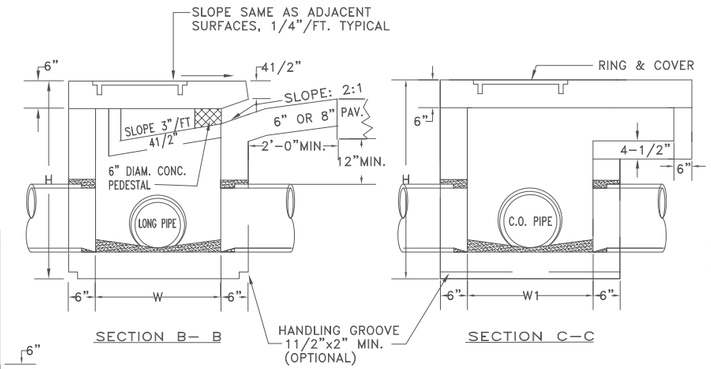
NOTE: FOR ALL CATCH BASINS:
1/2" EXPANSION JOINT MATERIAL SHALL BE PLACED AROUND THE CATCH BASIN WHERE SIDEWALK OR MEDIAN PAVEMENT IS PLACED ADJACENT TO THE CATCH BASIN.

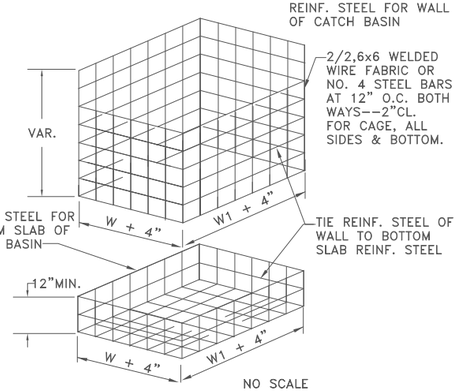


CATCH BASIN

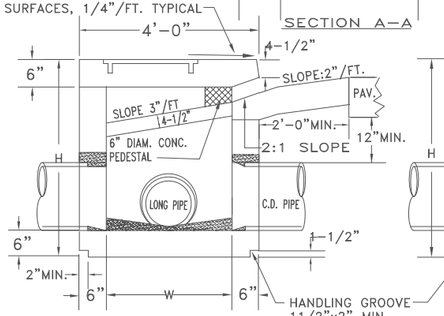
(IF CATCH BASIN HAS LONGITUDINAL PIPE OVER 24".)

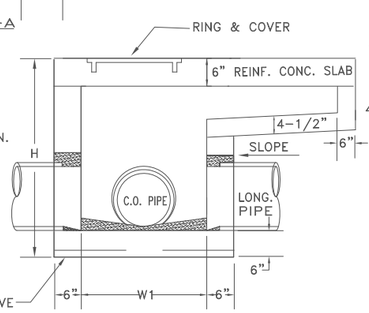


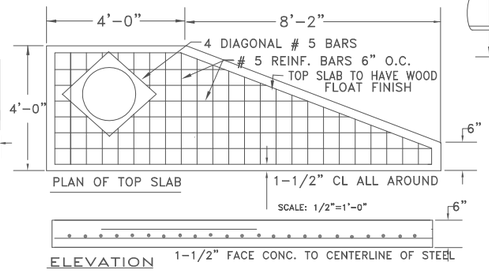


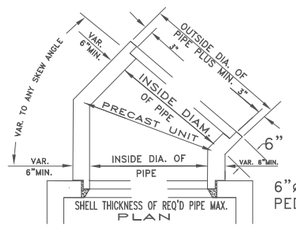


NOTE:
REINFORCING SHOWN ABOVE IS REQUIRED FOR BOX SHAPED BASIN. REINFORCING FOR CIRCULAR PRECAST ALTERNATE SHALL BE ACCORDING TO STD. 1040.



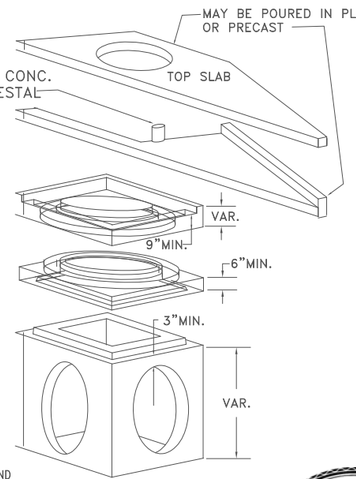






A METHOD OF CONNECTING SKEWED PIPE

IF THIS SWIVEL SECTION SLAB IS USED TO REDUCE THE W AND W1 DIMENSIONS, INCREASE THE MIN. THICKNESS TO 9" AND USE REINF. STEEL. SEE DETAIL BELOW.



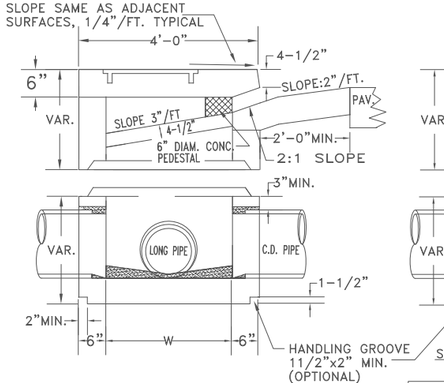
ALL JOINT BETWEEN PRECAST RISERS OR BETWEEN PRECAST BASE AND RISER WILL BE KEYED. KEYED JOINTS SHOWN ARE TYPICAL AND MAY BE VARIED.

NOTE:
DIMENSIONS FOR CATCH BASINS ARE BASED UPON TYPICAL OUTSIDE DIAMETERS OF CONCRETE PIPES AND MAY BE VARIED IF CONDITIONS PERMIT AND THE ENGINEER APPROVES. W & W1 DIMENSIONS DO NOT HAVE TO BE EQUAL.

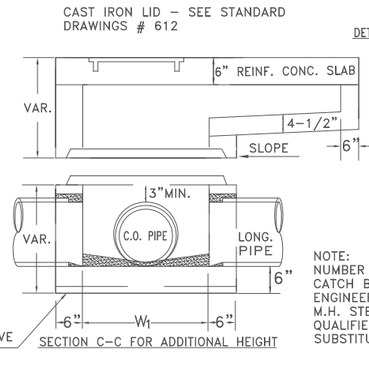
ALTERNATE:
BUILT-IN-PLACE, PRECAST BOX, AND/OR PRECAST CIRCULAR UNITS WITH THE REQUIRED ADAPTERS, REDUCERS, FITTINGS, CONNECTIONS, ETC. MAY BE USED IN COMBINATIONS.

NOTE:
FOR CAST IRON COVER DETAILS SEE STANDARD DWG. #611

DIMENSIONS FOR CATCH BASINS		
PIPE SIZE	NORMAL W OR W1	MIN. H
12"	3'-0"	4'-4"
15"	3'-0"	4'-7"
18"	3'-0"	4'-10"
24"	3'-0"	5'-6"
30"	3'-6"	6'-2"
36"	4'-0"	6'-10"
42"	5'-0"	7'-4"
48"	5'-0"	8'-0"
54"	6'-0"	8'-6"
60"	6'-0"	9'-2"



SECTION B-B FOR MIN. HEIGHT

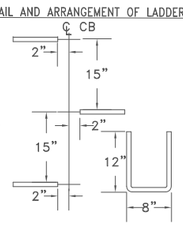


SECTION C-C FOR ADDITIONAL HEIGHT

CAST IRON RING - SEE STANDARD FOR BUILT-IN-PLACE CATCH BASIN

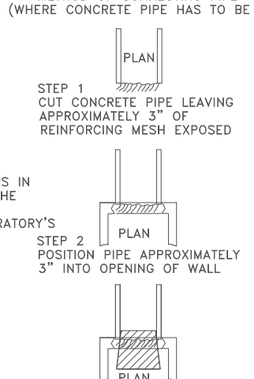
CAST IRON LID - SEE STANDARD DRAWINGS # 612

DETAIL AND ARRANGEMENT OF LADDER BARS

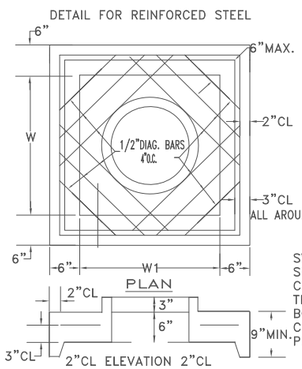


NOTE:
NUMBER AND LOCATION OF LADDER BARS IN CATCH BASIN TO BE AS DIRECTED BY THE ENGINEER.
M.H. STEPS LISTED IN GA. D.O.T. LABORATORY'S QUALIFIED PRODUCTS LIST MAY BE SUBSTITUTED.

METHOD OF CONNECTING PIPE (WHERE CONCRETE PIPE HAS TO BE CUT)

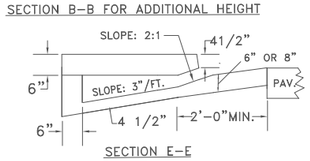


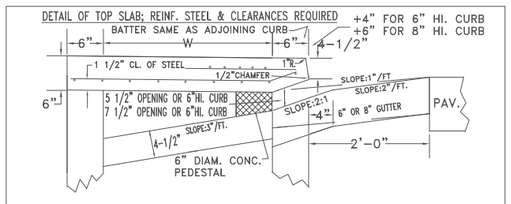
DETAIL FOR REINFORCED STEEL



SWIVEL SECTION MAY BE USED WHERE SKEWED PIPE CONNECTS TO PRECAST CONCRETE BOX.
THE ABOVE VIEW DEPICTS PRECAST BOX. SEE SEPARATE STANDARD FOR CIRCULAR ALTERNATE OR BUILT-IN-PLACE BOX.

SECTION B-B FOR ADDITIONAL HEIGHT





GWINNETT COUNTY • GEORGIA • ESTABLISHED 1818

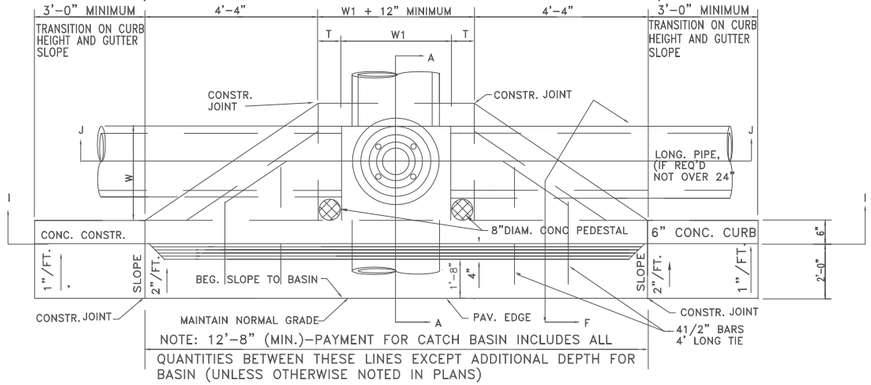
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD CATCH BASINS

DATE: JANUARY 1988 SHEET: 603
REVISED: DECEMBER 2017

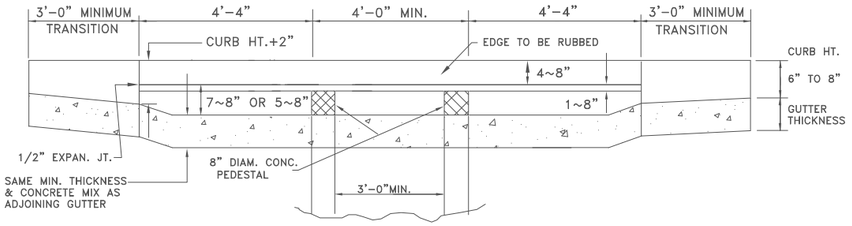
CATCH BASIN

(IF CATCH BASIN HAS LONGITUDINAL PIPE OVER 24", SEE DETAILS AT RIGHT)

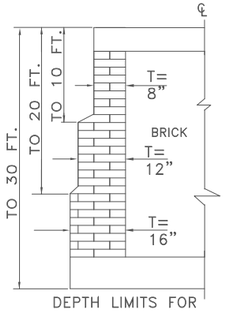


NOTE: 12'-8" (MIN.)-PAYMENT FOR CATCH BASIN INCLUDES ALL QUANTITIES BETWEEN THESE LINES EXCEPT ADDITIONAL DEPTH FOR BASIN (UNLESS OTHERWISE NOTED IN PLANS)

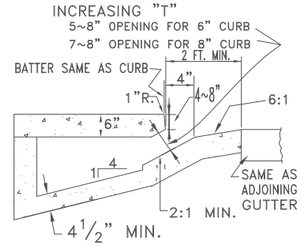
PLAN



SECTION I-I

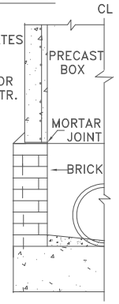


DEPTH LIMITS FOR INCREASING "T"

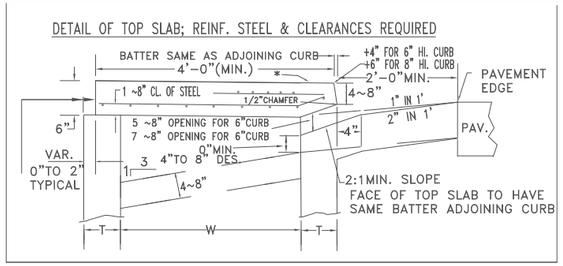


SECTION F-F

NOTE:
SEE SEPARATE STD. FOR PRECAST ALTERNATES ADAPTERS (STD. 606) WILL BE REQUIRED WITH CIRCULAR, AND/OR BUILT-IN-PLACE CONSTR. MAY BE USED IN COMBINATIONS.

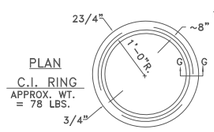


PRECAST BOX ON BRICK (HALF-SECTION)

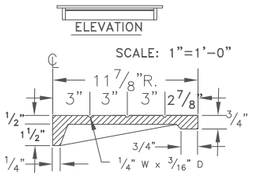


DETAIL OF TOP SLAB; REINF. STEEL & CLEARANCES REQUIRED

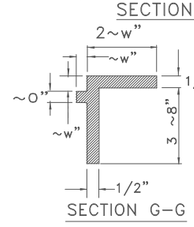
CASTING DETAILS



FOR C.I. COVER DETAILS SEE STD. DWG. NO. #611



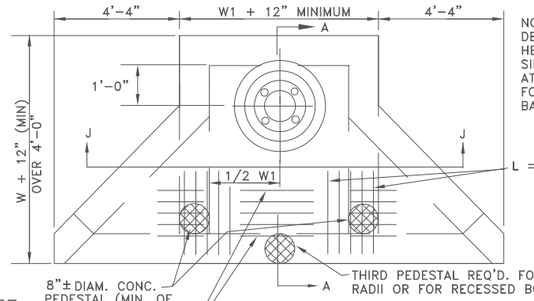
SECTION H-H



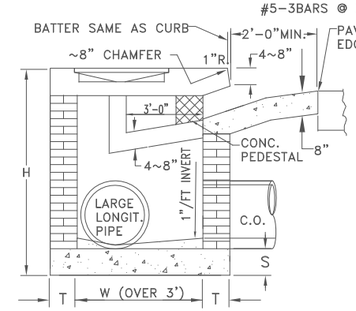
SECTION G-G

CATCH BASIN (WITH PROTRUDED BACK)

(TYPICAL FOR CATCH BASIN WITH LARGE LONGITUDINAL PIPE OR RECESSED BOX)



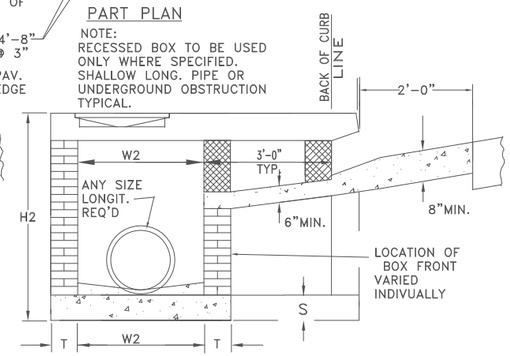
NOTE:
DETAILS NOT SHOWN HERE WILL BE SIMILAR TO THOSE AT FAR LEFT FOR NORMAL CATCH BASINS.



SECTION A-A
(FOR LONGITUDINAL PIPE OVER 24")

PART PLAN

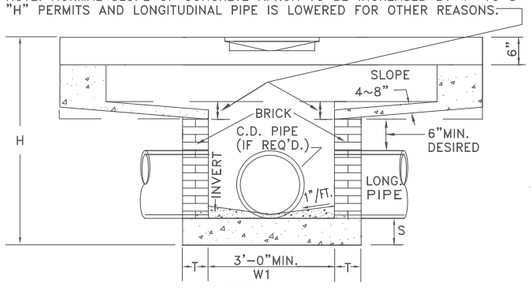
NOTE:
RECESSED BOX TO BE USED ONLY WHERE SPECIFIED. SHALLOW LONG. PIPE OR UNDERGROUND OBSTRUCTION TYPICAL.



NOTE: H2 & W2 TO BE SHOWN IN THE PLANS

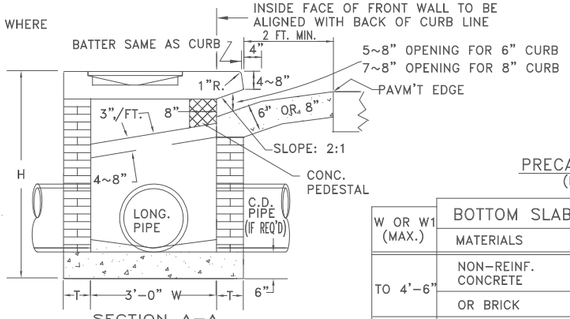
SECTION A-A
(WITH RECESSED BOX)

NOTE: NORMAL SLOPE OF CONCRETE APRON TO BE INCREASED BY 4" TO 8" WHERE "H" PERMITS AND LONGITUDINAL PIPE IS LOWERED FOR OTHER REASONS.



SECTION J-J

SCALE: ~8"=1'-0"

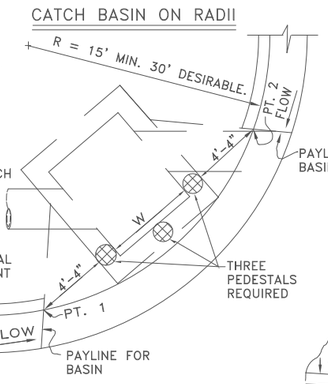


SECTION A-A

NOTE: PIPE SIZES, NUMBER, ALIGNMENT, AND INVERT SHOWN ARE ILLUSTRATIVE, SEE PLANS FOR SPECIFICS. INVERTS TO BE FORMED WITH GROUT OR CONCRETE AS DIRECTED BY THE ENGINEER OR AS SHOWN IN THE PLANS.

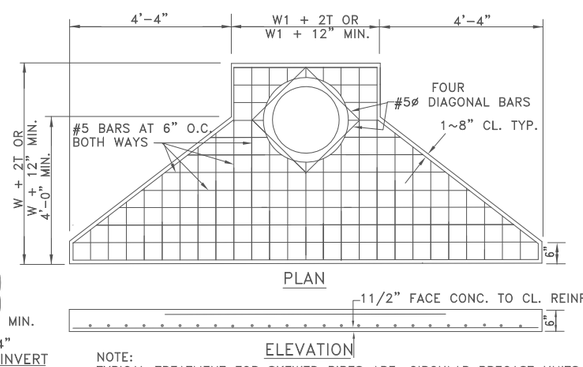
W OR W1 (MAX.)	BOTTOM SLAB MATERIALS	S
TO 4'-6"	NON-REINF. CONCRETE	6"
	OR BRICK	8"
OVER 4'-6"	CONC. REINF. W1 #4 BARS 12" O.C. BOTH WAYS 2" CL. FROM SLAB TOP	8"

CATCH BASIN ON RADII

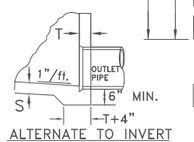


NOTE:
DO NOT LOCATE CATCH BASIN ON RADII IF OTHER ALTERNATES ARE FEASABLE.
DETAILS NOT SHOWN HERE ARE SIMILAR TO THOSE FOR NORMAL CATCH BASINS,PAYMENT FOR CATCH BASIN INCLUDES ALL QUANTITIES FROM PT. 1 TO PT. 2.

DETAIL OF REINFORCED CONCRETE SLAB

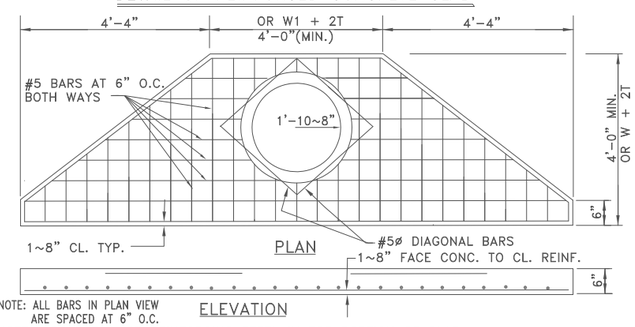


NOTE:
TYPICAL TREATMENT FOR SKEWED PIPES ARE: CIRCULAR PRECAST UNITS; PRECAST SWIVEL SECTIONS; PIPE ELBOWS OR INCREASED BOX SIZES TO ACCOMODATE THE SKEWS.
SEE SEPARATE STANDARDS FOR PRECAST ALTERNATES.

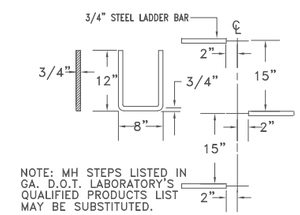


ALTERNATE TO INVERT

DETAIL OF REINFORCED CONCRETE SLAB



NOTE: ALL BARS IN PLAN VIEW ARE SPACED AT 6" O.C.
NOTE: FOR DETAIL OF REINFORCING STEEL IN TOP PORTION OF SLAB, SEE PART PLAN AT TOP RIGHT.
NOTE: TOP SLAB MAY BE CAST IN PLACE OR PRECAST IF CAST IN PLACE, BUILDER'S PAPER IS TO BE PLACED BETWEEN THE CATCH BASIN AND TOP SLAB.



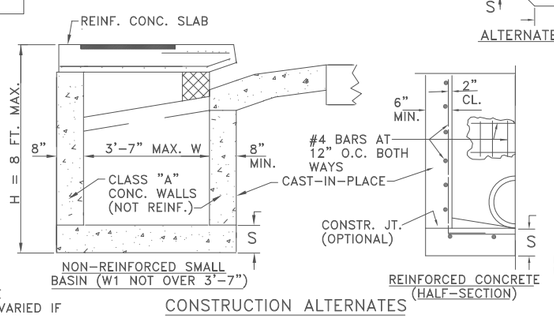
NOTE: MH STEPS LISTED IN GA. D.O.T. LABORATORY'S QUALIFIED PRODUCTS LIST MAY BE SUBSTITUTED.
ALL CATCH BASINS WILL HAVE STEPS OR LADDER BARS NUMBER & LOCATION TO BE AS DIRECTED BY THE ENGINEER.

