# GREENVILLE COUNTY STORM WATER MANAGEMENT DESIGN MANUAL

JANUARY 2013

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| AMC | Antecedent moisture condition |
| BFM | Bonded Fiber Matrix |
| BMP | Best Management Practice |
| CEC | Cation Exchange Capacity |
| cfs | Cubic Feet per Second |
| CLOMR | Conditional Letter of Map Revision |
| CM | Corrugated Metal |
| CMP | Corrugated metal pipe |
| cms | Cubic Meter per Second |
| CN | Curve number |
| CREAMS | Chemicals, Runoff and Erosion in Agricultural Management Systems |
| CWA | Clean Water Act |
| DO | Dissolved Oxygen |
| ECB | Erosion Control Blanket |
| EI | Erosivity Index |
| EPSC | Erosion Prevention and Sediment Control |
| EPSD | Eroded Particle Size Distribution |
| ERU | Equivalent Residential Unit |
| ETV | Environmental Technology Verification |
| FEMA | Federal Emergency Management Agency |
| FGM | Flexible Growth Matrix |
| FHWA | Federal Highway Administration |
| FIA | Federal Insurance Administration |
| GIS | Geographic Information System |
| HECP | Hydraulic Erosion Control Product |
| HSG | Hydrologic Soil Group |
| HW | Headwater |
| IDEAL | Integrated Design and Assessment for Environmental Loadings |
| IMP | Integrated Management Practice |
| LDD | Land Development Division |
| LEED | Leadership in Energy and Environmental Design |
| LID | Low Impact Development |
| MEP | Maximum Extent Practicable |
| MS4 | Municipal Separate Storm Sewer System |
| MSDS | Material Safety Data Sheet |
| MTD | Manufactured Treatment Device |
| MUSLE | Modified Universal Soil Loss Equation |
| NCRS | Natural Resource Conservation Service |
| NJCAT | New Jersey Corporation for Advanced Technology |
| NPDES | National Pollutant Discharge Elimination System |
| NURP | National Urban Runoff Program |
| NWS | National Weather Service |
| PAM | Polyacrylamide |
| PRF | Peak Rate Factor |
| PVC | Polyvinyl Chloride |
| RC | Reinforced Concrete |
| RCP | Reinforced Concrete Pipe |

# ACRONYMS AND ABBREVIATIONS (CONTINUED)

| | |
|---|---|
| RECP | Rolled Erosion Control Product |
| RUSLE | Revised Universal Soil Loss Equation |
| SCDHEC | South Carolina Department of Health and Environmental Control |
| SCDOT | South Carolina Department of Transportation |
| SCPCA | South Carolina Pollution Control Act |
| SCS | Soil Conservation Service |
| SMSRA | Storm Water Management and Sediment Reduction Act |
| SUDS | Simplified Urban Drainage System |
| SWPPP | Storm Water Pollution Prevention Plan |
| SWMP | Storm Water Management Plan |
| TMDL | Total Maximum Daily Load |
| TRM | Turf Reinforcement Mat |
| TRP | Tree Protection Plan |
| TSS | Total Suspended Solids |
| TW | Tailwater |
| USDA | United States Department of Agriculture |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| USLE | Universal Soil Loss Equation |
| VFS | Vegetated Filter Strip |
| WQV | Water Quality Volume |

# Chapter 1. INTRODUCTION

## 1.1 Purpose of the Manual

**The purpose of this Storm Water Management Design Manual is to provide engineers, developers, plan reviewers, inspectors, contractors, property owners, and interested citizens involved in land development within the unincorporated, non-South Carolina Department of Transportation (SCDOT) regulated areas of Greenville County and within the municipalities that chose to participate with Greenville County as co-permitees (Simpsonville, Mauldin, Travelers Rest and Fountain Inn are co-permittees) in its National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Permit, with the following information:**

- Storm water management requirements;
- Summarization of the permit application process;
- Submittal requirements and the plan review process;
- Technical guidance to meet storm water management design requirements; and,
- Guidelines for designing, implementing, and maintaining storm water best management practices (BMPs) used in Greenville County to improve water quality, and minimize storm water runoff impacts due to increased flow volumes and peak discharge rates from developed areas.

This Storm Water Management Design Manual has been prepared in fulfillment of the requirements of the Greenville County Storm Water Management Ordinance as imposed by NPDES Permit No. SC230001 and the South Carolina Storm Water Management and Sediment Reduction Act to accomplish the following objectives:

- Reduce storm water adverse impacts on water quality;
- Reduce storm water adverse impacts on water quantity;
- Protect downstream areas from adverse storm water quantity and quality impacts resulting from development;
- Identification of what is required for storm water plan submittal and plan reviews; and,
- Submittal of high quality storm water design plans from the design community.

## 1.2 Description and Use of the Manual

The Design Manual was developed under the assumption that the user possesses a basic understanding in storm water control design, construction, or land development depending on the users particular area of expertise. Users of this Manual who are not justly qualified by education or experience in the fields of storm water control design, construction, or land development should consult with a qualified professional in one or more of these areas prior to adhering to the requirements contained within the Manual.

This Manual is not intended to be a systematic design methodology that addresses every land development situation that may occur in Greenville County. The application of engineering principles and judgment combined with the information contained within this Manual are required to successfully complete the planning, design, and preparation of documents for storm water management plan submittal.

This Manual is not intended to restrain or inhibit engineering creativity, freedom of design, or the need for engineering judgment. When shown to be applicable, it is encouraged that new procedures, techniques, and innovative storm water BMPs be submitted with supporting documentation. The documentation submitted by design professionals should show that these procedures are equal to, or exceed the procedures and/or controls contained in this Design Manual.

## 1.3 Design Manual Organization

The Design Manual contains 12 chapters. A general Table of Contents is found at the beginning of the Manual. This Design Manual is organized to present technical and engineering procedures along with the criteria needed to comply with Greenville County's Storm Water Management regulations and standards. Each chapter of the Design Manual presents all the policies and procedures that must be met for approval. In general, references are included in Appendix L. However, Chapters 5 and 10 have their own list of references at the end of those chapters

## 1.4 Updates to the Design Manual

This Design Manual is intended to be a dynamic document. As design technology and criteria evolve, the Manual may and/or will require updates, modifications, and improvements. As updates are made, they will be available for download from Greenville County's website. It will be each users responsibility to maintain a current edition of the Design Manual. The website format will allow the user to easily obtain or update new Design Manual information.

## 1.5 The Need for Storm Water Management

Urbanization has the potential to alter the natural drainage system and flow of water in the environment. Typical patterns of urbanization change the physical chemical and biological conditions of natural waterways. When land is developed the natural hydrology of the watershed is disrupted and may become altered. Clearing removes vegetation that originally intercepted and slowed rainfall runoff. Grading removes beneficial topsoil, compacts the subsoil and fills in natural depressions that originally provided temporary storage. As a result of land development infiltration is decreased and rainfall that once seeped into the ground runs off the surface at an accelerated rate.

### Effects of Urbanization on Watershed Hydrology

Development and urbanization have the following impacts on receiving waterbodies:

- Changes to Stream Flow:
  - Increased runoff volumes
  - Increased peak runoff discharges
  - Greater runoff velocities
  - Increased flooding frequency
  - Lower dry weather flows (baseflow)
- Changes to Stream Geometry:
  - Stream channel enlargement and erosion
  - Stream downcutting
  - Changes in channel bed due to sedimentation
  - Increase in floodplain elevation
- Degradation of Aquatic Habitat:
  - Degradation of habitat structure
  - Decline in stream biological functions
- Water Quality Impacts:
  - Reduced oxygen in streams
  - Microbial contamination
  - Hydrocarbons and toxic materials
  - Sedimentation
- Property damage and safety concerns
- Unsightly aesthetic stream channel conditions

## 1.5.1. Innovative Design Approach

When designing for maximum water quantity, erosion prevention, sediment control, and water quality benefits, the design professional should take the following considerations in mind:

- Storm water quantity and quality are best controlled at the source of the problem by reducing the potential maximum amount of runoff and pollutants; and
- Best site design techniques implement storm water management by using simple, nonstructural methods along with or in place of traditional storm water management structures when applicable.

Innovative approaches to site design are more of a source control for storm water runoff – the site design practices limit the amount of runoff generated as well as use certain BMPs within the design. Now many communities are focusing on runoff reduction measures and incorporating them into low impact design applications. These types of design concepts are described in detail in several sources including*:* Georgia Storm Water Manual, Volume 1: Policy Guidebook, First Edition, Atlanta Regional Commission, August 2001; and, Low-Impact Development Design Manual, Prince George's County Maryland, Department of Environmental Resources, November 1997. Some general concepts from these sources are provided in the following Sections.

## 1.5.2. Best Site Design Practices and Site Planning Process

The first step in addressing storm water management begins in the site planning and design stage of the development project. By implementing Best Site Design Practices during the site planning process, the amount of runoff and pollutants generated from a site can be reduced by minimizing the amount of impervious area and utilizing natural on-site treatments. The minimizing of adverse storm water runoff impacts by the use of Best Site Design Practices and site planning should be a major consideration for a design professional.

The reduction of runoff volumes and storm water pollutants reduces the total number and size of storm water management controls that must be implemented under the guidelines set forth in this Design Manual. Best Site Design Practices reduce the amount of total post-development impervious areas and maintains natural characteristics of the pre-development site conditions. Therefore, the post-development curve number and time of concentrations are maintained more closely to those of the pre-development condition, thereby reducing the overall hydrologic and hydraulic impact of the development. Implementing Best Site Design Practices can reduce the Storm Water Utility Fee by decreasing the total impervious area of a development site.

### Maintaining Site Resources and Natural Undisturbed Areas

Conservation of site resources and natural undisturbed areas helps to reduce the post development runoff volume and provide areas for natural storm water management. Some natural site resources that should be maintained include, but are not limited to:

- Natural drainage ways;
- Vegetated buffer areas along natural waterways;
- Floodplains;
- Areas of undisturbed vegetation;
- Low areas within the site terrain;
- Natural forested infiltration areas; and,
- Wetlands.

### Land Disturbance Limits

- In steeply sloping areas with 15% or greater slopes, limit the amount of land disturbance to 5 acres at one time; non-active areas must be stabilized prior to disturbing additional areas; and,
- In areas with slopes less 15%, limit land disturbances to 17 acres or less at one time without applying stabilization practices.

### Lower Impact Site Layout Techniques

Lower impact site layout techniques involve identifying and analyzing the location and configuration of structures on the site to be developed. Where applicable, the following options that create lower impacts layouts should be used:

- Fit the design layout to follow the natural contours of the site to minimize clearing and grading and preserve natural drainage ways;

- Limit the amount of clearing and grading by identifying the smallest possible area on the site that would require land disturbance;

- Place development areas on the least sensitive areas of the site; and,

- Utilize nontraditional lot designs for residential areas to reduce the overall imperviousness of the site by providing more undisturbed open space by minimizing clear-cutting.

## Reduction of Impervious Cover

The reduction of total impervious cover directly relates to a reduction in storm water runoff volume and the associated pollutants from a development site. The amount of impervious cover on a site can be reduced by the following techniques where applicable:

- Refer to and use the "High Intensity Residential Street Configuration Guidance";
- Reduce building footprints by requiring some buildings to be multi-story;
- Reduce parking lot areas and/or the use of porous paver surfaces for desired overflow parking;
- Use clustering and provide more open space and green areas;
- Increase the amount of vegetated parking lot "islands" that can also be utilized for storm water management practices such as bioretention areas;
- Reduce the number of cul-de-sacs in residential areas and incorporate landscaped areas within them to reduce the amount of impervious cover; and,
- Use engineered soil mixtures to enhance infiltration from pervious covers.

## Utilization of Natural Features for Storm Water Management

Traditional storm water drainage design does not utilize the natural drainage patterns of the pre-developed site. Structural storm water drainage controls are traditionally designed to quickly remove storm water runoff from the site without utilizing any of the natural storage areas. These natural drainage areas should be considered as potential storm water drainage systems. These natural areas can be utilized in the following ways where applicable:

- Vegetated buffers and undisturbed areas on the site are useful to control sheet flow (not concentrated flows) by providing infiltration, runoff velocity reduction, and pollutant removal;
- Various natural drainage ways should be maintained and not disturbed to provide a natural storm water drainage system to carry flows to their natural outlets. The use of these natural drainage ways allows for more storage of storm water runoff, lower peak flow rates, a reduction in erosive runoff velocities, and the capture and treatment of pollutants;
- Use of vegetated swales instead of curb and gutter applications where applicable. This application allows for more storage of storm water runoff, lower peak flow rates, a reduction in erosive runoff velocities, and the capture and treatment of pollutants which does not occur with curb and gutter systems;
- Where ditched roadways are not practicable, curb and gutter systems may be combined with vegetated swales at outfalls to provide added water quality benefits versus the traditional piped outfall designs;
- When applicable, direct rooftop runoff to pervious natural areas for water quality treatment and

infiltration instead of connecting rooftop drains to roadways and other structural storm water conveyance systems; and,

- Include the use of cisterns and rain gardens for individual residential units.

# 1.6 Storm Water Management Regulations and Policies

To address the adverse impacts of urbanization and land development, Federal, State and Local regulations have been adopted to protect the quantity and quality of the runoff received by the natural receiving waterbodies.

## 1.6.1 Federal and State Regulations

### Clean Water Act

With the mandate of the Clean Water Act (CWA), the United States Environmental Protection Agency (USEPA) stated that it is illegal to discharge pollutants to the "Waters of the United States" without a NPDES Permit. The various types of NPDES storm water permits are described in this section. The CWA requires that a NPDES permit be obtained for every point source discharge of wastewater. The 1987 amendments to the CWA also required NPDES permits for industrial discharges, including storm water runoff associated with land disturbing activity (typically land development and construction) of five acres or greater. The threshold five-acre area was challenged and the federal NPDES regulations were amended in accordance with a court order for storm water discharges in December 1999. These amendments lower the acreage for when an NPDES permit is required for construction or land clearing to one acre while allowing a case-by-case determination for sites less than one acre.

The 1987 CWA Amendments also require NPDES permitting for storm water runoff from urbanized areas. A MS4 NPDES permit is required based on population. MS4s are divided into three categories: large (250,000 or greater); medium (less than 250,000 but equal to and greater than 100,000); and small (greater than 50,000). The implementation schedule for these MS4 permits has been repeatedly delayed, but large and medium permits are now in the process of being implemented.

For both the land disturbing and MS4 nonpoint source permits, preventing the pollution at the source through the use of BMPs is the preferred and most practical method. Additional BMPs can be used as needed to address capture, control and treatment of pollutants after they have been generated or released from a source area. Authority to administer the NPDES permit program was delegated to the South Carolina Department of Health and Environmental Control (SCDHEC) in accordance with the CWA by the USEPA.

### South Carolina Pollution Control Act

The South Carolina Pollution Control Act (SCPCA) was originally enacted in 1950 and last amended in 1970 during the initial stages of the environmental movement. It was written very broadly and because of that is applicable to essentially any activity.

An important provision of the statute is Section 48-1-90, which states that it is "unlawful for any person, directly or indirectly, to throw, drain, run, allow to seep or otherwise discharge into the environment …[any] wastes, except as in compliance with a permit" issued by SCDHEC.

## South Carolina Storm Water Management and Sediment Reduction Act

The South Carolina Storm Water Management and Sediment Reduction Act of 1991 (SMSRA), S.C. Code Ann. §§ 48-14-10 et seq., was enacted to address the increase in storm water runoff rate and quantity, the decrease of rainwater infiltration, and the increase in erosion associated with the extensive urban development that has been occurring throughout the state. Greenville County has the right to implement the requirements of this Act and its associated regulations.

## NPDES Permit for Storm Water Discharges Associated with Industrial Activity

All storm water runoff from "industrial activities" is considered an illegal discharge without an NPDES Storm Water Permit (SCR100000). These permits require certain industries to develop and implement a Storm Water Pollution Prevention Plan (SWPPP), which must include appropriate BMPs to minimize pollution to the receiving waterbodies. There are two general types of industrial activity permits: "construction related" and "other". A NPDES storm water permit for storm water discharges from construction sites is required for all construction sites that disturb one or more acres of land. The requirements for obtaining and complying with this type of permit are covered in this Design Manual.

## NPDES Municipal Separate Storm Sewer System Water (MS4) Permit

Greenville County is required to obtain a NPDES MS4 Permit from the SCDHEC for storm water discharges. The permit requires the County to develop and implement a Storm Water Management Program (SWMP) to control the discharge of pollutants from its MS4 to the maximum extent practicable (MEP).

Greenville County has been granted the authority by the State of South Carolina and the South Carolina General Assembly for the following responsibilities:

- Comply with all Federal and State regulatory requirements imposed by the NPDES Permit in accordance with the CWA to manage storm water discharges from the Greenville County MS4;
- Conduct all activities necessary to carry out the storm water management programs and other requirements included in the Greenville County NPDES Permit, the SWMP and the Storm Water Management Ordinance, and pursue the necessary means and resources required to properly fulfill this responsibility;
- Enter contractual agreement with other governmental entities or private persons or entities to provide or procure services to conduct and carry out storm water management activities;
- Maintain the storm water system consistent with provisions of the Greenville County NPDES Permit, the SWMP and the Storm Water Management Ordinance, and pursue the necessary means and resources required to properly fulfill this responsibility;
- Direct and oversee the continuous implementation of the Greenville County SWMP and the Storm Water Management Ordinance and to direct and ensure compliance with the Greenville County NPDES permit;
- Direct, review, and recommend for approval by County Council, the Storm Water Management Program Operating Budget; and,
- Direct, review, and recommend for approval by County Council, the necessary changes to the existing Storm Water Management Funding.

### 1.6.2 Local Ordinances

There are three Greenville County Ordinances that affect storm water management within Greenville County. These are:

- The Storm Water Management Ordinance;
- Tree Ordinance #4173; and
- The Flood Control Ordinance.

A description of each ordinance is provided below.

#### Storm Water Management Ordinance of Greenville County, South Carolina

The purpose of this ordinance is to protect, maintain, and enhance the environment of Greenville County and the short- and long-term public health, safety, and general welfare of the citizens of Greenville County by establishing requirements and procedures to control the adverse effects of increased storm water runoff associated with both future development and existing developed land. It is further the purpose of this ordinance to comply with the Federal and corresponding State storm water discharge (NPDES) regulations.

The ordinance gives Greenville County the legal authority at a minimum to:

- Control the contribution of pollutants to receiving waters by storm water discharges associated with residential, commercial, industrial, and related facility activity;

- Prohibit illicit discharges to receiving waters;

- Control discharge to receiving waters of spills, dumping or disposal of materials other than storm water;

- Control through intergovernmental agreements, contribution of pollutants from one MS4 to another;

- Require compliance conditions in ordinances, permits, contracts or orders; and,

- Carry out all inspections, surveillance and monitoring procedures necessary to determine compliance and noncompliance with permit conditions including the prohibition of illicit discharges to the Greenville County MS4 and receiving waters.

The Director of Greenville County's Storm Water Management Program shall coordinate the County's activities with other Federal, State, and Local agencies that manage and perform functions relating to the protection of receiving water bodies.

Greenville County may open agreements with other governmental and private entities to carry out the purposes of the Storm Water Management Ordinance. These agreements may include but are not limited to:

- Enforcement;
- Resolution of disputes;
- Cooperative monitoring;
- Cooperative management of storm water systems; and
- Cooperative implementation of storm water management programs.

Nothing in the Storm Water Management Ordinance limits or appeals any Ordinance of local governments or the powers granted to these local governments by the South Carolina Constitution or South Carolina statues, including the power to require additional or more stringent storm water management requirements within their jurisdictional boundaries.

### Greenville Tree Ordinance # 4173

A Tree Ordinance is effective in Greenville County. This ordinance applies to all new development which disturbs one acre or more. The purpose of this ordinance is to mitigate the adverse effects of the loss of trees in Greenville County as a result of residential, commercial, institutional and industrial development practices. It is intended to protect and require re-establishment of the tree cover in Greenville County to reduce pollution of air, water and noise in the community. In general, the Tree Ordinance has the following requirements:

- Tree Protection Plans (TRP) may be required:
- Stream buffers are established by the Tree Ordinance:
- Tree population densities are required:
- Project development types are considered in the requirements; and
- Compliance required for development activities.

While the Land Development Department (LDD) does not review for compliance with this ordinance, compliance is required prior to issuance of a grading and storm water approvals or permits.

### Greenville County Flood Control Ordinance #4113

The purpose of this ordinance is to promote the public health, safety and general welfare and to minimize public and private losses due to flood conditions in specific areas by provisions designed to:

- Restrict or prohibit uses that are dangerous to health, safety and property due to water or erosion in flood heights or velocities;
- Require that uses vulnerable to floods, including facilities that serve such uses be protected against flood damage at the time of initial construction;
- Control the alteration of natural floodplains, stream channels and natural protective barriers that are involved in the accommodation of flood waters;
- Control filling, grading, dredging and other development that may increase erosion or flood damage; and,
- Prevent or regulate the construction of flood barriers that will unnaturally divert flood waters or that may increase flood hazards to other lands.

The objectives of this ordinance are to:

- Protect human life and health;
- Minimize expenditure of public money for costly flood projects;

- Minimize the need for rescue and relief efforts associated with flooding and generally undertaken at the expense of the general public;
- Minimize prolonged business interruptions;
- Minimize damage to public facilities and utilities such as water and gas mains, electric, telephone and sewer lines and streets and bridges located in floodplains;
- Help maintain a stable tax base by providing the sound use and development of flood prone areas in such a manner as to minimize future flood height areas; and,
- Ensure that potential homebuyers are notified that property is in a flood area.

A copy of the Greenville County Flood Control Ordinance can be found on the Greenville County website.

## Co-Permittee Ordinances

Greenville County's NPDES MS4 permit co-permittees also have municipal ordinances that affect storm water management within their jurisdictions. These are:

- Town of Simpsonville Code of Ordinances, Chapter 18, Environment, Article III Water; and, Chapter 22, Floods;
- Town of Mauldin Code of Ordinances, Chapter 32, Soil Erosion and Sedimentation Control; and, Chapter 40, Utilities, Article III, Storm Water Management;
- Town of Travelers Rest Municipal Codes, Title 5 Planning and Development, Chapter 5-20, Storm Water Management and Water Quality Controls, Chapter 5-24, Storm Water Management and Sediment Reduction, and Chapter 5-28, Floods;
- Town of Fountain Inn Code of Ordinances, Chapter 21 Floods; and, Land Development Regulations, Article II, Drainage System Design Standards.

# Chapter 2. STORM WATER MANAGEMENT REQUIREMENTS AND STANDARDS

## 2.1 Overview

This chapter presents a set of minimum requirements and standards for storm water management for development within Greenville County, South Carolina. The purpose of the minimum requirements and standards is to reduce the impact of storm water runoff on receiving waterbodies downstream from land development. The goal of this chapter is to address both water quantity and water quality requirements and standards associated with storm water runoff from land development.

## 2.2 Minimum Requirements for Development

### Applicability

Storm water management minimum requirements and standards apply to all land development within unincorporated, non-SCDOT regulated areas of Greenville County and within the municipalities that chose to participate with Greenville County as co-permitees (Simpsonville, Mauldin, Travelers Rest and Fountain Inn) in its NPDES MS4 storm water permit, that consists of one or more of the following:

- All development and redevelopment that involves the disturbance of one acre of land or greater;
- Any commercial or industrial development that falls under the NPDES Industrial Storm Water Permit;
- Development or redevelopment that creates a peak flow increase of greater than one cubic foot per second (cfs);
- Development or redevelopment that requires a storm drain pipe conveyance system (one or more pipes) or alterations to existing storm drain systems; and,
- Development or redevelopment that causes downstream impacts requiring preparation by an engineer or design professional.

As a general requirement for submittal purposes, all land development activities that fall under these provisions shall require the following:

- Land Disturbance Permit Application: Storm Water Management/ Sediment Control Plan (Non-Simplified Storm Water Application) plus the first two pages of a SCDHEC Notice of Intent (NOI) Application upon project submittal);
- Final Site Development Plan including Erosion Prevention and Sediment Control (EPSC) Plan; and
- Technical Report.

For land disturbing activities involving more than 5,000 square feet but less than one (1) acre of actual land disturbance which are not part of a common plan of development or sale, the person responsible for the land disturbing activity may submit a Simplified Storm Water Application. This plan does not require approval by the Director and does not require preparation or certification by the designers.

Commercial and industrial sites which disturb more than 5,000 square feet but less than one (1) acre of area and are otherwise not part of a larger common development plan may be eligible to submit a Simplified Storm Water Application.

### Land Disturbance Permit Application: Storm Water Management/ Sediment Control Plan

The Land Disturbance Permit: Storm Water Management/ Sediment Control Plan Form, hereinafter called the Storm Water Management Permit Application Form or the Non-Simplified Storm Water Application Form (available for download online) shall be completed and contain certification by the person responsible for the land disturbing activity that the land disturbing activity will be accomplished pursuant to the approved plan and that responsible personnel will be assigned to the project. The person responsible for the land disturbing activity shall provide certification to the Director to conduct on-site inspections when needed. Land Development also requires the first two pages of the SCDHEC NOI application in addition to the Non-Simplified Storm Water Application upon project submittal.

### Final Site Development Plans

The Final Site Development Plan shall consist of maps, narratives, and supporting design calculations for the proposed storm water system and should include the following sections when applicable:

- Pre-development hydrologic analysis and calculations that determines the existing storm water runoff volumes, peak flow rates and flow velocities;
- Post-development hydrologic analysis and calculations that determines the storm water runoff volumes, peak flow rates and flow velocities;
- Water quality control calculations for capturing and treating the first inch of runoff from the impervious area and releasing it over a 48 hour period;
- Storm water management control facility location, design, and supporting calculations; and,
- Downstream analysis calculations showing the effect of post-development design flows on downstream storm water conveyance systems and channels. This refers to the 10% rule application as given in the Ordinance. However, a simple time of concentration comparison is insufficient for this analysis. A routing study is required showing flows and water surface elevations at each point downstream.

### Erosion Prevention and Sediment Control Plans

The following items are required to be included as part of the EPSC Plans:

- Location of all erosion and sediment control structures;
- Provisions to preserve topsoil and limit the amount of total disturbed area;
- Details of site grading;
- Design details and computation for all erosion and sediment control structures;
- List of the trapping efficiency for each sediment control structure;
- Calculation of required sediment storage volumes;
- Explanation of any computer models or software used with highlights of the output data; and,
- Description of required clean-out frequencies and maintenance schedules.

### Technical Report

The technical report contains all of the engineering details of the proposed development project in an understandable, legible document. Failure of an applicant to provide all the information required in this section may result in the denial of receiving a Storm Water Management Permit from the Greenville County Storm Water Management Director. The items listed as the technical report submission requirements shall be used as a checklist to verify that all required items are properly submitted.

### Engineer Minimum Plan

Projects that are small in the scope of work but with design criteria that exceeds the applicant capability to prepare for permit submittal and require the service of a professional designer will submit an "engineer minimum plan". A design professional would be required if the project scope does not result in more than one cubic feet per second increase in peak runoff rates but involves one or more of the following conditions:

- Development of a lot where quantity is in place as part of a larger common plan but post-construction water quality may or not be in place and a construction erosion control plan is needed.
- Redevelopment of the site requires post construction water quality upgrades and a construction erosion control plan.
- Minor modification or reconstruction of an existing storm water quantity or quality feature or structure. (Only if revised drainage calculation for quantity are not required. If it does require a new analysis this project would require a permit)
- A small project draining to water bodies that are on the current 303(d) list or where a TMDL has been developed or have the potential for impact requiring a BMP and site stabilization plan as a means of correcting a site found in violation of grading without a permit.
- The small project may cause downstream impacts that could place the safety of the public at risk, property damage may occur, or negative impacts to the water bodies may occur.
- The small project requires a storm drain pipe conveyance system (one or more pipes) or alternations to an existing storm drain system.

The application and permit process for an engineer minimum plan are the same as the non simplified permit with exception to the design criteria and the fees. The minimum design criteria will be established on a case by case basis during the Pre Design Meeting with the Land Development Division representative. The fees will be the same as a simplified permit.

Engineer minimum plans will require project oversight by the design professional. Depending on the scope of work, CEPSCI inspections and certification by the engineer of record may be required. Based on the disturbed area and whether the project is a part of a larger common development, engineer minimums may be forwarded to SCDHEC for general permit coverage.

## 2.2.1 Exemptions

The following development activities within the unincorporated, non-SCDOT regulated areas of Greenville County and within the cities of Travelers Rest, Mauldin, Simpsonville, and Fountain Inn that that have chosen to participate as a co-permitee with Greenville County in its NPDES MS4 storm water permit shall be exempt from the minimum regulations and standards:

- Development that does not disturb more than 5,000 square feet.

- Development that does not create a peak flow increase of greater than one cfs.

- Construction or improvement of single family residences or their accessory that are separately built and not part of multiple construction of a subdivision development and that are anticipated to disturb an area of less than 5,000 square feet (1/9$^{th}$ of an acre).

- Land disturbing activities on agricultural land for production of plants and animals useful to man, including but not limited to forages and sod crops, grains and feed crops, tobacco, cotton, and peanuts; diary animals and dairy products; poultry and poultry products ; livestock, including beef cattle, sheep, swine, horses, ponies, mules, or goats, including the breeding and grazing of these animals, bees; fur animals and aquaculture, except that the construction of an agricultural structure resulting in the disturbance of one acre or more are not exempt. The construction of agricultural structures of one or more acres, such as broiler houses, machine sheds, repair shops and other major buildings which require the issuance of a building permit shall require the submittal and approval of a Storm Water Management Plan.

- Certain land disturbing activities undertaken by persons who are exempt from the provisions of the Storm Water Management and Sediment Reduction Act as set forth in Section 48-14-40 of the 1976 Code of Laws of South Carolina as amended.

- Land disturbance activities undertaken on forest land for the production and harvesting of timber and timber products as qualified by the South Carolina Forestry Commission as true to tree farming practices for stewardship.

- Land disturbing activities that are conducted under another State or Federal environmental permitting, licensing, or certification program where the State or Federal environmental permit, license, or certification is conditioned on compliance with the minimum standards and criteria developed under this Design Manual.

- Any land disturbing activities undertaken by any entity that provides gas, electrification, or communication services, subject to the jurisdiction of the South Carolina Public Service Commission.

- Emergency repairs of a temporary nature made on public or private property that are necessary for the preservation of life, health, or property and are made under circumstances where it would be impracticable to obtain a Storm Water Management Permit.

### 2.2.2 Waivers and Variances

The Greenville County Storm Water Management Director may grant waivers and variances from the storm water management requirements set forth in this Design Manual and other ordinances, standards, and regulations regarding storm water. The applicant must provide a written request for a waiver or variance in the Storm Water Management Permit application package. The Greenville County Storm Water Plan Review Agency has the authority to reject a written request for a waiver if the waiver is deemed unacceptable or is associated with a project located in sensitive areas of Greenville County where waivers have been deemed to be unacceptable.

The Greenville County Storm Water Plan Review Agency shall conduct its review of a waiver or variance submitted by the applicant within ten working days of the submittal. Failure of the Review Agency to act on the waiver by the end of ten working days will result in the automatic approval of the waiver.

### Waiver from Permanent Water Quality Control

A project may be eligible for a waiver of storm water management requirements for water quality control if the applicant can justly verify the following and the applicant requests a variance as given in Section 8-122 of the Storm Water Management Ordinance.

- The proposed land development activity will return the disturbed areas to the pre-development land use and runoff conditions;
- The proposed land development will create land use conditions that have the potential to discharge less pollutants than the pre-development land use conditions; and,
- The pre-development land use conditions are unchanged at the end of the project.

This waiver does not exclude water quality, erosion prevention, sediment control and water quantity controls from being implemented during the active construction phases of a particular project.

### Waiver from Permanent Water Quantity Control

A project may be eligible for a waiver of storm water management requirements for water quantity control if the applicant can justly verify the following and the applicant requests a variance as given in Section 8-122 of the Storm Water Management Ordinance. A map showing points where detention waivers can be considered is provided in **Figure 2-1**.

- The proposed project will not create any significant adverse effects on the receiving natural waterway or road crossings downstream of the property. These adverse impact may include but are not limited to the following:
    - Increased flow velocity that would enhance channel erosion;
    - Increased peak flow rates that are higher than the capacity of downstream bridges and culverts; and,
    - Increased flow depth that would flood outbuildings, air conditioning units, crawl spaces, or finished floor elevations.
- The installation of storm water management facilities would have insignificant effects on reducing downstream peak flow rates and flood peaks.
- Storm water management facilities are not needed to protect downstream developments and the downstream drainage system has sufficient capacity to receive the increases in runoff from the development.
- The imposition of peak flow rate control for storm water management would create, aggravate, or accelerate downstream flooding.

This waiver does not exclude water quality, erosion prevention, sediment control and water quantity controls from being implemented during the active construction phases of a particular project.

### Variances

The Greenville County Storm Water Plan Review Agency may grant or approve a written variance from any of the requirements of the regulations set forth in this Design Manual. These variances apply where there are exceptional circumstances applicable to sites such that strict adherence to the regulations could result in unnecessary hardship and not fulfill the intent of the regulations.

A written request for variance shall be provided to the Greenville County Storm Water Plan Review Agency and shall specifically state the variances sought and all data that supports the variance. The Greenville County Storm Water Plan Review Agency shall not grant a variance unless and/or until the applicant provides sufficient specific site data and justification for the variance.

## 2.3 Special Pollution Abatement Permits

A Special Pollution Abatement Permit is required when development or redevelopment occurs within a watershed that drains to a waterbody listed as impaired by the South Carolina Department of Health and Environmental Control (SCDHEC) or has an established total maximum daily load (TMDL) developed and implemented for a pollutant(s) of concern to ensure that effective best management practices (BMPs) are used to control water quality for these waterbodies. A Special Pollution Abatement Permit will be valid for a period of five (5) years, at which point it must be renewed. At the time of renewal, any deficiencies in the control of the targeted pollutants or management method must be corrected. Any development that occurs without a required permit shall be a violation of Division 9 of the Greenville County Storm Water Management Ordinance.

Development in other areas known to have particular adverse water quality pollutant impacts may also be required to comply with this requirement at the discretion of the Director. Areas that qualify have been identified by sampling and monitoring results and are given as priority areas for water quality treatment. Outstanding resource waters may also qualify for compliance with this requirement for protection of their classification.

Requirements for Special Pollution Abatement Permit requests are presented along with Anti-Degradation Rule requirements in Section 9.9 of this Design Manual.

# Chapter 3. PLAN SUBMITTAL

## 3.1 Storm Water Management Planning

### 3.1.1 Purpose

The purpose of Storm Water Management Planning is to ensure that storm water management is considered and fully integrated at the early planning stages of the site-development process. This involves a more comprehensive approach to site planning and a thorough understanding of the physical characteristics and resources associated with the project site. Site designers are encouraged to develop comprehensive Storm Water Management Plans for proposed development. This planning includes addressing each of the following categories separately:

- Storm water quantity controls;
- Erosion and sediment control;
- Storm water quality controls;
- Storm water conveyance controls; and,
- Pollution abatement controls.

The result of this planning is a comprehensive report that contains technical information and analysis to submit to the Greenville County Storm Water Management Review Agency to determine if the proposed development meets the Greenville County storm water regulations and the standards contained in this Design Manual.

### 3.1.2 Preferred Storm Water Management Facilities

Storm water management facilities may include structural and non- structural practices. Natural swales and other natural runoff conduits shall be retained where practicable.

Where additional storm water management facilities are required to satisfy the minimum control requirements, the following measures are examples of what may be used in their order of preference:

1. Low impact development (LID) practices, such as minimizing the area of streets, parking lots and rooftops; bio-retention swales and basins; porous pavement; or other innovative measures to reduce runoff volume and protect water quality.
2. Facilities designed to encourage overland flow, slow velocities of flow, and flow through buffer zones;
3. Regional storm water detention structures (dry basins);
4. Regional storm water retention structures (wet basins);
5. On-site storm water detention structures (dry basins);
6. On-site storm water retention structures (wet basins); and
7. Infiltration practices, where permeable soils are present.

## 3.1.3 Fee-in-Lieu of Storm Water Management Facilities

### 3.1.3.1 Introduction

Greenville County's Storm Water Ordinance provides a mechanism to allow for the payment of a fee-in-lieu of providing storm water detention on a development site. This fee may be allowed in certain areas of the county or for certain sites in lieu of a detention structure. This fee is also set to encourage the use of low impact development (LID) practices to reduce runoff and improve water quality.

### 3.1.3.2 Application

If the impervious area of a proposed development site is one acre or less it may qualify for a detention waiver and acceptance based on a fee-in-lieu of storm water detention requirements and fee schedule. Development sites with impervious areas greater than one acre may be eligible for a wavier from site specific storm water detention requirements based on contributing a fee-in-lieu of storm water detention requirements and a fee based on the cost to design, build, maintain, landscape, etc., where the land cost is not part of the fee equation.

Greenville County has specified watersheds where a fee-in-lieu of storm water detention requirements is preferred. On sites with impervious areas of one acre and less, this is the preferred method. To encourage this application, developers are subject to a fee wavier if appropriate LID practices are used to reduce runoff volumes and control peaks. Certain practices are required such as enhanced infiltration with use of permeable pavements, bio-swales and bio-retention cells, rain gardens, storm water harvesting and reuse, green roofs, etc. to most likely meet the criteria.

Sites with larger impervious areas must be able to prove no downstream impact and be in a location where the county intends to construct storm water conveyance upgrades or regional controls.

### 3.1.3.3 Criteria

The following criteria must be considered and determined to be favorable for applying the fee-in-lieu of storm water detention:

1. Modeling shows that the installation of site specific detention controls results in unfavorable increases in downstream peak discharges, flooding depths, erosion (channel degradation), and water quality impacts;

2. Runoff from the area is controlled via a regional, county maintained system of conveyance, storage and water quality enhancements;

3. Development of a site with one acre or less impervious area, or with a flow increase of 1 or more cfs. (The fee-in-lieu of detention is determined by a cost of $1.00 per square foot per impervious area up to 43,560 square feet. This fee can be waived with the use of LID practices that reduce runoff rates and volumes. The fee-in-lieu for sites with developed impervious areas of 43,561 square feet and greater is based on the construction, design, maintenance of the structure that would otherwise be required for the site. The fee-in-lieu does not include the cost of the land.)

4. The MS4 conveyance system and the natural system provides adequate capacity such that in full build out conditions in the watershed it can be demonstrated that there are no adverse effects due to

flooding or water quality or other detrimental effect to all upstream, adjacent and downstream properties.

5. The development adds a minimum of 5,000 square feet of impervious area. This does not apply to individual residential home construction that is separately built. It may apply to a residential subdivision that is part of a larger common plan of development. In the case of a subdivision the impervious area includes the roads, sidewalks, and individual homes.

6. The proposed development is located in a watershed where a model and master plan exists to evaluate the impact of fee in lieu of storm water detention and water quality impacts. Currently these areas are Horspen creek (i.e., Gilder), Brushy Creek, Rocky Creek, and Reedy River watersheds. Others will be included as plans are completed.

### 3.1.4 Steps for Successful Storm Water Management Plans

The design of successful storm water management plans involves adhering to the following requirements where applicable:

- Pre-design meeting.
- Review of site development requirements.
- Detailed site analysis.
- Creation of a Storm Water Concept Plan (for innovative techniques).
- Creation of a Preliminary Site Development Plan.
- Completion of Final Site Development Plan.

#### Pre-Design Meeting

One of the most important actions that happens at the beginning of the land-development process is a pre-design meeting between the Greenville County Storm Water Management Review Agency, developer/owner and design professional. This meeting allows all of the entities involved in the land development process to understand the storm water management requirements and identify the areas on the site that will require the most attention to meet the requirements of the regulations. Major incentives for the pre-submittal site meeting are establishing a partnership between all of the entities involved through the entire development process, and increasing the chances of faster Greenville County Storm Water Management Permit approval through an early understanding of the permitting and plan requirements. It shall be left to the discretion of the Greenville County Storm Water Management Review Agency and the Director if this meeting shall or shall not be required for a specific project.

#### Review of Site Development Requirements

The Storm Water Management Plan design professional should be familiar with the Greenville County Storm Water Management Permit requirements that are given in this Design Manual. Most of this guidance can be obtained at the pre-design meeting.

The plan design professional must also be familiar with other local requirements and ordinances such as, but not limited to the following:

- Zoning ordinances.
- Subdivision regulations.
- Road, SCDOT and utility requirements.
- Land development regulations.

- Floodplain management ordinances.
- Other Local, State, and Federal regulatory requirements and ordinances.

## Detailed Site Analysis

To better understand the existing topography, hydrology and hydraulics of the proposed development, the design professional should personally make a field site visit. During this visit, the design professional should collect as much information as necessary to create an accurate existing condition map of the proposed site. If the design professional has a good understanding of the existing site conditions, it should be easier to implement a storm water management plan that will effectively protect downstream water quantity and quality impacts. An actual site visit also gives the design professional an initial vision of how the potential storm water management system can fit with the natural surroundings. Items to be recorded during the site visit shall include, but are not be limited to the following:

- Topography of the site especially very steep sloped areas.
- Natural drainage patterns, swales, and detention areas.
- Natural perennial flowing streams and intermittent streams.
- Existing floodplain locations and elevations.
- Soil types and evidence of eroded and/or non-eroded soils.
- Existing vegetation including the corresponding density of each type of vegetation:
    - Trees
    - Grasslands
    - Various ground covers

- Existing development including roads, buildings, utility easements, parking areas, and ponds.
- Existing storm water facilities including ditches, storm sewer systems, and detention ponds.
- Adjacent property characteristics and storm water outfall points.
- Wetlands.
- Critical habitat areas.
- Boundaries of existing wooded areas.
- Existing buffer areas along natural drainage ways and channels.

## Creation of a Storm Water Concept Plan for Innovative Practices

The Storm Water Concept Plan involves the overall layout of the site including the storm water management system layout. This Concept Plan is an optional step which gives the design professional the opportunity to propose several potential site layout possibilities to the developer/owner and the Greenville County Review Agency. A concept plan may be needed if the design professional is proposing innovative design approaches not currently outlined in the design manual or if deviations from the design manual are proposed. Deviations will require a written request for exemptions or waivers. Innovative methods and technologies are encouraged and shall be accepted providing there is sufficient documentation to prove the effectiveness and reliability of the proposed approach.

This step is not required as part of the ordinance. However, it is encouraged for designs that are innovative and require some discussion and thought and may propose different challenges from a permitting perspective. This concept plan should focus on the proposed layout and BMPs for during and post construction applications that are unique and require a non standard approach. When LDD has agreed to the concept presented then the applicant can proceed to develop a preliminary set of plans that incorporates the concepts agreed upon.

Upon concurrence of the Concept Plan, the applicant shall create and submit a Final Site Development

Plan. However, concurrence in the concept stage will not prevent the Director from rejecting the Site Development Plan during the formal review process if it is determined that the plan does not comply with federal, state, or local laws and regulations including Greenville County ordinances. A Concept Plan may be submitted for review at the conclusion of the pre-design meeting if all the documentation required on the concept plan check list is included in the submittal.

The following steps should be followed when developing the Storm Water Concept Plan:

- Based on the review of the existing site conditions, utilize the appropriate best site design approaches. This will minimize the size and number of water quantity and water quality controls needed to comply with the Greenville County Storm Water Management Permit requirements.

- Perform preliminary selections and potential locations of all water quantity and water quality controls including storm water conveyance systems and erosion and sediment control structures. Suggested uses for temporary EPSC BMPs are summarized in Appendix E and permanent storm water quality BMPs are summarized in Appendix G.

It is very important that a Storm Water Concept Plan is integrated into the overall site design process and not procrastinated to be the last topic covered before submittal of the permit package. The application of a Concept Plan should expedite the final design process and review process to obtain a Greenville County Storm Water Management Permit.

To achieve maximum benefits, the Storm Water Concept Plan should include at a minimum the following elements when applicable:

- Site address and description of the site (owner and tax map number).
- Vicinity map of the project location.
- Existing conditions and proposed development plan having at least the following items:

    - Existing and proposed contours.
    - Perennial and intermittent streams.
    - Watershed delineation maps.
    - Existing vegetation boundaries and proposed clearing limits.
    - Location of all existing natural features such as wetlands, ponds, lakes, floodplains, and stream buffers.
    - Location of existing and proposed roads, buildings, parking areas and other impervious surfaces.
    - Existing and proposed utility easements.
    - Preliminary selection and location of all storm water management control facilities including erosion and sediment control structures.
    - Location of existing and proposed conveyance systems such as grass channels, swales, and storm sewer systems.
    - Preliminary location and dimensions of all culvert and bridge crossings.

## Preliminary Site Development Plan

The Preliminary Site Development Plan shall consist of maps, narratives, and supporting design calculations for the proposed storm water system and should include the following sections when applicable:

- Pre-development hydrologic analysis and calculations that determines the existing storm water runoff volumes, peak flow rates and flow velocities.

- Post-development hydrologic analysis and calculations that determines the storm water runoff volumes, peak flow rates and flow velocities.

- A 360 degree map showing:

  - Data to support the hydrology model
  - Areas delineated, curve numbers (CNs), slopes, contours, flow path segments
  - Photography
  - Network diagram for the hydrology model

- Storm water management control facility design:

  - Narrative describing the storm water management control facilities selected.
  - Location of all storm water management control facilities.
  - Supporting calculations that justify that the facilities meets the Greenville County Storm Water Management Permit requirements. Includes hydrographs, stage storage volumes, and stage discharge values for water quantity and water quality control facilities and design calculations and elevations for all storm water conveyance systems.
  - A permanent maintenance plan for each permanent storm water management facility.

- Erosion and sediment control plan:

  - Narrative describing the erosion and sediment control facilities selected.
  - Location of all erosion and sediment control facilities.
  - Resulting design calculations and trapping efficiencies for all sediment control facilities.

- Downstream analysis calculations showing the effect of post-development design flows on downstream storm water conveyance systems and channels.

### Minimum Preliminary Site Development Plan Requirements

All Preliminary Site Development Plans shall include as a minimum the following:

- A vicinity map indicating a north arrow, scale, boundary lines of the site and other information necessary to locate the development site.

- The existing and proposed topography of the development site except for individual lot grading plans in single-family subdivisions.

- Physical improvements on the site, including present development and proposed development.

- Location, dimensions, elevations, and characteristics of all storm water management facilities. As a minimum, easements shall have the following characteristics.

  - Provide adequate access to all portions of the drainage system and structures.
  - Provide sufficient land area for maintenance equipment and personnel to adequately and efficiently maintain the drainage system and all storm water facilities.
  - Restriction on easements shall include prohibiting all fences and structures which would

interfere with access to the easement areas and/or the maintenance function of the drainage system.

- All areas within the site which will be included in the land disturbing activities shall be identified and the total disturbed area calculated.

- The location of temporary and permanent vegetative and structural storm- water management control measures.

- An anticipated starting and completion date of the various stages of land, disturbing activities and the expected date the final stabilization will be completed.

- A determination that the development is in compliance with the County Floods and Flood Control Ordinance.

- At the discretion of the Director, for all portions of the drainage system which are expected to carry over 50 cubic feet per second (cfs) for the 100-year storm, the 100-year plus one foot flood elevation analysis shall be required if one of the following criteria apply:

  - The estimated runoff would create a hazard for adjacent property or residents
  - The flood limits would be of such magnitude that adjacent residents should be informed of these limits.

- For all portions of the drainage system which are expected to carry 150 cfs or more for the 100-year storm, the 100-year plus one foot flood elevation analysis shall be done and flood limits shall be shown on the drainage plans. Such data shall be submitted in digital form, as well as in print, in a format specified by the Director.

- Plans must meet all other applicable plan requirements in effect at the time of submittal.

- A Tree saving and planting plan consistent with the requirements in the Greenville County Tree Ordinance and the Landscape Plan requirements of this Design Manual.

- To prevent water quality degradation and to improve the water quality aspects of the drainage system, the plan shall include best management practices to control the water quality of the runoff during the land disturbing activities and during the life of the development. The plan shall include all engineering calculations needed to design the system and associated structures including pre- and post-development velocities, peak rates of discharge, inflow and outflow hydrographs of storm water runoff at all existing and proposed points of discharge from the site.

- Description of site conditions around points of all surface water discharge including vegetation and method of flow conveyance from the land disturbing activity.

- Construction and design details for structural controls.

- The expected timing of flood peaks through the downstream drainage system shall be assessed when planning the use of detention facilities.

- All storm water management facilities and all major portions of the conveyance system through the proposed development (i.e., channels, culverts) shall be analyzed, using the 100-year design storm, for design conditions and operating conditions which can reasonably be expected during the life of the facility. The results of the analysis shall be included in the hydrologic-hydraulic study.

- If the site development plan and/or design report indicates that there may be a drainage or flooding problem at the exit to the proposed development or at any point downstream as determined by the Director, the Director may require:
    - water surface profiles plotted for the conditions of pre- and post- development for the 2-year through 100-year design storm;
    - water surface profiles plotted for the conditions of pre- and post- development for the 100-year design storm;
    - elevations of all structures potentially damaged by the 2-year through 100-year flows.

- All plans submitted for approval shall comply with the applicable requirements in Divisions 3, 5, 6, and 7 of the Greenville County Storm Water Management Ordinance.

- All plans submitted for approval shall contain certification by the person responsible for the land disturbing activity that the land disturbing activity will be accomplished pursuant to the approved plan and that responsible personnel will be assigned to the project.

- The site development plan shall contain certification by the applicant that all land clearing, construction, development and drainage will be done according to the site development plan or previously approved revisions. Any and all site development permits may be revoked at any time if the construction of storm water management facilities is not in strict accordance with approved plans.

- All plans shall contain certification by the person responsible for the land disturbing activity of the right of the Director to conduct on-site inspections.

- The plan shall not be considered approved without the inclusion of an approval stamp with a signature and date on the plans by the Land Development Division. The stamp of approval on the plans is solely an acknowledgement of satisfactory compliance with the requirements of these regulations. The approval stamp does not constitute a representation or warranty to the applicant or any other person concerning the safety, appropriateness or effectiveness of any provision, or omission from the site development plan.

### Completion of Final Site Development Plan

The Final Site Development Plan shall include, and add further detail to the Preliminary Storm Water Management Plan if needed. This plan shall reflect any changes or modifications requested or required by the Storm Water Management Review Agency. The Final Site Development Plan shall include all of the revised elements from the Preliminary Site Development Plan and shall contain all of the Technical Report Submission Requirements. The completed Final Site Development Plan shall be submitted to the Greenville County Storm Water Management Review Agency for final review and approval prior to initiating any construction activities on the proposed development site.

## 3.2 Submittal Requirements for Sites with Less Than One Disturbed Acre

The person or entity responsible for any land disturbing activity, including commercial and industrial sites, that disturbs more than 5,000 square feet but less than one acre of land, and is not part of a larger common plan development, shall submit a Simplified Storm Water Management Control Plan. This plan does not require approval by the Public Works Department or the Storm Water Management Review

Agency, and does not require preparation or certification by a professional designer.

For all land disturbing activities that will result in more than one cubic foot per second increase in peak runoff rates, requires a storm drain pipe conveyance system (one or more pipes), or alterations to existing storm drain systems, or cause downstream impact requiring preparation by an engineer or design professional, the requirements for sites with one or more acres of land disturbed (see Section 3.3) including all requirements of a Site Development Plan (see Section 3.1.4) shall apply.

#### Simplified Storm Water Management Control Plan

The Simplified Storm Water Management Control Plan shall contain the following items:

1. Narrative description of the storm water management facilities to be used.

2. General description of topographic and soil conditions at the development site.

3. General description of the adjacent property and description of existing structures, buildings, and other fixed improvements located on surrounding properties.

4. A sketch to accompany the narrative containing the following when applicable:

    - Site location drawing of the proposed project showing project location in relation to roadways, jurisdictional boundaries, streams, rivers and the boundary lines of the site to be developed.
    - All areas within the site that will be included in the land disturbing activities shall be identified and the total disturbed area shall be calculated.
    - Topographic map of the site.
    - Anticipated starting and completion dates of the various stages of the land disturbing activities and the expected date of final stabilization shall be noted.
    - Location of temporary and permanent vegetative and structural sediment control and storm water management control measures.

5. Simplified Storm Water Management Control Plans shall contain certification by the persons responsible for the land disturbing activities that the activities will be accomplished pursuant to the plan.

6. Simplified Storm Water Management Control Plans shall contain certification by the person responsible for the land disturbing activities of the right of the Director to conduct on-site inspections.

## 3.3 Submittal Requirements for Sites with Greater Than One Disturbed Acre

The person or entity responsible for any land disturbing activity that disturbs one or more acres of land or will result in more than one cubic foot per second increase in peak runoff rates, requires a storm drain pipe conveyance system (one or more pipes), or alterations to existing storm drain systems or cause downstream impact requiring preparation by an engineer or design professional, all of the requirements of a Site Development Plan (see Section 3.1.4) shall apply. Professionally certified site development plans, erosion and sediment control plans, specifications, and supporting calculations and computations shall be submitted and stamped/sealed by professionally licensed engineers, landscape architects or Tier B land surveyors.

The Greenville County Storm Water Management Permit Application (Non-Simplified Storm Water Application) can be processed efficiently if all necessary information is included with the permit application. This section of the Design Manual explains the information required in order to obtain the desired permit. With proper planning and coordination, the permit processing time requirements can be kept to a minimum. The items discussed in this section of the Design Manual should be used as a checklist prior to the submittal of the permit application. The initial submittal package shall contain:

- A completed Greenville County Storm Water Management Permit Application (Non-Simplified Storm Water Application) Form,
- Completed first two pages of the SCDHEC NOI Application Form;
- One copy of the Final Site Development Plan including the Sediment Control Plan.
- One copy of the Technical Report and supporting calculations, and
- A completed checklist based on the Technical Report requirements.

### 3.3.1 Applications

All necessary application forms and checklists to use in the Non-Simplified Storm Water Application submittal package can be obtained from Greenville County. The Non-Simplified Storm Water Application must be completed accurately and submitted by the applicant to the Greenville County Storm Water Management Program.