DETAIL OF LADDER BARS

△E= MINIMUM DIFFERENCE IN ELEVATION FROM PAVEMENT EDGE TO FLOW LINE OF OUTLET PIPE.

TYPICAL MIN. DIMENSIONS			
PIPE SIZE	MIN. H	W OR W1	△E (MIN.)
12"	4'-4"	3'-0"	3'-3"
15"	4'-7"	3'-0"	3'-6"
18"	4'-10"	3'-0"	3'-9"
24"	5'-6"	3'-0"	4'-4"
30"	6'-2"	3'-7"	5'-0"
36"	6'-10"	4'-6"	5'-7"
42"	7'-4"	5'-3"	5'-11"
48"	8'-0"	6'-0"	6'-6"
54"	8'-6"	6'-8"	7'-0"
60"	9'-2"	7'-4"	7'-7"

NOTE:
THE MIN. H & MIN. △E GIVEN IN ABOVE TABLE ARE BASED UPON TYPICAL OUTSIDE DIAMETERS OF CONC. PIPE AND MAY BE VARIED IF CONDITIONS PERMIT WITH VARIED DIMENSIONS SPECIFIED IN THE PLANS OR DIRECTED BY THE ENGINEER. W. & W. DIMENSIONS DO NOT HAVE TO BE EQUAL.



CONSTRUCTION ALTERNATES

NOTE: DETAILS NOT SHOWN ABOVE FOR CONSTRUCTION ALTERNATES WILL BE SIMILAR TO BRICK CATCH BASIN DETAILS.

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD CATCH BASINS

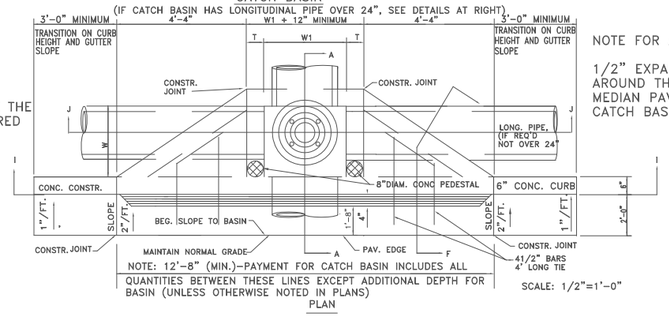
DATE: JANUARY 1988 SHEET: 604
REVISED: DECEMBER 2017

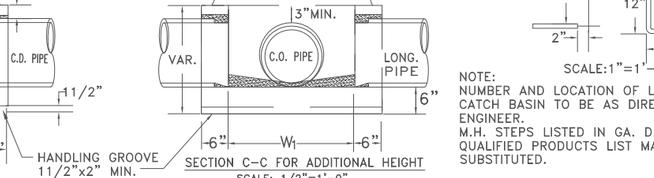
NOTE:

OPENING FOR THE PIPE SHALL BE THE OUTSIDE DIAMETER OF THE REQUIRED PIPE PLUS 1" MINIMUM OPENING SHALL HAVE CORRUGATIONS.

CATCH BASIN

(IF CATCH BASIN HAS LONGITUDINAL PIPE OVER 24", SEE DETAILS AT RIGHT)

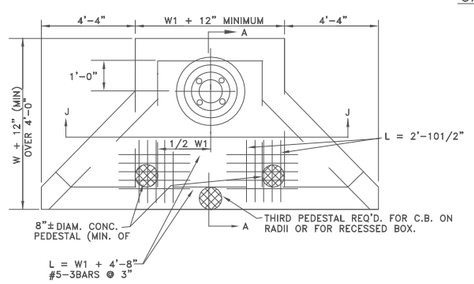


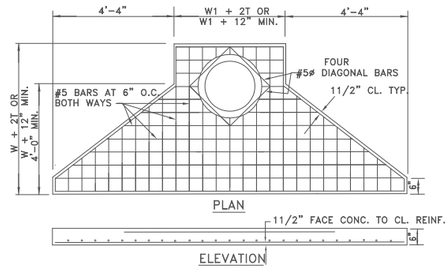


NOTE FOR ALL CATCH BASINS

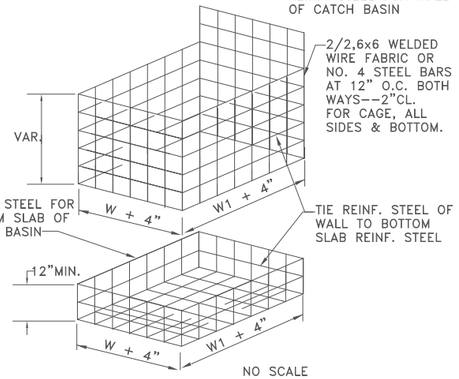
1/2" EXPANSION JOINT MATERIAL SHALL BE PLACED AROUND THE CATCH BASIN WHERE SIDEWALK OR MEDIAN PAVEMENT IS PLACED ADJACENT TO THE CATCH BASIN.

CATCH BASIN





REINFORCING — ISOMETRIC VIEW

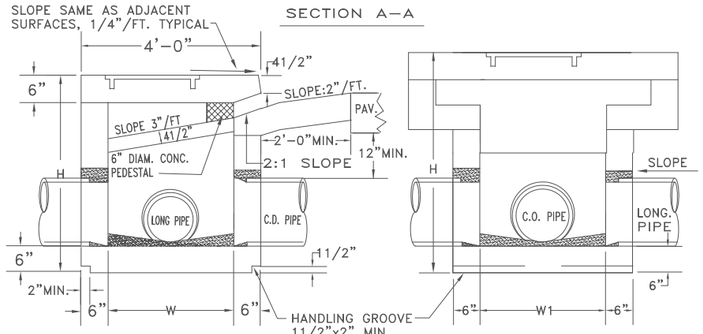


NO SCALE

NOTE:
REINFORCING SHOWN ABOVE IS REQUIRED FOR BOX SHAPED BASIN. REINFORCING FOR CIRCULAR PRECAST ALTERNATE SHALL BE ACCORDING TO STD. 1040.

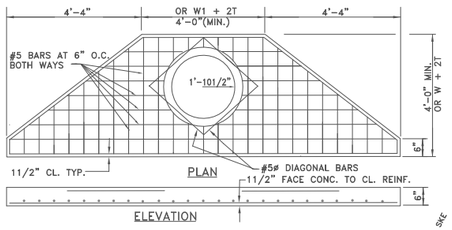
SLOPE SAME AS ADJACENT SURFACES, 1/4"/FT. TYPICAL

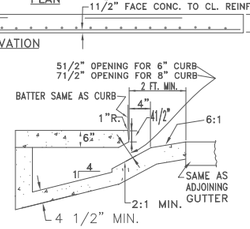
SECTION A–A



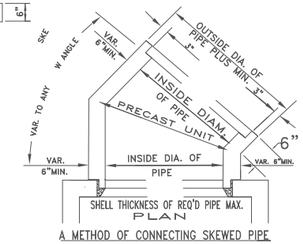
SECTION B–B FOR MIN. HEIGHT

SECTION C–C FOR MIN. HEIGHT



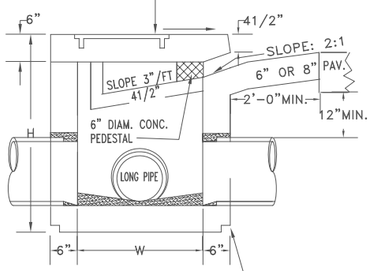


SECTION E–E

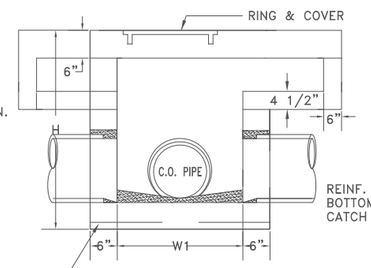


A METHOD OF CONNECTING SKEWED PIPE

SLOPE SAME AS ADJACENT SURFACES, 1/4"/FT. TYPICAL



SECTION B– B
SCALE: 1/2"=1'-0"

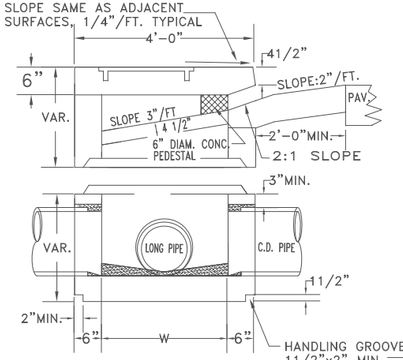


HANDLING GROOVE 11/2"x2" MIN. (OPTIONAL)

SECTION C–C
SCALE: 1/2"=1'-0"

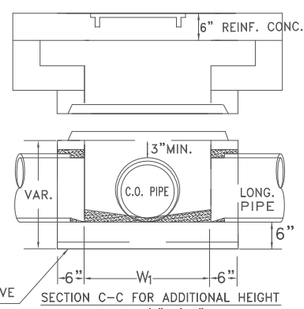
TYPICAL ISOMETRIC TOP VIEW

SLOPE SAME AS ADJACENT SURFACES, 1/4"/FT. TYPICAL



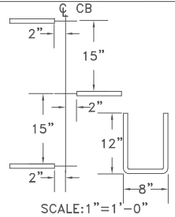
SECTION B–B FOR ADDITIONAL HEIGHT

RING & COVER – SEE STANDARD FOR BUILT–IN–PLACE CATCH BASIN



SECTION C–C FOR ADDITIONAL HEIGHT
SCALE: 1/2"=1'-0"

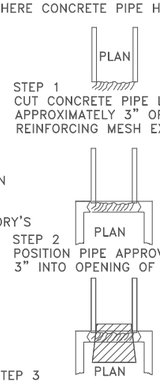
DETAIL AND ARRANGEMENT OF LADDER BARS



SCALE:1"=1'-0"

NOTE:
NUMBER AND LOCATION OF LADDER BARS IN CATCH BASIN TO BE AS DIRECTED BY THE ENGINEER.
M.H. STEPS LISTED IN GA. D.O.T. LABORATORY'S QUALIFIED PRODUCTS LIST MAY BE SUBSTITUTED.

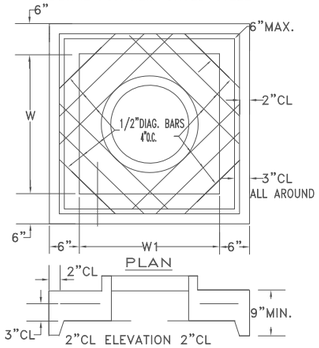
METHOD OF CONNECTING PIPE (WHERE CONCRETE PIPE HAS TO BE CUT)



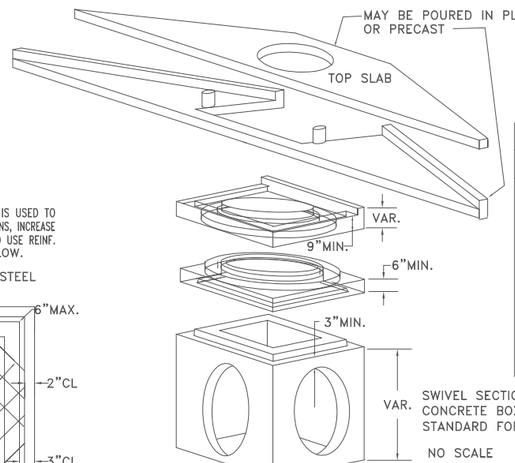
NO SCALE

IF THIS SWIVEL SECTION SLAB IS USED TO REDUCE THE W AND W1 DIMENSIONS, INCREASE THE MIN. THICKNESS TO 9" AND USE REINF. STEEL. SEE DETAIL BELOW.

DETAIL FOR REINFORCED STEEL



SCALE: 3/4"=1'-0"



ALL JOINT BETWEEN PRECAST RISERS OR BETWEEN PRECAST BASE AND RISER WILL BE KEYED. KEYED JOINTS SHOWN ARE TYPICAL AND MAY BE VARIED.

DIMENSIONS FOR CATCH BASINS		
PIPE SIZE	NORMAL W OR W1	MIN. H
12"	3'–0"	4'–4"
15"	3'–0"	4'–7"
18"	3'–0"	4'–10"
24"	3'–0"	5'–6"
30"	3'–6"	6'–2"
36"	4'–0"	6'–10"
42"	5'–0"	7'–4"
48"	5'–0"	8'–0"
54"	6'–0"	8'–6"
60"	6'–0"	9'–2"

NOTE:
DIMENSIONS FOR CATCH BASINS ARE BASED UPON TYPICAL OUTSIDE DIAMETERS OF CONCRETE PIPES AND MAY BE VARIED IF CONDITIONS PERMIT AND THE ENGINEER APPROVES. W & W1 DIMENSIONS DO NOT HAVE TO BE EQUAL.

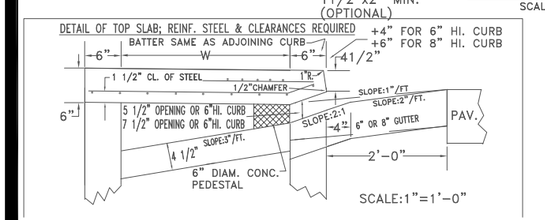
ALTERNATE:
BUILT–IN–PLACE, PRECAST BOX, AND/OR PRECAST CIRCULAR UNITS WITH THE REQUIRED ADAPTERS, REDUCERS, FITTINGS, CONNECTIONS, ETC. MAY BE USED IN COMBI–NATIONS.

NOTE:
FOR CAST IRON COVER DETAILS SEE STANDARD DWG. #611

SWIVEL SECTION MAY BE USED WHERE SKEWED PIPE CONNECTS TO PRECAST CONCRETE BOX. THE ABOVE VIEW DEPICTS PRECAST BOX. SEE SEPARATE STANDARD FOR CIRCULAR ALTERNATE OR BUILT–IN–PLACE BOX.

NO SCALE

DETAIL OF TOP SLAB; REINF. STEEL & CLEARANCES REQUIRED



SCALE:1"=1'-0"

GWINNETT COUNTY GOVERNMENT

STANDARD DRAWING

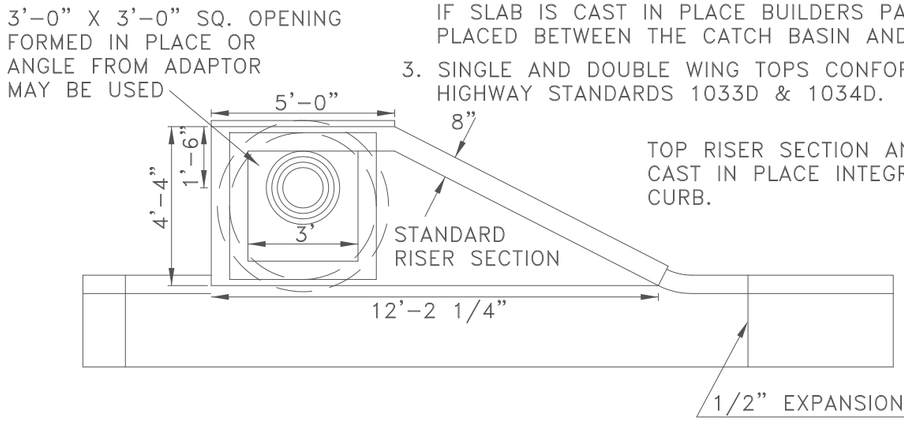
STANDARD CATCH BASINS

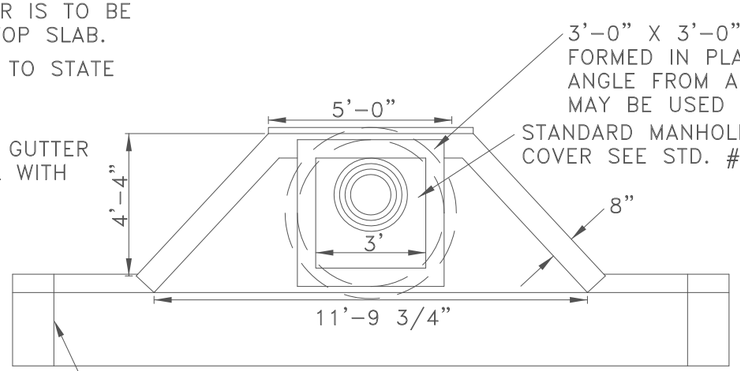
DATE: JANUARY 1988 SHEET: 605

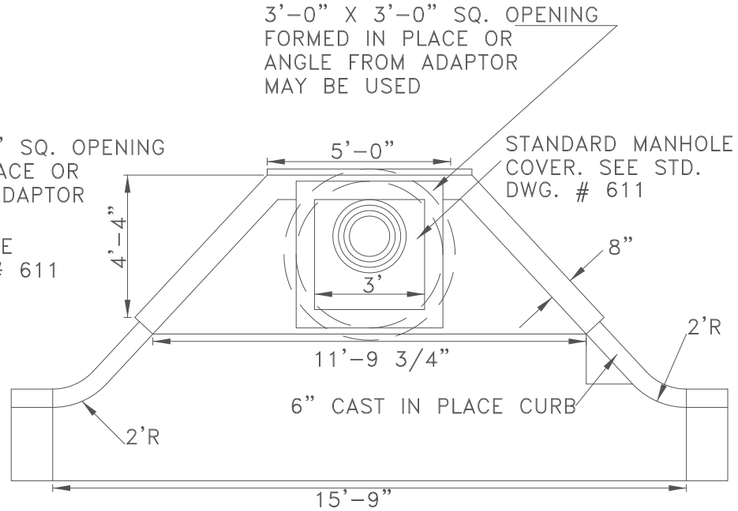
REVISED: DECEMBER 2017

NOTES:

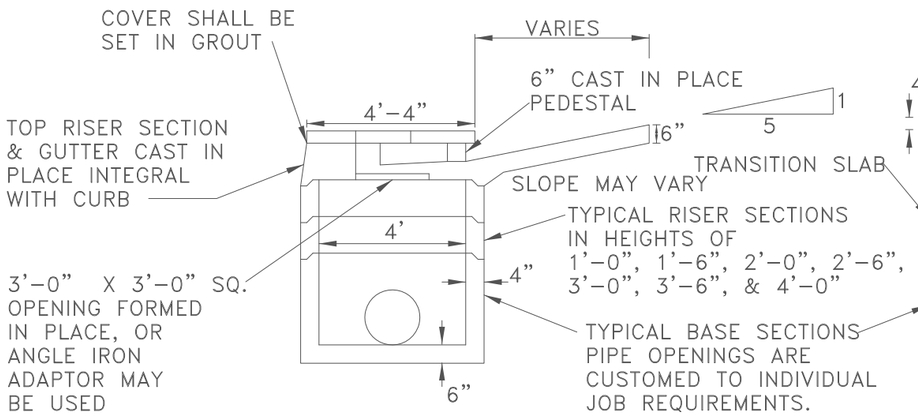
1. 1/2" EXPANSION MATERIAL SHALL BE PLACED AROUND COVER WHERE SIDEWALK IS PLACED ADJACENT TO C.B.
2. TOP SLAB MAY BE CAST IN PLACE OR PRECAST. IF SLAB IS CAST IN PLACE BUILDERS PAPER IS TO BE PLACED BETWEEN THE CATCH BASIN AND TOP SLAB.
3. SINGLE AND DOUBLE WING TOPS CONFORM TO STATE HIGHWAY STANDARDS 1033D & 1034D.







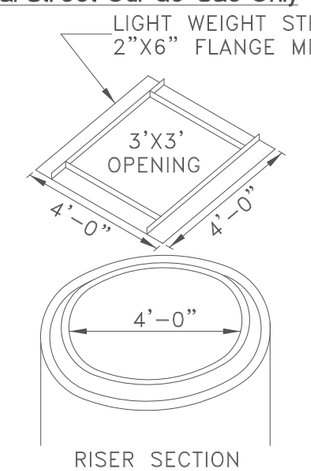
Local Street Cul-de-Sac Only



(WHERE PIPE DIA. REQUIRES 5' DIA. BASE)

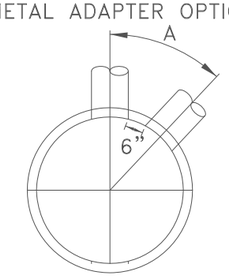
METHOD OF PIPE LAYOUT

ANGLE A					
4'–0" BASE		5'–0" BASE		6'–0" BASE	
PIPE SIZE	A	PIPE SIZE	A	PIPE SIZE	A
12	45°	12	40°		
15	52°	15	47°		
18	60°	18	55°		
21	67°	21	69°		
24	75°	24	70°		
		27	78°		
		30	86°		
		36	115°		
		42	140°	42	90°
				48	115°



RISER SECTION

METAL ADAPTER OPTIONAL



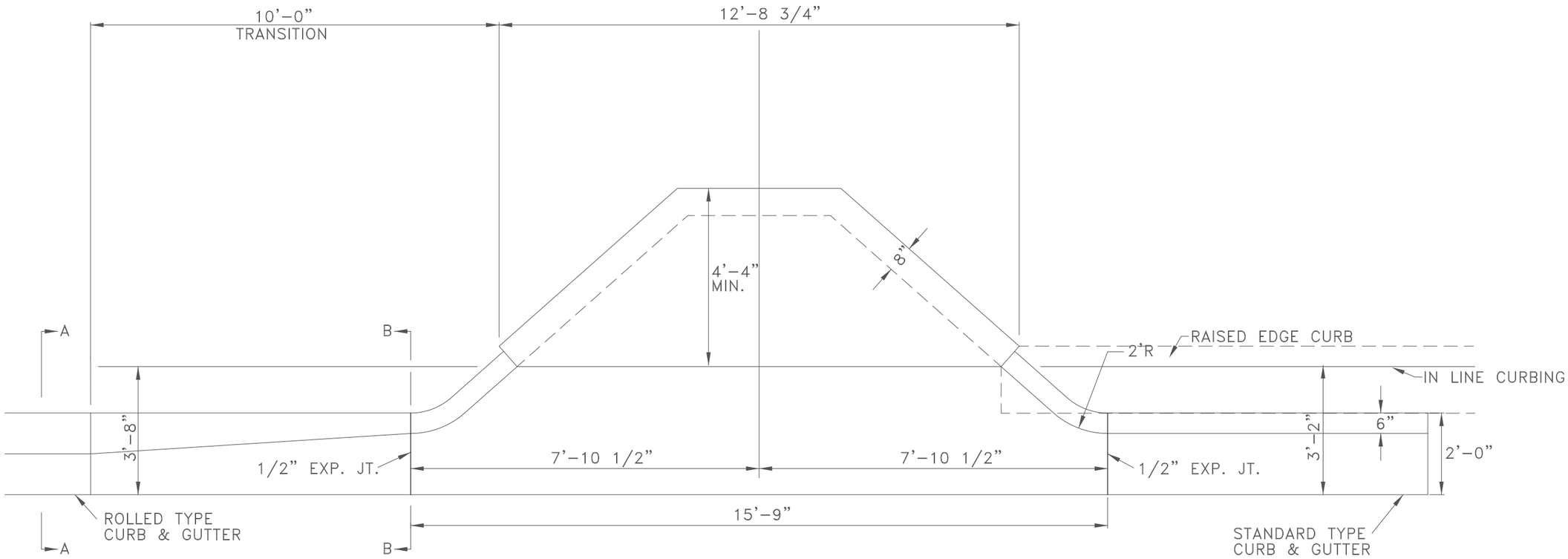
NOTES:

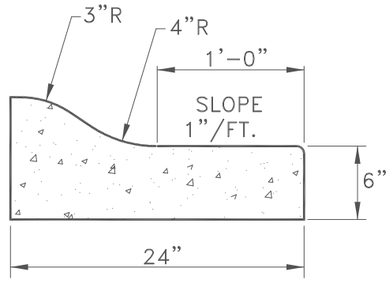
1. SUBGRADE TO BE COMPACTED TO 95% STANDARD PROCTOR.
2. REINFORCEMENT STEEL TO BE PLACED TO ALLOW A MINIMUM OF 2" CLEARENCE, EXCEPT WHERE NOTED.
3. REINFORCEMENT STEEL SHALL BE OF INTERMEDIATE GRADE AND SHALL BE 0.12 SQ. IN. PER FT. IN BOTH DIRECTIONS IN ACCORDANCE WITH A.S.T.M. C 476–76 MANHOLE SPECIFICATIONS.
4. ALL CONCRETE SHALL BE CLASS AA1 4500 PSI UNLESS NOTED OTHERWISE.
5. CHAMFER ALL EXPOSED EDGES 3/4"

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

ROUND PRECAST CONCRETE CATCH BASINS

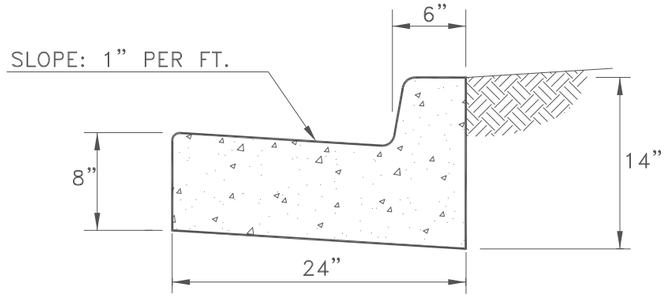
DATE: JANUARY 1988 SHEET: 606
REVISED: DECEMBER 2017





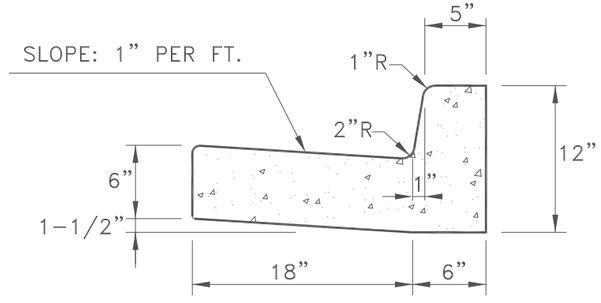
SECTION A-A

ROLLED TYPE CURB AND GUTTER
(WAIVER REQUIRED)



SECTION B-B

24" VERTICAL CURB AND GUTTER
(COMMERCIAL AND INDUSTRIAL)



SECTION B-B

24" VERTICAL CURB AND GUTTER
(RESIDENTIAL)

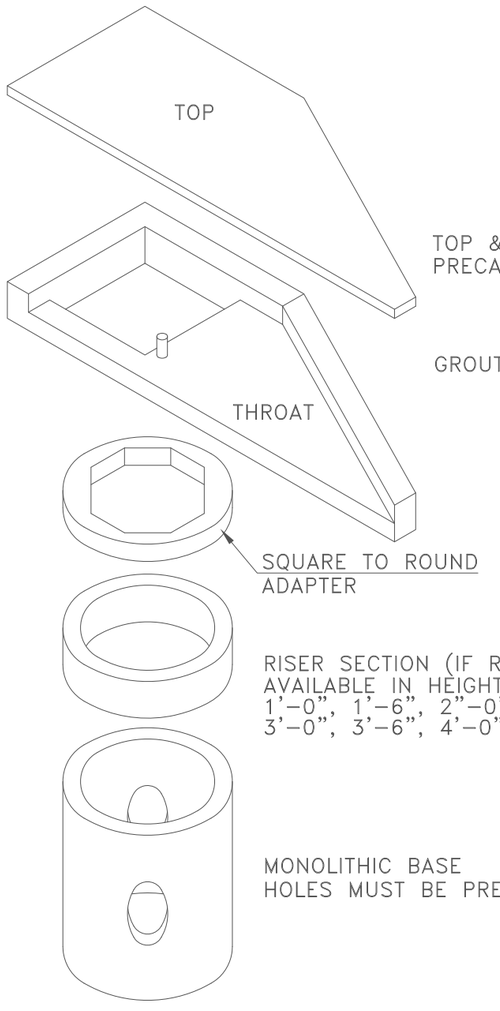
NOTES:

1. EXPANSION JOINTS REQUIRED AT ALL STRUCTURES AND CURB RETURNS.
2. MAXIMUM DISTANCE BETWEEN EXPANSION JOINTS = 250'
3. CONCRETE SHALL BE CLASS A 3000 PSI.

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

Transition from Rolled Type Curb and Gutter to Standard Type Curb and Gutter at the Catch Basin

DATE: JANUARY 1988 SHEET: 607
REVISED: DECEMBER 2017

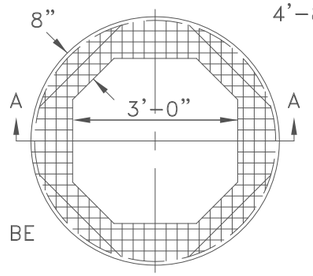


RISER SECTION (IF REQ'D)
AVAILABLE IN HEIGHTS
1'–0", 1'–6", 2"–0", 2'–6",
3'–0", 3'–6", 4'–0"

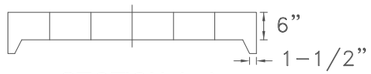
MONOLITHIC BASE
HOLES MUST BE PRECAST

TOP & THROAT WILL NOT BE PRECAST.

GROUT ALL JOINTS

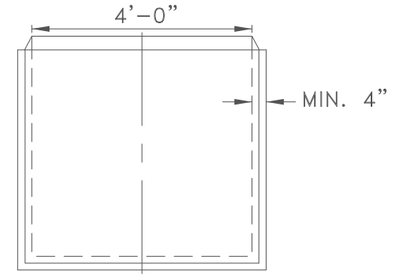


ROUND TO SQUARE ADAPTER

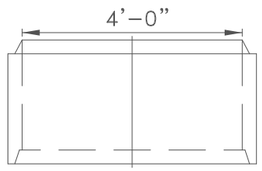


SECTION A-A

REINFORCING TO BE 2/2 6X6 WELDED 10 GUAGE WIRE FABRIC WITH 4 #5 BARS 4'–8" DIAMETER



REINFORCING TO BE 3/3 6X8 WELDED WIRE FABRIC



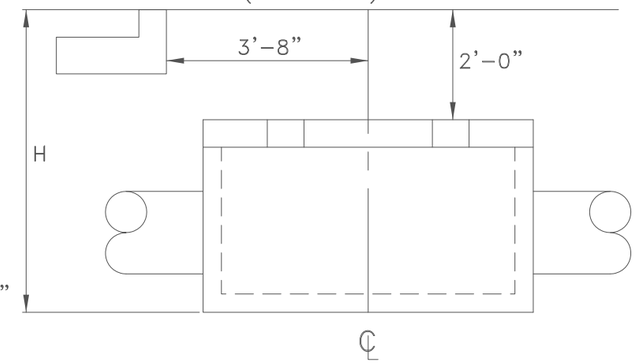
REINFORCING TO BE 2/2 6X6 WELDED WIRE FABRIC

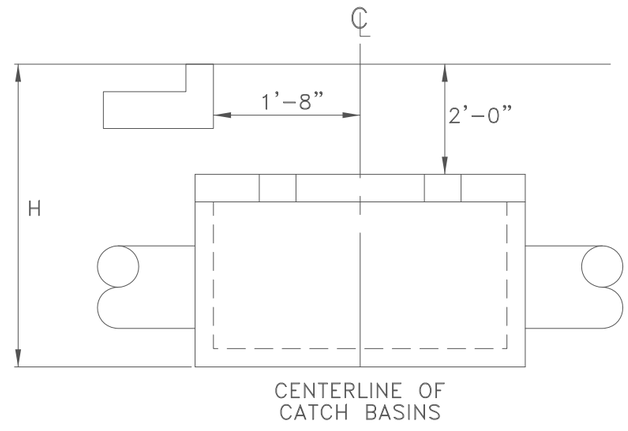
RISER

NOTE:

1. STEPS TO BE INSTALLED ON 15" VERTICAL SPACING. SEE PRECAST MANHOLE STANDARD FOR SPECIFICATION.

(2' OFFSET)





CENTERLINE OF CATCH BASINS

ON-LINE

BASE HEIGHT	METAL PIPE	CONC PIPE	H(MIN)
4' DIA – 2'–6"	18"	12"	5'–0"
3'–0"	24"	18"	5'–6"
3'–6"	30"	24"	6'–0"
4'–0"		30"	6'–6"

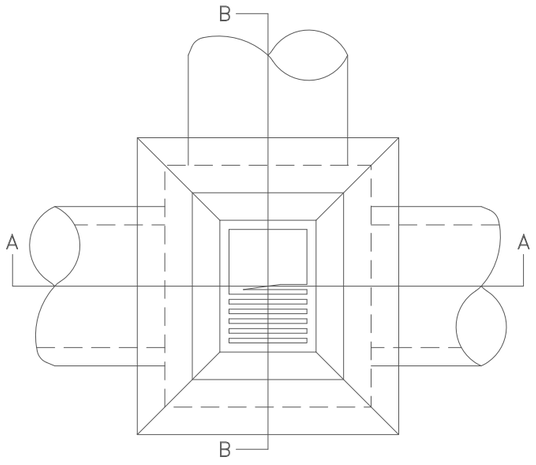
NOTES:

1. CATCH BASIN SHALL BE INSTALLED WITH PIPE OPENING AS SPECIFIED.
2. ALL CONCRETE SHALL BE CLASS AA1 4500 PSI.

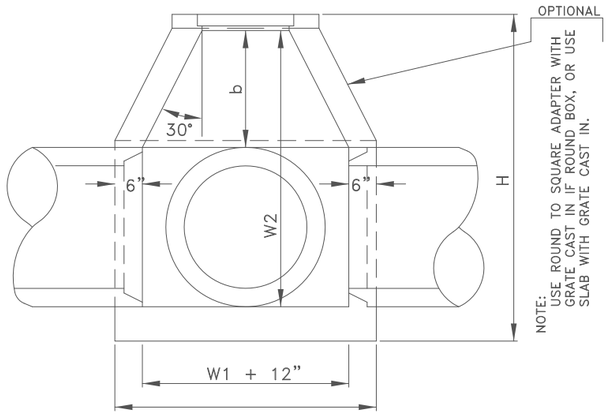
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD PRECAST ROUND CATCH BASIN

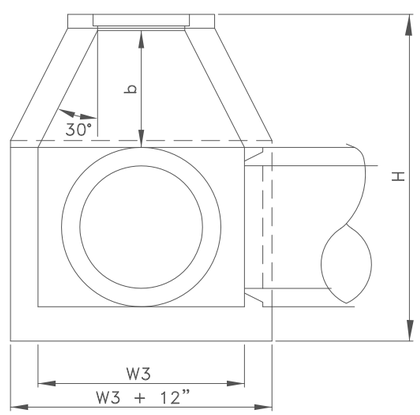
DATE: JANUARY 1988 SHEET: 608
REVISED: DECEMBER 2017



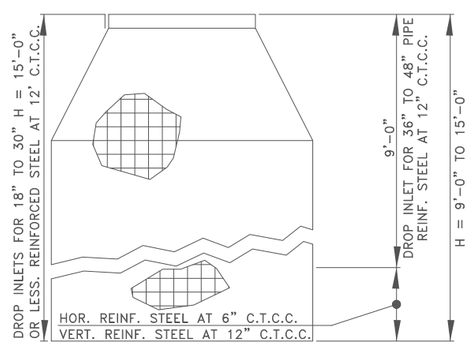
CAN BE BRICK OR PRECAST BOX.



SECTION A-A



SECTION B-B

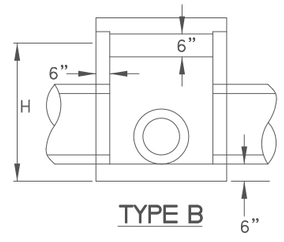


IN ALL DROP INLETS 1/2" Ø BAR REINFORCING STEEL TO BE PLACED NOT MORE THAN 12" C TO C AND COVERED NOT LESS THAN 2".

TYPE A

NOTES:

1. BRICK INVERTS REQUIRED AT ALL JUNCTION BOXES & DROP INLETS RAISE BOTTOM OF BOX TO OUTFLOW PIPE INVERT. MATCH DIFFERENT SIZE PIPES AT CROWNS.
2. MAXIMUM VERTICAL DEPTH FOR DROP INLET H = 15'-0"



TYPE B

1/2" Ø BARS AT 12" CENTER TO CENTER

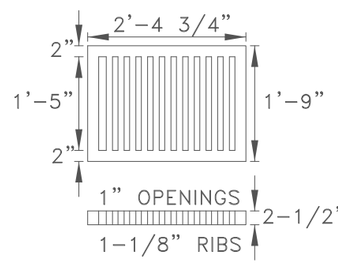
TYPE A							TYPE B		
D	W1	MIN.–W2	W3	a	b	MIN.–H	NORMAL W OR W1	MIN. b	MIN. H
15"	2'–0"	2'–6 1/2"	2'–7"	0'–3 1/2"	0'–6"	3'–3"	2'–0"	2'–7 1/2"	3'–9 1/2"
18"	2'–0"	2'–9 1/2"	2'–7"	0'–3 1/2"	0'–6"	3'–6"	2'–3"	2'–10"	4'–0"
24"	2'–6"	4'–1/2"	3'–3"	0'–7 1/2"	1'–1"	4'–9"	3'–0"	3'–6"	4'–10"
30"	3'–4"	5'–1 1/2"	3'–11"	0'–11 1/2"	1'–6"	5'–10"	3'–6 1/2"	4'–2 1/2"	5'–4 1/2"
36"	3'–10"	6'–1 1/2"	4'–5"	1'–2 1/2"	2'–1 1/4"	6'–10"	4'–2"	4'–10"	6'–0"
42"	4'–5"	7'–2 1/2"	5'–0"	1'–6"	2'–7 1/2"	7'–11"	4'–8 1/2"	5'–4 1/2"	6'–6 1/2"
48"	5'–0"	6'–3 1/2"	5'–7"	1'–9 1/2"	3'– 1 1/4"	9'–0"	5'–3 1/2"	5'–11 1/2"	7'–1 1/2"
54"	5'–7"	9'–4 1/2"	6'–2"	2'–1"	3'–7 1/4"	10'–1"	5'–10"	6'–6"	7'–6"
60"	6'–2"	10'–6 1/2"	6'–9"	2'–4 1/2"	4'–1 1/2"	11'–2"	6'–4 1/2"	7'–0 1/2"	8'–2 1/2"
66"	6'–9"	11'–6 1/2"	7'–4"	2'–6"	4'–7 1/2"	12'–3"	6'–11"	7'–7"	8'–9"
72"	7'–4"	12'–7 1/2"	7'–11"	2'–11 1/2"	5'–1 1/4"	13'–4"	7'–6 1/2"	8'–1 1/2"	9'–3"

CONCRETE D.I.

TYPE A							TYPE B		
D	W1	MIN.–W2	W3	a	b	MIN.–H	NORMAL W OR W1	MIN. b	MIN. H
15"	2'–2"	2'–11"	2'–9"	0'–4 1/2"	0'–6"	3'–9 1/2"	2'–0"	2'–7 1/2"	3'–7 1/2"
18"	2'–2"	3'–2 1/2"	2'–9"	0'–4 1/2"	0'–6"	4'–1"	2'–0"	2'–10"	3'–10"
24"	2'–8"	3'–8"	3'–3"	0'–7 1/2"	1'–1 1/4"	4'–9"	3'–0"	3'–6"	4'–6"
30"	3'–7 1/4"	4'–0"	3'–10"	1'–0"	1'–9"	5'–10"	3'–6 1/2"	4'–2 1/2"	5'–10"
36"	4'–2"	6'–0 1/2"	4'–5"	1'–4 1/2"	2'–1 1/4"	6'–11"	4'–2"	4'–10"	5'–10"
42"	4'–5"	7'–1 3/4"	5'–0"	1'–6"	2'–7 1/4"	8'–0 1/4"	4'–8 1/2"	5'–4 1/2"	6"–11 1/2"
48"	5'–0"	8'–2 3/4"	5'–7"	1'–9 1/2"	3'– 1 1/4"	9'–1 1/4"	5'–3 1/2"	5'–11 1/2"	6'–11 1/2"
54"	5'–7"	9'–4"	6'–2"	2'–1"	3'–7 1/2"	10'–2 1/2"	5'–10"	6'–6"	7'–6"
60"	6'–2"	10'–5"	6'–9"	2'–4 1/2"	4'–1 1/2"	11'–3 1/4"	6'–4 1/2"	7'–0 1/2"	8'–0 1/2"
66"	6'–9"	11'–6"	7'–4"	2'–6"	4'–7 1/2"	12'–4 1/2"	6'–11"	7'–7"	8'–7"
72"	7'–4"	12'–7"	7'–11"	2'–11 1/2"	5'–2"	13'–6 1/2"	7'–6 1/2"	8'–1 1/2"	9'–1 1/2""

BRICK D.I.

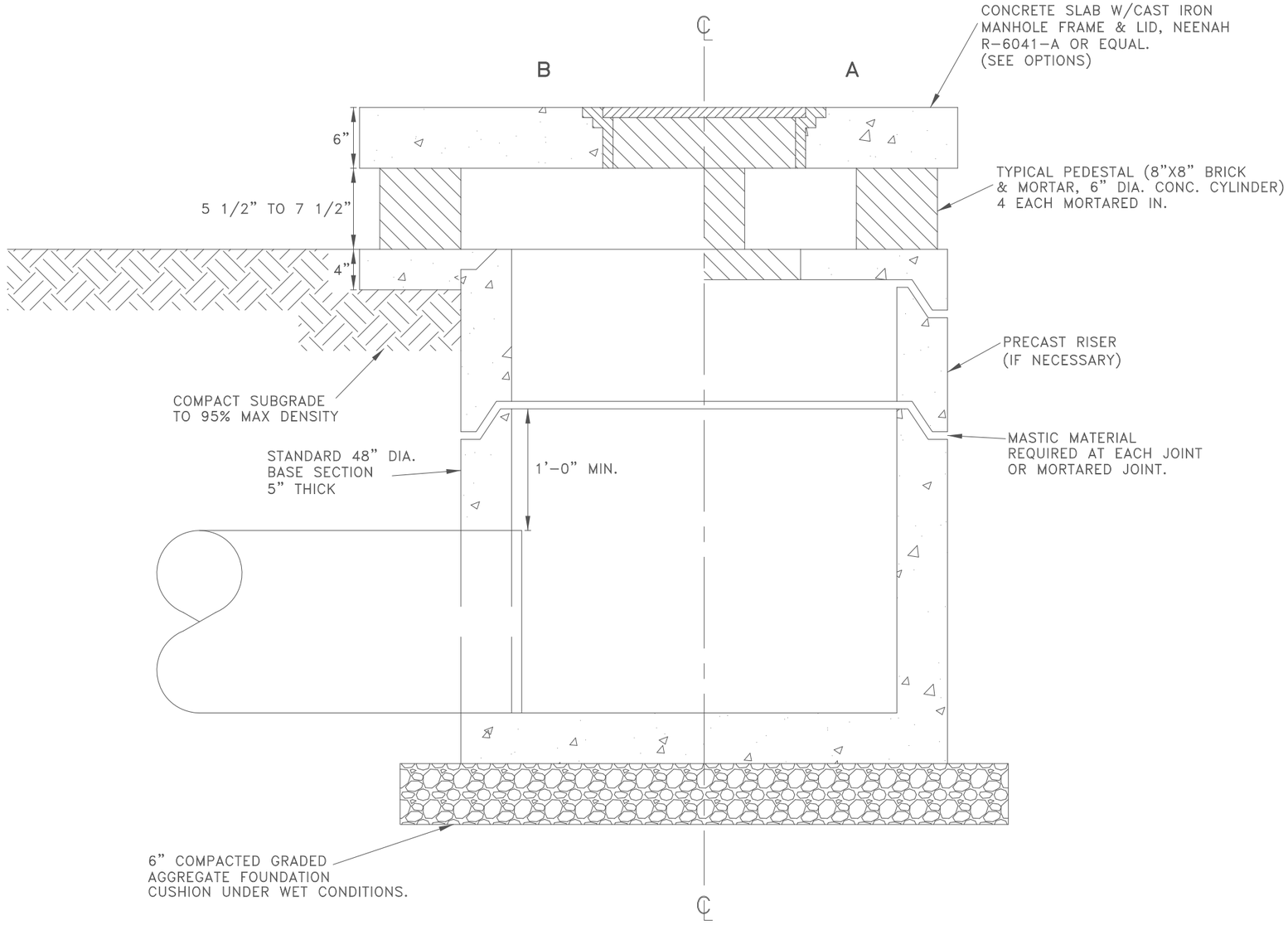
APPROX. WT. 200 LB.
DETAIL OF CAST IRON GRATING



GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD DROP INLET

DATE: JANUARY 1988 SHEET: 609
REVISED: DECEMBER 2017



SECTION

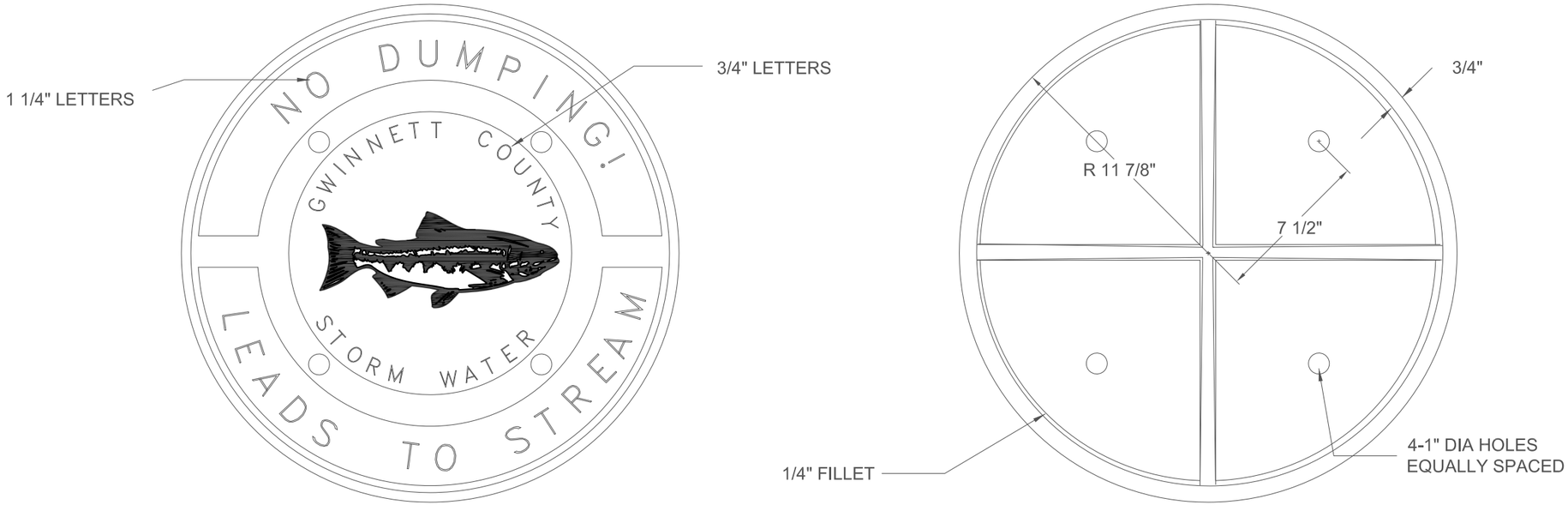
NOTES:

1. SUBGRADE TO BE COMPACTED TO 95% MAX. DRY DENSITY PER STANDARD PROCTOR.
2. REINFORCEMENT STEEL SHALL BE PLACED TO ALLOW A MIN. OF 1 1/2” COVER, EXCEPT WHERE NOTED.
3. REINFORCEMENT STEEL SHALL BE OF INTERMEDIATE GRADE AND SHALL CONSIST OF NO. 4 @ 6” O.C. E.W.
4. ALL CONCRETE SHALL BE CLASS AA1 4500 PSI.
5. WHEN 60” & 72” BASE SECTIONS ARE REQUIRED, AN ADAPTER SECTION SHALL BE USED IN CONJUNCTION WITH THE STANDARD CONE.
6. CONCRETE TOP COVER THICKNESS: 8” – VEHICULAR TRAFFIC AREAS.