The general submission requirements include the following:

- All required application forms completed neatly, legibly and accurately and signed by the owner or authorized agent.
- All required checklists completed neatly, legibly and accurately.
- One paper copy of the Final Storm Water Management and Sediment Control Plans completed neatly, legibly and accurately.
- One copy of the Technical Report providing a summarization of existing and proposed site conditions and the supporting calculations for all storm water management design procedures (See Section 3.3.8).

### 3.3.2 Permits

Unless specifically exempted, a Storm Water Management Permit as required by this Design Manual, shall be obtained prior to the commencement of any development, redevelopment, building, excavating, grading, re-grading, paving, landfilling, berming or diking of any property located within Greenville County.

Other applicable permits such as Federal, State or other local agency may be required for specific project sites. It is the applicant’s responsibility to recognize the need to obtain all necessary permits before submitting for a Storm Water Management Permit.

### 3.3.3 Storm Water Management Design Standards

It is an overall goal of this Design Manual to address storm water management to provide effective water quantity and water quality solutions due to the impact of runoff from land development. The following set of criteria shall be followed in the absence of designated specific watershed master plan criteria.

#### Hydrologic Computations

All hydrologic computations shall be completed using acceptable volume based hydrograph methods. The design storm duration for these computations shall be the 24-hour storm event and a SCS Type II distribution with a 0.1-hour duration time increment. Typical hydrologic input includes but is not limited to the following:

- Storm frequency and duration
- Rainfall depth or intensity
- United States Geological Survey (USGS) soil classification and hydrologic soil group
- Land use
- Time of concentration
- Abstractions

#### Water Quantity Control

Water quantity control is an integral component of overall storm water management. The following design criteria are established for water quantity control unless a waiver is granted on a case-by-case basis.

- May be controlled with above ground wet or dry detention basins, and/or underground detention facilities.
- Post-development discharge rates shall not exceed pre-development discharge rates for the 2-, 10-, and 25-year frequency 24-hour duration storm events.
- Post-development discharge velocities shall be reduced to provide non-erosive flow velocities from structures, channels or other control measures, or be equal to the pre-development 10-year 24-hour storm event flow velocities, whichever is greater.
- Emergency spillways shall be designed to safely pass the post-development 100-year 24-hour storm event without overtopping any dam structures.
- Downstream analysis shall be required for the 2-, 10-, 25-, and 100-year frequency 24-hour duration storm events for all development sites unless a waiver or variance is granted from this analysis. When water quantity controls are implemented, an off-site analysis waiver may not be required, provided that all required design criteria of the Design Manual are met.
- A downstream peak flow analysis shall include the assumptions, results and supporting calculations to show safe passage of post-development design flows downstream. The analysis of downstream conditions in the report shall address each and every point or area along the project site's boundaries at which runoff will exit the property. The analysis shall focus on the portion of the drainage channel or watercourse immediately downstream from the project. This area shall extend downstream from the project to a point in the drainage basin where the total area of the development comprises ten percent (10%) of the total basin area. In calculating runoff volumes and discharge rates,

consideration may need to be given to any planned future upstream land use changes. The analysis shall be performed in accordance with the requirements of this Design Manual

- Watersheds that have well documented water quantity problems may have more stringent or modified design criteria determined form master plan studies by Greenville County.

- All storm water systems shall be designed to have no increase in velocity, peak flow, water surface level elevation in relationship to upstream, adjacent, and downstream property in the 100-year storm, unless an adequate permanent drainage easement is obtained.

## Water Quality Control

All development and redevelopment projects and portions of redevelopment projects disturbing one acre or more or that will result in more than one cubic foot per second increase in peak runoff rates shall meet these requirements of this section even though there is not a change in land use.

Water quality control is integral component of overall storm water management. All storm water runoff generated from a site shall be adequately treated before discharge. It will be presumed that a storm water management system complies with this requirement if the following minimum design criteria are met unless a waiver is granted on a case-by-case basis:

1. The preferred method is to size permanent water quality capture devices to trap 85% of total suspended solids (TSS) based on annual loadings. An alternative as a default criteria, a device may be sized to capture the first inch of runoff from the impervious area of the site and discharge it over a twenty-four (24) hour period. and.
2. The Director has discretion to require more stringent controls for water quality where the Director determines the minimum standards of this section are not adequate. Areas where more stringent controls may apply include outstanding resource waters, trout waters, wetlands, steep slopes, TMDLs or other sensitive areas.
3. Appropriate structural storm water controls or non-structural practices are selected, designed, constructed or preserved, and maintained according to the specific criteria in this Manual.

- Any permanent water quality device shall be required to meet these requirements.

- When existing wetlands are intended to be water quality structures, the Storm Water Management Permit shall not be implemented until all necessary Federal and State permits have been obtained.

## General Storm Water Management Permit Submittal Items

The following items are required to be included in the submittal package for a Storm Water Management Permit.

- Watershed delineation maps.

- Location of all storm water management structures.

- Pre- and post-development peak flow volumes, peak flow rates, peak flow velocities and inflow and outflow hydrographs of storm water runoff at all existing and proposed points of discharge from the site for the 2-, 10-, 25-, and 100-year 24-hour storm events.

- Site conditions around points of all surface discharge including vegetation and method of conveyance from the land disturbing activity.

- Design details and computation for all storm water management controls, including the following:
    - Drainage area calculations.
    - Weighted curve number or runoff coefficient calculations.
    - Time of concentration calculations.
    - Pipe size capacity and velocity calculations.
    - Open channel capacity and velocity calculations.

## 3.3.4 Erosion and Sediment Control Design Standards

It is an overall goal of this Design Manual to address erosion and sediment control to provide effective water quality solutions due to the impact of runoff from land development. The following set of criteria shall be followed in the design of erosion and sediment control solutions.

### Design Removal Efficiency Goal

All sediment control structures shall be designed and installed to accommodate the anticipated sediment loading from all land disturbing activities and meet a minimum design removal efficiency of 80 percent total suspended solids (TSS) or 0.5 ml/L settleable solids effluent standard, whichever is less, for disturbed conditions for the ten-year 24-hour storm event.

### Design Requirements

A sediment detention basin is required when ten or more acres of disturbed land area drain to a single outlet point. Such basins shall be designed to have a minimum design removal efficiency of 80 percent TSS or 0.5 ml/L settleable solids effluent standard using a 10-year 24-hour design storm, whichever is less, and control the 10-year 24-hour storm event to pre-development conditions and successfully pass the 100-year 24-hour storm event. The person responsible for the activity shall submit a full Non-Simplified Storm Water Application which shall be prepared or certified by a registered engineer, landscape architect, or Tier B land surveyor.

Land disturbing activities that create between one and ten acres of land area that do not drain to a single outlet point may incorporate other practices other than a sediment basin to achieve the equivalent removal efficiency of 80 percent TSS or 0.5 ml/L settleable solids effluent standard, whichever is less using a 10-year 24-hour design storm.

The person responsible for the activity shall submit a full Non-Simplified Storm Water Application which shall be prepared or certified by a registered engineer, landscape architect, or Tier B land surveyor.

Land disturbing activities that create less than one acre of disturbed area are **not** required to receive approval for a Storm Water Management Permit from the Storm Water Plan Review Agency. The person responsible for the activity shall submit a Simplified Storm Water Application which does not require preparation or certification by a registered engineer, landscape architect, or Tier B land surveyor.

Sediment storage volumes shall be calculated for all sediment controls to determine the required clean-out frequencies and maintenance schedules. The Universal Soil Loss Equation (USLE) or other acceptable methods that determine sediment yield may be used to predict the required sediment storage volumes for specific sediment control structures.

Additional design requirements for erosion and sediment control practices are as follows:

- Development shall be fitted to the topography and soils so as to create the least erosion potential;
- Natural vegetation shall be retained and protected wherever possible;
- Natural vegetation and non-structural methods shall be employed to the extent possible, for streambank stabilization and erosion control in place of structural methods wherever possible;
- Only the smallest practical area shall be exposed and then only for the shortest practical period of time;
- Erosion control practices such as interceptor ditches, berms, terraces, contour ripping, soil erosion checks, and sediment basins shall be installed to minimize soil and water losses;
- Temporary vegetation or mulching shall be used to protect areas exposed during the time of development;
- During and after development, storm water management practices shall be utilized to effectively accommodate increased runoff caused by changes in soil and surface conditions, and to avoid siltation of receiving streams;
- Permanent vegetation and structures shall be installed in the development as soon as the weather permits;
- The design of outlet channels for the discharge of storm runoff shall be based on the runoff from predicted storm frequency and shall include the vegetative or structural measures required to protect the channel from scour and erosion;
- Waterway stabilization structures such as drop structures, grade stabilization structures, and channel liners shall be utilized to dissipate the energy of flowing water by holding the waterway slopes and velocities within non-erosive limits;
- Sediment basins and traps:
    1) Sediment shall be removed mechanically when the sediment basin behind the temporary barrier or the dam becomes filled, to an elevation shown on the plan or when the design capacity has been reduced by 50%. The structure may be removed once stability is reached in the development area;
    2) A sediment basin or sediment trap may be required to be enclosed, in the discretion of the Director, when necessary to ensure public safety;
- Cut and fill slopes and other exposed areas shall be planted or otherwise protected from erosion before the release of the permit obligations. The responsibility shall remain with the permittee or owner until the planting is well established;
- Fill may not be deposited beyond the mean high-water line unless the fill is used for marsh creation or shore restoration and does not extend beyond the mean low-water line or the fill is placed behind a structural shoreline erosion control device;
- Calculations for design of all BMPs for sediment control must be included as part of the permit application. Locations and timing of installation of sediment control BMPs must be shown on the Sediment and Erosion Control Plan and included as part of the SWPPP;
- Description of measures to prevent the discharge of solid materials, including building materials, to waters of the State and the United States, except as authorized by a permit issued under section 404

of the Clean Water Act;

- Description of measures to minimize, to the extent practicable, off-site tracking of sediments onto paved surfaces and the generation of dust;
- Description of construction and waste materials expected to be stored on-site, updated as appropriate, and controls, including storage practices, to minimize the exposure of the materials to storm water;
- Description of spill prevention and response practices;
- All sediment laden diversion channels and ditches shall be designed such that applicable shear stress and velocities are non erosive. The design storm event that should be used is the 10-year 24-hour event; and,
- The surface of stripped or disturbed areas shall be permanently or temporarily stabilized within 14 days after final grade is reached or when left idle for more than 14 days. Temporary erosion and sediment control measures shall be maintained continuously until permanent soil erosion control measures have reached final stabilization.

### General Erosion and Sediment Control Plan Submittal Items

The following items shall be included in the submittal package for a Storm Water Management Permit:

- Location of all erosion and sediment control structures.
- Provisions to preserve topsoil and limit the amount of total disturbed area.
- Details of site grading.
- Design details and computation for all erosion and sediment control structures.
- List of the trapping efficiency of each sediment control structure.
- Calculation of required sediment storage volumes.
- Explanation of any computer models or software used with highlights of the output data.
- Description of required clean-out frequencies and maintenance schedules.

## 3.3.5 Single- and Multi-Family Development Requirements

A storm water management plan must be submitted for single-and multi-family developments to obtain a Storm Water Management Permit. In addition to the requirements of the submittal package highlighted in this Section of the Design Manual, the following is a list of the minimum requirements for the submittal package for single- and multi-family developments where applicable:

- Legal description of all properties located on the plans including tax map numbers.
- The exact legal street names and addresses for the properties.
- The dimensions and border of the lot parcels.
- The name address of the owners of the parcels.
- The minimum finished floor elevations in flood areas.
- Maintenance responsibilities shall be defined in a maintenance agreement with the County for permanent water quality and quantity structures such as ponds, easement, and buffers.
- Digital files compatible with the County’s geographic information system (GIS) must be submitted.

- Calculations and narratives must be submitted documenting compliance with total maximum daily load (TMDL) requirements as appropriate.

In developing plans for residential subdivisions, individual lots shall be required to obtain and comply with a general permit and the residential subdivision development, as a whole, shall be considered a single land disturbing activity requiring a permit. Hydrologic parameters that reflect the ultimate subdivision development shall be used in all engineering calculations.

If individual lots or sections of a subdivision are being developed by different property owners, all land disturbing activities related to the subdivision shall be covered by the approved drainage plan for the entire subdivision. Individual lot owners or developers shall sign a certificate of compliance that all activities on that lot will be carried out in accordance with the approved drainage plan for the residential subdivision.

When the subdivision development reaches the condition where it is fifty (50) percent built the following actions must be taken.

- Where a detention pond is installed as-built certification and drawings are due to the Director
- The detention pond shall be cleaned and stabilized
- Home owners association documents must be filed with the Director defining the responsible party for maintaining the detention pond and any water quality devices installed in the subdivision.
- When the subdivision development is developed to a point between fifty and eighty percent built; individual lot controls as well as other erosion and sediment control BMPs in addition to the sediment/detention pond shall provide the sediment control to meet 80 percent trapping efficiency rather than only the detention pond. Once the subdivision is eighty percent or greater built and the disturbed areas are stabilized according to the requirements of SCR100000 and 72-300 (SC Code of Regulations) then the permittee may file a request for a Notice of Termination of the permit coverage for the subdivision.

## 3.3.6 100-Year Floodplain

The goal of this section of the Design Manual is to provide an overview of the requirements and procedures for proposed land development occurring in the 100-year floodplain. Development is defined as any manmade change to improved or unimproved real estate including, but not limited to, buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations. Ordinance No. 4113 is administered by the County Building Official and provides a comprehensive set of requirements for developing in the floodplain. This section is not intended to replace or supersede the requirements of that ordinance.

### Floodplain Policy

The provisions in this section apply to all development in areas of special flood hazard identified by the Federal Insurance Administration (FIA) in its Floodway Boundary Map and Flood Insurance Rate Maps, dated December 2, 2004 and any revisions thereto, and areas that have base flood elevations determined due to ordinances enforced by the Greenville County.

It is the purpose of the Flood Control Ordinance # 4113 and this section to promote the public health, safety and general welfare and to minimize public and private losses due to flood conditions in specific areas by provisions designed to:

1. Restrict or prohibit uses that are dangerous to health, safety and property due to water or erosion in flood heights or velocities.

2. Require that uses vulnerable to floods, including facilities which serve such uses, be protected against flood damage at the time of initial construction;

3. Control the alteration of natural floodplains, stream channels and natural protective barriers, which are involved in the accommodation of floodwaters.

4. Control filling, grading, dredging and other development which may increase erosion or flood damage; and,

5. Prevent or regulate the construction of flood barriers which will unnaturally divert floodwaters or which may increase flood hazards to other lands.

## Floodplain Standards

The following is a general summary of the provisions contained within the Flood Control Ordinance. This section is not intended to be comprehensive and complete but rather an overview of the general provisions. Ordinance No. 4113 should be reviewed to determine the specific requirements related to development in the floodplain.

- A permit must be obtained from Greenville County for all development in the floodplain.

- Development within the limits of a floodplain cannot cause an increase of the level of the base flood. If such increase is anticipated, then the applicant must submit an application for a Conditional Letter of Map Revision (CLOMR) to the County and the Federal Emergency Management Agency (FEMA).

- If an adverse effect is determined, engineering justification by the use of hydraulic computer models and compensatory storage at hydraulically equivalent sites for the proposed development shall be required.

- No structures are allowed within the floodway or adopted regulatory floodplain in Unnumbered A Zones unless acceptable engineering justification is provided.

- Where conveyance systems carry between 50 and 150 cfs adjacent first floor elevations shall be set 1 foot above the hydraulic grade line.

- There is a 4-feet freeboard requirement on all new construction and substantial improvements.

- All new construction or substantial improvements shall be constructed on properly designed and compacted fill (ASTM D-698 or equivalent) that extends beyond the building walls before dropping below the base flood elevation and has appropriate protection from erosion and scour. The design of the fill or the fill standard must be approved by a registered engineer or meet the engineered support requirements similar to those for V-Zones (as set out in 44 CFR 60.3 (e) (4)).

- All new and replacement water supply and sanitary sewer systems must be designed to minimize or eliminate infiltration into the system.

## Floodplain Study General Criteria

All floodplain studies shall follow the guidelines and procedures as set forth by FEMA and the County. The following general criteria and requirements have been established to help clarify the procedures related to performing a floodplain study in Greenville County.

- The project must be consistent with applicable State and Federal regulations.
- A professional engineer registered in the State of South Carolina shall prepare all studies.
- The following hydraulic computer models for floodplain development in Greenville County are recommended but is not limited to:
  - HEC-RAS
  - WSPRO
- The floodplain analysis shall include the 10-, 50-, 100-, and 500-year, 24-hour storm events.
- Hydrologic analyses should utilize the current land use conditions based on the most updated data within the desired watershed. FEMA only allows for consideration of existing conditions in the watershed. The County can require particular models to be based on built out conditions for its own purposes, but FEMA will not accept these future conditions in the FEMA submittal.
- Volume as well as peak flow shall be evaluated.
- Limits of the 100-year floodplain for the pre-development and post-development conditions shall be shown on the site plan.
- Backwater conditions, local obstructions, bridges, culverts, and storm water conveyance systems shall be considered.
- Digital data shall have the following characteristics:
  - Horizontal Datum: NAD83 (1994)
  - Coordinate System: SPC Lambert Zone 3900
  - Vertical datum: NAD88
  - Units: International Feet
- Data capture methods must result in new data meeting national horizontal and vertical accuracy standards, which are scale dependent. In 1997, the County was mapped at three different scales, 1-inch = 100-feet (100 scale), 1-inch = 200-feet (200 scale), and 1-inch = 400-feet (400 scale). Horizontal accuracy standards are approximately (+/-) 2.5-feet, +/- 5.0-feet, and (+/-) 10.0-feet, respectively for each mapping scale. Vertical accuracy is (+/-) one half of the contour interval for a given area. Therefore, the vertical accuracy standards are (+/-) 2.0-feet for the 100 and 200 scale and (+/-) 4-feet for the 400 scale. New data should not significantly exceed the above standards.
- All proposed work within Unnumbered A zones must be accompanied by hydrologic and hydraulic modeling.
- Calculated flood boundaries shall be submitted in a digital format that is compatible with Greenville County's GIS.

### Floodplain Study Submittal Criteria

Each permit must include:

- Applicants Name
- Address where the work will be done
- Correct tax map I.D. number
- Subdivision name if applicable

A type of development must be chosen. If the work being done falls into "other", please elaborate in the comments section.

Under "Flood Zone" all properties that have floodplains must check either "No. A or A Zone". The No. A zones are floodplain areas that have had a detailed study performed and a base flood elevation is known. The base flood elevation in A Zones have been approximated.

Under "Location in relation to Floodway/Floodplain", all properties that have floodplains must chose "inside adopted floodplain". In the comments section, if the work to be done includes a structure, make a note as to whether the structure is located within the floodplain.
The application must be signed and stamped by a South Carolina Registered Engineer or Surveyor and the applicant must sign the application.

Hydrologic and hydraulic analyses must be contained in a report describing the study methodology, a listing of all assumptions (e.g., rationale for Manning's 'n' values, reasons for revising hydrology, source of topographic information and land use), bridge and cross section data, and a brief description of the project.

All projects being submitted to FEMA must have a completed FEMA MT-1 or MT-2 form as appropriate. These forms can be obtained from the following.

**FEMA website:** www.fema.gov

**FEMA Region IV**
3003 Chamblee Tucker Road
Atlanta, Georgia 30341
(770.220.5400)

**The South Carolina Department of Natural Resources**
Flood Mitigation Program
2221 Devine Street, Suite 222
Columbia, South Carolina 29205
(803.734.9103)

## 3.3.7 Storm Water Facility Ownership and Maintenance

### Ownership

All permanent storm water management facilities shall be privately owned and maintained unless Greenville County accepts the facility for County ownership and maintenance. The owner of all private facilities shall grant the County a perpetual, non-exclusive easement that makes the facility accessible for public inspection and emergency repair.

## On-Going Inspection and Maintenance

A permanent maintenance plan for each permanent storm water management facility shall be included in the Final Site Development Plan. Requirements for on-going inspection and maintenance of permanent storm water management facilities are as follows:

- Storm water management facilities and practices, included in a site development plan, which are subject to an inspection and maintenance agreement, must undergo ongoing inspections to document maintenance and repair needs and ensure that maintenance is completed in compliance with the SWPPP, any agreements and the County's Storm Water Management Ordinance. For developments, which establish a POA or HOA, provisions for long term maintenance, as outlined in SWPPP, must be defined in a maintenance agreement. The provisions of this agreement must also identify a source of funding to support future required maintenance and upkeep activities, and a responsible party. The maintenance agreement shall be recorded in the Greenville County Register of Deed's Office and shall constitute a covenant running with the land to all heirs, successors, and assigns. The Director must be notified of changes in status and personnel or contract information for record keeping and inventory purposes in accordance with its MS4 permit requirements.

- Subdivision site runoff storage areas, and storm water facilities not located in dedicated rights-of-way or easement, shall be granted or dedicated to and accepted by a public entity, or shall be conveyed by plat as undivided equal interests to each lot in the subdivision or to dedicated entities approved by the Director . Included in the dedication shall be a plan for continued management, operation, and maintenance of the storm water facility, including designation of the person or persons responsible for long-term operational management and dedicated funding sources. If title to the land underlying site runoff storage areas and storm water facilities is conveyed by agreement to each of the lots in the subdivision, then:

- A covenant on the face of the plat shall be provided; and

  - Subdivision property owners shall establish a property owner's association to provide for the maintenance of site runoff storage areas and storm water facilities. The association shall be duly incorporated and the property owners' association agreement shall be recorded for all the lots in that subdivision; and

  - The proposed property owners' association by-laws and declaration shall provide for a long term maintenance agreement.

- A storm water management facility or practice shall be inspected on a periodic basis by the responsible person in accordance with the approved inspection and maintenance agreement. In the event that the storm water management facility has not been maintained and/or becomes a danger to public safety or public health, the County shall notify the person responsible for carrying out the maintenance plan by registered or certified mail to the person specified in the inspection and maintenance agreement. The notice shall specify the measures needed to comply with the agreement and the plan and shall specify the time within which such measures shall be completed.

- Inspection programs by the County may be established on any reasonable basis, including but not limited to: routine inspections; random inspections; inspections based upon complaints or other notice of possible violations; and joint inspections with other agencies inspecting under environmental or safety laws. Inspections may include, but are not limited to: reviewing maintenance and repair records; sampling discharges, surface water, groundwater, and material or water in storm water management facilities; and evaluating the condition of storm water management facilities and practices.

- Parties responsible for the operation and maintenance of a storm water management facility shall provide records of all maintenance and repairs to the County.

### 3.3.8 Technical Report Submission Requirements

Failure of an applicant to provide all of the information detailed in this section may result in the denial of receiving a Storm Water Management Permit from the Greenville County Storm Water Management Director. The items listed as the technical report submission requirements shall be used as a checklist to verify that all required items are properly submitted.

The general submission requirements for all projects requiring a Storm Water Management Permit approval shall include the following information when applicable:

1. Standard completed application form.

2. Evidence of acquisition of all applicable local, state, and federal permits.

3. Anticipated starting and completion dates of the various stages of land disturbing activities and the expected date of final stabilization.

4. A vicinity map indicating north arrow, scale, boundary lines of the site, and other useful information to successfully locate the property where than land development is to take place. It shall include at least one major roadway intersection for reference.
5. A plan with an appropriate written and graphical scale (not less than 1-inch = 200 ft.) accompanied by a design technical report indicating at least:

   a) The location of the property where the land development is to take place shown on a Greenville County GIS map or a United States Geological Survey (USGS) 7.5-minute topographic map.
   b) The location of the soils shown on a Greenville County GIS map or United States Department of Agriculture (USDA) soils map, with the major USDA soil types and Hydrologic Soil Groups identified.
   c) Existing and proposed contour lines except for individual lot grading in single-family subdivisions.
   d) Existing and proposed physical structures on site including buildings, roads, easements, and parking areas.
   e) Proposed grading and land disturbance information including:
      1) Surface area of entire project in acres.
      2) Surface area of planned land disturbance project area in acres.
      3) Limits of grading.
   f) Drainage area maps including:
      1) Existing off site- and on-site drainage areas including flow paths.
      2) Proposed off site- and on-site drainage areas including flow paths.
   g) Storm water management facilities water quantity and water quality (temporary and permanent) including:
      1) Location
      2) Dimensions
      3) Elevations

4) Maintenance Plan
5) Calculations:
- Pre- and post-development flow rates,
- Pre- and post-development velocities,
- Hydrographs,
- Stage storage volume information,
- Stage discharge information.

h) Erosion and sediment control plans including:
1) Location
2) Dimensions
3) Elevations
4) Calculations:
- hydrographs,
- stage storage volume information,
- stage discharge information
- trapping efficiencies

6. Compliance with County Flood Control Ordinance and FEMA flood maps and Floodplain study material where applicable.

7. Right-of-ways and easements.

a) Location of easements
b) Designation of easements that require inspection and maintenance

8. Landscape plan.

a) Tree saving and planting plan consistent with the requirements of the Greenville County Tree Ordinance
b) Vegetation to be used for streambank stabilization, erosion control, sediment control, aesthetics, and water quality
c) Special requirements to preserve the natural aspects of the drainage system

9. Description of conditions around points of all surface water discharge.

10. Construction details for all storm water management controls.

11. Downstream impact analysis.

12. Federal and State wetland maps, where appropriate.

13. Appropriate fees for the project.

14. The Plan Review Agency shall require the following:

a) All plans and design reports are to be sealed by a qualified design professional.
b) All plans are to be designed in accordance with all ordinances, programs, regulations, standards and criteria.

15. The Plan Review Agency may require additional information as deemed necessary for complete project review.

# 3.4 Digital Submittal Requirements

Plans that have received preliminary approval shall be followed by the submittal of an electronic copy in accordance with Greenville County's Electronic Submission Standards and Procedures which are posted on Greenville County's website at http://www.greenvillecounty.org/land_development/Planning.asp.

The only use of electronic information submitted will be for the anonymous inclusion into the Greenville County GIS. Disclaimers and limiting statements may be placed in electronic submissions, provided such disclaimers do not direct liability to the County or create indemnification by the party submitting electronic files.

Electronic submission standards and procedures are as follows:

1. Drawings will be submitted as a drawing file in DWG or DXF format to the County's ftp site or on standard storage media approved by Greenville County. Such media include CD-ROM or DVD-ROM disks. The use of alternate media requires County approval prior to submission. PDF format is acceptable for notes and details.
2. The submitted media shall be legibly labeled with the drawing or plan name, filename, drawing type (construction plan), project contact information (name, affiliation, phone number, and e-mail address), and submittal and file creation dates
3. Coordinate datum shall be the current South Carolina State Plane Coordinate System as specified in the South Carolina Code of Laws.
4. South Carolina State Plane Coordinates shall be inherent to the submitted drawing file. That is, the submitted drawing file shall contain South Carolina State Plane coordinates, not local grid or paper space coordinates.
5. Survey requirements for this section shall be consistent with the State Minimum Standards published by the State Board of Registration for Professional Engineers and Land Surveyors and Section 5.8-C of the Greenville County Land Development Regulations unless more stringent requirements are specified herein.
6. The vertical accuracy of surveys submitted for this section shall be ± one-half of the elevation contour interval shown on the approved plan. The vertical datum shall be the North American Vertical Datum of 1988 (NAVD 1988).
7. The submitted drawing file must be clearly named and not exceed 27 characters. For example, Cedar Cove Phase II would be named CedarCovePhll.dwg (or dxf) and Cliffs Valley, Stone Creek Phase II; Lots 42 thru 45 would be named CliffsVa!StnCrkPhIILts42-45.dwg. Long subdivision names may be abbreviated as long as there is a clear relationship to the submitted plan name.
8. The submitted drawing file will include features and text classified by the standard layer and naming convention as shown in Exhibit 3.5-1 of the Greenville County Electronic Submission Standards and Procedures document which is available on the County's website. Drawing features and associated text shall not be combined in one layer. Text included in drawing files will use standard fonts that can be read without third-party software.
9. Closure is critical in converting CAD features to GIS features. All linear and polygon features must be snapped closed, when applicable, and free of symbols (circles at property comers) that break line continuity.