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

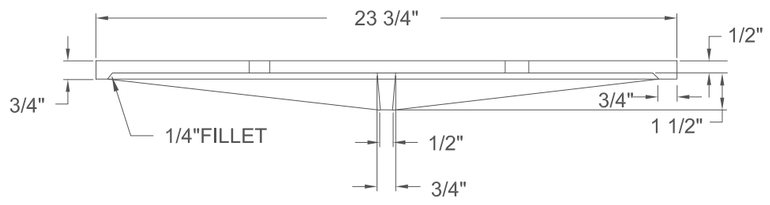
STANDARD ROUND PRECAST DROP INLET

DATE: JANUARY 1988 SHEET: 610
REVISED: DECEMBER 2017



TOP VIEW

BOTTOM VIEW



COVER SECTION

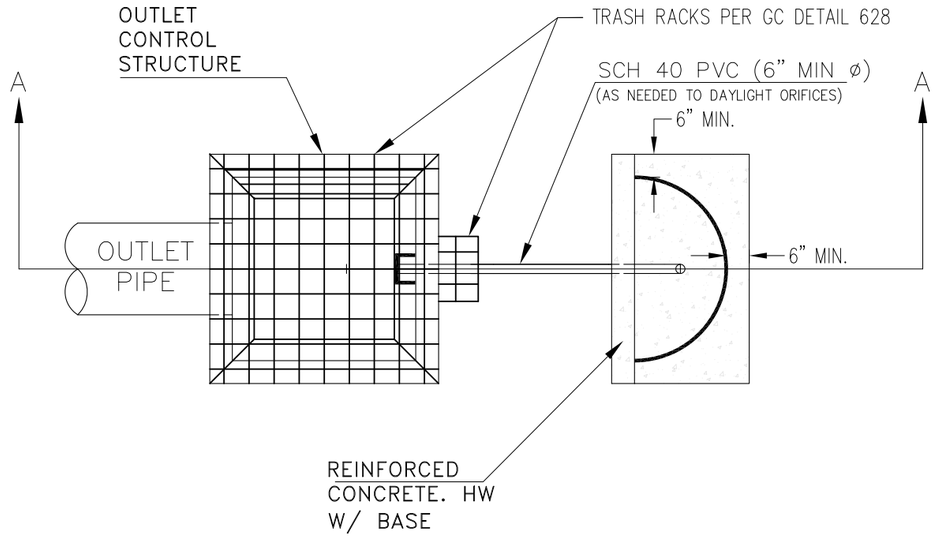
NOTES:

- Approximate Weight: C.I. Cover 63 lbs.
- Load Rating: Non-Traffic
- Engraving Depth Max.: 3/16"

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

MANHOLE CASTINGS – NON TRAFFIC AREAS

DATE: NOVEMBER 2000 SHEET: 611
REVISED: DECEMBER 2017



PLAN VIEW

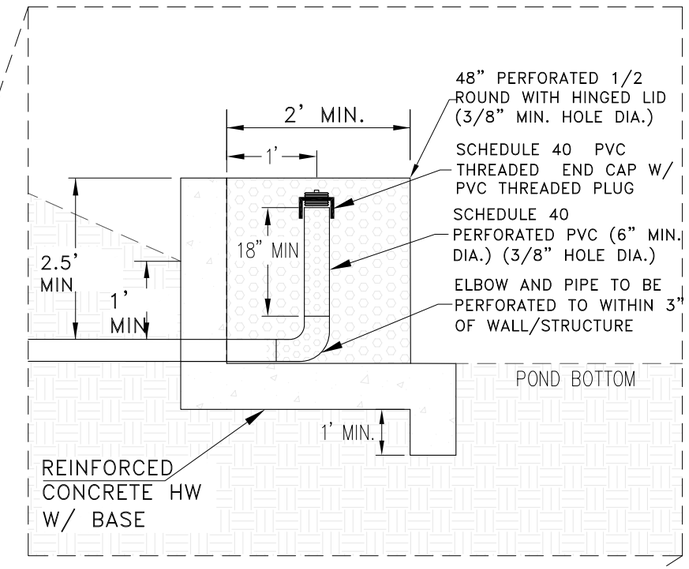
NOTES:

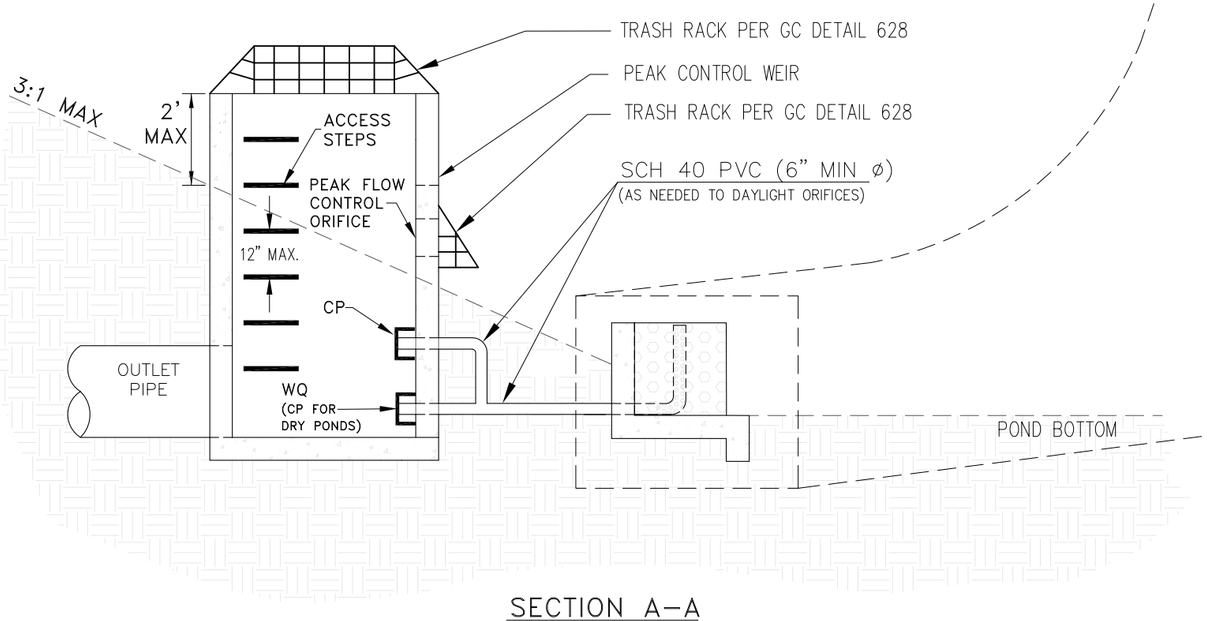
1.) REFER TO GC STD DETAIL 629 FOR ORIFICE END CAP DETAILS.

2.) WEIR CONFIGURATION SHOWN FOR CONCEPTUAL PURPOSES ONLY.

3.) PERFORATED HALF–ROUND CAN BE MOVED TO OCS IF GRADES ALLOW.

4.) HALF–ROUND TO BE ALUMINIZED TYPE 2 STEEL PIPE.





SECTION A–A

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

OUTLET CONTROL DETAIL
DRY & EXTENDED DRY DETENTION PONDS

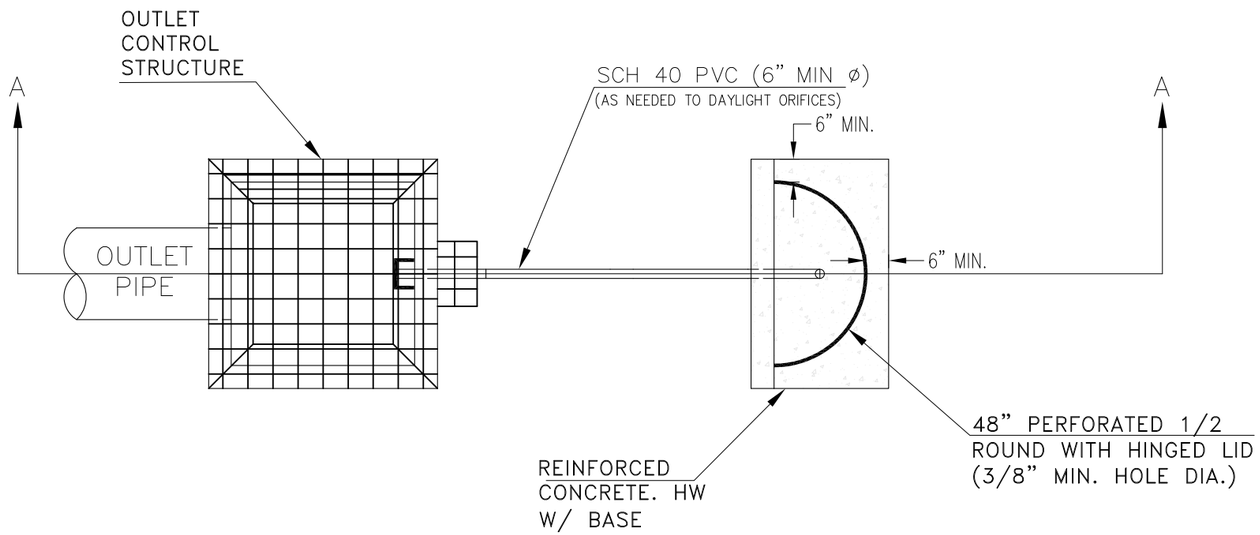
DATE: NOVEMBER 2002 SHEET: 612
REVISED: DECEMBER 2017

NOTES:
1.) REFER TO GC STD DETAIL 629 FOR ORIFICE END CAP DETAILS.

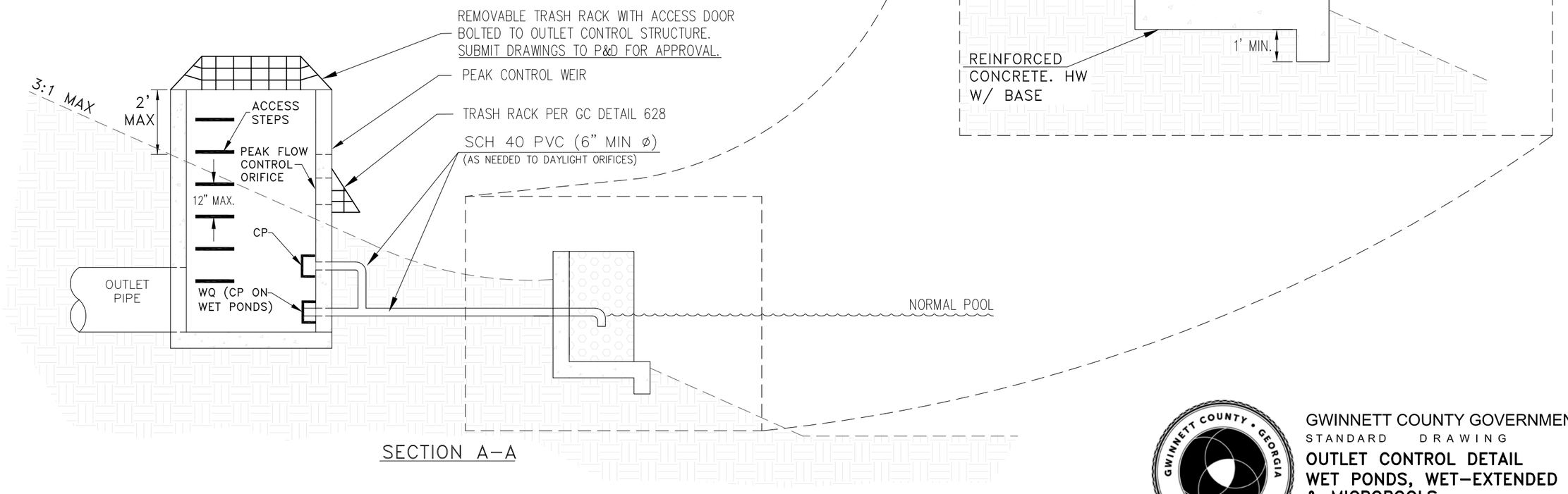
2.) WEIR CONFIGURATION SHOWN FOR CONCEPTUAL PURPOSES ONLY.

3.) PERFORATED HALF-ROUND CAN BE MOVED TO OCS IF GRADES ALLOW.

4.) HALF-ROUND TO BE ALUMINIZED TYPE 2 STEEL PIPE.



PLAN VIEW



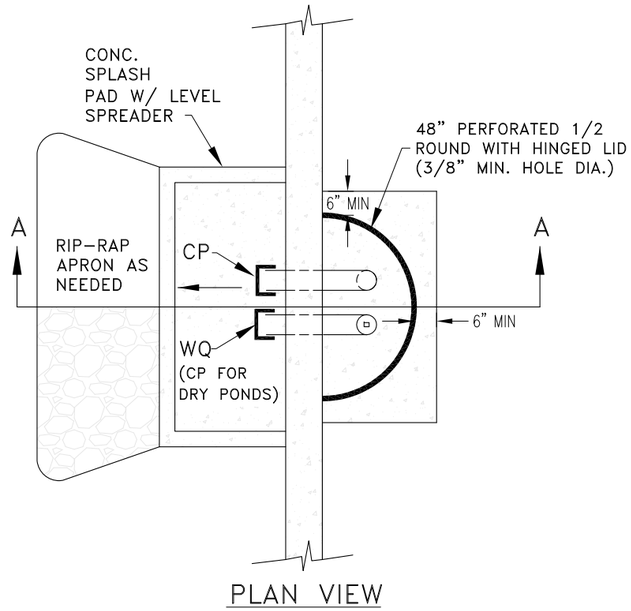
SECTION A-A

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

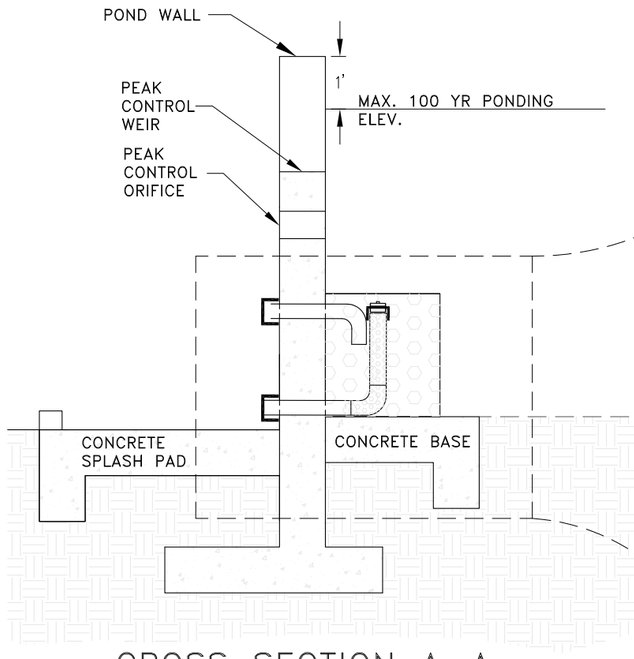
OUTLET CONTROL DETAIL WET PONDS, WET-EXTENDED PONDS & MICROPOOLS

DATE: NOVEMBER 2002 SHEET: 614
REVISED: DECEMBER 2017

DRY & DRY -EXTENDED PONDS

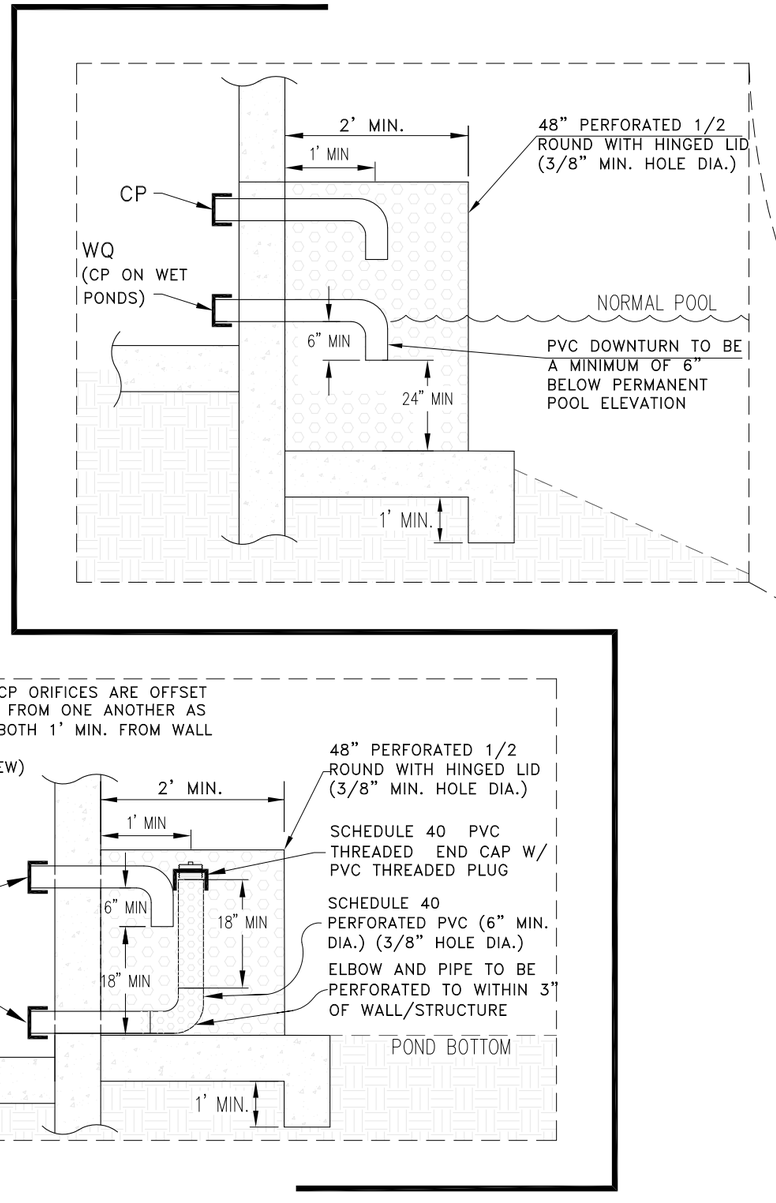


PLAN VIEW

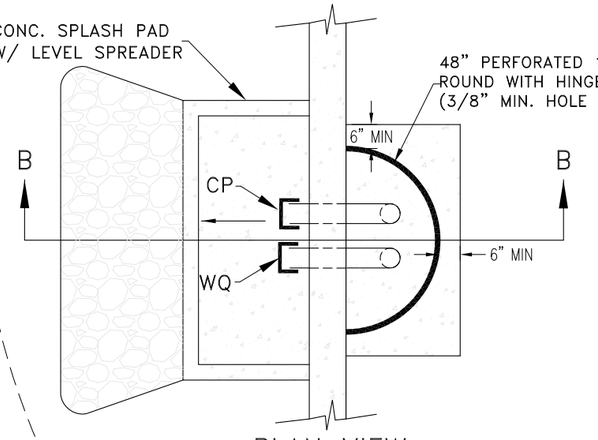


CROSS SECTION A-A

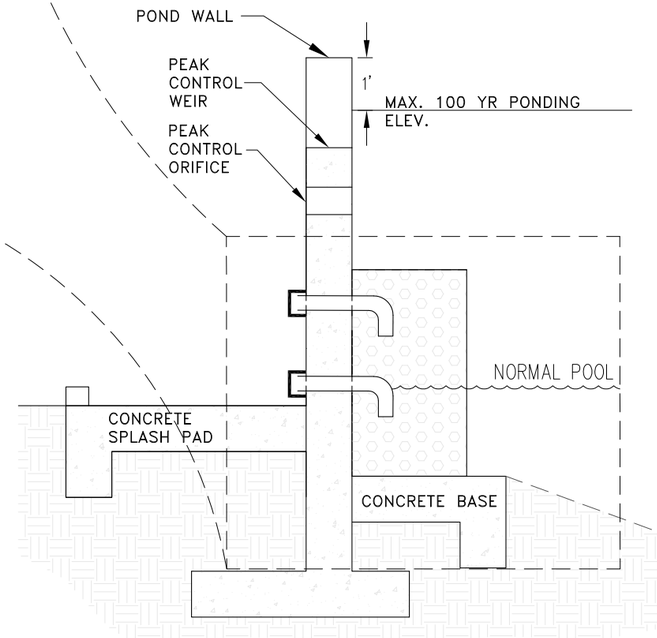
NOTES:
1.) REFER TO GC STD DETAIL 629 FOR ORIFICE END CAP DETAILS.
2.) WEIR CONFIGURATION SHOWN FOR CONCEPTUAL PURPOSES ONLY.
3.) HALF-ROUND TO BE ALUMINIZED TYPE 2 STEEL PIPE.