10. Submitted drawing files shall contain only complete features in certain layers identified in Exhibit 3.5-1 of the Greenville County Electronic Submission Standards and Procedures which is available on the County's website. Incomplete features provided for reference, may be included in an open layer, not identified in Exhibit 3.5-1 of the Greenville County Electronic Submission Standards and Procedures document.

11. A metadata text file with the same name as the drawing file (drawing_file_name.txt) is required with each electronic submission. This text file will provide technical parameters and contact information for the survey as specified in Exhibit 3.5-2 of the Greenville County Electronic Submission Standards and Procedures document which is available on the County's website.

12. A Portable Document Format (PDF) file shall be included in the submittal for each approved plan drawing that contains details relating to the layers specified in Exhibit 3.5-1 of the Greenville County Electronic Submission Standards and Procedures which is available on the County's website. The file(s) shall have the same name as the drawing file followed by a number that begins with 1 for the first file (drawing_filc_namel.pdf) and increases sequentially for subsequent files (drawing_file_name2.pdf, drawing file_name3.pdf, etc.)

A land disturbance permit will not be issued until the electronic submittal has been received and approved by the County. A completed metadata sheet, as specified in Exhibit 3.5-2 of the Greenville County Electronic Submission Standards and Procedures document which is available on the County's website, must accompany the drawing file in the electronic submission.

# 3.5 Plan Submittal, Review and Approval Process

## 3.5.1 Plan Submittal

A Storm Water Management Permit Submittal Flow Diagram is provided in Appendix A.

When the Greenville County Storm Water Plan Review Agency receives the initial submittal package it shall be reviewed by a certified plan reviewer for compliance. After the plans have been reviewed to determine compliance with the regulations set forth by this Design Manual the plan reviewer will contact the applicant/design professional and request any necessary changes or notify the applicant/design professional that the plans are in compliance. A copy of all correspondence shall be sent to the owner.

## 3.5.2 Plan Review Period

Upon receipt of a completed application for a Storm Water Management Permit and submittal of the Final Site Development Plans, the Greenville County Storm Water Plan Review Agency shall accomplish its review and have either the approval or review comments transmitted to the applicant within twenty (20) working days.

The Greenville County Storm Water Plan Review Agency shall conduct its review of a waiver or variance submitted by the applicant within ten working days of the submittal. Failure of the Review Agency to act on the waiver by the end of ten (10) working days will result in the automatic approval of the waiver.

### 3.5.3 Incomplete Storm Water Management Permit Applications

Engineering design plans, permit applications, specifications, and submittal packages submitted to the Plan Review Agency that do not meet the minimum requirements of Chapter 3 of the Design Manual shall be handled in the following manner:

- If the original Storm Water Management Permit application submittal package has all of the major components in accordance with Chapter 3 but is missing some information, a written notice will be sent to the applicant with a copy to the owner.

- The written notice from the Plan Review Agency shall state the following:
  - The specific information that must be re-submitted to the Plan Review Agency in order for the permit application to be considered complete for review and processing.
  - The Storm Water Management Permit application has been removed from the review process.
  - Re-submittal of the application with all of the required modifications shall return the application to the review process.
  - The Plan Review Agency shall hold the incomplete plan for a period of 60 working days from the date of the written notice.
  - If an adequate response is not received within 60 working days, the submittal shall be rejected, and the entire submittal process must be initiated again.

- If the original Storm Water Management Permit application submittal does not contain the major required components, it shall be returned to the applicant for re-submittal without review.

### 3.5.4 Plan Approval and Final Submittal

When the plans have been determined to be in compliance, then the applicant/design professional shall send four (4) additional copies for stamp approval. One copy of the plans is for the applicant/design professional, one is for the owner of the development project, one is for the contractor and must be available on site at all times, and one copy is for Greenville County Storm Water Management Inspectors.

Approved plans remain valid for two (2) calendar years or five (5) calendar years, at the discretion of the applicant, from the date of approval. Extensions or renewals of the approved plans shall be granted by the Director upon written request by the person responsible for the land disturbing activity.

The Final Storm Water Drainage Plan shall not be considered approved without an approval stamp with a signature and date on the plans by the Land Development Division (LDD). The stamp of approval on the plans is solely an acknowledgement of satisfactory compliance with the requirements of the Storm Water Management Ordinance. The approval stamp does not constitute a warranty to the applicant or any other person concerning safety, appropriateness or effectiveness of any provision, or omission from the Drainage Plan.

Approvals of land disturbing activities that were approved prior to the effective date of this Design Manual shall remain in effect for the original term of the approval. For land disturbing activities which were not initiated during the original term of approval, the person responsible for the land disturbing activity shall re-submit the Site Development Plan including the Sediment Control Plan to the appropriate Plan Review Agency for review and approval subject to the requirements of this Design Manual.

### Notification of Work

A Stop Work Order shall be issued on all projects proceeding without the required pre construction meeting and issuance of a grading permit.

# 3.6 Construction Requirements

## 3.6.1 Deviations from Approved Plans

Substantial deviations from the approved site development plans and specifications shall not be made on-site without written approval from the Plan Review Agency. Realistically and practically, there are always minor variations to the proposed plan during land development activities. These minor variations will be allowable without the need for approval from the Plan Review Agency, though sound engineering judgment should be exercised in assessing the impacts of these minor changes.

Examples of substantial deviations that would require written approval from the Plan Review Agency include, but are not limited to the following:

- Pipe size changes.
- Pipe grade changes that will affect the hydraulic capacity of the storm water facilities.
- The movement of storm water facility that would put them outside of specific easements and right-of-ways.
- Changes in grade on the site which would effect the direction of storm water flows, flow velocities, flow volumes, or other hydrologic impacts that would cause the existing plans to fail in protecting water quantity and water quality impacts.

## 3.6.2 As-Built Requirements

The permitee shall submit an as-built plan certified by a registered professional upon the completion of the construction of the storm water management control structures submitted in the Final Storm Water Management Site Plan. The registered professional shall certify the following:

- The facilities have been constructed as shown on the As-Built plans.
- The facilities meet the approved site plan and specifications or achieve the function they were designed to perform.

Acceptable as-built plans shall be submitted prior to the following:

- The use or occupancy of any commercial or industrial site.
- Final acceptance of any road into the Official County road inventory.
- Release of any bond held by Greenville County.
- Approval and/or acceptance for recording of map, plat, or drawing to divide a single parcel into two or more parcels.

The Director may perform a final inspection upon completion of the installation of storm water management structures to determine if the work is completed and constructed in accordance with the

Final Storm Water Management Site Plan.

## 3.7 Performance Security

A monetary performance guarantee for every new development is required. This guarantee will provide assurance that all exposed soil surfaces will be stabilized and any other areas of storm water management and sediment control deficiency addressed, in the event a development discontinues or proper control measures are not installed and/or maintained.

Prior to the issuance of any building and/or land disturbance permit for a development or phase of development, every applicant must pay Greenville County a non-refundable Resource Remediation Fee. The non-refundable Resource Remediation Fee is set at $150.00 per disturbed acre. These Fees will be held in a separate, use restricted, interest bearing account known collectively as the Resource Remediation Fund (the "RRF"). Monies deposited into the RRF may be used by the County to remediate sites that have been abandoned, sites left in an unstable condition, or sites with storm water management or sediment control deficiencies, as determined by the Director.

By submitting an application for land disturbing activity, each applicant gives the County express authority to enter upon the subject property during and after development activities for the purpose of performing inspections and/or needed remediation, as determined by the Director.

For all new development and all redevelopment of sites, an applicant must provide to the County a notarized certification that the applicant has no known direct or indirect contractual, business, financial, or familial relationship ("Relationship") to a RRF site where fund money is outstanding or Person Responsible for Land Disturbing Activity at such site. Based on this statement, the County has the right to request, and the applicant must supply, additional specific information concerning any such affiliations.

For sites at which monies from the RRF are spent, an applicant with a Relationship to any Person Responsible for the Land Disturbing Activity on such RRF site(s) or a Relationship with a person who in the past has significantly failed to comply with any provision of this ordinance or previously issued permit, will not be allowed to further participate in this program and no further review of a permit for land disturbing activity will be conducted by the County or permit issued, until such time that all RRF monies are repaid to the County in full by the applicant or other such related person. This is in addition to any other penalty or injunctive relief authorized under this ordinance.

Staff will review funding on an annual basis and recommend any needed changes.

RRF fund monies can be used to complete proposed site improvements including but not limited to the following:

- Storm drain pipe, culverts, manholes, and box inlet installation.
- Site filling and grading, including the construction of open drainage swales and detention facilities.
- Establishment of erosion and sediment control.
- Re-grading of the site to minimize the erosive effects of storm water runoff.
- Temporary or permanent seeding and stabilization of disturbed areas to minimize the erosive effects of storm water runoff.

- Maintenance and cleaning of sediment control structures.

## 3.8 Application Fees

Permits authorized by the provisions of this Design Manual shall be effective only upon the payment of the appropriate fees. The current fees required can be found on the Greenville County Webpage.

Any land development project disturbing one or more acres or must obtain either NPDES general permit coverage or an NPDES permit. There is an additional NPDES fee for these projects. There are no exemptions from this fee, therefore local, State and Federal entities must submit the NPDES fee as part of their Storm Water Management Permit submittal package.

## 3.9 Storm Water Service Coordination

A Storm Water Service fee may be assessed on all land properties within the unincorporated, non-SCDOT regulated areas of Greenville County and within any Municipality that chooses to participate as a co permitee with Greenville County in its NPDES permit. The financing of the Storm Water Service is based on the principle that each user of the storm water system pays to the extent to which the user contributes to the need for the storm water system, and the charges reflect a substantial relationship to the cost of the service. The main objective of the Greenville County Storm Water Utility is to reduce the amount of pollutants that are discharged to the natural waterbodies of the County. Therefore, the County offers credit on the Storm Water Service Fee to those who implement approved structural and nonstructural storm water quality BMPs on site.

## 3.10 Storm Water Service Fee Credit Policy

### 3.10.1 Purpose

Greenville County (County) has established a policy and procedure for providing credits (i.e. reductions) against the Storm Water Service Fee for Classification 2 properties (developed non residential properties) in an effort to provide equity and consistency in the application of the Storm Water Service Fee to individual properties. It is the County's intent to encourage sound technical design practices and the use of applicable BMPs to reduce the impact of development on the drainage system and reduce water quality impairment on the environment through a simple but effective crediting system. Credits will be granted for water quantity and/or water quality impact reductions.

### 3.10.2 Applicability

Any Classification 2 property on which an approved, on-site post-construction storm water control facility or an approved water quality facility or BMP was installed may be eligible for a reduction of the Storm Water Service Fee billed to that specific parcel. The County will evaluate each case individually in determining the appropriate level of credit. Credit for facilities or BMPs, will remain in effect as long as:

1. The post-construction storm water control facility or BMP is contained within a recorded sanitary sewer easement, drainage easement, or equivalent restrictions to future changes in use. See *Appendix K* for exceptions.

2. The owner has obtained applicable permits and the facility or BMP has been constructed in compliance with approved plans.
3. The property owner and/or applicant remain(s) responsible for all cost of operation and maintenance of the facility or BMP.
4. The facility or BMP is maintained in compliance with County standards.
5. The County is permitted access to the facility or BMP for purposes of inspecting the facility's or BMPs compliance with design, maintenance and operating standards.
6. There are no significant changes in land use or impervious surface within the watershed that is serviced by the facility or BMP. If significant land use changes occur, the owner and/or applicant may be required to re-evaluate the performance of the facility or BMP in order to continue receiving a reduction in their Storm Water Service Fee.

### 3.10.3 Credit Schedule

A total maximum of up to a 25% credit against the Storm Water Service Fee may be granted. The following criteria shall apply:

1. The credit will be applied by reducing the number of billable equivalent residential units (ERUs).
2. The property can qualify for both water quantity and water quality credits.
3. The maximum allowable water quantity credit percentage = 25%.
4. The maximum allowable water quality credit percentage = 25%.
5. The adjusted ERU includes the credit for both water quantity and water quality.
6. The minimum adjusted ERU is one.

### 3.10.4 Inspections

The County may perform periodic evaluations of facilities or BMPs. These evaluations will ensure that the facilities and BMPs are being maintained and functioning as intended. If a facility or BMP fails an evaluation a notice of violation will be sent to the property owner stating that improvements and/or corrections need to be made. If adequate improvements and/or corrections to the facility or BMP in question are not completed or addressed within the time frame specified in the notice of violation the credit shall be rescinded. In order to reinstate the credit the owner must reapply using the procedures required by the County. The owner will not be eligible for reinstatement of credits for a period of one year.

### 3.10.5 Facility and BMP Maintenance

The post construction storm water control facilities and BMPs shall be constructed in compliance with approved plans, functioning as intended, and properly maintained prior to the submittal of a Credit Application. The property owner's engineer shall inspect the facility or BMP using forms provided by the County. Most nuisance and maintenance deficiencies can be corrected within a short period of time. A longer period of time for corrections may be granted if any structural and/or construction related deficiencies are found during inspection. All facility or BMP deficiencies shall be corrected or addressed prior to the approval of any credit to be applied against the Storm Water Service Fee. An annual report and certification of proper operation and maintenance is required to maintain the credit annually.

### 3.10.6 Maintenance Agreement

Applicants may request a credit for post construction storm water control facilities or BMPs located on upstream and/or downstream properties. To be eligible for a credit, the facility or BMP must be designed to mitigate the impacts of storm water runoff from the property in question. Both the applicant and the facility or BMP owner must agree on the contents of the Credit Application and ensure that the facility or BMP is maintained in accordance with County guidelines. Requests for credits for storm water facilities or BMPs located on adjacent upstream and/or downstream properties must include a maintenance agreement between the applicant and the facility or BMP owner.

### 3.10.7 BMP Not Located in a Dedicated Easement

An applicant may request a credit for a post construction storm water control facility or BMP not located in a recorded sanitary sewer easement, drainage easement, or equivalent restriction to future changes in use. Although the County prefers that post construction storm water control facilities or BMPs be located in a recorded sanitary sewer easement, drainage easement, or equivalent restrictions to future changes in use, credit may be allowed in situations where the applicant enters into an agreement with the County to maintain the facility or BMP as designed in lieu of establishing a recorded sanitary sewer easement, drainage easement, or equivalent restrictions to future changes in use. Acceptance of this alternative will be determined at the discretion of the County. The applicant should contact the County for the viability of using this option prior to requesting the Credit Application.

### 3.10.8 Storm Water Service Fee Credit Percentage Calculation Procedure

All credits must be rounded to the nearest whole number.

**Water Quantity Credit**

**The maximum allowable water quantity credit percentage = 25%**

1. *Tree Preservation Credit* – up to a 10% credit will be available for property owners that go above the requirements of the Greenville County Tree Ordinance.

   Credit will be considered for the preservation of natural undisturbed areas within a parcel of at least 1 contiguous acre that are preserved and maintained as a natural and undisturbed area. Natural undisturbed land areas must meet the standards necessary to qualify for a conservation use as outlined in the South Carolina guidelines on Nature Conservancy and recorded as such in the restrictive covenants. The fee credit allowance for such areas will be 1 percent for each acre of contiguous area up to a maximum of 10 percent.

   A credit will also be considered for parcels for which storm water runoff from impervious surfaces is effectively treated by a stream buffer. Stream buffers must meet the minimum current standards stipulated by the Storm Water Design Manual. The fee credit allowance for such areas will be 1 percent for each acre of impervious surface that drains to the stream buffer up to a maximum of 10 percent.

2. *Upgrade of Existing Detention or Retention Facilities Credit* – up to a 15% credit will be available for property owners who re-construct existing detention or retention facilities that comply with the current storm water regulations. To be eligible for this credit, the property owner shall submit a certification from a licensed engineer verifying that the facility meets the requirements of current County storm water regulations for both water quantity and water quality.

3. *Over Detention/Retention Credit* – up to a 25% credit will be available for property owners that construct detention or retention facilities designed to detain/retain storm water runoff from the property in excess of the values required under the current storm water regulations. To be eligible for this credit, the property owner shall submit a certification from a licensed engineer verifying that the facility detains/retains storm water runoff from the property in excess of the values required in the current County storm water regulations

   The Over Detention/Retention credit shall be determined using the following formula:

   $\mathbf{C_{100} + C_{50} + C_{25} + C_{10} + C_2}$ **= Over Detention/Retention Credit** (Not to exceed 25%)

   With maximum credit per storm event to total 25% as follows:

   Maximum credit for control of 100-year runoff = 1%
   Maximum credit for control of 50-year runoff = 2%
   Maximum credit for control of 25-year runoff = 11%
   Maximum credit for control of 10-year runoff = 6%
   Maximum credit for control of 2-year runoff = 5%

   Where:

$$\text{Credit}_{100} = \left[ \frac{(\text{Qpost}_{100} - \text{Q w/controls}_{100})}{(\text{Qpost}_{100})} \right] \text{ x } 0.01 \text{ x } 100$$

$$\text{Credit}_{50} = \left[ \frac{(\text{Qpost}_{50} - \text{Q w/controls}_{50})}{(\text{Qpost}_{50})} \right] \text{ x } 0.02 \text{ x } 100$$

$$\text{Credit}_{25} = \left[ \frac{(\text{Qpost}_{25} - \text{Q w/controls}_{25})}{(\text{Qpost}_{25})} \right] \text{ x } 0.11 \text{ x } 100$$

$$\text{Credit}_{10} = \left[ \frac{(\text{Qpost}_{10} - \text{Q w/controls}_{10})}{(\text{Qpost}_{10} - \text{Q predeveloped}_{10})} - 1 \right] \text{ x } 0.06 \text{ x } 100$$

$$\text{Credit}_{2} = \left[ \frac{(\text{Qpost}_{2} - \text{Q w/controls}_{2})}{(\text{Qpost}_{2} - \text{Q predeveloped}_{2})} - 1 \right] \text{ x } 0.05 \text{ x } 100$$

   $\mathbf{Q}_{\textbf{pre-developed}}$ = the peak discharge without development (cfs)

   $\mathbf{Q}_{\textbf{post}}$ = the post-developed peak discharge without controls (cfs).

$Q_{w/controls}$ = the post-development peak discharge from the developed site with storm water controls (i.e. detention/retention facility) in place (cfs).

To be eligible for the over detention/retention credit, the ratio must be *greater* than one (1.0). Over detention/ retention credit percentage calculations shall reflect a pre-development land use without development and/or prior to any land disturbing activities (i.e., clearing, grading, existing development, addition of impervious surfaces, etc.).

4. *Discharge Elimination* – up to 25% will be available for property owners that do not discharge runoff to the county storm water management system. These areas treat, store, dispose, transpire, evaporate, infiltrate or otherwise manage all rainfall events up to and including the 100 year reoccurrence event with no discharge or releases of water or pollutants to the county storm water management system. To be eligible for this credit, the property owner shall submit a certification from a licensed engineer verifying that the facility retains storm water runoff from the property.

## Water Quality Credit

**The maximum allowable water quality credit percentage = 25%**

1. *New Development, New BMP Facilities* – Up to a 10% credit will be available for property owners that install water quality facilities and best management practices (BMPs) on their properties. All storm water quality BMP structural controls must be designed in accordance with the Greenville County Storm Water Manual. All other water quality protection structural control systems will be considered on a case-by-case basis. Innovative solutions addressing storm water quality issues are encouraged by Greenville County.

   The water quality facilities and BMPs shall be designed to effectively reduce pollutants associated with post-construction storm water runoff. To be eligible for this credit, the property owner shall submit a certification from a licensed engineer verifying that the flow from the percentage of the property indicated is routed through the water quality facility or BMP.

   A Water Quality Factor is also provided in Appendix K. This Water Quality Factor shall be used along with the percent impervious drainage area of the property draining to the BMP to determine the Water Quality Credit for new water quality BMPs as follows:

   - ***New Storm Water Quality Control BMP Credit = Percentage of the impervious area of the property that is routed through the BMP X Water Quality Factor % (from Appendix K) X 10%***

   Before the approval of structural storm water quality facilities or BMPs that are not included in the County Design Manual or BMP Manual, the County may require valid documentation from full-scale testing by an independent third party to verify that the pollutants of concern will be properly controlled.

2. *Retrofitting Existing Facilities* – The current design and development standards of the County have established the standards that all new developments must meet. The new standards were developed and adopted to control and minimize the negative impacts of development on flooding and water quality and to put measures into place that protect watershed resources. These new standards were not retro-active. A number of properties were designed and built prior to the new standards. In many cases, properties built to the previous standards can be altered or retro-fitted to meet the new

standards. The following conditions and stipulations apply:

a) Developments that intend to retro-fit their storm water facilities and properties to the new standards must file the credit application and obtain a development permit from the County prior to making any changes.

b) Only one credit application per parcel, the credit applies to the property served by the retro-fit and meeting the news standards. Calculations are to be provided to support the requested credit amount.

c) A site map prepared a sealed by a licensed SC professional engineer or a licensed SC surveyor showing property boundaries, easements, topography, drainage features, natural conservation areas (and acreage), floodplain/floodway locations (and acreage), stream buffers (with width and length), overland flow and recharge areas (with acreage), and structures is to be submitted with the service fee credit application.

d) A storm water design analysis and a hydrologic/hydraulic report with calculations in accordance with the design manual prepared and sealed by a SC licensed PE is to be submitted with the service fee credit application.

e) It is the responsibility of the property owner to provide all necessary documentation and certification that the property has been brought up to the current County standards. This will include as-built plans that are signed and sealed by a license SC professional engineer.

f) The service free credit is for a term of up to 5 years beginning the billing period following acceptance of the application and as-built plans. An annual report and certification of proper operation and maintenance is required.

g) Failure to properly maintain storm water management facilities or property features that are the basis for the credit will nullify the credit and may disqualify the property fro further service fee consideration.

A storm water fee credit of **25%** for each applicable minimum standard, up to the maximum allowable, will be considered for property owners that retro-fit or other modify and maintain their property to meet current minimum stands. Additional credits for qualifying properties may also be available in conjunction with any other credit defined by the policy up to the maximum allowable.

3. *Offsite Storm Water Quality Control Credit* – A Storm Water fee credit, up to 25% of the fee, may be granted if the property owner demonstrates to the satisfaction of the County (with supporting data and calculations) that the storm water treatment facility provided on the property is adequate (designed in accordance with the Storm Water Design Manual) to treat offsite runoff from one or more developed properties (for which no storm water controls exist at the time of the application for credit), in addition to the onsite runoff. No credit will be granted for non-point source pollution control for offsite undeveloped properties, since the provisions for this control have to be made onsite on the respective properties. To be eligible for offsite runoff quality control treatment credit, the offsite drainage area must be contiguous with the onsite drainage area. The credit will be allowed only if there is no contractual BMP maintenance agreement between the owners of the upstream offsite development and the credit applicant. A notarized signature statement to this fact must be submitted with the credit application from a Licensed SC Professional Engineer.

   At such time that the offsite runoff is treated prior to draining onsite through BMP structure, or a maintenance agreement is executed between the appropriate parties, the offsite runoff quality control treatment credit may be re-evaluated for reduction or cancellation accordingly, based on the following formula:

   - ***Offsite Storm Water Quality Control Credit = Offsite Drainage Area / Onsite Drainage Area X***

***Water Quality Factor % (from Appendix K) X 25%***

**Total Credit Percentage and Adjusted ERU Calculations**

After the water quantity credit percentage and the water quality credit percentage are determined, the adjusted Storm Water Service Fee will be calculated as follows:

1. Total Base Credit Percentage = 100% - ((Water Quantity Credit Percentage + Water Quality Credit Percentage) --> not to exceed 25%)
2. Adjusted Storm Water Service Fee = Total Credit Base Percentage x Number of ERUs for the Property multiplied by the Storm Water Service Rate for the property
3. The minimum adjusted ERU is one.

## 3.10.9 Approved Best Management Practices

A listing of the County-approved water quality facilities and BMPs for water quality credits are included in Appendix K of this Design Manual and the County's Design and Best Management Practices Manuals. These manuals includes the design and maintenance requirements that must be followed, as well as the performance specifications that must be met in order to receive water quality credits for these water quality facilities and BMPs.

The County may consider other water quality facilities and BMPs for credits based on information submitted by the property owner. The credit values given by the County for these other water quality BMPs will be at the County's discretion.

## 3.10.10 Disqualifying Provisions

The effectiveness of the various credits may be significantly diminished by certain conditions or practices. These conditions or practice include but are not limited to the following:

1. Development and construction in the floodplain
2. Development and construction on slopes, particularly in excess of 15 percent
3. Siting on porous or erodible soils
4. Excessive soil removal and excavation
5. Severe topography modifications
6. Channelization
7. Development in sensitive areas
8. Clear cutting
9. Excessive grading
10. Windborne dust and soils
11. Transfer of pollutions by vehicles and equipment

The County reserves the right to deny or reduce the amount of credit on the basis of any of the above considerations or others that may diminish or mitigate the effectiveness of various storm water management measures and that have an unfavorable impact on water quality or the county's associated cost of storm water management services. The County may disqualify egregious conditions that result in construction site stop work orders or citations related to excessive windborne dust and soils, transfer of pollution by vehicles and equipment, erosion control and illicit discharge violations.

# Chapter 4. EASEMENTS

## 4.1. Purpose

All public storm sewer, storm water conveyance drainage systems and open channels must be constructed on public right-of-ways, easements, publicly owned or Greenville County owned properties. No approval will be given for the construction or improvement of any public storm sewer, storm water conveyance systems or open channels without provision of suitable permanent easement or right-of-way. Restriction on easements shall include prohibiting all fences and structures that would interfere with access to the easement areas and/or the maintenance function of the drainage system.

Any increase of runoff volume from or across the easement shall be calculated and reported to Greenville County. Greenville County, adjacent property owners and any affected utilities shall be in agreement with any increase in runoff volume from a storm water easement before the easement will be granted.

All storm water systems shall be designed to have no increase in velocity, peak flow, water surface elevation in relationship to upstream, adjacent, and downstream property in the 100-year storm, unless an adequate permanent drainage easement is obtained.

## 4.2. Existing Easements

Each existing easement to be used shall be shown on the plans included in the Storm Water Management Permit submittal package. The information on the plans shall include the Deed Book and page number of the recorded instrument. All restrictive clauses as to the use of the easement shall be noted on the plan adjacent to the specific easement. The restrictions may include but are not limited to:

- Utility (gas, electric, telephone, and water) purposes only,
- Drainage purposes only; and,
- Sanitary sewer purposes only.