WET PONDS, WET-EXTENDED PONDS & MICROPOOLS



PLAN VIEW

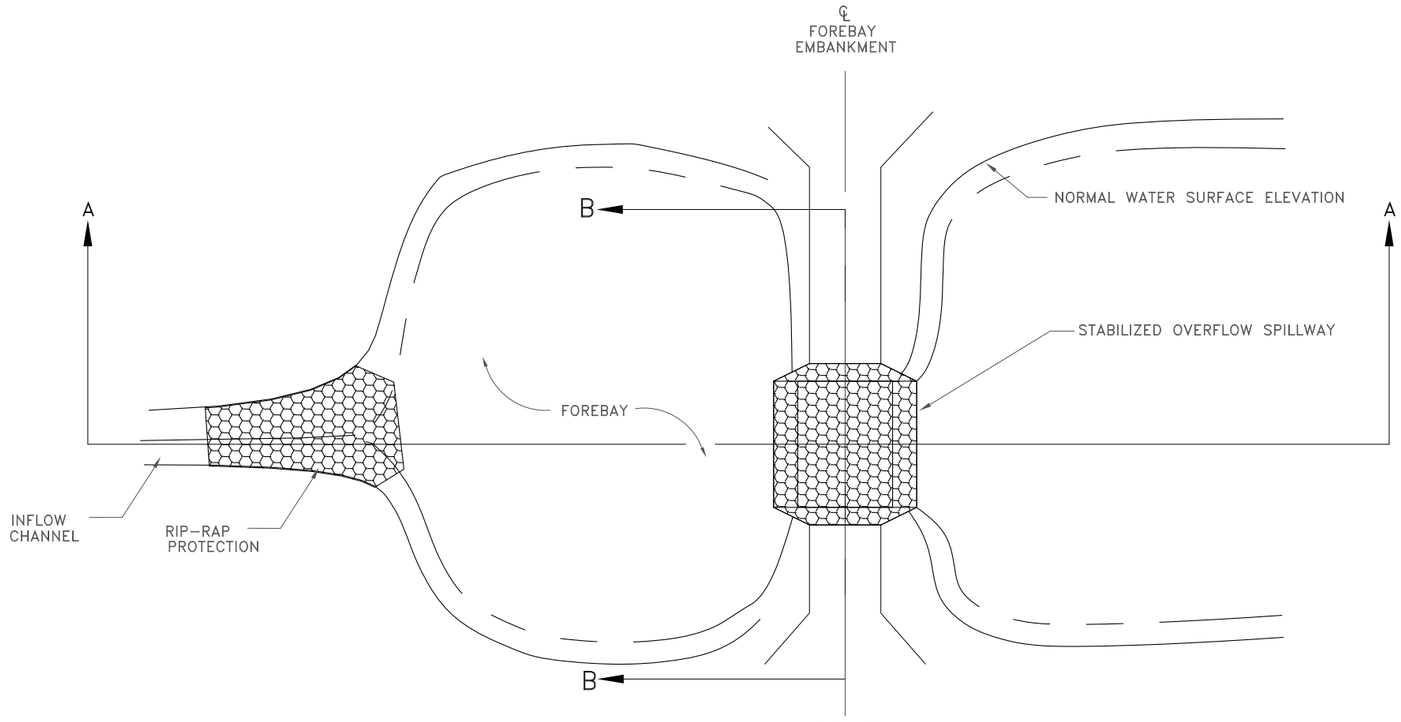


CROSS SECTION B-B

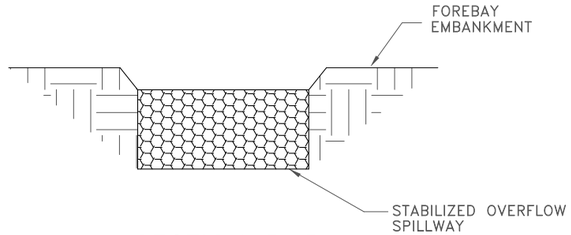
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

WALL OUTLET CONTROL STRUCTURE DETAIL

DATE: NOVEMBER 2002 SHEET: 618
REVISED: DECEMBER 2017



PLAN

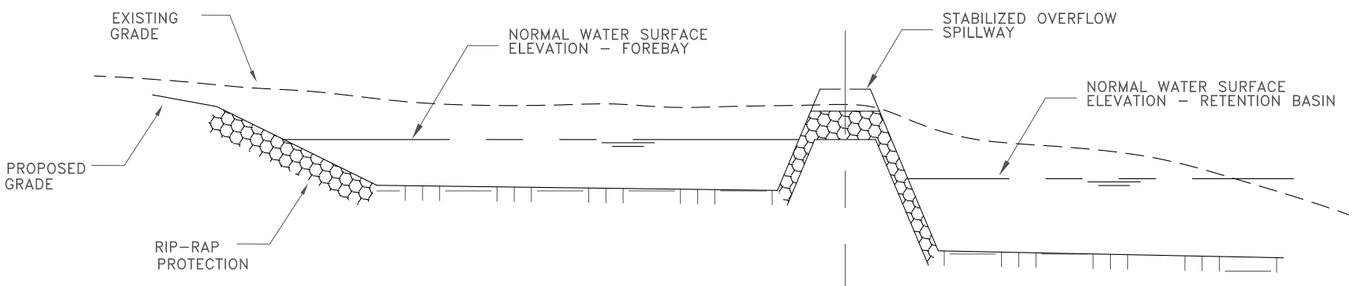


SECTION B–B

NOTES:

1.) STABILIZED OVERFLOW SPILLWAY SHOWN AS RIPRAP. CONCRETE, GABION BASKETS, OR OTHER TYPES OF ARMOR MAY BE USED.

2.) IF PIPE USED INSTEAD OF IN–FLOW CHANNEL, PIPE INVERT SHALL DISCHARGE ABOVE NORMAL POOL.

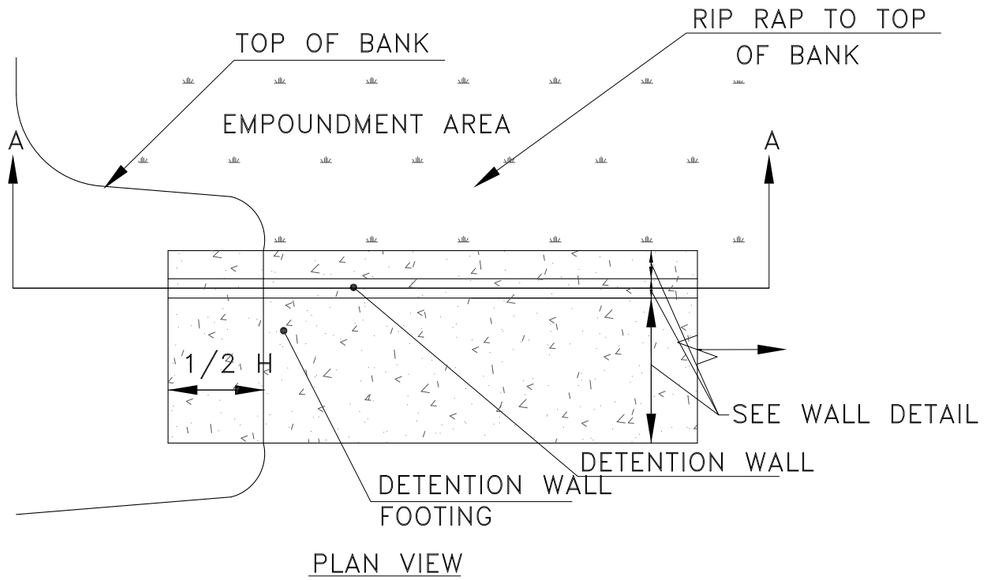


SECTION A–A

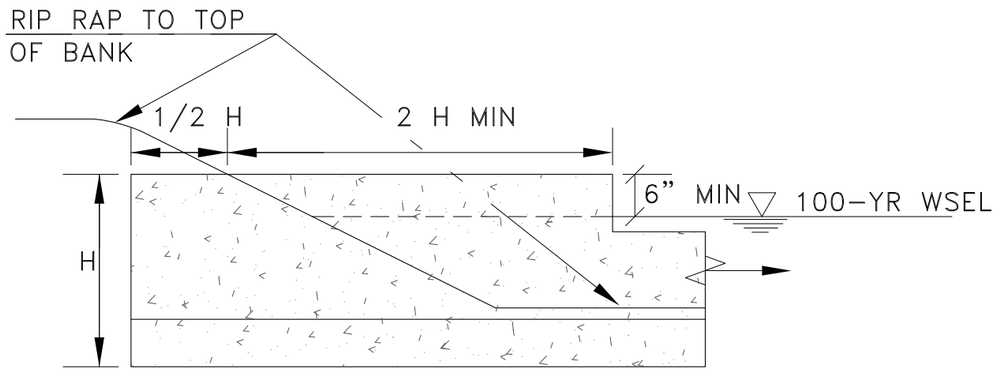
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

FOREBAY

DATE: AUGUST 2002 SHEET: 625
REVISED: DECEMBER 2017



PLAN VIEW

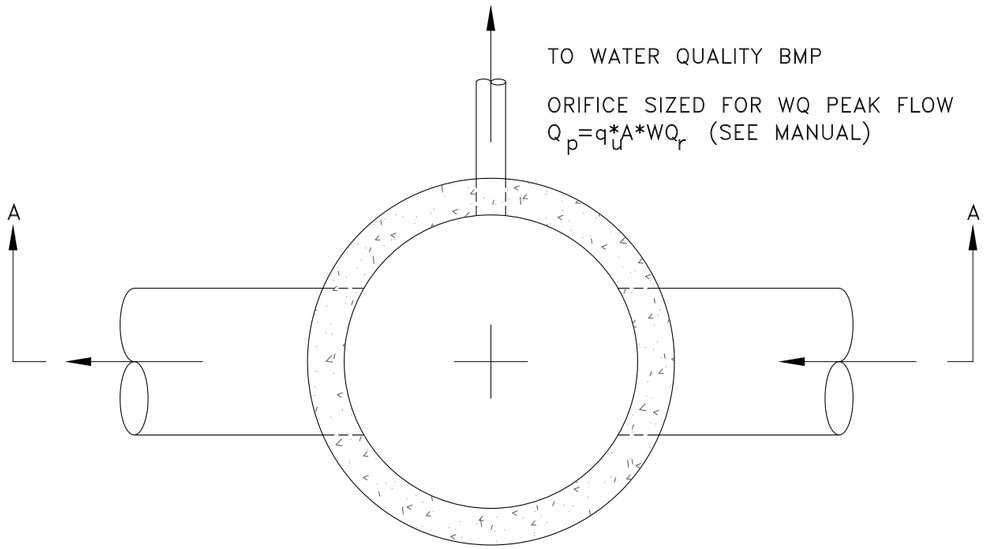


SIDE VIEW
SECTION A–A

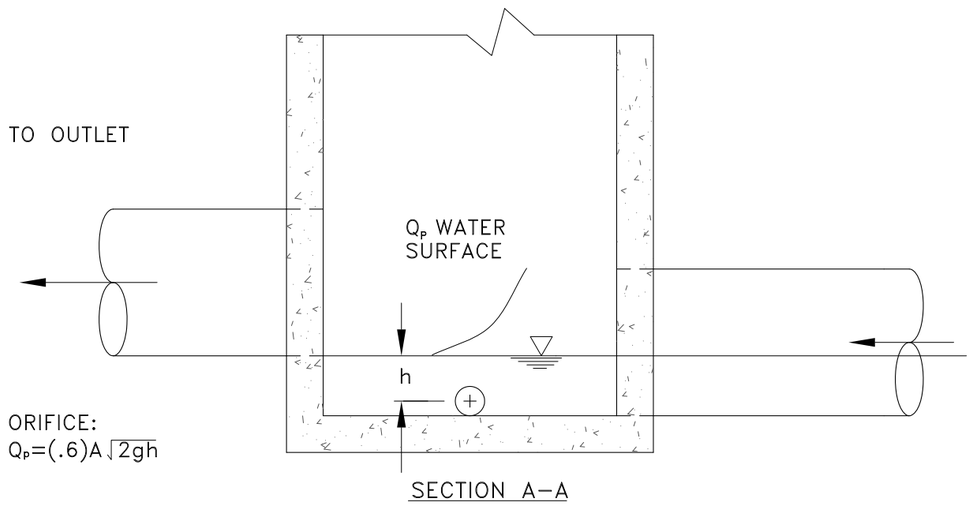
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

TYPICAL DETENTION POND WALL TIE IN

DATE: FEBRUARY 2002 SHEET: 626
REVISED: DECEMBER 2017



PLAN VIEW

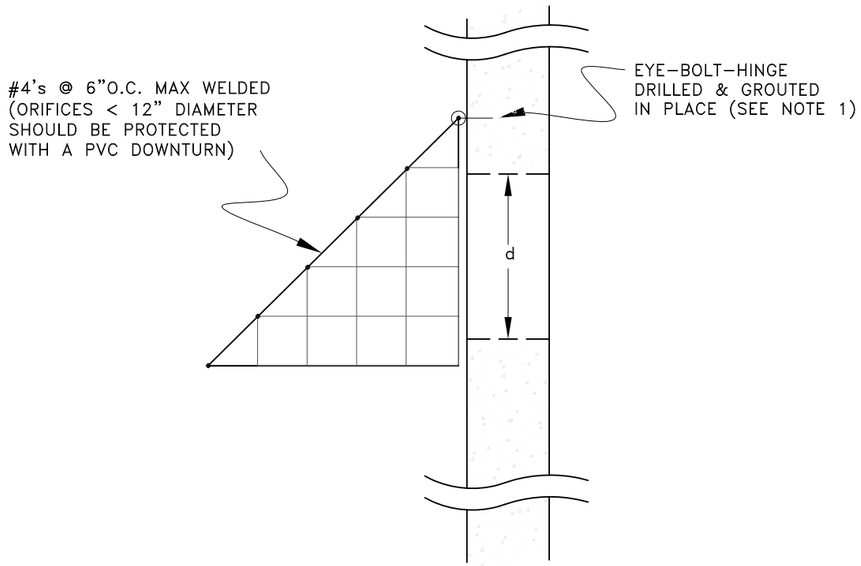


SECTION A–A

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

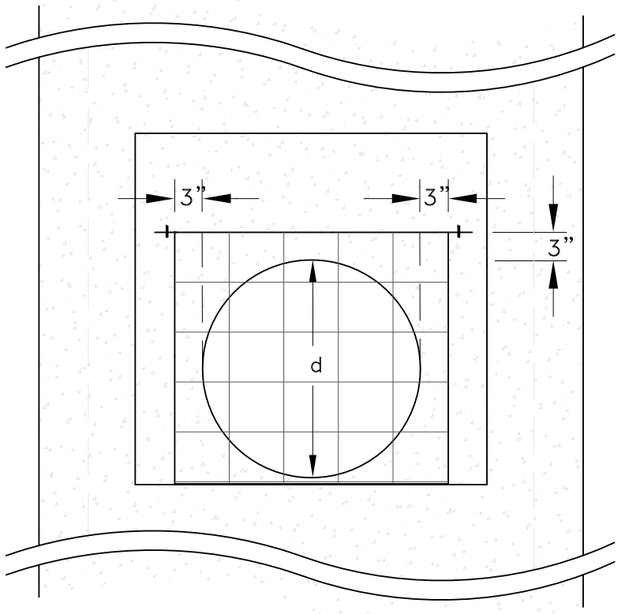
FLOWSPLITTER – MANHOLE

DATE: FEBRUARY 2002 SHEET: 627
REVISED: DECEMBER 2017

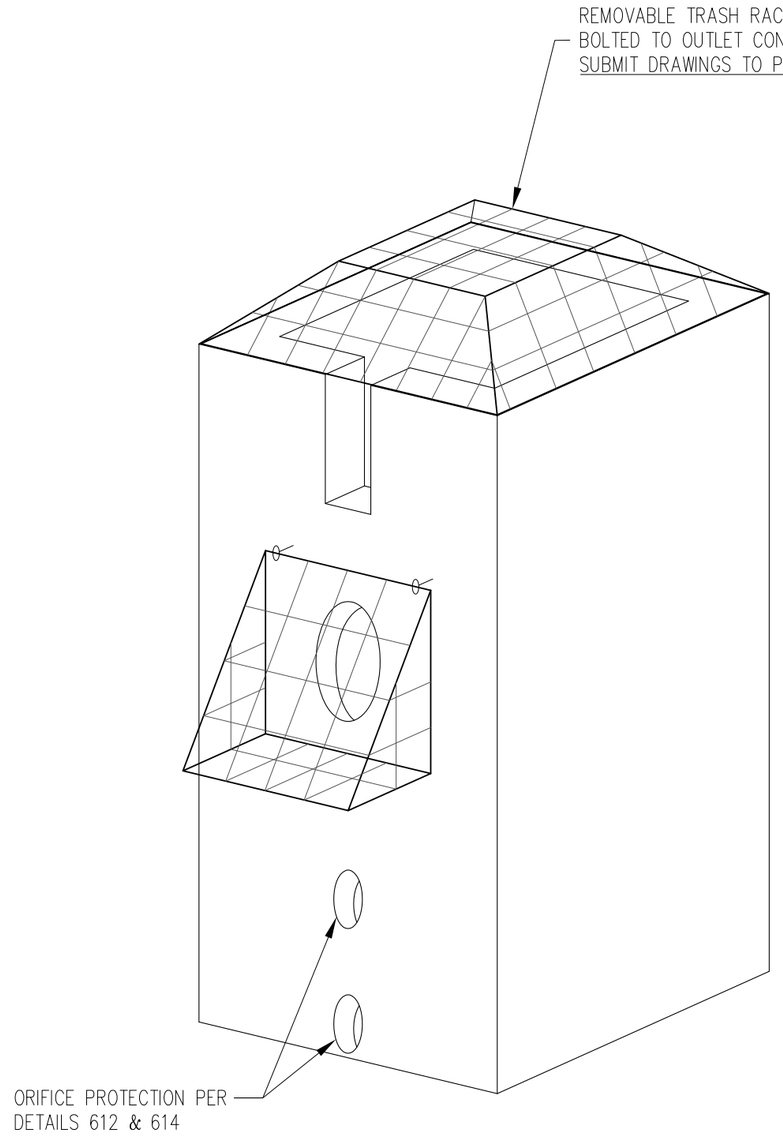


SIDE VIEW

NOTES:
1.) 3/4" ANCHORED BOLTS (EMBEDDED 3")



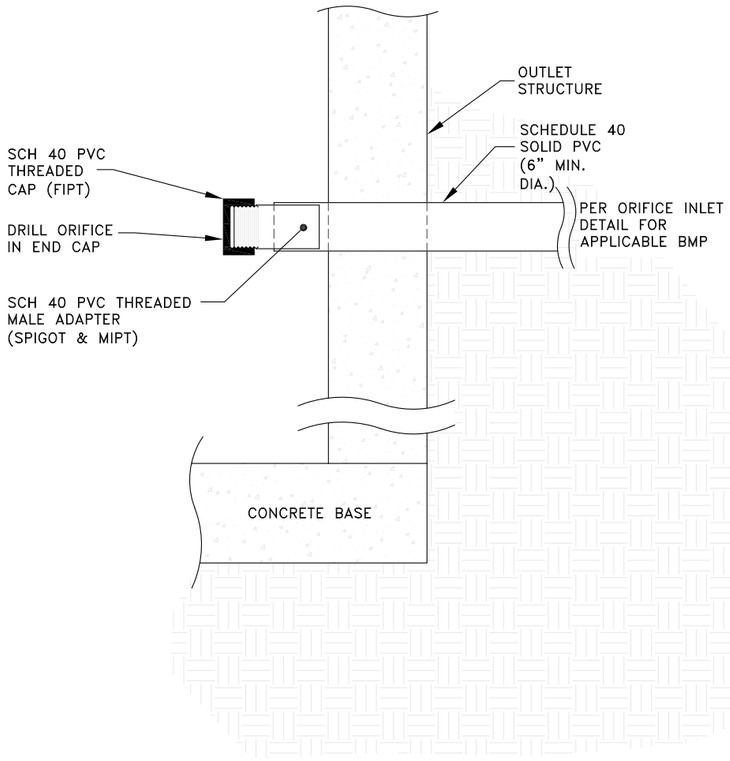
FRONT VIEW



GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

TRASHRACKS FOR OUTLET CONTROL STRUCTURES

DATE: NOVEMBER 2002 SHEET: 628
REVISED: NOVEMBER 2004
REVISED: DECEMBER 2017



NOTES:

1.) FILL GAP BETWEEN STRUCTURE & PVC WITH MORTAR OR INSTALL A FERNCO ADAPTER.

2.) SIZE ORIFICE PER APPROVED PLANS.

3.) PIPE SIZE SHALL BE SPECIFIED PER TABLE BELOW.

OUTLET ORIFICE DIAMETER	PIPE SIZE
<3"	6"
3" TO <5"	8"
5" TO <8"	12"
8" TO <12	16"

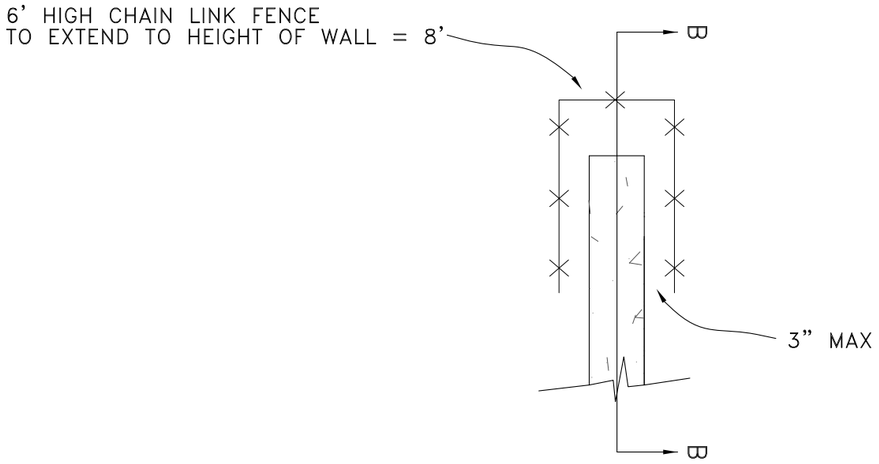
4.) VARIATIONS TO THIS DETAIL MAY BE ACCEPTABLE ON A CASE BY CASE BASIS. MODIFICATIONS SHALL BE SUBJECT TO REVIEW AND APPROVAL BY GWINNETT COUNTY PLANNING AND DEVELOPMENT.

5.) ALL PVC TO BE SCHEDULE 40.

6.) ALL NON-THREADED PVC TO PVC CONNECTIONS TO BE BONDED WITH PVC CEMENT.

7.) MONOLITHIC WALLS SHALL HAVE ORIFICES ON DOWNSTREAM FACE AND BE FULLY ACCESSIBLE FROM POND EXTERIOR.

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING
ORFICE END-CAP DETAIL
DATE: NOVEMBER 2002 SHEET: 629
REVISED: DECEMBER 2004
REVISED: MARCH 2005
REVISED: MAY 2005
REVISED: JUNE 2006
REVISED: DECEMBER 2017



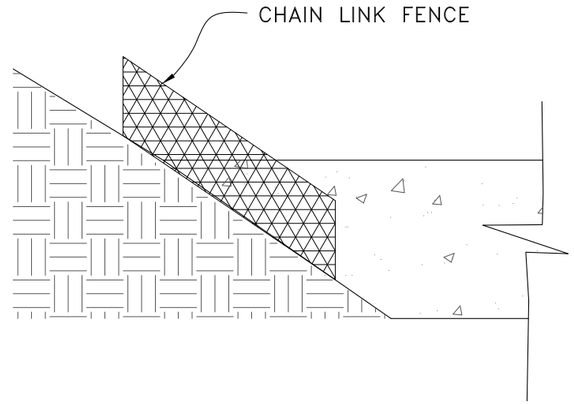
PLAN VIEW

NOTES:

1.) FENCE POST SHALL BE SET IN CONCRETE

2.) MINIMUM GAUGE OF WIRE SHALL BE 12.

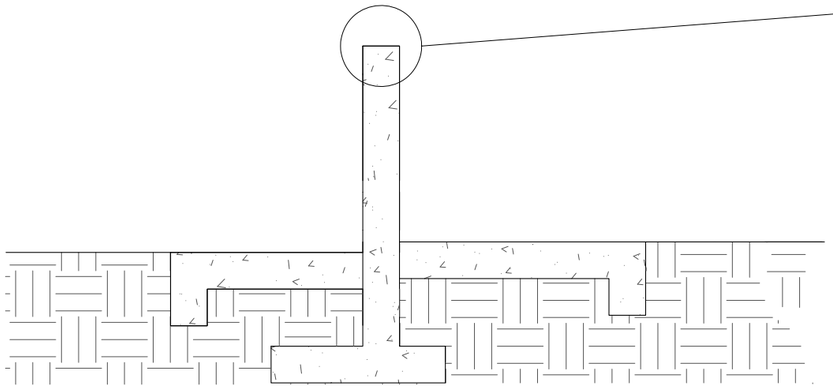
3.) FOR DETENTION POND WALLS GREATER THAN 4’, SOME METHOD TO DISCOURAGE ACCESS TO THE TOP OF THE WALL SHALL BE PROVIDED. ONE OF THE THREE OPTIONS PRESENTED OR OTHER COUNTY ACCEPTED METHOD MAY BE USED.



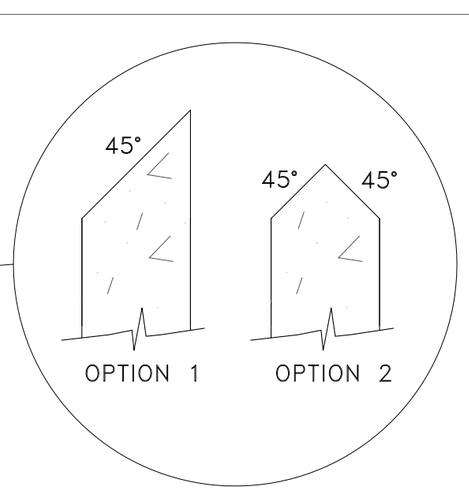
CROSS SECTION B–B

NOTES:

1.) OPTION #2 SHALL HAVE A METAL ANGLE



CROSS SECTION



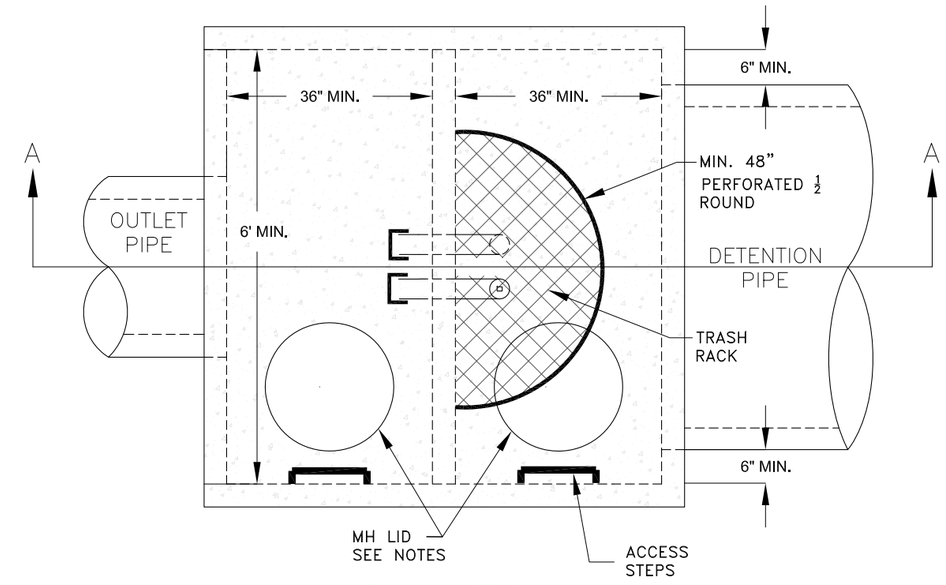
GWINNETT COUNTY GOVERNMENT

STANDARD DRAWING

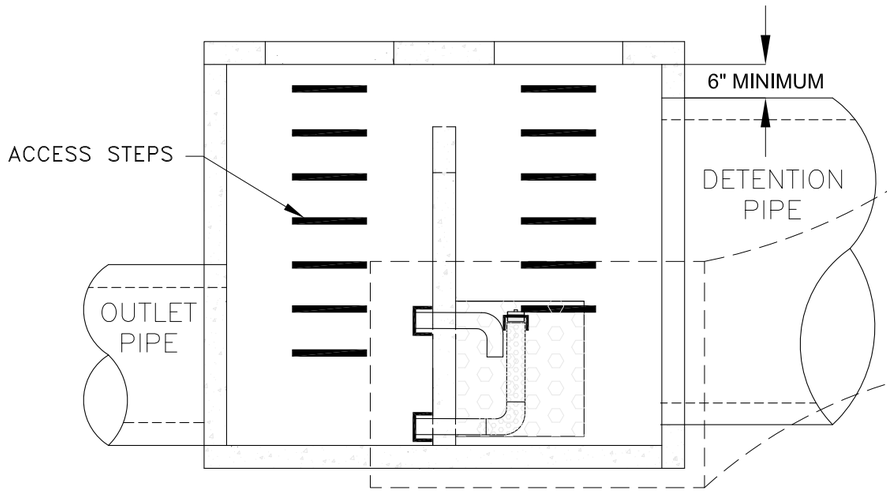
RETAINING WALL SAFETY TREATMENTS DETAIL FOR DETENTION PONDS GREATER THAN 4’

DATE: JUNE 2005 SHEET: 630

REVISED: DECEMBER 2017



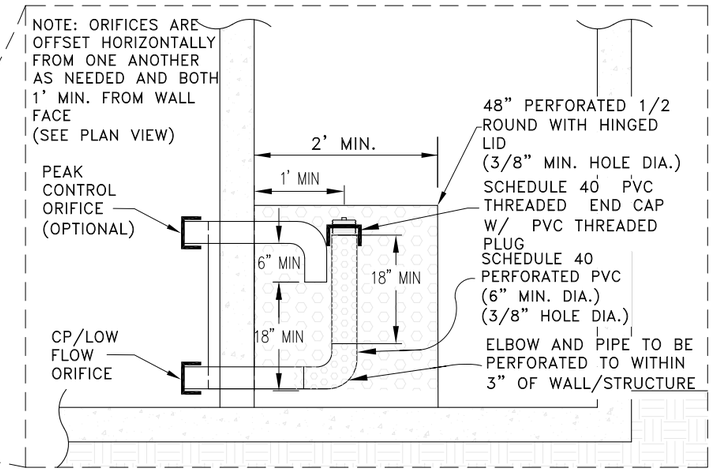
PLAN VIEW



SECTION A–A

NOTES:

1.) WEIR CONFIGURATION SHOWN FOR CONCEPTUAL PURPOSES ONLY.
2.) TRASH RACK TO BE 1" EXPANDED METAL DIAMOND MESH.
3.) REFER TO GC STD. DRAWING 629 FOR ORIFICE END–CAP DETAILS.
4.) REFER TO GC STD. DRAWING 611 FOR MANHOLE LID.
5.) IF OCS IS LOCATED IN AREA ACCESSIBLE TO VEHICULAR TRAFFIC, MANHOLE LID & STRUCTURES TO BE TRAFFIC RATED.
6.) ALL CONCRETE TO BE 6" MIN. THICKNESS
7.) OCS MANHOLE SHALL BE OFFSET TO PROVIDE DIRECT ACCESS TO STRUCTURE ACCESS STEPS.
8.) TWO MANHOLES ARE TO BE PROVIDED SO THAT BOTH SIDES OF THE WEIR WALL CAN BE EASILY OBSERVED/ACCESSED.



GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

OUTLET CONTROL STRUCTURE FOR UNDERGROUND DETENTION FACILITY

DATE: MAY 2008 SHEET: 631
REVISED: DECEMBER 2017

ROUND PIPE - 2-2/3" X 1/2" CORRUGATION

D (IN)	AREA (SQ. FT.)	MAXIMUM HEIGHT OF COVER (FT.) SHEET THICKNESS IN INCHES (GAGE) 0.064 (16)	0.079 (14)	0.109 (12)	0.138 (10)	0.168 (8)	MIN. HEIGHT OF COVER (FT.)
12	.79	100+	100+	NA	NA	NA	
15	1.23	100+	100+	NA	NA	NA	
18	1.77	100+	100+	100+	NA	NA	
21	2.40	100+	100+	100+	NA	NA	
24	3.14	100+	100+	100+	NA	NA	SEE
30	4.91	85	100+	100+	NA	NA	DWG
36	7.1	71+	88	100+	100+	NA	703
42	9.6	NS	76	100+	100+	NA	
48	12.6	NS	66	93	100+	100+*	
54	16.0	NS	NS	82	100+	100+*	
60	19.6	NS	NS	74	95	100+*	
66	23.8	NS	NS	NS	87	100+*	
72	28.3	NS	NS	NS	79	97*	
78	33.2	NS	NS	NS	NS	90*	
84	38.5	NS	NS	NS	NS	83*	

ROUND PIPE - 3" X 1" CORRUGATION

D (IN)	AREA (SQ. FT.)	MAXIMUM HEIGHT OF COVER (FT.) SHEET THICKNESS IN INCHES (GAGE) 0.064 (16)	0.079 (14)	0.109 (12)	0.138 (10)	0.168 (8)	MIN. HEIGHT OF COVER (FT.)
36	7.1	81	100+	100+	NA	NA	
42	9.6	70	87	100+	NA	NA	
48	12.6	61	76	100+	100+	NA	
54	16.0	54	68	95	100+	NA	
60	19.6	48	61	85	100+	NA	SEE
66	23.8	44	55	78	100+	100+*	DWG
72	28.3	NS	51	71	91	100+*	703
78	33.2	NS	47	66	84	100+*	
84	38.5	NS	43	61	78	100+*	
90	44.2	NS	40	57	73	90*	
96	50.3	NS	NS	53	68	84*	
102	56.7	NS	NS	50	64	79*	
108	63.6	NS	NS	47	61	75*	
114	70.9	NS	NS	NS	58	71*	
120	78.5	NS	NS	NS	55	67*	
132	95.0	NS	NS	NS	50	61*	

ROUND PIPE - 5" X 1" CORRUGATION

D (IN)	AREA (SQ. FT.)	MAXIMUM HEIGHT OF COVER (FT.) SHEET THICKNESS IN INCHES (GAGE) 0.064 (16)	0.079 (14)	0.109 (12)	0.138 (10)	0.168 (8)	MIN. HEIGHT OF COVER (FT.)
36	7.1	72	90	100+	NA	NA	
42	9.6	62	77	100+	NA	NA	
48	12.6	54	68	95	100+	NA	
54	16.0	48	60	84	100+	NA	
60	19.6	43	54	76	98	NA	SEE
66	23.8	39	49	69	89	100+*	DWG
72	28.3	NS	45	63	81	100+*	703
78	33.2	NS	41	58	75	92*	
84	38.5	NS	38	54	70	85*	
90	44.2	NS	36	50	65	80*	
96	50.3	NS	NS	47	61	75*	
102	56.7	NS	NS	44	57	70*	
108	63.6	NS	NS	42	54	66*	
114	70.9	NS	NS	NS	51	63*	
120	78.5	NS	NS	NS	49	60*	
132	95.0	NS	NS	NS	44	54*	

PIPE ARCH - 2-2/3" X 1/2" CORRUGATION

SPAN (IN)	RISE (IN)	EQUIV. ROUND PIPE (IN)	AREA (SQ. FT.)	MINIMUM SHEET THICKNESS REQUIRED (IN) (GA)	MAXIMUM HEIGHT OF COVER (FT) MAXIMUM CORNER PRESSURE-LBS/SQ.FT 4000	6000	MIN. HEIGHT OF COVER (FT.)
17	13	15	1.1	.064 (16)	12	14	
21	15	18	1.6	.064 (16)	10	14	
24	18	21	2.2	.064 (16)	7	13	
28	20	24	2.9	.064 (16)	5	11	
35	24	30	4.5	.064 (16)	NS	7	SEE
42	29	36	6.5	.079 (14)	NS	7	DWG
49	33	42	8.9	.079 (14)	NS	6	703
57	38	48	11.6	.109 (12)	NS	8	
64	43	54	14.7	.109 (12)	NS	9	
71	47	60	18.1	.138 (10)	NS	10	
77	52	66	21.9	.168 (8)*	5	10	
83	57	72	26.0	.168 (8)*	5	10	

PIPE ARCH - 3" X1" AND 5" X 1" CORRUGATION

SPAN (IN)	RISE (IN)	EQUIV. ROUND PIPE (IN)	AREA (SQ. FT.)	MINIMUM SHEET THICKNESS REQUIRED (IN) (GA)	MAXIMUM HEIGHT OF COVER (FT) MAXIMUM CORNER PRESSURE-LBS/SQ.FT 4000	6000	MIN. HEIGHT OF COVER (FT.)
40	31	36	7.0	.079 (14)	8	12	
46	36	42	9.4	.079 (14)	8	13	
53	41	48	12.3	.079 (14)	8	13	
60	46	54	15.6	.079 (14)	8	13	
66	51	60	19.3	.079 (14)	9	13	SEE
73	55	66	23.2	.079 (14)	11	16	DWG
81	59	72	27.4	.079 (14)	11	17	703
87	63	78	32.1	.109 (12)	10	16	
95	67	84	37.0	.109 (12)	11	17	
103	71	90	42.4	.109 (12)	10	15	
112	75	96	48.0	.109 (12)	10	16	
117	79	102	54.2	.109 (12)	10	15	
128	83	108	60.5	.138 (10)	9	14	
137	87	114	67.4	.138 (10)	8	13	
142	91	120	74.5	.168 (8)*	7	12	

* AVAILABILITY SHOULD BE QUALIFIED BEFORE SPECIFYING

NA – NOT AVAILABLE

NS – NOT APPROVED (FOR HIGHWAY H-20 LOADINGS)

GWINNETT COUNTY GOVERNMENT

STANDARD DRAWING

STANDARD PIPE CULVERTS – DETAIL NO. 1

DATE: JANUARY 1988 SHEET: 701
REVISED: DECEMBER 2017

ROUND PIPE - 2-2/3" X 1/2" CORRUGATION

D (IN)	AREA (SQ. FT.)	MAXIMUM HEIGHT OF COVER (FT.) SHEET THICKNESS IN INCHES (GAGE) 0.060 (16)	0.075 (14)	0.105 (12)	0.135 (10)	0.164 (8)	MIN. HEIGHT OF COVER (FT.)
12	0.8	90	100+	NA	NA	NA	
15	1.2	72	90	NA	NA	NA	
18	1.8	59	75	100+	NA	NA	
21	2.4	52	65	92	NA	NA	
24	3.1	44	56	79	NA	NA	SEE
30	4.9	NS	44	63	NA	NA	DWG
36	7.1	NS	NS	52	68	NA	703
42	9.6	NS	NS	NS	58	NA	
48	12.6	NS	NS	NS	NS	61	
54	15.9	NS	NS	NS	NS	NS	
60	19.6	NS	NS	NS	NS	NS	
66	23.8	NS	NS	NS	NS	NS	
72	28.3	NS	NS	NS	NS	NS	

ROUND PIPE - 3" X 1" CORRUGATION

D (IN)	AREA (SQ. FT.)	MAXIMUM HEIGHT OF COVER (FT.) SHEET THICKNESS IN INCHES (GAGE) 0.060 (16)	0.075 (14)	0.105 (12)	0.135 (10)	0.164 (8)	MIN. HEIGHT OF COVER (FT.)
36	7.1	33	42	60	NA	NA	
42	9.6	28	36	51	NA	NA	
48	12.6	24	31	45	58	NA	
54	15.9	NS	28	39	51	NA	
60	19.6	NS	24	35	46	NA	SEE
66	23.8	NS	NS	32	42	51	DWG
72	28.3	NS	NS	29	38	47	703
78	33.2	NS	NS	NS	35	43	
84	38.5	NS	NS	NS	32	40	
90	44.2	NS	NS	NS	30	37	
96	50.3	NS	NS	NS	NS	34	
102	56.7	NS	NS	NS	NS	32	
108	63.6	NS	NS	NS	NS	NS	
114	70.9	NS	NS	NS	NS	NS	
120	78.5	NS	NS	NS	NS	NS	

PIPE ARCH - 2-2/3" X 1/2" CORRUGATION

SPAN (IN)	RISE (IN)	EQUIV. ROUND PIPE (IN)	AREA (SQ. FT.)	MINIMUM SHEET THICKNESS REQUIRED (IN) (GA)	MAXIMUM HEIGHT OF COVER (FT) MAXIMUM CORNER PRESSURE-LBS/SQ.FT 4000	6000	MIN. HEIGHT OF COVER (FT.)
17	13	15	1.1	.060 (16)	12	15	
21	15	18	1.6	.060 (16)	10	14	
24	18	21	2.2	.060 (16)	7	13	
28	20	24	2.9	.075 (14)	5	11	
35	24	30	4.5	.105 (12)	NS	7	SEE
42	29	36	6.5	.105 (12)	NS	7	DWG
49	33	42	8.9	.135 (10)	NS	6	703
57	38	48	11.6	.164 (8)	NS	8	
64	43	54	14.7	.164 (8)	NS	9	
71	47	60	18.1	.164 (8)	NS	10	
77	52	66	21.9	.164 (8)	NS	10	
83	57	72	26.0	.164 (8)	NS	10	

PIPE ARCH - 3" X 1" AND 5" X 1" CORRUGATION

SPAN (IN)	RISE (IN)	EQUIV. ROUND PIPE (IN)	AREA (SQ. FT.)	MINIMUM SHEET THICKNESS REQUIRED (IN) (GA)	MAXIMUM HEIGHT OF COVER (FT) MAXIMUM CORNER PRESSURE-LBS/SQ.FT 4000	6000	MIN. HEIGHT OF COVER (FT.)
40	31	36	7.0	.075 (14)	8	12	
46	36	42	9.4	.075 (14)	8	13	
53	41	48	12.3	.075 (14)	8	13	
60	46	54	15.6	.075 (14)	8	13	
66	51	60	19.3	.075 (14)	8	13	SEE
73	55	66	23.2	.105 (12)	11	16	DWG
81	59	72	27.4	.105 (12)	11	17	703
87	63	78	32.1	.135 (10)	10	16	
95	67	84	37.0	.135 (10)	11	17	
103	71	90	42.4	.135 (10)	10	15	
112	75	96	48.0	.164 (8)	10	16	
117	79	102	54.2	.164 (8)	10	15	

NA – NOT AVAILABLE

LA – LIMITED AVAILABILITY

NS – NOT APPROVED (FOR HIGHWAY H-20 LOADINGS)

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD PIPE CULVERTS – DETAIL NO. 2

DATE: JANUARY 1988 SHEET: 702
REVISED: DECEMBER 2017

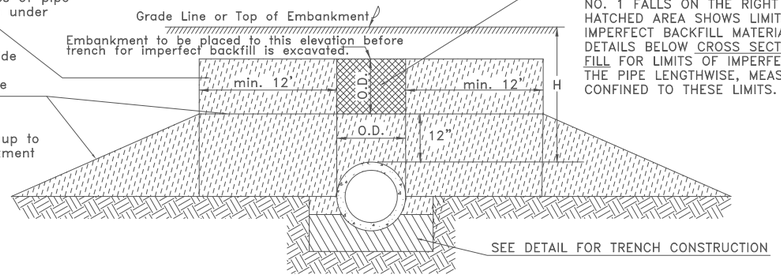
NORMAL BACKFILL

Backfill, as shown by the broken line sections, shall consist of placing compactable soil in 6"(Loose) layers and compacting each layer (according to Georgia Standard Specifications) on both sides of pipe for its full length. Measurement and payment will be made under Roadway Excavation items for formaton of embankments.

Normal embankment shall be placed a minimum of 12' wide on each side of the pipe and at least the minimum cover over the pipe and compacted to the required density before equipment is allowed to cross.

After backfill has been compacted, the balance of the fill up to grade line shall be constructed in accordance with embankment specifications.

LONGITUDINAL SECTION OF IMPERFECT TRENCH BACKFILL AND BACKFILL METHODS



IMPERFECT BACKFILL

IMPERFECT BACKFILL WILL BE USED WITH CONCRETE PIPE IF AN EXTRAPOLATION OF FILL HEIGHT AND PIPE DIAMETER IN TABLE NO. 1 FALLS ON THE RIGHT SIDE OF THE HEAVY LINE, CROSS HATCHED AREA SHOWS LIMITS OF STRUCTURE EVACUATION AND IMPERFECT BACKFILL MATERIAL TYPE III IN THIS VIEW. SEE DETAILS BELOW CROSS SECTIONS OF IMPERFECT TRENCH BACK-FILL FOR LIMITS OF IMPERFECT BACKFILL AS MEASURED OVER THE PIPE LENGTHWISE, MEASUREMENT AND PAYMENT WILL BE CONFINED TO THESE LIMITS.

TABLE NO. 1

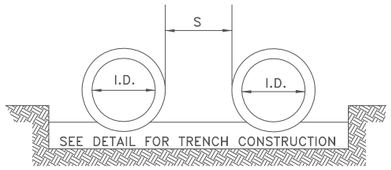
TABLE SHOWING THE MINIMUM CLASSES OF CONCRETE PIPE FOR VARIOUS HEIGHTS OF FILL ABOVE TOP OF PIPE

PIPE DIAMETER (inches)	HEIGHT OF FILL IN FEET ABOVE TOP OF PIPE											
	1–10	10–15	15–20	20–25	25–30	30–35	35–40	40–50	50–60	60–70	70–80	80–90
12	III	III	IV	V	V	IV	IV	IV	V	V	V	
15	III	III	IV	V	V	IV	IV	IV	V	V	V	
18	III	III	IV	V	V	IV	IV	IV	V	V	V	
24	III	III	IV	V	V	IV	IV	IV	V	V	V	
30	III	III	IV	V	V	IV	IV	IV	V	V	V	
36	III	III	IV	V	V	IV	IV	IV	V	V	V	
42	III	III	IV	V	V	IV	IV	IV	V	V	V	
48	III	III	IV	V	V	IV	IV	IV	V	V	V	
54	III	III	IV	V	V	IV	IV	IV	V	V	V	
60	III	III	IV	V	V	IV	IV	IV	V	V	V	
66	III	III	IV	V	V	IV	IV	IV	V	V		
72	III	III	IV	V	V	IV	IV	IV	V	V		
78	III	III	IV	IV	IV	IV	IV	IV	V			
84	III	III	IV	IV	IV	IV	IV	IV	V			
90	III	III										
96	III	III										
102	III	III										
108	III	III										

FOR CONDITIONS BETWEEN THE HEAVY LINE & DOUBLE LINE CLASS IV CONCRETE PIPE REQUIRES IMPERFECT BACKFILL ACCORDING TO DETAIL "A".