Construction of storm water conveyance drainage systems will not be permitted in existing exclusive gas, electric, water, telephone, or sanitary easements unless a drainage easement is acquired overlapping the existing easement with approval from Greenville County and the affected utility.

## 4.3. Temporary Construction Easements

Temporary construction easements may be required to be adjacent to storm water conveyance drainage easements when necessary for development operations. Temporary construction easements may be required for structure removal, access roads, stockpiling, and other common land development activities. Sufficient area shall be provided for movement of equipment and materials to accomplish the intended activity within the temporary construction easement.

Temporary construction easements should not be acquired on adjacent private property when the proposed permanent easement is not located on the adjacent property.

## Easement Widths

The total easement width, permanent plus any temporary requirements should be sufficient to allow the contractor to have flexibility in the method of construction. However, easements shall not have excessive widths requiring needless clearing and cutting of wooded or vegetated areas. The Ordinance requires , as a minimum, that easements have the following characteristics:

1. Provide adequate access to all portions of the drainage system and structures;

2. Provide sufficient land area for maintenance equipment and personnel to adequately and efficiently maintain the drainage system and all storm water facilities;

3. Restriction on easements shall include prohibiting all fences and structures which would interfere with access to the easement areas and/or the maintenance function of the drainage system.

Table 4-1 lists suggested minimum widths of drainage easements and temporary easements using trench construction for pipes. Table 4-2 lists suggested easement requirements for open storm drainage channels. In no case shall these suggested easement width guidelines be a substitute for sound engineering judgment.

**Table 4-1. Minimum Pipe Easement Widths**

| | Minimum Easement Width (feet) | | |
|---|---|---|---|
| Pipe Size (inches) | Permanent | Temporary | Total |
| ≤ 12 | 15 | 15 on each side | 45 |
| 15 < 24 | 15 | 15 on each side | 45 |
| 24 < 54 | 20 | 25 on each side | 70 |
| ≥ 54 | 30 min | 30 on each side | 90 |

**Table 4-2. Minimum Open Storm Channel Easement Widths**

| Drainage Area in Acres | Minimum Easement Width* (feet) |
|---|---|
| 0- 45 | 20 |
| 45 – 120 | 30 |
| 120 – 500 | 40 |
| > 500 | Top Width of Channel + 25-feet (40-feet minimum) |

*For open channels, the minimum easement must contain the width of the stream from top of bank to top of bank.

# 4.4. Easement Plat Criteria

## 4.5.1 General

Final plats, summary plats and easement plats shall be used for property having an easement or other type of applicable acquisition of land. All plats shall have the title block in the lower right hand corner of the plat describing the type of easement. A land surveyor certification and seal shall be located in the lower left hand corner of the plat. No other format shall be submitted or accepted. Many times easements are not granted to Greenville County but are simply a reciprocal agreement between property owners to convey their drainages or to convey drainages of others across their property.

Permanent easements shall be hatched on all plans for clarity, while temporary easements shall have no hatching or shading added to identify them.

### 4.5.2 Plat Information

All easement plats shall include the following information:

- North arrow.
- Location map and north arrow with sufficient data to locate the parcel.
- Written and graphic scale.
- Subject easement labeled and hatched on plat, and subject temporary easement labeled and not hatched on the plat.
- Parcel property line distances and line bearings.
- Dimensions to nearest one-hundredth of a foot from easement to property lines.
- Easement angles and dimensions to the nearest one-hundredth of a foot.
- Easement size and description.
- Existing easements and right-of-ways.
- Engineer or land surveyor firm name and address.
- Parcel number shall be shown in the title block and inside the property boundary.
- Property owner’s name, property address and mailing address shall be shown in the title block.
- Adjacent property owner’s name, deed book number, and page number.
- Land surveyor’s stamp, certification, signature, and date.
- Reference tax block and lot number.
- Area of easement to be acquired in square feet or acres.
- Description of all monuments.
- Adjoining road names and right-of-way width.
- Statement if bearings and distances as shown on the plat have been adjusted for closure.
- Statement that the unadjusted error of closure meets or exceeds the minimum standards.

# Chapter 5. HYDROLOGY

## 5.1 Introduction

The definition of hydrology is the scientific study of water and its properties, distribution, and effects on the earth's surface, in the soil and the atmosphere. Hydrology deals with estimating peak flow rates, volumes, and time distributions of storm water runoff. Basic hydrology is fundamental in the design of storm water management control facilities. This chapter addresses the movement of water over the land resulting directly from precipitation in the form of storm water runoff.

Urbanization and land development changes a watershed's response to precipitation. The most common effects are reduced infiltration and decreased travel time, which have the potential to significantly increase peak discharges and runoff volumes. Total runoff volume is determined by the amount of precipitation and the receiving watershed's infiltration characteristics related to soil type, antecedent moisture conditions, cover type, impervious surfaces, and surface detention and/or retention.

The travel time, or time of concentration, of the watershed is directly related to the slope, flow path length, depth of flow, and roughness of the flow surfaces due to the type of ground cover. Peak discharge rates are based on the relationship of these parameters and on the total drainage area of the watershed, the location of the development, the effect of any flood controls or other manmade storage, and the time distribution of rainfall during a given storm event.

The primary purpose of this chapter is to define the minimum computational standards and methods required to comply with the regulatory requirements of the Greenville County Storm Water Management Permit. Any type of computer software program that utilizes the methods describe in this chapter shall be deemed as being an acceptable procedure.

## 5.2 Computational Standard Methods

This section describes the recommended procedures for calculating the runoff generated from a project site. Correct utilization of these procedures should result in the best available estimation of existing and projected runoff. Their use will also provide the consistency of results necessary when applied to project sites throughout Greenville County.

It is assumed that practicing design professionals involved with preparing drainage plans have adequate knowledge of the recommended procedures. Therefore, there is no attempt in this Design Manual to provide systematic calculation methodologies.

All hydrologic computational methods shall be accomplished using a volume hydrograph method acceptable by Greenville County. The storm duration for computational purposes for these methods shall be the 24-hour rainfall event, using the Soil Conservation Service (SCS) Type II rainfall distribution with a 0.1 hour burst duration time increment.

In general the following guidelines should be followed when selecting hydrologic computation standards:

- If the contributing drainage area is 20 acres or less and if no storage design or runoff volume is required, the Rational Method or the SCS Method of runoff calculation shall be acceptable.
- If the contributing drainage area is greater than 20 acres, or if storage or runoff volume design is

required, only the SCS Method or other County accepted runoff volume based calculation procedure shall be acceptable.

- Drainage channels may be designed by the Rational Method if the drainage area of the channel is 20 acres or less and no storage design is required, otherwise, the channel shall be designed using SCS runoff calculation methodology.

## 5.2.1 Rational Method

The Rational Method formula is utilized to determine peak flow rates in urban areas and small watersheds for the following situations:

- The total drainage area is 20 acres or less.
- No storage or volume design is required.
- Sizing individual gutters, storm drain inlets, storm drain pipes, culverts, and small ditches that do not have a total contributing drainage area greater than 20 acres.

The Rational Method shall not be used to do the following:

- Detailed storage design.
- Any application where detailed routing procedures are required.
- Calculating peak flows downstream of bridges, culverts, or storm sewers that may act as temporary storage and require routing calculations.

The Rational Method is recommended for small, highly impervious drainage areas such as parking lots and roadways draining into inlets and gutters as well as small rural watersheds. The Rational Method calculates peak discharge only (as opposed to developing a runoff hydrograph for an area). It makes a basic assumption that the design storm has a constant rainfall intensity for a time period equaling the project area time of concentration ($T_c$).

### 5.2.1.1. Rational Method Equation

The most common form of the Rational Method equation estimates the peak runoff at any location in a watershed or sub-basin as a function of drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration, and is expressed as:

$$Q_p = CIA$$

Where $Q_p$ is the peak runoff rate in $ft^3$/sec, C is a dimensionless runoff coefficient, I is the rainfall intensity in inches/hr, and A is the contributing area in acres.

The assumptions of the Rational Formula are as follows:

- Considers the entire drainage area as one unit.
- The peak flow occurs when the entire watershed is contributing to the runoff.
- The rainfall intensity is uniform over a duration of time equal to or greater than the time of concentration, $T_c$.

- The frequency of the peak flow is equal to the frequency of the rainfall intensity. For example, the 10-year rainfall intensity I, is assumed to produce the 10-year flood event.

#### 5.2.1.2. Runoff Coefficient, C

The runoff coefficient, C, is taken to be a function of ground cover only and is considered independent of the intensity of rainfall. The coefficient C is a volumetric coefficient that relates peak discharge to the theoretical peak discharge equal to 100 percent runoff. Therefore, C is a function of infiltration and other hydrologic abstractions. Typical accepted values for C for 5- to 10-year frequency storm events are given in Tables 5-1 and 5-2 for urban and rural areas, respectively.

If the watershed contains varying amounts of different ground cover, an appropriate weighted C-Factor must be calculated based upon the percentages of the areas with different C-Factors. The general calculation to determine the weighted C value is:

$$\text{Weighted C} = \frac{C_1A_1 + C_2A_2 + ... + C_nA_n}{A_{Total}}$$

**Table 5-1. Recommended Rational Method Runoff Coefficient (C) Values* for Urban Areas**

| Description of Area | Runoff Coefficient |
|---|---|
| **Business** | |
| Downtown areas | 0.95 |
| Neighborhood area | 0.70 |
| **Residential** | |
| Single-family areas | 0.50 |
| Multi-units, detached | 0.60 |
| Multi-units, attached | 0.70 |
| Suburban residential | 0.40 |
| Apartment dwelling areas | 0.70 |
| **Industrial** | |
| Light areas | 0.70 |
| Heavy Areas | 0.80 |
| **Parks, cemeteries, golf courses** | 0.25 |
| **Playgrounds** | 0.35 |
| **Lawns** | |
| Sandy soil, flat, < 2% | 0.10 |
| Sandy soil, average, 2-7% | 0.15 |
| Sandy soil, steep, > 7% | 0.20 |
| Clay soil, flat, < 2% | 0.17 |
| Clay soil, average, 2-7% | 0.22 |
| Clay soil, steep, > 7% | 0.35 |
| **Railroad yard areas** | 0.40 |
| **Streets** | |
| Asphalt and concrete | 0.95 |
| Brick | 0.85 |
| **Drives, walks, roofs** | 0.95 |

| Description of Area | Runoff Coefficient |
|---|---|
| **Gravel areas** | 0.50 |
| **Unimproved areas** | 0.30 |
| **Graded with no plant cover** | |
| Sandy soil, flat, < 2% | 0.30 |
| Sandy soil, average, 2-7% | 0.40 |
| Clay soil, flat, < 2% | 0.50 |
| Clay soil, average, 2-7% | 0.60 |

* These recommended C values are applicable for 5- to 10-year frequency storms. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on the runoff.

**Table 5-2. Recommended Rational Method Runoff Coefficient (C) Values* for Rural Areas**

| Description of Area | Runoff Coefficient For Hydrologic Soil Groups | | | |
|---|---|---|---|---|
| | HSG A | HSG B | HSG C | HSG D |
| **Woodland** | | | | |
| Flat, 0-5% slope | 0.10 | 0.10 | 0.30 | 0.40 |
| Rolling, 5-10% slope | 0.25 | 0.25 | 0.35 | 0.50 |
| Hilly 10-30% slope | 0.30 | 0.30 | 0.50 | 0.60 |
| **Pasture** | | | | |
| Flat, 0-5% slope | 0.10 | 0.10 | 0.30 | 0.40 |
| Rolling, 5-10% slope | 0.16 | 0.16 | 0.36 | 0.55 |
| Hilly 10-30% slope | 0.22 | 0.22 | 0.42 | 0.60 |
| **Cultivated Bare Soil** | | | | |
| Flat, 0-5% slope | 0.30 | 0.30 | 0.50 | 0.60 |
| Rolling, 5-10% slope | 0.40 | 0.40 | 0.60 | 0.70 |
| Hilly 10-30% slope | 0.52 | 0.52 | 0.72 | 0.82 |

* These recommended C values are applicable for 5- to 10-year frequency storms. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on the runoff.

### 5.2.1.3. Rainfall Intensity, I

The rainfall intensity factor, I, is presented in Appendix B.

### 5.2.1.4. Time of Concentration

The time of concentration ($T_c$) shall be determined by calculating the time for a particle of water to travel from the hydraulically most remote point of the project area to the point of interest. The time of concentration shall be calculated using the SCS TR-55 method procedure that is discussed in Section

5.2.3.

The storm duration for computational purposes for this method shall be equal to the time of concentration ($T_c$) of the contributing drainage area, with a minimum time of concentration equal to 0.1 hours (six minutes).

### 5.2.1.5. Infrequent Storms

The Ration Method runoff coefficients given in Tables 5-1 and 5-2 are applicable for 5- to 10-year frequency storm events. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on the runoff. The adjustment of the rational method for use with major storms can be made by multiplying the runoff coefficient by a frequency factor, $C_f$.

For infrequent storm events, the rational equation is then expressed as:

$$Q = C_f CIA$$

Where $C_f$ is a frequency factor based on recurrence interval given in Table 5-3.

**Table 5-3. Runoff Coefficient Frequency Factors**

| Recurrence Interval (years) | Frequency Factor $C_f$ |
|---|---|
| 25 | 1.1 |
| 50 | 1.2 |
| 100 | 1.25 |

* The product of $C_f$ times C shall not exceed 1.0.

## 5.2.2 Natural Resource Conservation Service (NRCS) Curve Number (CN) Method

The Natural Resource Conservation Service (NRCS) Curve Number (CN) Method, also known as the Soil Conservation Service (SCS) CN Method requires the following basic data that is similar to the Rational Method:

- Total drainage area of watershed or sub-basin.
- Runoff factor defined by a Curve Number (CN)
- Time of concentration ($T_c$).
- Rainfall data.

The SCS CN Method is more sophisticated than the Rational Method in that it also considers the following:

- Time of distribution of the rainfall.
- Initial rainfall losses due to interception and depression storage.
- Infiltration rates.

The SCS CN Method begins with a rainfall amount uniformly imposed on the watershed over a specified time distribution. Mass rainfall is converted to mass runoff by using a runoff CN that is based on soil type, plant cover, amount of impervious areas, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed.

The SCS Method shall be used to determine storm water runoff peak flow rates, runoff volumes, and the generation of hydrographs for the routing of storm flows in urban areas and project sites where:

- The total drainage area is greater than 20 acres, the SCS CN Method must be used.
- The total drainage area is less than 20 acres, the SCS CN Method may be used.
- Runoff volume is required.
- Routing is required.
- The design of storage facilities and outlet structure is required.

When these project conditions exist, the design professional shall use the SCS Method in model form (any computer software program that utilizes TR-20, TR-55 or similar NRCS (or SCS) based runoff computations) or complete the calculations by hand using the various equations and charts listed in this section of the Design Manual.

### 5.2.2.1. Calculating Runoff Volume

The total runoff volume for a designated watershed or sub-basin for a particular storm event can be calculated using the SCS CN Method by using the following equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where Q is the total runoff volume for the specified storm event in inches, P is the rainfall volume for the specified storm event in inches, $k_a$ is a dimensionless coefficient approximated by 0.2, $I_a$ is initial abstraction, and S is the maximum retention after runoff begins defined by the following equation.

$$S = k_s\left(\frac{1000}{CN} - 10\right)$$

Where $k_s$ is the retention depth units conversion factor (1.0 for S in inches, and 25.4 for S in mm), and CN is the SCS CN for the designated watershed.

### 5.2.2.2. Initial Abstractions

Initial abstractions ($I_a$) are all losses in the watershed before runoff begins. These abstractions include water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration. $I_a$ is highly variable but generally is correlated with soil and cover parameters. Through the study of many small agricultural watersheds, $I_a$ is approximated by the following empirical equation:

$$I_a = k_a S$$

### 5.2.2.3. Curve Number

The major factors that determine the SCS CN are cover type, treatment, hydrologic condition, hydrologic soil group (HSG) of the watershed soils, and antecedent moisture condition (AMC). Another factor of consideration is whether impervious areas are directly connected to the system or if the system is unconnected and flows from impervious areas spread over pervious areas before reaching the outfall point. The curve number is similar to the Rational Method C Factor in that it is based on the surface condition of the project site. Values of CN based on land use description can be found in 5-5 for the four Hydrologic Soil Groups (HSGs).

#### 5.2.2.2.1. Hydrologic Soil Groups

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils can be classified into the following four HSGs base on their minimum infiltration rate:

- HSG A- Soils with a low runoff potential due to high infiltration rates, primarily deep well-drained sands.
- HSG B- Soils with a moderate runoff potential due to moderate infiltration rates, primarily moderately deep to deep with coarse to moderately fine textures.
- HSG C- Soils having a moderately high runoff potential due to low infiltration rates, primarily moderately fine to fine textures.
- HSG D- Soils having a high runoff potential due to very low infiltration rates, predominantly clay soils or soils with high water tables.

#### 5.2.2.2.2. Urban Impervious Area Modifications

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 when computing the CN for urban areas.

- Connected Impervious Areas: An impervious area is considered connected if runoff from it flows directly into the storm drainage system. It is also considered connected if runoff from the area occurs as concentrated shallow flow that runs over a pervious area and then into a 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 5-4 are not applicable, use **Figure 5-1** to compute a composite CN.

For example, Table 5-4 gives a CN of 70 for a ½-acre lot with HSG B soils, with an assumed impervious area of 25 percent. If the lot actually has 20 percent impervious area and a pervious area CN of 61, the composite CN obtained from **Figure 5-1** is 68. The decrease in the CN from 70 to 68 reflects the decrease in the percent impervious area.

- Unconnected Impervious Areas: Runoff from these areas is spread over a pervious area as sheet flow.

- Use **Figure 5-1** (Composite CN) if the total unconnected impervious area is less than 30 percent.

The composite CN can be computed by entering the right half of **Figure 5-1** with the percentage of total impervious area and the ratio of total unconnected impervious are to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN.

For example, a ½-acre lot with 25 percent total impervious area (75 percent of that is unconnected) and a pervious CN of 61, the composite CN from **Figure 5-1** is 66.

- Use **Figure 5-1** (Connected Impervious Area) if the total unconnected impervious area is equal to or greater than 30 percent, because the absorptive capacity of the reaming pervious area will not significantly affect runoff.

### 5.2.2.2.3. Antecedent Moisture Conditions

The index of runoff potential before a storm event is termed the Antecedent Moisture Condition (AMC). The AMC is an attempt to account for the variation in CN at a particular site for various storm conditions. The CNs listed in Table 5-4 are for average AMC II, which are used primarily for design applications. The three AMC classifications are:

- **AMC I-** Little rain or drought conditions preceding rainfall event. The curve numbers for AMC I can be calculated using the following equation:

$$CN_{AMC\ I} = \frac{4.2 \cdot CN_{AMC\ II}}{10 - 0.058 \cdot CN_{AMC\ II}}$$

- **AMC II-** Standard CNs developed from rainfall and runoff data.

- **AMC III-** Considerable rainfall prior to rain event in question. The curve numbers for AMC III can be calculated using the following equation:

$$CN_{AMC\ III} = \frac{23 \cdot CN_{AMC\ II}}{10 - 0.13 \cdot CN_{AMC\ II}}$$

**Table 5-4. Recommended Runoff Curve Number Values**

| Source: Soil Conservation Service (1986)<br>**Land Use Description:** | Hydrologic Soil Group | | | |
|---|---|---|---|---|
| | **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: < 50% ground cover | 68 | 79 | 86 | 89 |
| Good condition: > 75% ground cover | 39 | 61 | 74 | 80 |
| **Meadow of Continuous Grass Protected from Grazing** | 30 | 58 | 71 | 78 |

| | | | | |
|---|---|---|---|---|
| **Wood or Forest Land** | | | | |
| Poor: forest litter, small trees, and brush are regularly cleared | 45 | 66 | 77 | 83 |
| Fair: grazed with some forest litter covering the soil | 36 | 60 | 73 | 79 |
| Good: no grazing, litter and brush adequately cover the soil | 30 | 55 | 70 | 77 |
| **Open Spaces (lawns, parks, golf courses, and cemeteries)** | | | | |
| Poor: grass cover > 50% | 68 | 79 | 86 | 89 |
| Fair: grass cover from 50% to 75% | 49 | 69 | 79 | 84 |
| Good: grass cover > 75% | 39 | 61 | 74 | 80 |
| **Impervious Areas** | | | | |
| Paved parking lots, roofs, and driveways | 98 | 98 | 98 | 98 |
| **Streets and Roads** | | | | |
| Paved curb and storm sewers 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% average impervious area) | 89 | 92 | 94 | 95 |
| Industrial (72% average impervious area) | 81 | 88 | 91 | 93 |
| **Residential Districts by Lot Size** | | | | |
| 1/8 acre or less, townhomes (65% average impervious area) | 77 | 85 | 90 | 92 |
| ¼ acre (38% average impervious area) | 61 | 75 | 83 | 87 |
| 1/3 acre (30% average impervious area) | 57 | 72 | 81 | 86 |
| ½ acre (25% average impervious area) | 54 | 70 | 80 | 85 |
| 1 acre (20% average impervious area) | 51 | 68 | 79 | 84 |
| 2 acres (12% average impervious area) | 46 | 65 | 77 | 82 |
| **Developing Urban Areas, Newly Graded Areas with no Vegetation** | 77 | 86 | 91 | 94 |

* The average percent impervious areas shown were used to develop the composite CNs for the described land use. The impervious areas are assumed to be directly connected to the drainage system, with the impervious areas having a CN of 98 and the pervious areas being equivalent to open space in good hydrologic condition. If the impervious area is not connected, the SCS method has an adjustment to reduce the effect.

## 5.2.3 Time of Concentration

### 5.2.3.1. Definition

The time of concentration ($T_c$) is defined as being the time it takes runoff to travel from the hydraulically most distant or remote point of a watershed or subbasin to the point of interest within the watershed or subbasin. Therefore, the time of concentration is the time for water to travel through the watershed, which is not always the maximum distance of flow through the watershed to the outlet point. The time of concentration is computed by summing all the travel times for consecutive components of the watershed's drainage conveyance system. The time of concentration influences the shape and peak of the runoff hydrograph. Urbanization and land development usually decreases the $T_c$, thereby increasing the peak discharge.

### 5.2.3.2. Minimum Time of Concentration

The minimum time of concentration ($T_c$) used for the SCS CN Method and TR 55 application is 0.1 hours (six minutes).

### 5.2.3.3. Factors Affecting the Time of Concentration

One of the most significant effects of urbanization and land development on flow velocity is the reduction of the natural flow retardance produced by vegetation. Land development typically modifies undeveloped areas originally having shallow overland flow through vegetation. These modifications include adding roads, curb and gutters, and storm sewers that transport runoff downstream more rapidly than the existing pre-development conditions. Therefore, the $T_c$ for the entire watershed is generally decreased due to the effects of urbanization and land development.

### 5.2.3.4. Calculating the Time of Concentration

Water will travel through a sub-basin in one, or a combination of the following forms:

- Overland Sheet Flow
- Shallow Concentrated Flow
- Open Channel Flow

The type of flow that occurs at a particular point in the watershed is a function of land cover, flow depth, and the conveyance system present.

The total time of concentration is the sum of the various consecutive overland sheet, shallow concentrated, and open channel flow segments. The actual time of concentration shall be the longest travel time when all possible flowpaths are considered.

$$T_c = T_{t,i} + T_{t,i+1} + \ldots + T_{t,n}$$

Where $T_c$ is the time of concentration, and $T_t$ is the travel time over segment i.

#### 5.2.3.2.1 Overland Sheet Flow

Overland sheet flow is flow over plane surfaces. It usually occurs in the headwater area of stream watersheds, and in wooded and vegetated areas. When examining sheet flow, Manning's Roughness Coefficient for Sheet Flow is the major resistant factor that includes:

- Effects of raindrop impact,
- Drag over the plane surface,
- Obstacles such as litter, crop ridges, and rocks,
- Erosion,
- Sediment transport, and
- Very shallow sheet flow depths not much greater than 0.1-feet.

Manning's kinematic solution to compute the travel time for sheet flow is defined by the following equation:

$$T_t = \frac{0.007 \cdot (nL)^{0.8}}{P_2^{0.5} \cdot S^{0.4}}$$

Where “n” is Manning’s Roughness Coefficient from Table 5-5, L is the flow length in feet (≤ 300-ft for rural areas, and ≤ 150-feet for urban areas unless specific considerations are made), $P_2$ is the 2-yr, 24-hr rainfall depth in inches, and S is the slope of the hydraulic grade line (land slope) in ft/ft.

This simplified form of Manning’s kinematic solution is based on the following assumptions:

- The flow is shallow steady uniform flow,
- Constant intensity if rainfall excess (runoff),
- Maximum flow length of 300-feet,
- Rainfall duration of 24-hours; and,
- Minor effect of infiltration on the travel time for sheet flow.

**Table 5-5. Manning’s Roughness Coefficient for Sheet Flow**

| Surface Description: Source: Soil Conservation Service, (1986) | | Manning’s Sheet Flow “n” |
|---|---|---|
| **Smooth Surfaces (concrete, asphalt, gravel, 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 | 0.24 |
| | Bermuda Grass | 0.41 |
| **Range (natural)** | | 0.13 |
| **Woods** | Light underbrush | 0.40 |
| | Medium underbrush | 0.60 |
| | Dense underbrush | 0.80 |

### 5.2.3.2.2 Shallow Concentrated Flow

After a maximum of 300-feet of flow, sheet flow becomes shallow concentrated flow. The average velocity for this flow can be determined from **Figure 5-2**, in which the average velocity is a function of watercourse slope and type of channel. Flow may not always be directly down the watershed slope if tillage or contours run across the slope.

After the average velocity of the flow is determined from **Figure 5-2**, the following equation can be used to estimate the travel time for the shallow concentrated flow segment.

$$T_t = \frac{L}{3600 \cdot V}$$

Where V is the average velocity (ft/sec) from **Figure 5-2.**

### 5.2.3.2.3 Open Channel Flow

Open channel flow occurs when shallow concentrated flows reach visible channels that have obtainable dimensions, depths and sizes. These channels may include, but are not limited to:

- Diversion,
- Swales,
- Paved gutters,
- Road side ditches,
- Intermittent streams,
- Perennial blue line streams that appear on USGS quadrangle sheets, and
- Storm sewer pipes

The average flow velocity in the open channels is calculated by using Manning's equation:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where R is the hydraulic radius (ft) calculated as the cross-sectional area (A) over the wetted perimeter (P) of the channel. The wetted perimeter is the length of the perimeter of the cross section that is in contact with water.

Once the average flow velocity is calculated, the travel time for the open channel flow segment is then calculated in the same manner as the shallow concentrated flow.

# 5.3 Rainfall

One of the most important steps in hydrologic analysis of a watershed or sub-basin is estimating the amount of rainfall that will fall on the particular site for a given time period. The amount of rainfall can be defined by the following characteristics.

- Duration (hours): The length of time over which storm events occur.
- Depth (inches): The total amount of rainfall occurring during the storm duration.
- Intensity (inches per hour): The average rainfall rate.

The frequency of a rainfall event is the recurrence interval of storms having the same duration and volume. The frequency can be defined either in terms of exceedence probability or return period.

<u>Exceedence probability</u>- The probability that a storm event having the specified duration and volume will be exceeded in one given period, typically one year.

<u>Return period</u>- The average length of time between storm events that have the same duration and volume.

Therefore, if a storm event with a specified duration and volume has a 10 percent chance of occurring in any one year, then it has an exceedence probability of 0.1 and a return period of 10-years.

## 5.3.1 Rainfall Intensity

The rainfall intensity factor, I, is shown in Appendix B.

### 5.3.2 Rainfall Depth

The corresponding 24-hour rainfall depths (inches) for the 1, 2, 5, 10, 25, 50, and 100-year frequency storm events is provided in Appendix B.

## 5.4 Graphical Peak Discharge Method

### 5.4.1 Equation

This section presents the graphical peak discharge method for computing peak discharge rates using the SCS methodology. The graphical method was developed from the hydrograph analysis using TR-20, Computer Program for Project Formulation Hydrology (SCS 1983). This same methodology is available in current computer software programs, therefore TR-20 is not required to calculate the peak discharge. The peak discharge equation used is:

$$q_p = q_u AQF$$

Where $\mathbf{q_p}$ is the peak discharge in cfs, $\mathbf{q_u}$ is the unit peak discharge in CSM/in given in **Figure 5-3**, **A** is the drainage area in square miles, and **F** is the pond swamp adjustment factor given in Table 5-8.

The input requirements for the graphical method are as follows:

- Time of concentration ($T_c$ hours)
- Drainage area (square miles)
- Appropriate rainfall distribution (Type II for Greenville County)
- Storm frequency 24-hour rainfall (inches)
- Drainage area applicable curve numbers

If pond and swamp areas are spread throughout the watershed and not considered in the time of concentration ($T_c$) computations, an adjustment for the pond and swamp factor must be included.

### 5.4.2 Calculating the Peak Discharge

The following items must be obtained to calculate peak discharges using the SCS methodology:

- **P:** For a selected rainfall frequency, the 24-hour rainfall (P in inches) should be read from Appendix B

- **Q:** The total runoff (Q in inches) for the watershed or sub-basin shall be calculated using the steps found in Section 5.2.2.1.

- **CN:** The curve number (CN) for the watershed or sub-basin shall be calculated using the steps found in Section 5.2.2.2.

- **$I_a$:** The initial abstractions ($I_a$) shall be calculated using the steps found in Section 5.2.2.2.

- **$I_a$/P:** The initial abstraction to rainfall ratio ($I_a$/P) shall be computed.

- **$T_c$:** Time of concentration ($T_c$) shall be calculated using the steps found in Section 5.2.3.

If the $I_a/P$ ratio computed is outside the range of **Figure 5-3**, then the limiting value shall be used. If the $I_a/P$ ratio falls between the limiting values of **Figure 5-3**, linear interpolation shall be used.

The peak discharge per square mile per inch of runoff $q_u$ (unit peak discharge csm/in) is obtained from **Figure 5-3** by identifying the point where the $I_a/P$ ratio and the $T_c$ (hours) intersect.

If applicable, the pond and swamp adjustment factor shall be obtained from Table 5-6.

**Table 5-6. Pond and Swamp Adjustment Factor**

| Watershed Percentage of Pond and Swamp | Adjustment Factor $F_p$ |
|---|---|
| 0.0 | 1.00 |
| 0.2 | 0.97 |
| 1.0 | 0.87 |
| 3.0 | 0.75 |
| 5.0 | 0.72 |

The peak discharge may then be calculated using the equation in Section 5.4.1.

### 5.4.3 Limitations and Assumptions of the Graphical Method

The graphical method has the following assumptions and limitations:

- The graphical method calculates peak discharge rate (cfs) only. If a hydrograph is needed, the tabular hydrograph method may be used or any approved hydrograph-based computer model may be used.
- The watershed or sub-basin is assumed to be hydrologically homogeneous.
- The weighted CN calculated for the watershed or sub-basin should be greater than 40.
- The watershed or sub-basin is assumed to have only one main stream or, if more than one, the branches must have similar times of concentration.
- The graphical method cannot perform reservoir routing calculations.
- The time of concentration used shall range from 0.1 to 10 hours.
- Accuracy of the peak discharge calculated will be reduced if values are used outside the range given in **Figure 5-3**. The limiting $I_a/P$ values shall be used in these circumstances.

## 5.5 Unit Hydrograph Method

In addition to estimating runoff volumes and peak discharge rates, the SCS methodology can be used to estimate the entire hydrograph for a watershed or sub-basin. SCS has developed a tabular hydrograph procedure that can be used to generate hydrographs for small drainage areas less than 2,000 acres. The tabular hydrograph procedure uses the unit discharge hydrographs that have been generated for a series of time of concentrations. A unit hydrograph represents the time of flow resulting from one inch of direct runoff occurring over the watershed in a specified period of time. In addition, SCS has developed hydrograph procedures to be used to generate composite flood hydrographs. When hydrographs need to be generated from separate sub-basin areas and then routed and combined at a point downstream, the design professional is referred to the procedures by the SCS in the 1986 version of TR-55 or other current computer software that utilize the techniques used in TR-55.

The development of a runoff hydrograph from a watershed is a tedious, laborious process not normally performed by hand because of the simplicity of current computer model applications. For that reason, only an overview of the process is outlined in this Design Manual to assist the design professional in reviewing and understanding the input and output from typical computer hydrograph generation programs and models.

### 5.5.1 Basin Lag Time

Characteristics of the dimensionless hydrograph vary with size, shape, and slope of the tributary drainage area. The most significant characteristics affecting the dimensionless hydrograph shape are the basin lag and the peak discharge for a given rainfall. Basin lag in this application is defined as being the time from the center of mass of rainfall excess to hydrograph peak. The following equation is used to determine basin lag time:

$$T_L = 0.6 \cdot T_C$$

Where $T_L$ is the basin lag time in hours ($T_c$ also specified in hours).

### 5.5.2 Hydrograph Time to Peak

The time to peak is calculated from the basin lag time by:

$$T_p = (D/2) + T_L$$

Where $T_p$ is the time to peak in hours, D is the duration of excess unit rainfall calculated as $0.4T_L$, where $T_L$ is given in hours.

### 5.5.3 Peak Rate Factors

The unit hydrograph equations used in the SCS method for generating hydrographs includes a constant to account for the general land slope in the drainage basin. The constant is commonly referred to as the peak rate factor, and can be adjusted to match the characteristics of the basin. A default value of 484 for the peak rate factor represents rolling hills and a medium level of relief. SCS indicates that for mountainous terrain the peak rate factor can reach values as high as 600, and as low as 300 for flat and/or coastal areas.

For general calculations, the SCS unit hydrograph method can be used without modifications assuming a peak rate factor of 484.
The SCS method can be modified with a peak rate factor of 300 when watersheds are flat and have significant storage in the overbanks. These watersheds generally have the following characteristics:

- Mild slopes less than 2 percent.
- Significant surface storage throughout the watershed in the form of standing water during storm events or inefficient drainage systems.

Unit hydrograph time and discharge ratios are shown in Table 5-7 for peak discharge factors of 484 and 300. The SCS unit hydrograph method develops incremental hydrographs for small durations of the total design storm. These incremental hydrographs are then combined into a composite hydrograph for the drainage area.

For ease of spreadsheet development and calculations, the dimensionless unit hydrograph time and discharge ratios can be approximated by the following equation (Haan 1970):

$$\frac{q}{q_p} = \left[ \frac{t}{T_p} e^{\left(1-\frac{t}{T_p}\right)} \right]^k$$

Where $q/q_p$ is the discharge ratio, $t/T_P$ is the Time ratio, and K is a dimensionless parameter based on watershed characteristics and hydrograph shape.

K has the following approximate values:

- K = 3.77 for the dimensionless SCS unit hydrograph.
- K = 3.79 for a watershed having a peak rate factor of 484.
- K = 1.50 for a watershed having a peak rate factor of 300.

### 5.5.4 Peak Discharge and Unit Hydrograph Development

The peak discharge $q_p$ is calculated from the following equation:

$$q_p = \frac{PRF \cdot A}{T_p}$$

Where PRF is the Peak Rate Factor (typ. 484 or 300), A is the drainage area in Square Miles, and $T_p$ is the Time to Peak in hours.

To develop the actual unit hydrograph from the dimensionless unit hydrograph involves the following steps:

- Estimating rainfall from the 24-hour storm event,
- Estimating total rainfall excess by incorporating initial abstraction and curve numbers,
- Estimating the unit hydrograph time parameter ratios,
- Estimating the unit hydrograph peak flow rate ($q_p$),
- Multiplying each time ratio value ($t/T_P$) by the actual time to peak ($T_P$), and

- Multiplying each discharge ratio ($q/q_p$) by the peak flow rate ($q_p$).

### Table 5-7 Dimensionless Unit Hydrographs

| | 484 | | 300 | |
|---|---|---|---|---|
| t/Tt | q/qu | Q/Qp | q/qu | Q/Qp |
| 0.0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 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 |

| | 484 | | 300 | |
|---|---|---|---|---|
| t/Tt | q/qu | Q/Qp | q/qu | Q/Qp |
| 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 |

## 5.6 First Flush Water Quality Volume

In early stages of storm runoff from small catchments, pollutants that have accumulated on land surfaces since the previous rainfall, particularly on impervious areas such as roofs and pavements, can be washed quickly into nearby receiving waters. The initial flush of contaminants from the catchment, known as the "first flush" or "first foul flush" has been confirmed by experimental studies for both pollutant concentrations and pollutant quantities, particularly in sewered catchments where comparatively large expanses of land are covered by impervious surfaces.

Regulations for mitigating nonpoint source pollution from urban areas often include requirements for treating a "first-flush" depth of runoff, usually by detaining storm water until it can be treated and released, or until it infiltrates into soils. Greenville County minimum water quality control requirements are to size water quality capture devices to trap 85% of total suspended solids (TSS) based on annual loadings by particle class. An alternative as a default criteria is to size the device to capture the first inch of runoff from the impervious area of the site and discharge it over a twenty-four (24) hour period.

If first-flush runoff is held in a storage area not connected directly to the main drainage channel (that is, if runoff is held in an off-stream storage area), a control device needs to be built to divert stream flow until the desired volume is captured. Contaminants, mostly floating debris and suspended solids, may also be removed from the initial runoff by passing the storm water through a treatment device of some kind. In either case, the structural measure provided for water quality control needs to be designed or selected to accommodate a specific flow rate.

An uncomplicated graphical procedure for calculating first-flush design flow rates is presented that is based on standard NRCS rainfall-runoff computation methods in which excess precipitation obtained by applying the runoff curve-number approached to 24-hour design storm storms is transformed to runoff using triangular unit hydrographs. The solution is carried out using dimensionless parameters, which reduces the number of variables involved in the calculations. As a consequence, the entire procedure is condensed into a single graph that gives the discharge $q_f$ needed to design or size water quality control structures for a specified first flush depth $Q_f$ where rainfall frequency characteristics are constant.

An example is presented to show how first-flush flow rates can be found for a small catchment where the first full inch of runoff ($Q_f$ = 1.0 in) from an NRCS 10-year, 24-hour design storm is to be treated. Although graphs have to be prepared for each combination of $Q_f$ and $P_{24}$ that occur, once completed, flow rates needed to design or size water quality control structures can be calculated accurately and without difficulty.

### 5.6.1.1. Rainfall Distributions

Standard rainfall patterns for storms of 24-hour duration (called Types 1, 1a, 2, and 3 storms) have been prepared by the NRCS for four different geographic regions of the United States. The synthetic design storms are based on National Weather Service (NWS) rainfall maps (SCS 1983; SCS 1986; Chow et al. 1988, pages 460-463; McCuen 1989, pages 143-147; Ponce 1989, pages 188-190), and are presented as ratios of cumulative rainfall depth to total rainfall depth as functions of time. The rainfall patterns are intended for use in catchments with areas of 250 $km^2$ (100 $mi^2$) or less, and they are considered applicable to storms of any average recurrence interval.

NRCS Type 1 24-hour storms are characteristic of the Pacific coast maritime climate with wet winters and dry summers common in southern California, Alaska, and Hawaii. Type 1A storms are representative of low-intensity rainfall associated with frontal storms west of the Cascade and Sierra Nevada mountain ranges in northern California, Oregon, and Washington. Type 3 storms characterize coastal areas along the Atlantic and Gulf of Mexico where tropical storms are responsible for large 24-hour rainfalls. Type 2 storms typify high intensity thunderstorms and are applicable in Greenville County. See **Figure 5-4** for Cumulative Normalized Rainfall for Standard Design Storms.

### 5.6.1.2. Runoff Hydrographs

Unit hydrograph methods are based on the idea introduced by Sherman (1932) that a linear relation exists between excess rainfall and the time distribution of runoff from a catchment. A dimensionless curvilinear unit hydrograph developed by the NRCS has 3/8 of the total runoff volume in the rising side, and is approximated closely by a triangle (Snider 2001; McCuen 1989, pages 399-402). Consequently, for the triangular approximation, $k_r = t_r/t_p = 5/3$ where $t_p$ is the time-to-peak or time between the beginning of runoff from a short high-intensity storm and the corresponding peak rate of runoff from the catchment, and $t_r$ is recession time or time from peak flow rate to the end of direct runoff, as shown in **Figure 5-5**. The ratio $k_r$ might vary depending on watershed topography, amount of impervious land cover, and the extent to which natural stream channels have been replaced by storm sewers. However, for $k_r = 5/3$, the peak discharge from a catchment of area A given by the triangular unit hydrograph for an effective rainfall depth $Q$ is then found as

$$q_p = k_q \frac{AQ}{t_p}\left(\frac{2}{1+k_r}\right)$$

where $k_q$ = units conversion factor that depends on the units of $q_p$, $A$, $Q$, and $t_p$ ($k_q$ for $q_p$ in $m^3/s$ and $ft^3/s$ for various combinations of possible units of $A$, $Q$, and $t_p$ is given in Table 5-10).

### Table 5-8. Values of the Peak Discharge Units Conversion Factor, $k_q$,

| Unit of the Following Parameters | | | | Units of Conversion Factor $k_q$ |
|---|---|---|---|---|
| $q_p$ | $A$ | $Q$ | $t_c$ | |
| $m^3/s$ | $km^2$ | mm | H | 0.2778 |
| | $km^2$ | mm | min | 16.67 |
| | $km^2$ | cm | h | 2.778 |
| | $km^2$ | cm | min | 166.7 |
| | ha | mm | H | 0.002778 |
| | ha | mm | min | 0.1667 |
| | ha | cm | h | 0.92778 |
| | ha | cm | min | 1.667 |
| $ft^3/s$ | $mi^2$ | in | h | 645.3 |
| | $mi^2$ | in | min | 38720 |
| | ac | in | h | 1.008 |
| | ac | in | min | 60.5 |

From evaluation of hydrographs from a large number of watersheds, the optimal rainfall duration of the unit hydrograph $D=t_p/5$ (Kent 2001; McCuen 1989, page 399). The dimensionless representation of the NRCS triangular unit hydrograph 3 is given by:

$$\frac{q}{q_p} = \begin{cases} \frac{t}{t_p}; \text{for } \frac{t}{t_p} \le 1 \\ \frac{1}{k_r}\left(\frac{t}{t_p} - 1\right); \text{for } 1 < \frac{t}{t_p} \le (1 + k_r) \\ 0; \text{for } \frac{t}{t_p} > (1 + k_r) \end{cases}$$

Where $t$ is the time since the start of runoff. These relations are shown in **Figure 5-5**.

### 5.6.1 Dimensionless Runoff Calculations

Making use of the NRCS rainfall-runoff procedures, which include the 24-hour storm distribution, the runoff curve-number method to calculate the rainfall excess, and the triangular unit hydrograph to transform excess rainfall into runoff rates, outflow from a catchment is given by the following functional relation:

$$q = f\{t, t_c, A, S, k_a P_{24}, t_d, StormType, k_r\}$$

where $S$ = function of $CN$ given by (2), $P_{24}$ = 24-hour rainfall depth, $td$ = storm duration, and $StormType$ = NRCS standard 24-h design storm type (1, 1 A, 2, or 3). By creating a set of dimensionless parameters, the number of variables can be reduced, and the task of calculating runoff can be made less complicated. Using appropriate combinations of $t_c$, $P_{24}$, and $A$ to normalize the remaining variables, the following dimensionless functional relation results:

$$\frac{qt_c}{P_{24}A} = f\left\{\frac{t}{t_c}, \frac{S}{P_{24}}, k_a, \frac{t_d}{t_c}, StormType, k_r\right\}$$

For specified values of $k_a$, $k_r$, and a particular 24-hour rainfall distribution, the above equation reduces to

$$q_* = f\{t_*, S_*, t_{d*}\}$$

Where

$$q_* = \frac{qt_c}{P_{24}A}, t_* = \frac{t}{t_c}, S_* = \frac{S}{P_{24}}, \text{and } t_{d*} = \frac{t_d}{t_c}.$$

Because storm duration $t_d$ = 24 hours is constant in our analysis, $t_c$ can replace $t_d$*, which gives

$$q_* = f\{t_*, S_*, t_c\}$$

Making use of dimensionless NRCS rainfall-runoff procedures, graphical solutions for peak discharge rates $q_p$ and flow rates needed to design water quality control structures, called the first-flush flow rate and denoted here as $q_f$, can be developed as functions of the dimensionless independent parameters as shown.

## 5.6.2 Normalized Peak Flow Rate

If only peak discharge $q_p$ is needed to size water quality control structures, as it might be if the first-flush volume equals runoff from a storm having a specified rainfall depth, the time-distribution of runoff is not involved and the functional relation for the normalized peak rate of runoff is given by

$$q_{p*} = f\{S_*, t_c\} = \frac{q_p t_c}{P_{24} A}$$

Because $q_{p*}$ depends on only two variables, the relation can be graphed easily, thereby providing a rapid and uncomplicated means of finding the peak rate or runoff from small catchments. Graphical solutions for $k_r = 5/3$, $k_a = 0.2$, and the NRCS Type 2 rainfall distribution created by generating dimensionless runoff hydrographs for various combinations of $S*$ (ranging from 0 to 3 by increments of 0.01) and $t_c$ (5, 10, 15, 20, 30, 45, and 60 min) and plotting $q_p*$ as a function of $S*$ for each of the times-of-concentration are shown in **Figure 5-6.** The curves are based on highly accurate numerical runoff solutions. Accuracy of graphical estimates of $q_p$ depends only on the precision of interpolated values.

The graph for normalized peak flow rate given in **Figure 5-6** has been divided into three sections for successive ranges of $S*$, with the ordinate scale changing in each to provide more accurate estimates of $q_p*$ as the $t_c$ curves converge. With values of $A$, $t_c$, $CN$, and $P_{24}$ having been obtained for a catchment, the peak outflow rate $q_p$ is found as follows:

Step 1. Calculate $S = k_s\left(\frac{1000}{CN} - 10\right)$;

Step 2. Calculate $S_* = S / P_{24}$;

Step 3. Obtain $q_{p*}$ from **Figure 5-6** from the appropriate $t_c$ curve (interpolation between adjacent curves might be needed);

Step 4. Calculate the units conversion factor $k_q$

Step 5. Calculate $q_p = k_q \frac{P_{24} A}{t_c} q_p *$.

Graphical solutions for $q_{p*}$ similar to the one in **Figure 5-6** need to be used for other NRCS storm types, and for coefficients $k_a$ and $k_r$ that differ from the standard values.

## 5.6.3 Normalized First-Flush Flow Rate

The functional relation for $q_f$ is the same as for $q_p$, except for the addition the specified first-flush runoff depth $Q_f$ and can be written in dimensionless form as

$$q_{f*} = f\{S_*, t_c, Q_f *\}$$

Where

$$q_{f*} = \frac{q_f t_c}{P_{24} A}, \text{ and } Q_f* = \frac{Q_f}{P_{24}}$$

are the normalized first-flush flow rate and first-flush runoff depth, respectively. Graphical representations of (12) providing $q_{f*}$ as a function of $S^*$ and $t_c$ can be prepared for specified values of $Q_f$ and $P_{24}$. If the peak rate of runoff occurs before the specified first-flush depth $Q_f$ is reached, $q_f$ is set equal to $q_p$ because water quality control structures will need to be designed for the maximum discharge. However, this condition is likely to take place only when the catchment runoff curve number is comparatively small, signifying a highly pervious drainage basin.

For example, two regions having homogenous rainfall characteristics have been defined in Greenville County, South Carolina, where the initial one inch of runoff from a 10-year, 24-hour NRCS Type 2 design storm needs to be treated. The 10-year, 24-hour rainfall depth in the northern part of the county is 5.9 inches, and in the southern section it is 5.5 inches. Graphical relations for $q_{f*}$ in northern Greenville County are shown in **Figure 5-7** for $Q_f$ = 1.0 in. The ordinate scale for $S*$ ranges from 0 to 0.6 in **Figure 5-7** because first-flush runoff volumes beyond $S_*$ = 0.6 are all reached following the discharge peak. A similar graph has been developed for southern Greenville County where the 10-year, 24-h rainfall depth is less. With known values *of* $A$, $t_c$, $CN$, and $P_{24}$, the first-flush flow rate $q_f$ is found as follows:

Step 1. Calculate $S = k_s\left(\frac{1000}{CN} - 10\right)$;

Step 2. Calculate $S_* = S / P_{24}$

Step 3. Obtain $q_{f*}$ from **Figure 5-7** and **Figure 5-8** for North and South Greenville County, respectively, from the appropriate $t_c$ curve (interpolation between adjacent curves might be needed);

Step 4. Calculate the units conversion factor $k_q$

Step 5. Calculate $$q_f = k_q \frac{P_{24} A}{t_c} q_f{}^*.$$

Curves in **Figure 5-7** and **Figure 5-8** have been smoothed slightly. Nonetheless, solutions for $q_f$* found from the graph are highly accurate, depending largely on the precision of interpolated values, which will be high enough for design of water quality control structures.

### 5.6.4 Example Application

An example is presented for a small catchment in Northern Greenville County, South Carolina where the first full inch of runoff ($Q_f$ = 1.0 in) from an NRCS 10-year, 24-hour design storm needs to be treated. The watershed has a drainage area A = 6 ac, a time-of-concentration $t_c$ = 20 min, a runoff curve number $CN$ = 85, and a 10-year, 24-hour rainfall depth $P_{24}$ = 5.9 in. The 24-hour rainfall depths and rainfall intensities for various return period events for both Northern Greenville County and Southern Greenville County are provided in Appendix B. The first-flush flow rate $q_f$ in $ft^3/s$ is to be found along with the peak discharge from the catchment.

Rainfall-runoff calculations carried out using the NRCS curve number procedure along with the triangular unit hydrograph provide the cumulative runoff depth for the storm, which shows that the specified first-flush depth $Q_f$ = 1.0 in is reached at time $t_f$ = 11:54:40 (hh:mm:ss). Catchment outflow $q_f$= 16.9 $ft^3/s$ at time $t_f$ as shown in the runoff hydrograph in **Figure 5-7**, in which the computed peak discharge $q_p$ = 27.5 $ft^3/s$ is also noted. Although the calculations were made quickly by computer, $q_f$ can be found even more simply using the graph provided in **Figure 5-7** as follows:

Step 1. With $k_s$ = 1.0, the potential maximum retention depth is found as

$$S = k_s\left(\frac{1000}{CN} - 10\right) = 1.0\left(\frac{1000}{85} - 10\right) = 1.76 \text{ in};$$

Step 2. $S_* = S / P_{24} = 1.76 / 6.1 = 0.289$;

Step 3. From Figures 5-6, $q_{f*}$ =0.153

Step 4. $k_q$ = 60.5 for the given units of $A$ (ac), $t_c$ (min), and $P_{24}$ (in), and $q_p$ ($ft^3/s$).

Step 5. Then $q_f = k_q \dfrac{P_{24} A}{t_c} q_f^{\ *} = 60.5 \times \dfrac{6.1 \times 6.0}{20} \times 0.153 = 16.9 \text{ft}^3 / s.$

Peak discharge from the 10-year storm is found just as easily and with high accuracy using the graphical solution for $q_p$.

# Chapter 5 References


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# Chapter 6. HYDRAULICS

## 6.1. Open Channel Flow

When dealing with the hydraulics of open channel flow, there are three basic relationships:

1. Continuity Equation
2. Energy Equation
3. Momentum Equation

### 6.1.1 Continuity Equation

The continuity equation may be written as:

**Inflow – Outflow = Change in Storage**

Where inflow represents the volume of flow into the system during a time interval and the outflow represents the volume of flow out of the system during the same time interval. The change in storage represents the change in volume of water stored in the system.

The continuity equation may also be expressed by:

**Inflow Rate –Outflow Rate = Rate of Change in Storage**

The flow rate, Q, is generally expressed in cubic feet per second (cfs), and may be written as:

$$Q = VA$$

Where:

**V** = Average flow velocity over a cross section (ft/sec); and,
**A** = Area of cross section ($ft^2$).

It should be noted that (V) in the flow equation is the average velocity of the flow perpendicular to the cross section. The actual pattern of flow velocity is complex, and the velocity varies greatly from the bottom of the channel to the top of the water surface. However, the velocity along the boundary of the channel bottom is considerably lower than average flow velocity for a particular cross section.

### 6.1.2 Energy Equation

In basic fluid mechanics, the energy equation is written in the form of Bernoulli's Equation:

$$\frac{{v_1}^2}{2g} + y_1 + z_1 + \frac{\rho_1}{\gamma} = \frac{{v_2}^2}{2g} + y_2 + z_2 + \frac{\rho_2}{\gamma} + h_L$$

Where:

| | | |
|---|---|---|
| **v** | = | Average flow velocity (ft/sec), |
| **g** | = | Gravitational constant, |
| **y** | = | Depth of flow, |
| **z** | = | Elevation of channel bottom, |
| **γ** | = | Unit weight of water, and |
| $h_L$ | = | Energy loss between the sections of interest. |

The energy equation represents an energy balance between two points along a channel. Since the equation is an energy equation, the terms represent energy per unit width of flowing fluid. Since the units are a length, the terms are commonly known as "head". Therefore,

| | | |
|---|---|---|
| $v^2/2g$ | = | Velocity head |
| **y + z** | = | Elevation head |
| ρ/γ | = | Pressure head. |

The sum of the velocity head, elevation head, and pressure head represents the total energy, also known as the energy grade line (EGL). The energy grade must be sloping downward in the direction of the flow unless external energy (pump) is added to the system.

The sum of the elevation head and pressure head is known as the hydraulic grade line (HGL).

The difference between open channel flow and pipe flow, is that the free water surface of open channel flow is exposed to the atmosphere and the pressure head is zero. Therefore, for open channel flow the pressure head is ignored and the HGL represents the water surface.

### 6.1.2.1. Critical Depth

Critical depth (yc) occurs when the Froude Number (F) is equal to 1.

$$F = \frac{v}{\sqrt{gd_h}} \quad where \quad d_h = \frac{A}{t}$$

The hydraulic depth dh is defined as being the flow area (A) divided by the flow top width (t).