FOR CONDITIONS TO THE RIGHT OF THE DOUBLE LINE CLASS V CONCRETE PIPE REQUIRES IMPERFECT BACKFILL ACCORDING TO DETAIL "B".

MULTIPLE PIPE CULVERT SPACING

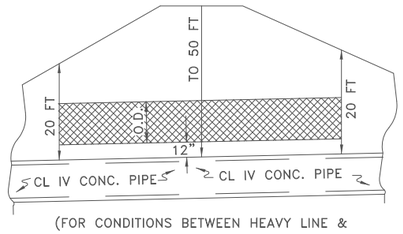


S= One inside diameter of pipe or 3 feet, whichever is smaller.
For pipe arch culverts, substitute span for inside diameter.

NOTE:
For Multiple Lines of C.M. Pipe with metal Flared End Sections, S may be increased enough to avoid overlap of End Section wingtips. Location of metal End Section should be determined before placement of pipe.

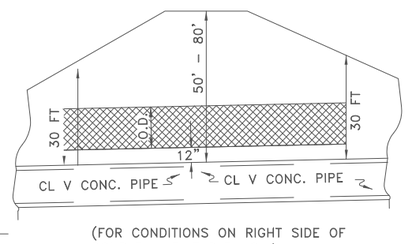
CROSS SECTIONS OF IMPERFECT TRENCH BACKFILL

CROSS HATCHED AREAS SHOW LIMITS OF CONSTRUCTION & MEASUREMENT FOR STRUCTURE EXCAVATION & IMPERFECT TRENCH BACKFILL MATERIAL, TYPE III



(FOR CONDITIONS BETWEEN HEAVY LINE & & DOUBLE LINE, TABLE NO.1)

DETAIL "A"



(FOR CONDITIONS ON RIGHT SIDE OF DOUBLE LINE, TABLE NO.1)

DETAIL "B"

DETAIL SHOWING MINIMUM COVER FOR PIPE CULVERTS

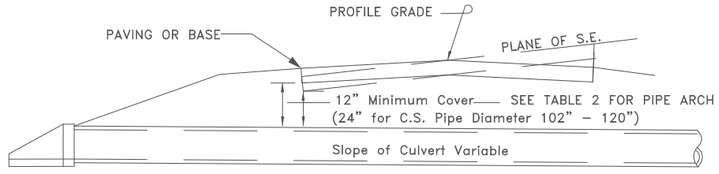
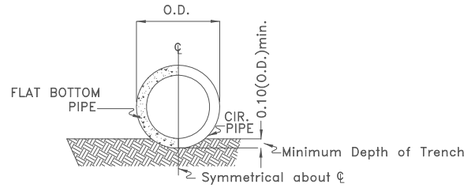


TABLE NO. 3 – (INFORMATION ONLY)

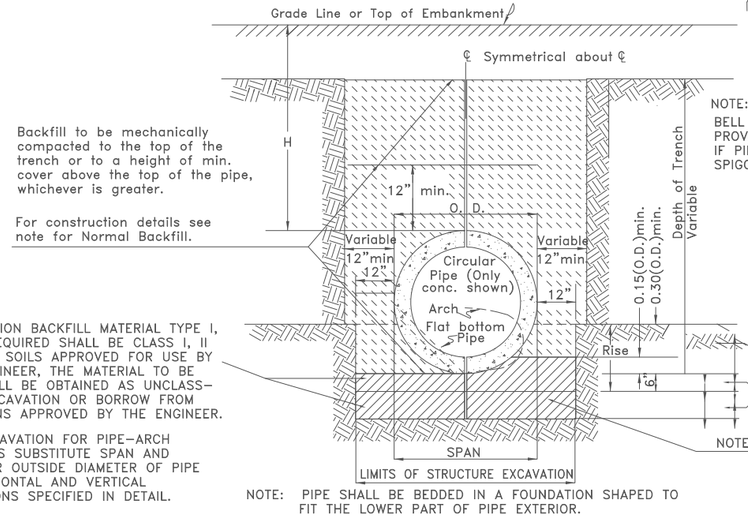
	Cor. Metal Thickness	Equivalent Gage
STEEL	0.064	16
	0.079	14
	0.109	12
	0.138	10
	0.168	8
ALUMINUM	0.060	16
	0.075	14
	0.105	12
	0.135	10
	0.164	8

TRENCH CONSTRUCTION FOR SIDE DRAIN



NOTE:
THE PIPE SHALL BE BEDDED TO LINE AND GRADE IN A FIRM FOUDATION SHAPED TO FIT THE LOWER PART OF THE PIPE EXTERIOR. WHERE ROCK EXISTS, EXCAVATE AND BACKFILL WITH COMPRESSIBLE MATERIAL(Unclassified Excavation) A MINIMUM OF 6" BELOW THE PIPE.

TRENCH CONSTRUCTION FOR STORM DRAIN



NOTE: BELL HOLES SHALL BE PROVIDED IN BEDDING IF PIPE HAS BELL AND SPIGOT JOINTS.

FOUNDATION BACKFILL MATERIAL TYPE I, WHEN REQUIRED SHALL BE CLASS I, II OR III–A SOILS APPROVED FOR USE BY THE ENGINEER, THE MATERIAL TO BE USED WILL BE OBTAINED AS UNCLASS–IFIED EXCAVATION OR BORROW FROM LOCATIONS APPROVED BY THE ENGINEER.

FOR EXCAVATION FOR PIPE–ARCH CULVERTS SUBSTITUTE SPAN AND RISE FOR OUTSIDE DIAMETER OF PIPE IN HORIZONTAL AND VERTICAL DIMENSIONS SPECIFIED IN DETAIL.

NOTE: PIPE SHALL BE BEDDED IN A FOUNDATION SHAPED TO FIT THE LOWER PART OF PIPE EXTERIOR.

minimum Depth of Trench 0.030(O.D.)

FOUNDATION BACKFILL MATERIAL TYPE I OR II

NOTE: Where an incompressible foundation exists, excavate an additional 6". Where an unstable foundation material is encountered, excavate an additional depth as shown on Plans or as directed by the Engineer.

TABLE NO. 2 (PIPE–ARCH)

TABLE SHOWING MINIMUM THICKNESS IN INCHES OF CORRUGATED STEEL AND CORRUGATED ALUMINUM PIPE–ARCH AND MAXIMUM HEIGHTS OF FILL ABOVE THE TOP OF THE PIPE–ARCH.

Diameter of Pipe of Equal Periphery Inch	SPAN INCH	RISE INCH	MIN. THICKNESS (inches) COR. STEEL ①	COR. STEEL ②	COR. ALUMINUM	MINIMUM COVER INCHES	MAX. HT. FILL FEET
15	17	13	.064			18	13
					.060	18	15
18	21	15	.064			18	12
					.060	18	14
21	24	18	.064			18	10
					.060	18	13
24	28	20	.064			18	9
					.060	18	11
30	35	24	.064			18	9
					.060	18	9
36	42	29	.064			18	7
					.075	18	7
	40	31		.079		18	12
42	49	33	.079			18	7
					.105	18	7
	46	36	.079	.079		18	12
48	57	38	.109			18	7
					.135	18	7
	53	41		.079		18	12
54	64	43	.109			18	7
					.135	18	7
	60	46		.079		18	12
60	71	47	.138			18	7
					.164	18	7
	66	51		.079		18	12
66	77	52	.168			18	7
	73	55		.079		18	15
72	83	57	.168			18	8
	81	59		.079		18	15
78	87	63		.079		18	14
84	95	67		.109		18	12
90	103	71		.109		24	11

① DENOTES 2–2/3"X1/2" CORRUGATION.

② DENOTES 3"X1" CORRUGATION.

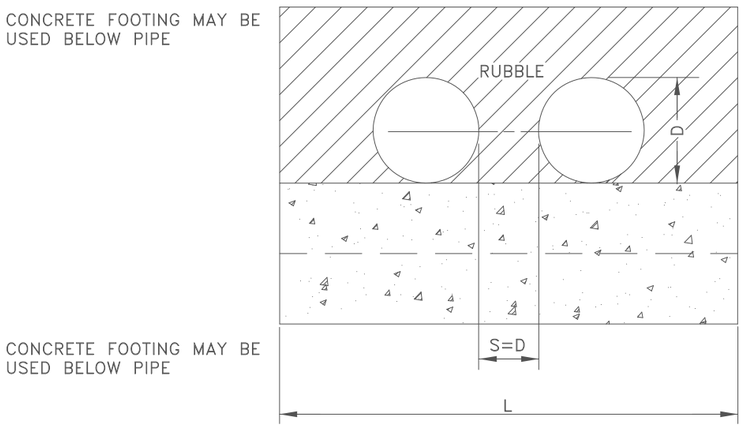
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD PIPE CULVERTS – CONCRETE PIPE

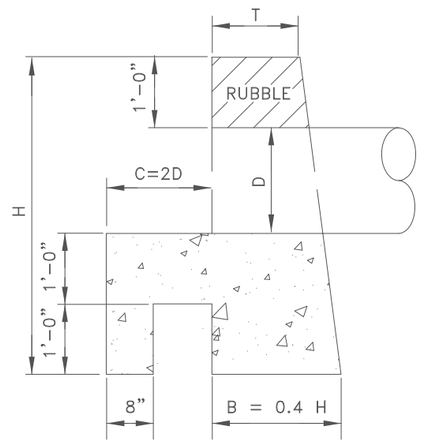
DATE: JANUARY 1988 SHEET: 703
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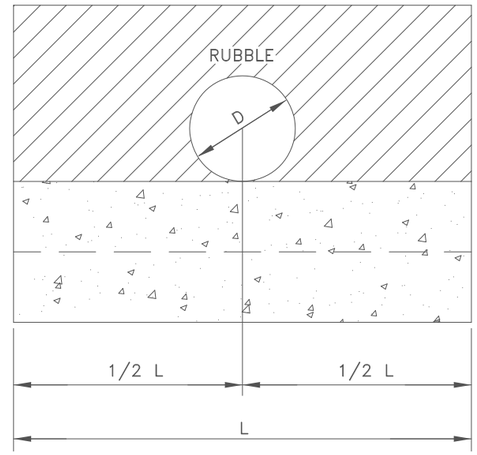
TO BE USED WHERE SPILLING OF MATERIAL AROUND THE END OF WALL WILL NOT IMPEDE FLOW. USE ONLY AS DIRECTED BY THE DEPARTMENT.



DOUBLE LINE OF PIPE



SECTION



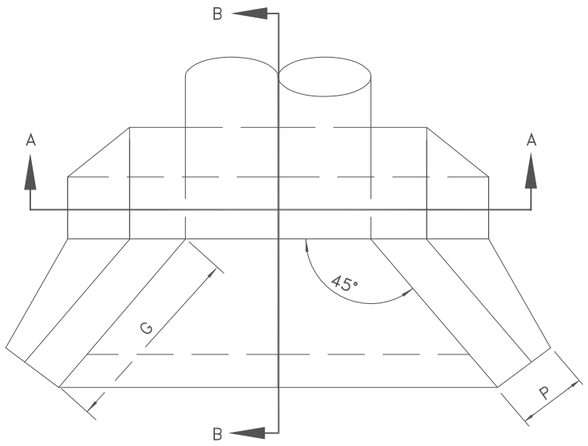
SINGLE LINE OF PIPE

DIMENSIONS AND QUANTITIES FOR ONE END WALL – SINGLE LINE OF PIPE						
D	H	L	T	B	BATTER	CY
12"	4'–0"	4'–6"	15"	1'–7"	1:1	0.91
15"	4'–3"	5'–6"	15"	1'–8"	1–1/4:1	1.22
18"	4'–6"	6'–6"	15"	1'–10"	1–5/8:1	1.58
21"	4'–9"	7'–6"	15"	1'–11"	1–3/4:1	2.03
24"	5'–0"	8'–6"	15"	2'–0"	1–3/4:1	2.37
30"	5'–6"	10'–6"	15"	2'–2"	2–1/8:1	3.40
36"	6'–0"	12'–6"	15"	2'–5"	2–3/8:1	4.68
42"	6'–6"	14'–6"	15"	2'–7"	2–1/2:1	5.30
48"	7'–0"	16'–6"	15"	2'–10"	2–3/4:1	6.12
54"	7'–6"	18'–6"	15"	3'–0"	2–7/8:1	6.99
60"	8'–0"	20'–6"	15"	3'–3"	3:1	7.92
66"	8'–6"	22'–6"	15"	3'–5"	3:1	8.93
72"	9'–0"	24'–6"	15"	3'–7"	3–1/8:1	9.99

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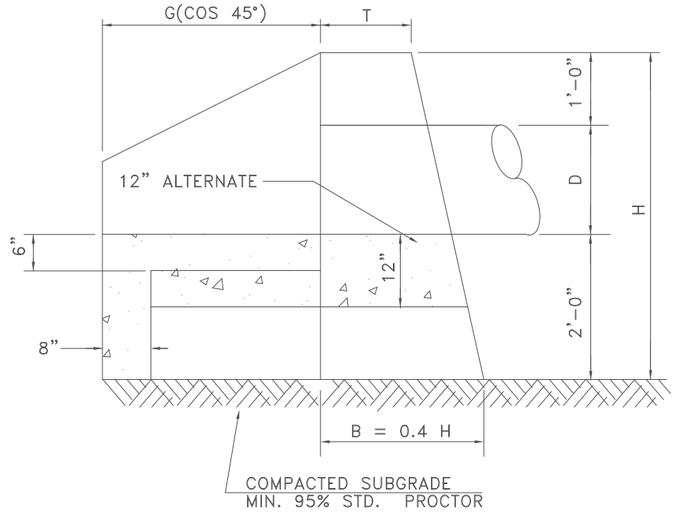
STANDARD RUBBLE HEADWALL

DATE: JANUARY 1988 SHEET: 706
REVISED: DECEMBER 2017

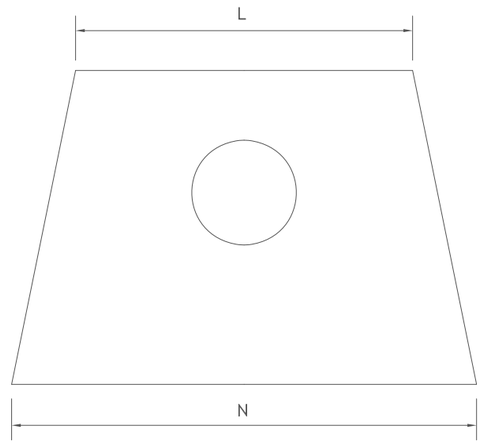


CONCRETE APRON SHALL BE CLASS "A" (3000 PSI)

PLAN



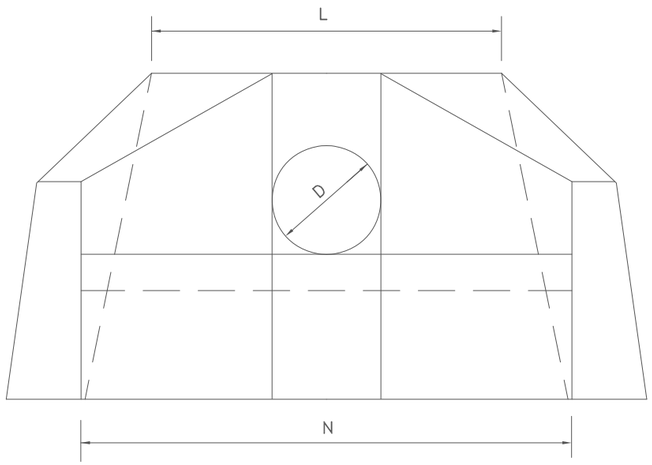
SECTION B-B



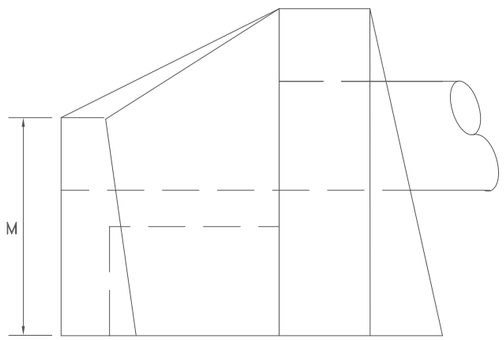
SECTION A-A

NOTE:

HEADWALLS SHALL BE BUILT ACCORDING TO STANDARD SPECIFICATIONS FOR CEMENT RUBBLE MASONRY. STONE SHALL BE BEDDED IN 1/3 PORTLAND CEMENT MORTAR. HEADERS SHALL BE DISTRIBUTED THROUGH WALLS SO AS TO FORM ABOUT ONE SIXTH OF FACE OF WALL, AND SHALL EXTEND ENTIRELY THROUGH THE WALL.
WALLS SHALL BE NEATLY TOPPED WITH A LAYER OF 1–1 MORTAR, AT LEAST 1" THICK, TROWELED SMOOTH, AND BEVELED AT EDGES. DEPTH OF WALL BELOW PIPE TO BE VARIED TO SUIT LOCAL CONDITIONS.
WHERE DEPTH OF WALL IS INCREASED BY MORE THAN 2'–0" USE 0.4 OF HEIGHT FOR WIDTH OF BASE INSTEAD OF CONTINUING BATTER.
12" ALTERNATE FOOTING MAY BE USED.



FRONT ELEVATION



SIDE ELEVATION

VARIABLE DIMENSIONS

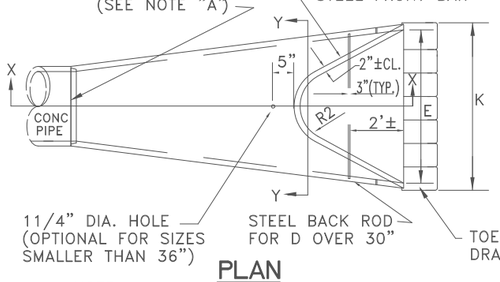
D	B	G	H	L	M	N	P	T
18	1'–10"	3'–4"	4'–6"	5'–0"	3'–4"	6'–4"	1'–4"	15"
21	1'–11"	3'–6"	4'–9"	5'–3"	3'–6"	6'–11"	1'–5"	15"
24	2'–0"	3'–9"	5'–0"	5'–6"	3'–9"	7'–4"	1'–6"	15"
30	2'–2"	4'–0"	5'–6"	6'–0"	4'–1"	8'–4"	1'–8"	15"
36	2'–5"	4'–6"	6'–0"	6'–6"	4'–5"	9'–4"	1'–10"	15"
42	2'–7"	4'–11"	6'–6"	7'–0"	4'–9"	10'–2"	1'–11"	15"
48	2'–10"	5'–5"	7'–0"	7'–6"	5'–1"	11'–4"	2'–1"	15"
54	3'–0"	5'–11"	7'–6"	8'–0"	5'–5"	12'–2"	2'–2"	15"
60	3'–3"	6'–4"	8'–0"	8'–6"	5'–9"	13'–4"	2'–5"	15"
66	3'–5"	6'–10"	8'–6"	9'–0"	6'–1"	14'–6"	2'–6"	15"
72	3'–7"	7'–4"	9'–0"	9'–6"	6'–5"	15'–2"	2'–7"	15"

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD RUBBLE HEADWALL WITH WINGS

DATE: JANUARY 1988 SHEET: 707
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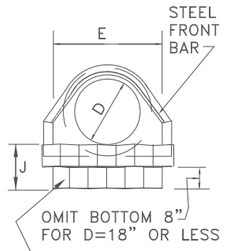
END SECTION TO PIPE JOINT SHOWN AS TYPICAL: HUB END ON OUTLET END SECTIONS; SOCKET END ON INLET END SECTIONS (SEE NOTE "A")



PLAN

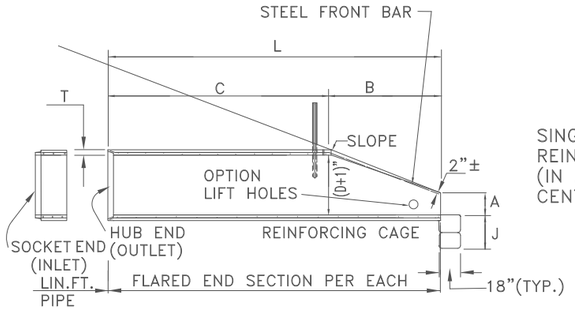
CONCRETE FLARED END SECTION

INSTALLATION:(D OVER 30") CABLE,CHAIN,OR LIFTING PIN WILL EXTEND THRU 1-1/4" HOLE WITH A PLATE OR REBAR CONNECTED INSIDE THE CONC. SECTION TO PROVIDE ADEQUATE BEARING AREA OR A LIFTING ASSEMBLY DEVICE MAY BE USED TO GIVE 3 LIFT POINTS. HOOKS CONNECTED DIRECTLY TO CONCRETE IS NOT PERMITTED DAMAGE FROM IMPROPER HANDLING SHALL BE CAUSE FOR REJECTION.

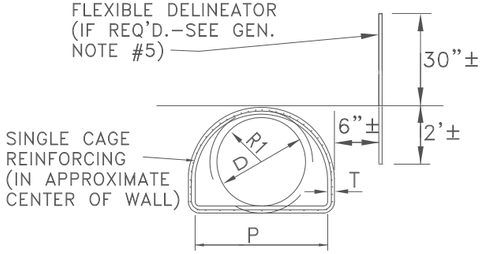


FRONT

NOTE:
DO NOT CUT CONCRETE PIPE. USE FULL LENGTH SECTIONS ONLY. WARP SLOPE TO CONFORM WITH PIPE LENGTH AND END SECTION.



SECTION X-X



SECTION Y-Y

REINFORCING CAGE:
(1) WIRE FABRIC HAVING SAME STEEL AREA AS INNER CAGE FOR CL. III PIPE, AASHTO M-170, BUT PLACED IN CENTER OF WALL.
(2) ALTERNATE; #3 BARS SPACED 12"± LONGITUDINALLY WITH #2 BARS TRANSVERSELY AT 6"O.C. MAX. SPACING, SPOT WELDED OR TIED TO FORM CAGE. (BACK RODS MAY BE OMITTED.)