Since the Froude number is independent on slope, critical depth (yc) depends only on discharge for a given channel. Channel roughness, velocity, discharge, and slope are interrelated. For a given discharge and roughness, the velocity can be increased and the depth of flow decreased by increasing the channel slope. When the channel slope is such that the flow depth resulting from uniform flow equals critical depth, the slope is called the critical slope. For subcritical flow, the slope is less than critical slope, and for supercritical flow, the channel slope is greater than critical slope. Critical depth, slope, and velocity for a given channel section change with discharge.

When designing channels for controlling and conveying runoff, it is desirable to design the channel for subcritical flow.

### 6.1.3 Momentum Equation

The momentum principle in open channel flow is defined by the basic relationship of mechanics:

$$\sum F_s = \Delta(mv_s)$$

This relationship states that the sum of forces in the s-direction equals the change in momentum in that direction. The depth corresponding to the minimum force plus momentum (M) is the critical depth (yc).

### 6.1.4 Uniform Flow

Open channel flow is classified with respect to changes in flow properties with time and location along a channel. If the flow characteristics are not changing with time, the flow is steady flow. If the flow properties are the same at every location along the channel, the flow is uniform. Flow with properties that change with channel location is classified as being non-uniform flow.

In natural flow conditions, the flow is usually non-steady and non-uniform. However, for channel design, steady, uniform flow is assumed based on a peak or maximum discharge.

### 6.1.5 Manning's Equation

Manning's equation is used to calculate average flow velocities for open channels where the factor related to channel roughness increases as the roughness increases.

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

Where:

| | | |
|---|---|---|
| **V** | = | Average flow velocity (ft/sec) |
| **N** | = | Manning roughness coefficient |
| **R** | = | Hydraulic radius (feet), Calculated to be A/P where: |
| **A** | = | flow cross sectional area (feet2) |
| **P** | = | wetted perimeter (feet) (length of boundary between water and channel) |
| **S** | = | Channel slope (ft/ft) |

Manning's Roughness Coefficient (n) is influenced by many factors including:

- Physical roughness of the channel surface,
- The irregularity of the channel cross section,
- Channel alignment and bends,
- Vegetation,
- Silting and scouring, and
- Obstructions within the channel.

Manning's n is very important and critical in open channel flow computations. Variations in this variable can significantly affect discharge, depth, and velocity calculations. Sound engineering judgment must be exercised when selecting appropriate Manning's n values. Typical values for Manning's Roughness Coefficient (n) are located in Table 6-1.

**Table 6-1 Uniform Flow Values for Manning's Roughness Coefficients**

| Type of Flow Media | Min | Normal | Max |
|---|---|---|---|
| **Pipes** | | | |
| Plastic (PVC and ABS) | | 0.009 | |
| Cast iron, coated | 0.011 | 0.013 | 0.014 |
| Cast iron, uncoated | 0.012 | | 0.015 |
| Clay or concrete drain tile | 0.010 | 0.011 | 0.020 |
| Concrete | | 0.013 | |
| Corrugated metal | 0.021 | 0.025 | 0.027 |
| Steel, riveted and spiral | 0.013 | 0.016 | 0.017 |
| Brick | | 0.016 | |
| Vitrified sewer pipe | 0.010 | 0.014 | 0.017 |
| Wrought iron, black | 0.012 | | 0.015 |
| Wrought iron, galvanized | 0.013 | 0.016 | 0.017 |
| **Excavated or Dredged Ditches and Channels** | | | |
| Earth Straight and Uniform | | | |
| Clean recently completed | 0.016 | 0.018 | 0.020 |
| Clean after weathering | 0.022 | 0.025 | 0.030 |
| Gravel, uniform section, clean | 0.022 | 0.027 | 0.033 |
| Earth Winding and Sluggish | | | |
| No vegetation | 0.023 | 0.025 | 0.030 |
| Grass, some weeds | 0.025 | 0.030 | 0.033 |
| Dense weeds, plants in deep channels | 0.030 | 0.035 | 0.040 |
| Earth bottom and rubble sides | 0.025 | 0.030 | 0.035 |
| Stony bottom and weed sides | 0.025 | 0.035 | 0.045 |
| Cobble bottom and clean sides | 0.030 | 0.040 | 0.050 |
| Dragline Excavated or Dredged | | | |
| No vegetation | 0.025 | 0.028 | 0.033 |
| Light brush on banks | 0.035 | 0.050 | 0.060 |
| Rock Cuts | | | |
| Smooth and uniform | 0.025 | 0.035 | 0.040 |
| Jagged and irregular | 0.035 | 0.040 | 0.050 |
| **Channels Not Maintained, Vegetation and Brush Uncut** | | | |
| Dense vegetation in channel as high as flow depth | 0.050 | 0.080 | 0.120 |
| Clean bottom, vegetation and brush on sides | 0.040 | 0.050 | 0.080 |
| Clean bottom, brush and vegetation up to high stage | 0.045 | 0.070 | 0.110 |
| Clean bottom, dense brush and vegetation on overbanks | 0.080 | 0.100 | 0.140 |

| Type of Flow Media | Min | Normal | Max |
|---|---|---|---|
| **Natural Streams on Plain** | | | |
| Clean straight, full stage, no rifts or pools | 0.025 | 0.030 | 0.033 |
| Stones, vegetation, straight, full stage | 0.030 | 0.035 | 0.040 |
| Clean, winding, some pools and shoals | 0.033 | 0.040 | 0.045 |
| Vegetation, stones, winding, some pools and shoals | 0.035 | 0.045 | 0.050 |
| Sluggish reaches, vegetation, deep pools | 0.050 | 0.070 | 0.080 |
| Much vegetation, deep pools, or floodways with timber and underbrush | 0.075 | 0.100 | 0.150 |
| **Natural Mountain Streams with no Vegetation in Channel, Trees and Brush Along Banks are only Submerged at High Stages** | | | |
| Bottom consists of gravel cobbles and few boulders | 0.030 | 0.040 | 0.050 |
| Bottom consists of cobbles with large boulders | 0.040 | 0.050 | 0.070 |
| **Floodplains** | | | |
| Pasture, no Brush | | | |
| Short grass | 0.025 | 0.030 | 0.035 |
| High grass | 0.030 | 0.035 | 0.050 |
| Cultivated Areas | | | |
| No crop | 0.020 | 0.030 | 0.040 |
| Mature row crop | 0.025 | 0.035 | 0.045 |
| Mature field crop | 0.030 | 0.040 | 0.050 |
| Brush | | | |
| Scattered brush, heavy weeds | 0.035 | 0.050 | 0.070 |
| Light brush and trees in winter | 0.035 | 0.050 | 0.060 |
| Light brush and trees in summer | 0.040 | 0.060 | 0.080 |
| Medium to dense brush in winter | 0.045 | 0.070 | 0.110 |
| Medium to dense brush in summer | 0.070 | 0.100 | 0.160 |
| Trees | | | |
| Dense willows, summer, straight | 0.110 | 0.150 | 0.200 |
| Cleared land, tree stumps, no sprouts | 0.030 | 0.040 | 0.050 |
| Cleared land, tree stumps, with heavy sprouts | 0.050 | 0.060 | 0.080 |
| Heavy stand of timber, floodstage below branches | 0.080 | 0.100 | 0.120 |
| Heavy stand of timber, floodstage above branches | 0.100 | 0.120 | 0.160 |

| Type of Flow Media | Min | Normal | Max |
|---|---|---|---|
| **Lined Channels** | | | |
| Asphaltic concrete machine placed | | 0.014 | |
| Asphaltic exposed, prefabricated | 0.015 | 0.016 | 0.018 |
| Concrete | | 0.013 | 0.015 |
| Concrete Rubble | 0.016 | | 0.029 |
| Shotcrete | 0.016 | | 0.017 |
| Grouted Riprap | 0.028 | 0.030 | 0.040 |
| Stone Masonry | 0.030 | 0.032 | 0.040 |
| Jute Net | 0.019 | 0.022 | 0.028 |
| Straw with net | 0.025 | 0.033 | 0.065 |
| Curled wood mat | 0.028 | 0.035 | 0.066 |
| Synthetic geotextile mat | 0.021 | 0.025 | 0.036 |
| Gravel Riprap | | | |
| 1-inch D50 | 0.030 | 0.033 | 0.044 |
| 2-inch D50 | 0.034 | 0.041 | 0.066 |
| Rock Riprap | | | |
| 6-inch D50 | 0.035 | 0.069 | 0.104 |
| 12-inch D50 | 0.040 | 0.078 | 0.120 |

Sources: Design Hydrology and Sedimentology for Small Catchments, Hann et. al., 1995 and HEC-15

## 6.1.6 Trapezoidal Channels

The hydraulic radius (R) is defined as:

$$R = \frac{A}{P}$$

Where:

**A** = Cross sectional flow area ($ft^2$)
**P** = Wetted perimeter (ft)

The wetted perimeter is defined as being the length of the boundary between water and the channel sides and bottom at any cross section. The wetted perimeter is the distance around the flow cross section starting at one edge of the channel and traveling along the sides and bottom to the other channel edge.

The cross sectional area (A) for a trapezoidal channel can be determined from:

$$A = bd + Zd^2$$

Where:

**A** = Cross sectional flow area ($ft^2$)
**b** = Bottom width of channel (ft)
**d** = Flow depth of channel (ft)
**Z** = Channel side slopes (ZH:1V)

The hydraulic radius (R) for a trapezoidal channel can be calculated from:

$$R = \frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$$

The expression for the hydraulic radius for wide, shallow channels can be simplified for calculations. Consider a trapezoidal channel that is wide and shallow. The trapezoid can then be approximated by a rectangle.

$$R = \frac{A}{P} = \frac{bd}{b + 2d}$$

If b is much larger than d (b >> d), then the 2d in the denominator can be ignored leaving:

$$R = \frac{A}{P} = \frac{bd}{b} = d$$

### 6.1.7 Circular Channels (Pipes)

The maximum flow capacity of a circular pipe occurs at a depth equal to 0.938D.

The hydraulic radius of a pipe is defined by the flow depth and an angle (θ) that is measured in radians.

$$A = \frac{D^2}{8}(\theta - \sin\theta)$$

$$R = \frac{D}{4}\left(1 - \frac{\sin\theta}{\theta}\right)$$

#### 6.1.7.1. Flow Depth 0 < y < D/2

For the flow depth (y) in a pipe and pipe diameter (D) where: **0 < y < D/2**

$$\theta = 2\ \tan^{-1}\left[\frac{\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - Y\right)^2}}{\frac{D}{2} - Y}\right]$$

### Flow Depth y = D/2

For the flow depth (y) in the pipe and pipe diameter (D) where: **y = D/2**

$$\theta = \pi$$

### Flow Depth D/2 < y < D

For the flow depth (y) in the pipe and pipe diameter (D) where: **D/2 < y < D**

$$\theta = 2\pi \; + \; 2\tan^{-1}\left[\frac{\sqrt{\left(\frac{D}{2}\right)^2 - \left(Y - \frac{D}{2}\right)^2}}{\frac{D}{2} - Y}\right]$$

## 6.1.8 Normal Depth Calculation

Normal depth calculations can be found by using the following methods:

- Trial and Error
- Graphical Procedures
- Computer Models

### Trial and Error

A trial and error procedure for solving Manning's equation can be used to calculate the normal depth of flow in a uniform channel when the channel shape, slope, roughness and design discharge known.

The flow rate, Q, is generally expressed in cubic feet per second (cfs), and may be written as

$$Q = VA$$

Where:

| | | |
|---|---|---|
| **V** | = | Average flow velocity over a cross section (ft/sec), calculated using Manning's equation |
| **A** | = | Area of cross section ($ft^2$) |

Using Manning's Equation, the continuity equation can be solved as:

$$Q = \frac{1.49}{n} A\, R^{2/3} S^{1/2}$$

Rearrangement of the continuity equation results in the following ratio:

$$A\,R^{2/3} = \frac{n\,Q}{1.49\,S^{1/2}}$$

To calculate the normal depth of flow (dn) by the trial and error process, trial values of depth (dn) are selected to calculate a corresponding flow area (A), wetted perimeter (P), and hydraulic radius (R). For each trial depth selected, a corresponding AR2/3 value is calculated. Trial values of the depth are selected until the AR2/3 value equals the known ratio calculated by using the known roughness, design discharge, and channel slope.

### Graphical Procedure

Graphical methods for simplifying the trial and error procedure have been created for trapezoidal channels to calculate the normal depth of flow. This method utilizes a known ratio based on the channel side slopes, channel bottom width, channel slope, Manning's roughness coefficient n, and design discharge.

The design ratio is expressed as:

$$d_n \; ratio = \frac{Q\;n}{b_o^{\;8/3} S^{1/2}}$$

Where:

- **Q** = Peak flow rate ($ft^3$/sec)
- **n** = Manning roughness coefficient
- **$b_o$** = Channel bottom width (ft)
- **S** = Channel slope (ft/ft)

Once the normal depth ratio is calculated, and the side slopes (ZH:1V) are determined, **Figure 6-1** may be used to determine the normal depth of flow.

- Locate the value for the normal depth ratio on the x-axis of **Figure 6-1**, and extend this value up to the appropriate side slope curve.
- From this intersection point, extend back to the y-axis to obtain the $d_n$/b ratio.
- Once the $d_n/b_o$ ratio has been obtained, multiply the $d_n/b_o$ ratio value by the channel bottom width ($b_o$) to calculate the normal depth of flow in the channel.

## 6.1.8.1. Graphical Procedure Example

**Given:** A channel is to be designed with the following parameters:

Peak flow rate Q = 50 cfs

| | | |
|---|---|---|
| Manning's n | = | 0.045 |
| Channel bottom width | = | 5 ft |
| Channel side slopes | = | 3H:1V |
| Channel bed slope | = | 0.01 ft/ft |

**Find:** The normal depth ($d_n$) of flow in the channel.

**Solution:**

1. Calculate the normal depth ratio ($d_n$ ratio).

$$d_n \ ratio = \frac{(50)\ (0.045)}{5^{8/3}(0.01)^{1/2}}$$

$$d_n \ ratio = 0.31$$

2. Locate the value for the normal depth ratio on the x-axis of **Figure 6.1**, and extend this value up to the appropriate side slope curve.

   - Locate 0.31 on the x-axis and extend this value up to the side slope curve Z=3.

3. From this intersection point read back to y-axis to obtain the dn/bo ratio.

   - The ratio intersection reads to be 0.31

4. Multiply the dn/bo ratio by the bottom width (bo) to obtain the normal depth.

   - 0.31 * 5.0 ft = 1.55 ft

   - The normal depth ($d_n$) of the channel is calculated to be **1.55-feet.**

### 6.1.8.2. Computer Models

There are various computer models available that are capable of calculating the flow depth in a given channel reach. Many of these models are capable of handling a full network of channels, or just the computations for a single channel reach. These models are also capable of calculating water surface elevations for subcritical, supercritical, and mixed flow regimes. The effects of various obstructions such as bridges, culverts, weirs, and structures in the overbank areas may also be considered in the calculations. The actual models used for these calculations shall be at the discretion of the design professional with approval from the Greenville County Storm Water Management Director.

## 6.2. Outlet Hydraulics

Outlet structures provide the critical function of regulating flow volumes and peak flow rates from storm water management control structures. Flow control devices can operate as either open channel flow, in which the flow has a free water surface, or pipe flow in which the flow is in a closed conduit. In either situation, an increase in head on a structure increases the discharge flow rate through the structure.

There are numerous different types of outlet structures designed for specific types of flow control:

- Water quality and channel protection flows are typically controlled with smaller, more protected outlet structures such as:
  - Perforated plates or risers,
  - Reverse slope under-surface pipes,
  - Orifices located within screened pipes or risers,
  - V-notch weirs, and
  - Hooded orifices where the hood invert is located beneath the permanent pool elevation to protect the outlet structure from floatable debris
- Larger storm event flows are typically controlled by:
  - Risers with different sized and shaped openings,
  - Flow over the top of risers and/or drop inlet structures,
  - Flow over broad crested weirs or emergency spillways through embankments.

The basic stage discharge relationship for basin outlet structures is controlled by weir, orifice or pipe flow.

## 6.2.1 Weir Flow

### 6.2.1.1. 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 various shapes including circular, rectangular, and triangular. The general equation for a broad-crested weir is:

$$Q = C\,L\,H^{\frac{3}{2}}$$

Where:

**Q** = Discharge (cfs),
**C** = Weir coefficient (weir shape dependant, typically between **3.0 and 3.2 for risers**),
**L** = Weir length (feet), the total length over which flow crosses the weir (circumference of a pipe for circular drop inlets), and
**H** = Water head (feet).

### 6.2.1.2. V-Notch Weirs

A weir in the form of a V or a pie shaped cut in a vertical wall is classified as a V-notch weir.

$$Q = 2.5 \tan\left(\theta / 2\right) H^{2.5}$$

Where:

**Q** = Discharge (cfs),
**θ** = Angle of v-notch (degrees),
**H** = Water head on apex of notch (feet).

## 6.2.2 Orifice Flow

An orifice is an opening of a designed size or shape. A typical orifice is circular or rectangular in shape.

The flow through an orifice is dependent of the height of water above the opening and the size and the edge treatment of the orifice.

$$Q = C' a \left(2gH\right)^{\frac{1}{2}}$$

Where:

**Q** = Discharge (cfs)
**C'** = Orifice coefficient
**C' = 0.60** for sharp-edged orifices, where the material is thinner than the orifice diameter
**C' = 0.80** where the material is thicker than the orifice diameter
**C' = 0.92** where orifice edges are rounded.
**A** = Cross sectional area of the orifice ($ft^2$)
**g** = **32.2 ft/sec$^2$**
**H** = Head on the orifice (feet)

## 6.2.3 Pipe Flow

The outlet hydraulics for pipe flow can be expressed by the following equation based on Bernoulli's Equation and continuity principles:

$$Q = \frac{a\left(2gH'\right)^{\frac{1}{2}}}{\left(1 + K_e + K_b + K_c L\right)^{\frac{1}{2}}}$$

Where:

**Q** = Discharge (cfs),
**A** = Cross sectional area of the pipe ($ft^2$),
**g** = 32.2 ft/sec$^2$,
**H'** = Head (feet) defined as the distance from the water surface in the basin to a point **0.6 D** above the invert of the outlet barrel.
**D** = Outlet barrel diameter in feet,
**$K_e$** = Pipe entrance loss (typical value of **$K_e$ = 1.0**),
**$K_b$** = Pipe bend loss if there is a bend (typical value of **$K_b$ = 0.5**),
**$K_c$** = Head loss coefficient due to friction
**$K_c$** = $5087 * n^2 / D^{4/3}$
**N** = Manning's roughness coefficient of the barrel, and
**D** = barrel diameter in inches,
**L** = Total length of the pipe (feet).

## 6.2.4 Outlet Control Combinations

Any given spillway can have a variety of stage discharge relationships depending on the head. When the water level is just above a riser crest (a very low head on the riser), the riser crest acts like a weir, and flow is weir controlled. As the water level in the basin increases, water begins flowing in from all sides including directly above the inlet, and the inlet begins to act like an orifice. As the head continues to increase, the outlet eventually begins to flow full, and pipe flow dictates. To determine which of the three flow mechanisms is controlling at a particular water level in a storm water management control structure, all three equations should be utilized at each level. The minimum flow for a given stage indicates the actual discharge from the storm water management control structure and the flow mechanism that is controlling at that water level. **Figure 6-2** shows drop inlet control scenarios.

# 6.3. Hydraulics of Culverts

Culverts are conduits that are commonly used to pass drainage water through embankments.

- The 25-year 24-hour storm event shall be used in the design of all cross-drain culverts.
- The 10-year 24-hour storm event shall be used in the design of all interior culverts.
- The 100-year 24-hour storm event shall be used to check all systems for overtopping, flooding and surcharge.

## 6.3.1 Culvert Classes

Chow (1959) divided culvert flow into six different categories. Chow indicated that the entrance of an ordinary culvert will not be submerged if the outlet is not submerged unless the head water is greater than some critical value H*. The value of H* may vary from 1.2 to 1.5 time the culvert height as a result of entrance geometry barrel characteristics and approach conditions.

### 6.3.1.1. Type 1-Outlet Submerged.

The pipe will flow full and the discharge can be calculated from the pipe flow equation in Section 6.2.3.

### 6.3.1.2. Type 2-Outlet Not Submerged, H > H* Pipe flowing full.

This condition corresponds to a hydraulically long condition. The tailwater depth should be less than the height of the culvert. Discharge can again be calculated by using the pipe flow equation in Section 6.2.3.

### 6.3.1.3. Type 3-Outlet Not Submerged, H > H*, Pipe not flowing full.

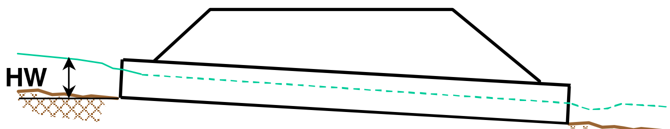
This condition corresponds to the hydraulically short condition. The tailwater depth should be less than the height of the culvert. Discharge is inlet controlled and can be determined form plots and nomographs.

### 6.3.1.4. Types 4-6 Outlet Not Submerged, H < H*.

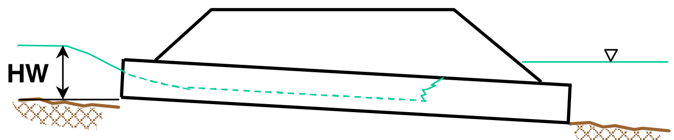
Under these conditions the pipe flows as an open channel. The discharge for a given head depends on the culvert slope entrance geometry culvert roughness and culvert size. A flow profile through the culvert must be developed to accurately predict the discharge. The exact shape of the profile will depend on the depth of the flow at the outlet. The factors that influence energy and hydraulic grade lines are used to determine the type of control for the discharge. The flows through the culvert are full flow partially full flow and free surface flow.

## 6.3.2 Inlet Control

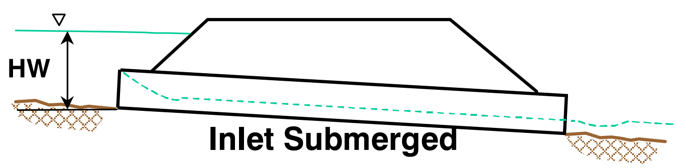
Inlet control occurs when the section that controls flow is located at or near the entrance of the culvert. Discharge is dependent only on the geometry of the inlet and the headwater depth for any particular culvert size and shape. The inlet will continue to control as long as water flowing through the culvert does not impede flow. If inlet control dictates downstream hydraulic factors such as slope culvert length and culvert roughness do not influence the flow capacity. If a culvert is operating under inlet control it will not flow full throughout the entire length of the culvert.




Outlet Unsubmerged



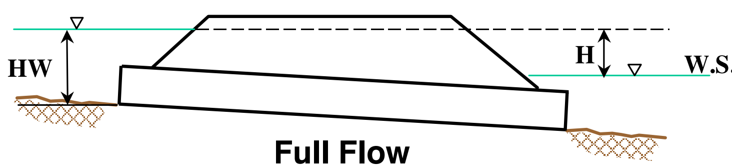

Outlet Submerged, Inlet Unsubmerged



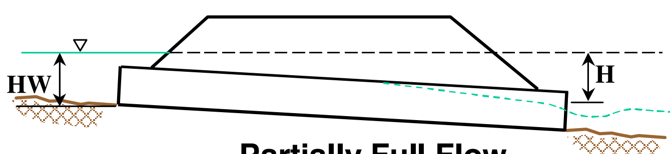

Inlet Submerged

## 6.3.3 Outlet Control

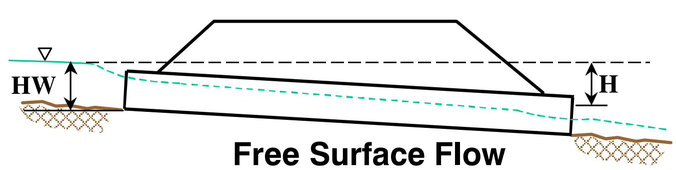
Outlet Control takes place when the control originates at or near the culvert outlet point. Outlet control discharge is dependent on all of the hydraulic factors upstream of the outlet and the tailwater depth.




Full Flow




Partially Full Flow




Free Surface Flow

## 6.3.4 Critical Depth in Culverts

When the sum of kinetic energy plus the potential energy for a specified discharge is at a minimum the maximum discharge through the culvert occurs with any specified total energy head. For a given flow rate critical flow occurs. During critical flow the depth of flow and slope associated with critical flow define the critical depth and critical slope. If a culvert has an unsubmerged outlet the maximum capacity of the culvert is established when critical flow occurs.

## 6.3.5 Culvert Selection and Design

Culvert selection techniques can range from solving empirical formulas, to using nomographs and charts, to comprehensive mathematical analysis for specific hydraulic conditions. The many hydraulic factors involved make precise evaluation time consuming and difficult without the help of computer programs and models. The actual models used for these calculations shall be at the discretion of the design professional with approval from the Greenville County Storm Water Plan Review Agency. Applicable computer models include, but are not limited to:

- HY8
- SEDCAD4
- Pond Pack
- HEC-RAS
- Culvert Master

The simple empirical and nomograph methods do not account for all of the factors that impact flow through culverts, but they can be easily used to estimate flow capacities for the conditions they represent.

## 6.3.6 Culvert Nomograph Procedure

The basic procedure for culvert design using nomographs based on a given flow rate involves selecting a trial culvert size and shape, determining if the culvert flow is classified as being inlet control or outlet control, and then finding the headwater (HW) required for controlling the condition. If the calculated headwater is unacceptable, another trial culvert size or shape may be selected and the process is repeated. The maximum headwater depth under inlet and outlet conditions shall be calculated for each trial culvert size and shape, and the larger of the two represent the controlling condition.

The nomographs referenced in this Design Manual are from the Federal Highway Administration (FHWA) Hydraulic Design Series Number 5 (HDS 5). Similar nomographs from other sources may be used if they are used in a similar manner as the techniques described for the FHWA nomographs.

### 6.3.6.1 Design Inputs

Culvert nomograph design procedure inputs include:

- Design discharge for design storm Q (cfs)
- Length of culvert L (ft)
- Slope of culvert S (ft/ft)
- Allowable headwater depth ($HW_{al}$) (= vertical distance from the culvert inlet invert to the maximum water elevation permissible on the upstream side of the culvert)
- Flow velocities or tailwater depth (TW)

- Culvert Shape:
  - Circular
  - Box, Rectangular
  - Elliptical
  - Pipe/Arch
  - Arch

- Culvert Material:
  - Corrugated Metal (CM)
  - Reinforced concrete (RC)

- Culvert entrance type
  - Headwall
  - Wingwalls
  - Projecting from fill
  - Square edge
  - Groove end
  - Chamfered Edge
  - Beveled Edge
  - Skewed

- Select a trial culvert size:

  - Suggest trial size to be a culvert with a diameter (circular) or height (rectangular) equal to 1/2 $HW_{al}$

### 6.3.6.2 Inlet Control

**Given:** Flow (Q), diameter (D) or culvert shape dimensions, entrance type, culvert material, and trial size, select the appropriate control nomograph from Appendix C.

On the appropriate nomograph, connect D or the culvert shape dimensions and Q with a straight line and continue that line to the first HW/D scale, indicated as (1).

Find HW/D scale that represents entrance.

- If required, extend the point of intersect at scale (1) to scales (2) and (3) with a horizontal line (do not follow the slope of the line connecting D and Q).