NOTE "A":
CONTRACTOR WILL INFORM PRODUCER IF CONCRETE FLARED END SECTION IS FOR INLET OR FOR OUTLET END. SOCKET (TONGUE OR SPIGOT) END IS REQUIRED FOR INLETS. HUB (GROOVE OR BELL) END IS REQUIRED FOR OUTLETS. SOCKET TO SOCKET OR HUB TO HUB JOINT WILL NOT BE ACCEPTED UNLESS A REINFORCED CONCRETE COLLAR IS BUILT AROUND THE JOINT WITH NO PAYMENT BEING MADE FOR THE COLLAR.
FLARED END SECTIONS SHALL BE JOINTED TO PIPE WITH ALL SPACE IN THE JOINT FILLED WITH EITHER BITUMINOUS PLASTIC CEMENT OR PRE-FORMED PLASTIC GASKET (SEC. 848).

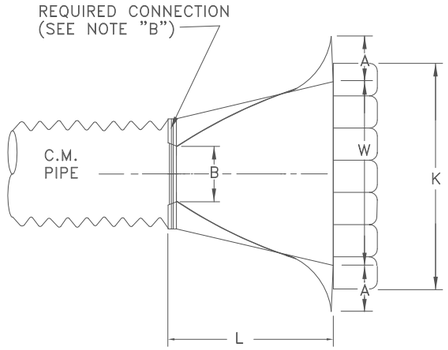
WALL THICKNESS (T) IS SHOWN AS NOMINAL AND MAY BE INCREASED AT PRODUCER'S OPTION FOR DESIRED JOINT DESIGN OR TO ALLOW A FLAT OUTSIDE BOTTOM ON THE FLARE, WITH INSIDE DIMENSIONS OF FLARE RETAINED AS SHOWN. T=PIPE WALL THICKNESS (0.0833D+1") TYPICAL)

DIMENSIONS AND REINFORCING FOR CONCRETE FLARED END SECTIONS (± 1" TOLERANCE)

PIPE DIA.	FRONT BAR	BACK RODS	SLOPE	A	B	C	L	E	P	R1	R2
12"	1-#3x5'4"	NOT REQ'D.	2.2:1	4"	2'0"	4'1"	6'1"	2'0"	1'8"	10"	9"
15"	1-#3x6'0"	NOT REQ'D.	2.2:1	6"	2'3"	3'10"	6'1"	2'6"	2'0"	1'0"	11"
18"	1-#3x7'2"	NOT REQ'D.	2.2:1	9"	2'3"	3'10"	6'1"	3'0"	2'5"	1'4"	1'0"
24"	1-#3x9'10"	NOT REQ'D.	2.4:1	10"	3'8"	2'6"	6'2"	4'0"	2'9"	1'5"	1'2"
30"	1-#4x11'8"	NOT REQ'D.	2.4:1	12"	4'6"	1'8"	6'2"	5'0"	3'1"	1'6"	1'3"
36"	1-#4x13'10	2-#4x6'3"	2.4:1	15"	5'3"	2'11"	8'2"	6'0"	4'0"	2'0"	1'8"
42"	1-#4x13'10	2-#4x7'4"	2.4:1	21"	5'3"	2'11"	8'2"	6'6"	4'6"	2'4"	1'10"

NOTE:
SPECIFIED REINFORCING IS MINIMAL AND MAY BE INCREASED AT PRODUCER'S OPTION TO AID CASTING & HANDLING. ALTERNATE REINFORCEMENT PERMITTED IF APPROVED.

METAL FLARED END SECTION
(USE ONLY WITH COR. METAL PIPE)



PLAN

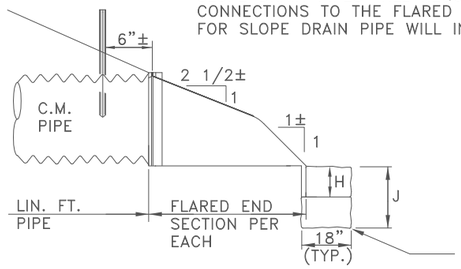
NOTE:
GALVANIZED STEEL FLARED END SECTIONS ARE TO BE USED ONLY WITH CORRUGATED STEEL PIPE AND ALUMINUM FLARED END SECTIONS ARE TO BE USED ONLY WITH CORRUGATED ALUMINUM PIPE UNLESS OTHERWISE APPROVED BY D.O.T. OFFICE OF MATERIALS AND TESTS.

FLARED END SECTION DIMENSIONS

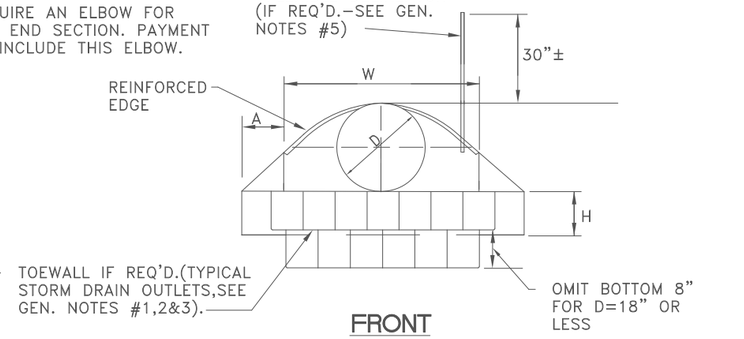
PIPE SIZE "D"	THICKNESS GALV. STEEL	THICKNESS ALUM.	A A=0.4D ± 1"	B B=0.5D ± 1"	H H=0.25D ±1"(MIN6")	L L=1.67D ± 11\2"	W W=2.0D ± 2"
12"	.064"	.060"	5"	6"	6"	1'8"	2'0"
15"	.064"	.060"	6"	7"	6"	2'3"	2'6"
18"	.064"	.060"	7"	9"	6"	2'6"	3'0"
24"	.064"	.060"	9"	1'0"	6"	3'4"	4'0"
30"	.079"	.105"	1'0"	1'3"	7"	4'2"	5'0"
36"	.079"	.105"	1'2"	1'6"	9"	5'0"	6'0"
42"	.109"	.164"	1'5"	1'9"	10"	5'10"	7'0"

NOTE:
WHERE METAL FLARED END SECTIONS ARE USED WITH MULTIPLE PIPE LINES, THE STANDARD SPACING BETWEEN PIPES. (S=D OR 3 FT.) MAY HAVE TO BE INCREASED (S=1.75D TYPICAL). TO PREVENT OVERLAP OF END SECTION WINGTIPS, SEE ALSO STD. 1030D.

NOTE:
SLOPE DRAIN PIPES WILL REQUIRE AN ELBOW FOR CONNECTIONS TO THE FLARED END SECTION. PAYMENT FOR SLOPE DRAIN PIPE WILL INCLUDE THIS ELBOW.



SIDE

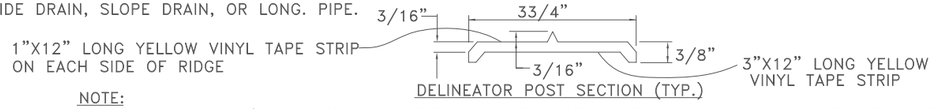


FRONT

TOEWALL DIMENSIONS AND QUANTITIES

D	J	K	ALTERNATE MATERIAL QUANTITIES: SAND CEMENT BAG RIP RAP 8" THICK NO. BAGS	SQ.YDS.	CONCRETE (CL. A OR B) OR MORTAR RUBBLE MASONRY CU.FT.⊗	CU.YDS.⊗	STONE GROUT RIP RAP OR STONE DUMP RIP RAP THICKNESS⊗	SQ.YDS.⊗
12"	8"	3'	3	0.500	3	0.111	8"	0.500
15"	8"	3'	3	0.500	3	0.111	8"	0.500
18"	8'	4'	4	0.667	4	0.148	8"	0.667
24"	16"	5'	9	1.500	10	0.370	16"	0.833
30"	16"	6'	11	1.833	12	0.444	16"	1.000
36"	16"	7'	13	2.167	14	0.518	16"	1.166
42"	16"	8'	15	2.500	16	0.592	16"	1.333

GENERAL NOTES:
1. TOEWALLS ARE FOR OUTLETS OF STORM DRAINS,EXCEPT WHERE CONCRETE DITCH PAVING OR OTHER EROSION PROTECTION IS PROVIDED OR WHERE THE OUTLET VELOCITY IS LESS THAN 8 FT./SEC. TOEWALLS ARE NOT REQUIRED FOR SIDE DRAINS, SLOPE DRAINS OR INLETS OF STORM DRAINS. THIS CRITERIA MAY BE VARIED WHERE SPECIFIED BY THE DESIGNER OR ENGINEER.
2. TOEWALLS WHICH ARE CONSTRUCTED WILL BE PAID FOR AS SQ. YDS. OF SAND CEMENT BAG RIPRAP 8" THICK, CONTRACTOR MAY ELECT TO USE ALTERNATE MATERIALS WITH NO ADJUSTMENTS TO BE MADE FOR PAYMENT.
3. TOEWALL DIMENSIONS ARE NOMINAL. TOEWALLS CONSTRUCTED WITH ALTERNATE MATERIALS TO HAVE APPROXIMATELY THE SAME DIMENSIONS AS INDICATED FOR RIP RAP. TOEWALLS CONSTRUCTED WITH CONCRETE MAY BE TRENCH FORMED, PLACEMENT OF RIP RAP MAY DIFFER FROM DETAILS SHOWN IF SO APPROVED BY THE ENGINEER.
4. CENTERLINE OF FLARED END SECTION WILL ALIGN WITH CENTERLINE OF PIPE. IF PIPE IS SKEWED, THE EMBANKMENT SLOPE WILL BE WARPED TO CONFORM WITH END SECTION.
5. FLEXIBLE DELINEATORS SHALL BE REQUIRED AT CROSS DRAIN FLARED END SECTIONS BOTH INLET AND OUTLET. PAYMENT FOR FLARED END SECTION WILL INCLUDE DELINEATORS. SEE DETAIL AND NOTES BELOW. DELINEATORS NOT REQ'D. FOR SIDE DRAIN, SLOPE DRAIN, OR LONG. PIPE.



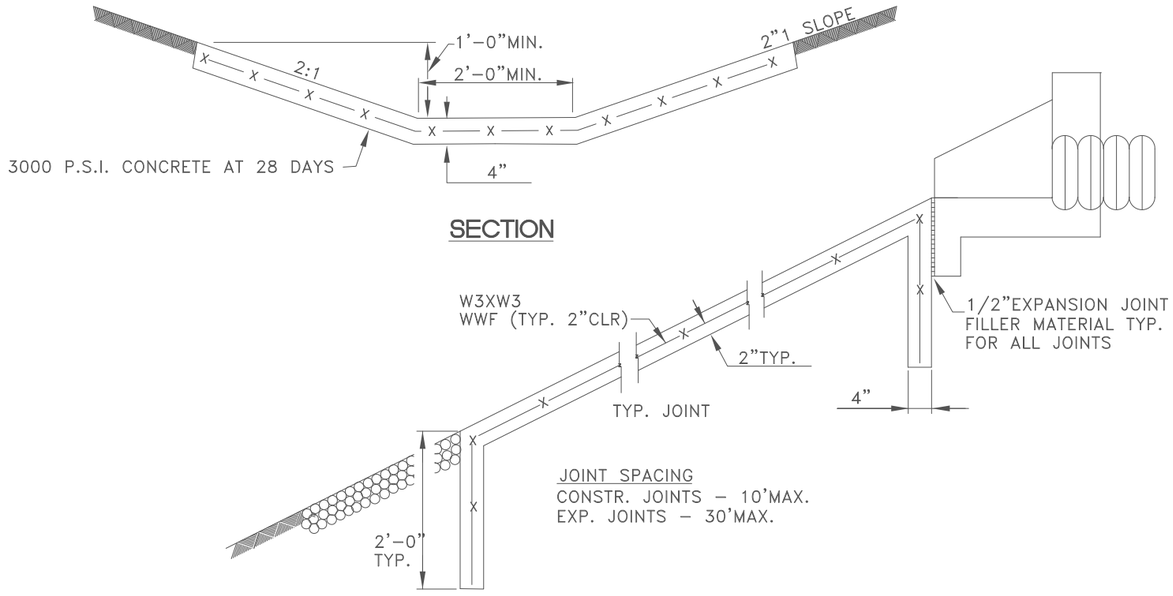
NOTE:
DELINEATOR POST SHALL CONFORM TO SEC. 911 FOR FLEXIBLE DELINEATOR POST, EXCEPT REFLECTIVE SHEETING IS NOT REQUIRED AND LENGTH IS 4'-6" FROM TOP TO BOTTOM POINT. ALTERNATES PERMITTED IF APPROVED BY D.O.T. LABORATORY.

NOTE "B":
THE CONNECTION BETWEEN METAL FLARED END SECTION AND C.M. PIPE WILL BE ONE OF THE FOLLOWING:
(a) A STRAP BAND OR THREADED ROD PROVIDED BY THE MANUFACTURER WILL LOCK END SECTION ONTO PIPE. A CORRUGATION AT THE PIPE END WILL BE NON-SPIRALED (PERPENDICULAR TO CENTERLINE OF PIPE).
(b) A DIMPLE BAND COLLAR WILL BE SHOP BOLTED TO END SECTION. PIPE WILL BE INSERTED INTO THE BAND COLLAR TO MEET THE END SECTION.
(c) A STUB PIPE WILL BE RIVITED TO THE END SECTION AND THE MAIN PIPE CONNECTED TO THE STUB WITH A NORMAL CONNECTING BAND.
(d) OTHER TYPE CONNECTION IF RECOMMENTED BY MANUFACTURER AND APPROVED BY THE D.O.T.

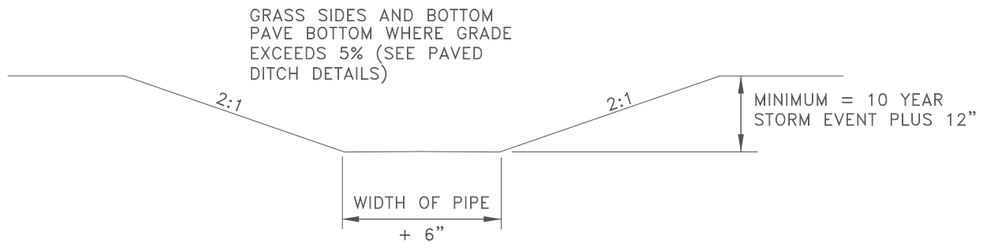
GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

STANDARD FLARED END SECTIONS FOR PIPES

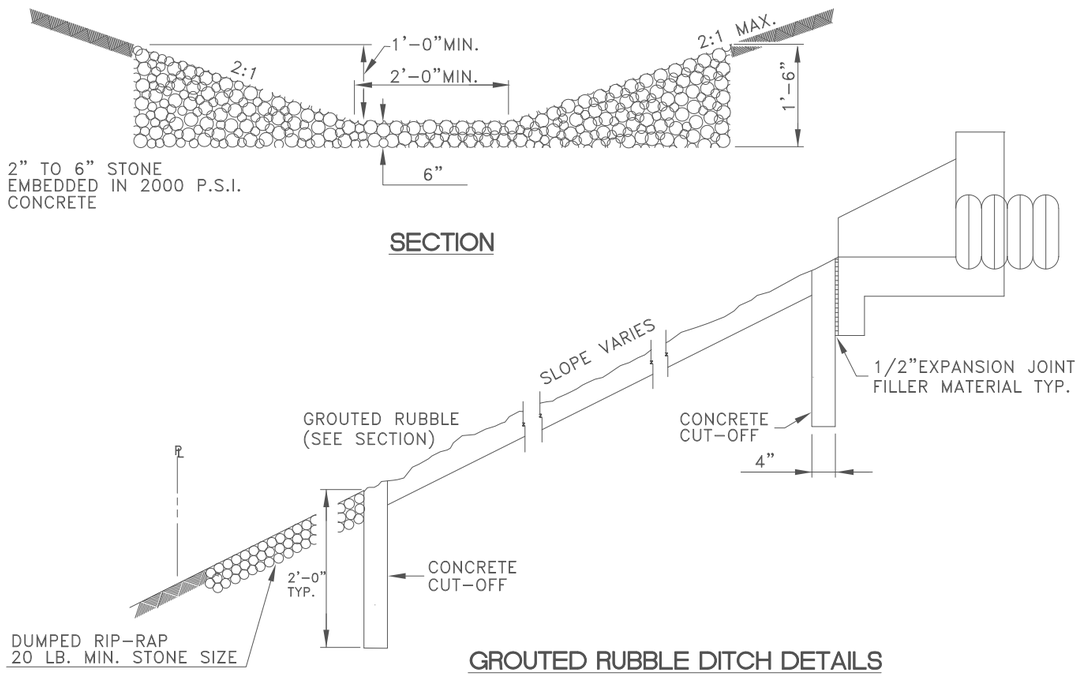
DATE: JANUARY 1988 SHEET: 708
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PAVED DITCH DETAILS



TYPICAL DRAINAGE DITCH CROSS SECTION



GROUTED RUBBLE DITCH DETAILS

GWINNETT COUNTY GOVERNMENT
STANDARD DRAWING

DRAINAGE DITCH DETAILS

DATE: JANUARY 1988 SHEET: 709
REVISED: DECEMBER 2017

Appendix G: Non-Volume Certification Tests for Best Management Practices

It is appropriate to test BMPs to make sure they are operating as they were designed to operate, and effectively reducing the pollutant load to the streams. This test must be matched to the BMP type. So, for a storage BMP type, like a detention pond, Volume Certifications are the appropriate test. But for an infiltration type of BMP, like a bioretention, an infiltrometer test is the appropriate test to verify the BMP is working effectively. These tests must be matched to the BMP type, as in Table G-1.

These tests need to be run when required, such as prior to Certificate of Occupancy, Final Plat, Surety Release, Stormwater Utility Credit Renewal and other related activities throughout the life of the BMP. The test run at various points before Surety Release serves two purposes; one is to ensure the BMP was built as designed, and the second purpose is to use it to compare the BMP effectiveness over the years, and plan for long-term maintenance costs. Inspectors are not usually at every BMP during all the phases of construction, so at least one BMP test prior to end of the project, appropriate for the BMP type, will verify that the BMP was built according to the plans and is operating effectively. This test will ensure that the final BMP owner will be provided a BMP that meets the Stormwater requirements. The other purpose for a BMP test prior to the end of the project is to be able to compare the BMP effectiveness over the years, and plan for long-term maintenance costs. As the years go by, and the BMP is tested, the owner can adjust their BMP maintenance schedules based on the effectiveness of the BMP. The initial BMP test is important to provide the long-term owner a comparison data point.

See Table G.1 for the BMP tests as matched to the BMP type. For additional information, refer to the Gwinnett County Monitoring Guidance and Equipment Evaluation.

Table G.1. Summary of recommended rapid assessment tests for Gwinnett County stormwater BMPs

Test Name	Photograph	Applicable BMPs	Description	Estimated Costs and Basic Materials	Estimated Labor Requirements[3]
Simple Infiltration Test (SIT)		- Permeable Paver Systems - Pervious Concrete - Porous Asphalt	Used to quantify surface drawdown of permeable pavement. Water from a 5-gallon bucket is rapidly poured into a wooden frame affixed to the pavement surface and the time to complete drawdown is recorded. Slow drawdown may indicate need for maintenance.	$250 - $500 Hardware to construct test frame Plumber's putty 5-gallon bucket Stopwatch Camera & field book	2 field technicians 2-4 hours per technician
Surface Infiltration Rate Test (Infiltrometer Method)		All filtration/infiltration practices[1].	Used to quantify surface drawdown of practices whose primary function is infiltration and/or filtration through a soil media. Water is added to a single- or double-ring infiltrometer and the time to drawdown is recorded to ensure that a BMP is performing as expected.	$650 - $1,000 Infiltrometer Installation hardware Graduated cylinder Measuring stick Stopwatch Camera & field book	2 field technicians 2 hours per technician
Drawdown (Dewatering) Test (Water Quality Volume Method)		All practices that are designed to infiltrate, convey, or temporarily store a specified stormwater volume[2].	Used to estimate drawdown rate in BMPs following a natural or simulated storm event; ideal storm for testing is at least 1 inch. Basic equipment (pressure transducer, data logger, and shuttle) installed to monitor water level recession. Drawdown rates that are slower or faster than expected may indicate performance problems.	$1,500 - $2,300 Pressure transducers Data logger & shuttle Rain gage Installation hardware Measuring weir, plastic bins, & graduated cylinder Camera & field book	2 field technicians 6-8 hours per technician
Visual Inspection of Soils		- All filtration/ infiltration practices[1]. - Soil Restoration	Involves visual inspection of soil color and texture to assess condition of a BMP. A soil scientist should examine soil condition at three locations in the practice. Signs of a high water table or restrictive (i.e., clay) layer may indicate performance problems.	$500 - $800 Shovel Soil auger Soil Color Charts Camera & field book	1 soil scientist 1-3 hours per scientist

Table G.1. Summary of recommended rapid assessment tests for Gwinnett County stormwater BMPs

Test Name	Photograph	Applicable BMPs	Description	Estimated Costs and Basic Materials	Estimated Labor Requirements[3]
Visual Inspection of Plants		All practices incorporating vegetation.	Involves visual inspection of plant condition including species, density, and health. Inspection should be performed by a horticulturalist or other qualified professional. Dying or undesirable vegetation may indicate performance problems.	$100 - $300 Camera & field book	1 plant specialist 1-3 hours per specialist
Visual Inspection of Sediment Accumulation and/or Loss		Assessment is applicable for virtually all BMPs, but is emphasized for storage-based practices.	Depending on BMP configuration, inlets, outlets, overflows, underdrains, forebays, etc. are inspected for sediment accumulation or erosion, which can negatively impact performance. A vertical sediment depth indicator may be installed to monitor accumulation. In some cases, a survey crew may be required to verify BMP capacity.	$200 - $400 (additional $3,000 for a survey crew, if required) Sediment depth marker Measuring stick Camera & field book	2 field technicians, 1 Professional Land Surveyor (if required) 1-3 hours per technician
Visual Inspection of BMP Components		- Downspout Disconnects - Proprietary Systems - Rainwater Harvesting	Involves visual inspection of BMP components to determine if they are functioning as designed. Inspectors may need to consult manufacturers' information to verify all components are present, properly configured, and in good condition.	$100 - $300 Camera & field book	1 field technician 1 hour per technician

[1] Filtration/infiltration practices include Bioretention Areas, Bioslopes, Dry Wells, Infiltration Practices, Organic Filters, Regenerative Stormwater Conveyance, Sand Filters (Surface Sand Filter, Perimeter Sand Filter, Underground Sand Filter), Stormwater Planters/Tree Boxes, and Vegetated Filter Strip.

[2] Includes all BMPs in the 2017 GCSMM except for Downspout Disconnects, Gravity Oil/Grit Separators, Green Roofs, Proprietary Systems, Rainwater Harvesting, Site Reforestation/Revegetation, and Soil Restoration.

[3] Infiltration/drawdown testing and BMP inspection can be performed by a licensed engineer or engineering firm with experience in stormwater BMP design and implementation, or a licensed and experienced engineering firm can provide training services to DWR staff. The local University Extension Service (UGA Extension Gwinnett) can be contacted for technical assistance related to soil science and horticulture (plant science).