Multiply HW/D value read from the nomograph by D to find $HW_{calc.}$

If $HW_{calc} <$ HW allowable, the trial culvert size is OK.

If $HW_{calc} >$ HW allowable, select another trial size and repeat the process.

### 6.3.6.3 Outlet Control

**Given**: Flow (Q), culvert diameter or depth (D) or culvert shape dimensions, entrance type, estimated tailwater depth (TW) above outlet invert, and trial culvert size, select control nomograph.

Select entrance coefficient $K_e$ from Table 6-2.

Connect $K_e$ point on length scale to trial culvert size or shape using a straight line.

- Mark the point where the line crosses the "turning line."

Form a straight line with point on the "turning line" and Q.

Project line to the head scale and read H from the nomograph.

If TW < top of culvert outlet (D),

$$h_o = \frac{d_c + D}{2}$$

Where $d_c$ = critical depth read from nomographs in Appendix C, and D = depth of culvert

- $h_o$ = TW, or
- Use the greatest $h_o$ value calculated.

If TW ≥ top of culvert outlet,

- $h_o$ = TW

Find HW using,

$$HW = H + h_o - S_o L$$

- H is read from applicable nomograph
- $h_o$ dependent on TW
- $S_o$ = culvert slope (ft/ft)
- L = culvert length (ft)

#### 6.3.6.4 Compare Inlet and Outlet Control Headwaters

1. Compare the two headwaters determined for inlet control and outlet control.

2. The higher headwater of the two controls is the flow control existing under the design conditions for the trial culvert size and shape.

#### 6.3.6.5 Outflow Velocity

1. If outlet control exists with tailwater, and the pipe is flowing full,

   - Outflow velocity = Q/A

2. If outlet control exists and the pipe is not flowing full

   - Flow area (A) is based on average flow depth (davg)
   - Average flow depth (davg) calculated by

$$d_{avg} = \frac{d_c + D}{2}$$

dc = critical depth (ft) read from nomographs in Appendix C
D = culvert diameter or depth (ft)

3. If inlet controls exists,

- Outflow velocity is approximated assuming open channel flow.
- Velocity calculated using Manning's open channel flow equation.

**Table 6-2 Culvert Entrance Loss Coefficients** $H_e = K_e [V^2/2g]$

| Type of Structure and Design of Entrance | Coefficient $K_e$ |
|---|---|
| **Pipe, Concrete** | |
| Projecting from fill, socket end (groove-end) | 0.2 |
| Projecting from fill, sq. cut end | 0.5 |
| Headwall or headwall and wingwalls | |
| Socket end of pipe (groove end) | 0.2 |
| Square-edge | 0.5 |
| Rounded (radius = D/12) | 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** | |
| Projecting from fill (no headwall) | 0.9 |
| Headwall or headwall and wingwalls square-edge | 0.5 |
| Mitered to conform 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 D/12 or B/12 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 D/12 or beveled top edge | 0.2 |
| Wingwall at 10° to 25° to barrel | |

| Type of Structure and Design of Entrance | Coefficient $K_e$ |
|---|---|
| Square-edged at crown | 0.5 |
| Wingwalls parallel (extension of sides) | |
| Square-edged at crown | 0.7 |
| Side or slope tapered inlet | 0.2 |

Note: "End Sections 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. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet.

### 6.3.7 Culvert Nomograph Example Problem

**Given:** Design flow (Q) = 200 cfs
Culvert length (L) = 180 ft
Culvert Slope (So) = 0.02 ft/ft
Allowable head (HWal) = 10 ft
Tailwater depth (TW) = 4 ft
Culvert material = RCP
Entrance type = Projecting

**Find:** Diameter for a circular culvert.

**Solution:**

**Trial Size:**

$D = HW_{al} /2 = 10/2 = 5ft$

**Inlet Control**

1. Select control nomograph for circular concrete pipes with projecting entrance.

2. On the nomograph, connect D = 5-ft. (60-inches) and Q = 200 with a straight line and continue the line to the first HW/D scale, indicated as (1).

3. Find HW/D scale that represents a projecting entrance.

- Extend the point of intersect at scale (1) to scale (3) with a horizontal line.
- **HW/D = 1.37**

4. Multiply HW/D value read from the nomograph by D to find $HW_{calc.}$

- **HW/D * D = 1.37 * 5 = 6.85-feet.**

5. $HW_{calc}$ < HW allowable, therefore the trial culvert size is OK.
   **6.85 ft < 10 ft**

**Outlet Control**

**Given**: Flow (Q) = 200, culvert diameter (D) = 5 ft, groove end projecting, and tailwater depth (TW) = 4 select outlet control nomograph for circular concrete pipes with projecting entrance.

Entrance coefficient from Table 6-2 for projecting from fill, socket end (groove-end) gives:

**$K_e$ = 0.2**.

Connect $K_e$ = 0.2 length scale L =180-feet, to trial culvert size D = 60-inches using a straight line and mark the point where the line crosses the "turning line."

Form a straight line with point on the "turning line" and Q.

Project line to the head scale and read H = 2.80.

TW (4 ft) < top of culvert outlet (5 ft)

- **$h_o$ = 4 ft**, or

$$h_o = \frac{d_c + D}{2}$$

Where critical depth read from Appendix C is **$d_c$ = 4.10 ft**

D = depth of culvert = 5-feet
$h_o$ = (4.1 + 5) /2 = **4.55-feet**

- Use the greatest ho value calculated
**$h_o$ = 4.55 ft**

If TW ≥ top of culvert outlet, ho = TW
Find HW using

$$HW = H + h_o - S_o L$$

- H = 2.80 ft read from graph
- ho = 4.55 ft
- So = 0.02 (ft/ft)
- L = 180-feet.

HW = 2.8+4.55 – 0.02(180) = **3.75-feet**

Compare Inlet Control and Outlet Control Headwaters

Compare the two headwaters determined for inlet control and outlet control.

| | |
|---|---|
| Inlet Control | HW = 6.85-feet. |
| Outlet Control | HW = 3.75-feet. |

The higher headwater of the two controls is the flow control existing under the design conditions for the trial culvert size.

Therefore, Inlet Control prevails and the maximum headwater located upstream of the culvert shall = **6.85-feet.**

# 6.4. Stage Discharge Equations for Rock Structures

Rock structures are commonly used as the outlet control structure of smaller sediment basins and sediment traps and in rock ditch checks. The flow through these structures is controlled by the following factors See **Figure 6-3**

- Static head drop as flow moves through the rockfill **(dh),**
- Upstream water depth **($h_1$),**
- Downstream water depth **($h_2$),**
- Flow length through the rockfill **(dl)** ,
- Average stone diameter of the rockfill **(d),**
- Porosity of the rockfill **($\xi$)** (0.46 for graded rockfills constructed by dumping), and
- Reynolds Number **($R_e$)** and friction factor **($f_k$)**, which are dictated by flow length through the rockfill, rock size, and porosity of the rockfill.

In the original equations proposed by Herrera (1989), porosity was included as a parameter. However, Herrera and Felton (1991) deleted porosity from the equations because it was found to have a constant value of approximately 0.46 in all of their laboratory tests. The Herrera and Felton equations require a trial and error computation process that requires six steps for each stage.

## 6.4.1 Calculating the Stage-Discharge Relationship for Rockfill Structures

The Herrera and Felton equations incorporate detailed computations requiring computers and spreadsheets that are capable of trial and error programming. However, when quick estimates are needed, graphical procedures are helpful. A graphical procedure for predicting the average gradient through rockfills **(dh /dl)** can be used to develop head loss as a power function of flow, which eliminates any trial and error procedures. The governing equation is:

$$\frac{dh}{dl} = aq^{b}$$

**dh** = Static head drop of water in meters (difference between upstream and downstream water surface elevations)
**dl** = Average flow path length through the rock in meters,
**a** = Dimensionless coefficient based on flow path length shown in **Figure 6-3**,
**b** = Dimensionless exponent based on average rock diameter (m) shown in **Figure 6-3**; and,
**q** = Flow per unit width of rockfill in cubic meters per second per meter (cms/m).

****All units must be converted to metric to use the graphical method.**

The equation can be rearranged so there is only one unknown, **q (csm/m)**.

$$q = \left[\frac{dh}{a(dl)}\right]^{\frac{1}{b}}$$

## 6.4.2 Flow Through a Rockfill Dam Example

**Given:** A rockfill dam is to be used as the principle spillway for a sediment trap. The average width of the dam is 10-feet (3 meters). The dam is 5-feet high with rock side slopes of 1:1. The flow length at the top of the dam is 3.3-feet, while the flow length at the bottom of the dam is 9.9-feet. The average stone diameter is 6-inches.

**Find:** Stage discharge relationship for the rock dam. Assume that the downstream depth is negligible so **dh** = upstream stage (Figure 6-3).

**Solution:**

Determine the number of desired stage elevations for computations.

- For this example calculations will be made every 1-foot.

Set up a table for each stage. (as shown below)

- Convert all units to **metric** before reading values from the graphs in Figure 6-4.

Calculate the discharge rate at each stage.

- At a stage = 1 foot

  dh = 0.31 meters
  dl = 3.0 meters
  stone diameter of 6-inches = 0.15 meters
  a = 1.80 (from Figure 6-4)
  b = 0.6657 (from Figure 6-4)

$$q = \left[\frac{dh}{a\,(dl)}\right]^{\frac{1}{b}} = \left[\frac{0.31}{1.80 * (3.0)}\right]^{\frac{1.0}{0.6657}} = 0.0137 \quad cms\ /\ m$$

- Convert cms/m to cms by multiplying by the average flow width at the stage

  (0.0137 cms/m) * (3 m) = **0.041 cms**

- Convert cms to cfs

  (0.041 cms) * (35.315 cfs/cms) = 1.447 cfs

| Stage (ft) | Flow Length (ft) | Flow Width (ft) | dh Stage (m) | dl Flow Length (m) | a | b | Flow cms/m | Flow Width (m) | Flow cms | Flow cfs |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 9.9 | 10 | 0.00 | 3.00 | 3.12 | 0.6657 | 0.0000 | 3.0 | 0.000 | 0.0 |
| 1 | 9.9 | 10 | 0.31 | 3.00 | 3.12 | 0.6657 | 0.0137 | 3.0 | 0.041 | 1.4 |
| 2 | 8.3 | 10 | 0.61 | 2.52 | 2.06 | 0.6657 | 0.0407 | 3.0 | 0.122 | 4.4 |
| 3 | 6.6 | 10 | 0.91 | 2.00 | 2.31 | 0.6657 | 0.0870 | 3.0 | 0.261 | 9.2 |
| 4 | 5.0 | 10 | 1.22 | 1.52 | 2.97 | 0.6657 | 0.1400 | 3.0 | 0.420 | 14.8 |
| 5 | 3.3 | 10 | 1.52 | 1.00 | 3.63 | 0.6657 | 0.2704 | 3.0 | 0.811 | 28.7 |

## 6.4.3 Flow Through a Rock Ditch Check Example

**<u>Given</u>:** A Rock Ditch Check with the following characteristics:

| Dimension | Standard Units | Metric Conversion |
|---|---|---|
| Bottom Width | 3-feet | 0.91 meters |
| Side Slopes | 3:1 | 3:1 |
| Depth | 2-feet | 0.61 meters |
| Top Width | 15-feet | 4.57 meters |
| Top Flow Length | 3-feet | 0.91 meters |
| Bottom Flow Length | 7-feet | 2.13 meters |
| Rock Fill Diameter | 6-inches | 0.15 meters |

**<u>Find:</u>** Stage discharge relationship for Rock Ditch Check.

**<u>Solution:</u>**

1. To properly apply the rock fill flow equation all values must be converted to **<u>metric units.</u>**

2. Determine the number of desired stage elevations for computations.

- For this example calculations will be made every 0.5-feet.

Based on the rock size and the flow lengths, an appropriate value for the exponent *b* must be selected from Table 6-3.

- Linear interpolation can be used to find <u>*b*</u> when the rock diameter = 0.15 m.

$\underline{b} = 0.6651 + [(.15 - .10) / (.20 - .10)] * (0.6662 - 0.6651)$
$\underline{b} = 0.6657$

Based on a rock size of 0.15 meters and the flow lengths at different stages, the appropriate values for the coefficient a can be selected from Table 6-3 by using linear interpolation.

| Stage (ft) | Stage (m) | Flow Length (m) | Coefficient a |
|---|---|---|---|
| 0.0 | 0.00 | 2.13 | 2.26 |
| 0.5 | 0.15 | 1.83 | 2.55 |
| 1.0 | 0.31 | 1.52 | 3.00 |
| 1.5 | 0.46 | 1.22 | 3.37 |
| 2.0 | 0.61 | 0.91 | 3.67 |

**Table 6-3. Values for Rock Check Flow Coefficient and Exponent**

| Stone Diameter(m) | Exponent b | Coefficient a<br>dl= 1m | dl = 2m | dl = 3m |
|---|---|---|---|---|
| 0.01 | 0.6371 | 9.40 | 6.05 | 4.60 |
| 0.02 | 0.6540 | 7.40 | 4.65 | 3.55 |
| 0.03 | 0.6589 | 6.40 | 4.08 | 3.08 |
| 0.04 | 0.6609 | 5.85 | 3.65 | 2.80 |
| 0.05 | 0.6624 | 5.40 | 3.35 | 2.60 |
| 0.06 | 0.6635 | 5.05 | 3.15 | 2.40 |
| 0.08 | 0.6644 | 4.50 | 2.85 | 2.20 |
| 0.09 | 0.6648 | 4.28 | 2.70 | 2.10 |
| 0.10 | 0.6651 | 4.13 | 2.60 | 2.05 |
| 0.20 | 0.6662 | 3.20 | 2.05 | 1.57 |
| 0.30 | 0.6664 | 2.80 | 1.75 | 1.30 |
| 0.40 | 0.6665 | 2.50 | 1.55 | 1.16 |
| 0.50 | 0.6666 | 2.30 | 1.40 | 1.08 |

Source: Design Hydrology and Sedimentology for Small Catchments, Hann et. al., 1995

1. Determine the total flows for each staging using the values determined above. The total flow is computed by multiplying the unit flow by the flow width.

$$q = \left[\frac{dh}{a\,(dl)}\right]^{\frac{1}{b}} = \left[\frac{0.61}{3.67*(0.91)}\right]^{\frac{1.0}{0.6657}} = 0.0778\ cms/m$$

- At the stage of 2-feet (0.61 meters) the flow is calculated to be:
- Convert cms/m to cms by multiplying by the average flow width at the stage
  (0.0778cms/m) * (4.57 m) = **0.355 cms**
- Convert cms to cfs
  (0.355 cms) * (35.315 cfs/cms) = **12.5 cfs**

| Stage (m) | Flow Length (m) | Unit Flow (cms/m) | Flow Width (m) | Total Flow (cms) | Stage (ft) | Total Flow (cfs) |
|---|---|---|---|---|---|---|
| 0.00 | 2.13 | 0.000 | 0.91 | 0.000 | 0.0 | 0.0 |
| 0.15 | 1.83 | 0.006 | 1.83 | 0.011 | 0.5 | 0.4 |
| 0.31 | 1.52 | 0.018 | 2.74 | 0.048 | 1.0 | 1.7 |
| 0.46 | 1.22 | 0.037 | 3.66 | 0.136 | 1.5 | 4.8 |
| 0.61 | 0.91 | 0.078 | 4.57 | 0.355 | 2.0 | 12.5 |

# 6.5 Storm Drainage Design Requirements

This section provides the design requirements for various storm water drainage system components including:

- Design storms,
- Design velocities; and,
- Design pipe sizes.

## 6.5.1 Storm Drainage Systems

Storm drainage systems shall include all storm drainage structures and pipes that do not convey runoff under public roadways. These systems are commonly referred to as lateral closed systems.

### 6.5.1.1 Design Storm Requirements

These storm drainage systems shall be designed based upon the following criteria:

- 10- to 25- year 24-hour design storm event capacity for pipe design.
- 10- to 25- year 24-hour design storm event capacity for inlet structure design.
- 25- year 24-hour design storm event capacity for drainage channels.
- 50-year 24-hour design storm event capacity for sump inlets, unless overflow facilities are designed.
- 100-year 24-hour storm event shall be used to check all drainage designs using for local flooding, and possible flood hazards to adjacent structures and/or property.
- The rational method and SCS method for peak runoff flow rates are acceptable under the conditions outlined in Sections 5.2.1 and 5.2.2.

### 6.5.1.2 Manning's Equation to Determine Flow Capacity

When a storm drainage system has less than 20 connections, Manning's Equation shall be acceptable for sizing the capacity of drain pipes for non submerged conditions where the free water surface elevation is below the crown of the pipes.

### 6.5.1.3 Hydraulic Grade Line

#### 6.5.1.3.1 Requirements

All head losses in a storm drainage system shall be considered when computing the hydraulic grade line to determine water surface elevations under design conditions.

Any system that contains 20 or more pipe connections shall have the hydraulic grade line computed, along with all head losses through the entire system.

If the outlet is submerged in a backwater condition, a more sophisticated design methodology than Manning's Equation shall be required. Individual head losses in the pipe systems shall be calculated. These head losses are added to a known downstream water surface elevation to give a design water surface elevation for a given flow at a desired upstream location. Various accepted computer models are available for analysis of storm drain systems under backwater and/or pipe flow surcharge conditions.

#### 6.5.1.3.2 Head Loss

Total head losses in a pipe system shall be determined as follows:

$$H_T = H_f + H_{MH} + H_V + H_J$$

Where:

| | | |
|---|---|---|
| $\mathbf{H_T}$ | = | Total head loss (ft.) |
| $\mathbf{H_f}$ | = | Friction head loss (ft.) |
| $\mathbf{H_{MH}}$ | = | Manhole head loss (ft.) |
| $\mathbf{H_V}$ | = | Velocity head loss (ft.) |
| $\mathbf{H_J}$ | = | Junction head loss (ft.) |

Frictional losses may be computed from Manning's Equation expressed as:

$$H_f = L \frac{(nV)^2}{2.221\ R^{\frac{4}{3}}}$$

Where:

| | | |
|---|---|---|
| $\mathbf{H_f}$ | = | Friction head loss (ft.) |
| **L** | = | Length of pipe section (ft.) |
| **n** | = | Manning roughness coefficient |
| **V** | = | Average flow velocity (ft/sec) |
| **R** | = | Hydraulic radius (ft.), Calculated to be A/P where:<br>A = flow cross sectional area (ft.$^2$)<br>P = wetted perimeter (ft.) (length of boundary between water and channel) |

The remaining components of the total head loss ($H_T$) may be computed using standard equations, charts, tables or may estimated by using graphical procedures.

### 6.5.1.4 Pipe Size

The minimum pipe size to be used in storm drainage systems is 15-inches in diameter

### 6.5.1.5 Flow Velocity and Pipe Slope

- The minimum design velocity for pipe flow shall be 2.0-feet/sec at the design flow or 2.5-feet/sec at full flow, whichever requires the greater slope.
- The maximum design velocity shall be 20-feet/sec.
- The minimum slope of storm drain systems shall be 0.5 percent.
- Storm drainage systems shall be designed to convey storm water runoff by gravity flow unless otherwise approved.

For very flat flow lines, flow velocities shall increase progressively throughout the system. Upper reaches of the pipe system may have flatter slopes than the lower end of the system. Progressively increasing slopes keep solids moving toward the outlet and inhibit the settling of particles.

The minimum required slope shall be calculated by a modified form of Manning's Equation.

$$S = \frac{(nV)^2}{2.208\ R^{\frac{4}{3}}}$$

Where:

**S** = Minimum slope of the hydraulic grade line (ft/ft)
**n** = Manning's roughness coefficient

**V** = Average flow velocity (ft/sec)

**R** = Hydraulic radius (ft.), Calculated to be A/P where:
**A** = flow cross sectional area ($ft.^2$)
**P** = wetted perimeter (ft.) (length of boundary between water and channel)

### 6.5.1.6 Fill Requirements

The minimum fill cover on all pipes shall be 1 foot. The maximum cover shall be based on the design loads which are calculated from pipe shape, pipe size, pipe material and location.

### 6.5.1.7 Catch Basin and Inlet Design

The design methodology utilized to compute the capacity of storm drain inlets and grates shall apply the weir, orifice and pipe flow characteristics as outlined in Section 6.2. The following design requirements shall be followed:

- Inlets shall be designed to convey the 10-year 24-hour storm event.
- The maximum depth in which the water may pond above or around an inlet must not threaten surrounding permanent structures or public facilities including vehicular or pedestrian traffic.

- Inlets placed in sump conditions shall have emergency overflow points designed.

- Inlets placed in roadway gutter lines must be spaced to prevent flow from entering public road intersections.

  - Maximum spread of 6-feet in the travel lane.
  - Valley gutter shall have a maximum allowable spread of 7-feet.
  - Standard 2-feet 6-inch curb and gutter is allowed a total maximum spread of 8-feet from the face of the curb.

- In depth design procedures for inlet design may be referenced in the American Association of State Highway and Transportation Officials (AASHTO) Model Drainage Manual, 1991.

### 6.5.2 Roadway Culvert Design

Roadway culvert design shall include all cross drainage facilities that transport storm water runoff under roadways. These systems shall be designed based upon SCDOT requirements where applicable. For non-SCDOT roads, the following criteria shall be followed:

- All cross-drain culverts shall be designed to pass the 25–year 24-hour design storm event without overtopping the road.

- All interior culverts shall be designed to pass the 10–year 24-hour design storm event without overtopping the road.

- Additional hydraulic capacity shall be required as necessary to prevent backwater effects that may adversely impact upstream property or structures.

- Refer to Section 6.3 for further details on culvert design.

## 6.6 Open Channel Design

### 6.6.1 General Requirements

Open channels shall include all permanent storm drainage channels including swales and diversions. These storm drainage systems shall be designed based upon the following criteria:

- Channels shall be designed to carry the 25-year 24-hour design storm event.

- Major channels may be designed for greater storm frequencies if directed by Greenville County.

- The minimum channel slope shall be 0.5 percent, unless supporting calculations show that there will be no pools or standing water areas formed in the channels at smaller slopes.

- Except for roadside ditches, the side slopes of grassed lined channels without Erosion Control Blankets or Turf Reinforcement Matting shall be no steeper than 3H to 1V.

- Manning's Equation (as described in Section 6.1.5) may be used to design open channels and swales where backwater effects created from obstructions and/or tailwater is not present.

- Channels may be designed with multiple stage levels with a low flow section to carry the 2-year storm event and a high flow section to carry storms of larger frequencies.

- Maximum flow velocities shall be determined based on the channel bottom material and bank slope material. Table 6-5 contains an expanded list of permissible velocities for various different types of channel vegetation and slopes.

## 6.6.2 Vegetated Channel Design

### 6.6.2.1 Background

The allowable velocities and tractive forces for non-vegetated (erodible) channels are relatively small and the design requires wide, shallow channels to carry the design flow rates. Vegetation protects the channel material from the erosive action of design flows and binds the channel material together. Vegetated channels can be used to carry storm water runoff but are generally not recommended to carry sustained base flows because most vegetation cannot survive continual submergence or saturation of the root zone.

The design of vegetated channels is more complex than a basic earth lined, or structurally lined channel. The additional design consideration for vegetated channels involves a variation in roughness (Manning's n) with the height and type of vegetation. Generally, a tall grass provides much resistance when flow in the channel is shallow. As the flow depth increases, the resistance of some vegetation may decrease. In many cases, the vegetation will lay over in the direction of the flow when the flow reaches a sufficient depth. When vegetation lies over, the resistance produced by the vegetation is considerably less than it is during shallow flow conditions.

The design of vegetated channels shall be performed for the following two design conditions:

Stability/Permissible Velocity: This design process involves evaluating how the channel will respond under low vegetation retardance conditions. This condition is defined when vegetation is cut low or lies down, producing a lower Manning's n value, lower flow depths, and higher flow velocities. The limiting factor for stability design is the permissible velocity of the flow in the vegetated channel.

Capacity: This design process involves evaluating how the channel will respond under high vegetation retardance conditions. This condition is defined when vegetation is not maintained or is very long and rigid, producing a higher Manning's n value, higher flow depths, and lower flow velocities. The limiting factor for capacity design is the cross sectional area of the vegetated channel.

The design of vegetated channels may be done using the techniques discussed in this section, or by using computer software that is capable of designing for stability and capacity.

### 6.6.2.2 Vegetation Retardance Classes

Vegetation used for channel design has been divided into five retardance classes designated as being A, B, C, D, and E. Tables 6-6 and 6-7 lists each vegetation retardance class with corresponding species and stand heights. If a particular vegetation type is not listed in Table 6-4, similar vegetation shall be used in determining the retardance class. If the vegetation will be mowed part of the time and long at others, both conditions and retardance classes must be considered.

### 6.6.2.3 Manning's n Relation to Vegetation

Manning's n value can be related to the product of the flow velocity and the hydraulic radius of the channel, **vR**. Different types of vegetation have different Manning's n to **vR** relationships. These relationships are shown in Figure 6-5. This relationship can be expressed using the following equation:

$$n = \exp\left[I\left(0.01319\ \ln(vR)^2 - 0.09543\ \ln(vR) + 0.2971\right) - 4.16\right]$$

Where:

- **n** = Manning's roughness coefficient.
- **I** = Coefficient based on Retardance Class as shown in Table 6-4.
- **vR** = Calculated value of **vR**.
- **v** = velocity (ft./sec)
- **R** = hydraulic radius (ft.)

**Table 6-4. Retardance Class Coefficient I**

| Retardance Class | Coefficient I |
|---|---|
| A | 10.000 |
| B | 7.643 |
| C | 5.601 |
| D | 4.436 |
| E | 2.876 |

Source: Design Hydrology and Sedimentology for Small Catchments, Hann et. al., 1995

### 6.6.2.4 Stability/Permissible Velocity Design

The following design parameters are required when designing a vegetated channel based on stability:

- Calculate the required discharge (Q) for the design storm using the procedures in Section 5.2.
- Determine the channel bottom slope (S).
- Select channel cross section dimensions including bottom width, depth, side slopes, and top width.
- Select the type of vegetation to be placed in the channel.
- Determine the retardance class of the vegetation.
    - When designing based on stability, the lowest applicable retardance class should be used.
    - Retardance class D is recommended for maintained permanent vegetation.
    - Retardance class E is recommended for temporary vegetation.
- Determine the permissible velocity (Vp) based on soil type, vegetation and slope from Table 6-5.

Once the design parameters have been determined, design the vegetated channel by using the following steps.

1) Assume a trial depth ($d_t$).

2) Knowing the channel dimensions, calculate the corresponding trial hydraulic radius (Rtrial) for this assumed depth using:

$$R_{trial} = \frac{bd_t + Zd_t^2}{b + 2d_t\sqrt{Z^2 + 1}}$$

Where:

**$R_{trial}$** = Hydraulic radius (ft.)
**b** = Known bottom width of channel (ft.)
**Z** = Known side slopes of channel
**$d_t$** = Trial depth of flow in channel (ft.)

3) Divide the known design flow rate (Q) by the vegetated channel cross sectional area to obtain a velocity (V).

4) Multiply the velocity (V), calculated in Step 3, by the trial hydraulic radius (Rtrial) calculated in Step 2 to obtain a value for vR.

5) Using the calculated vR value in Step 4, and the known Retardance Class of the vegetation, read the corresponding Manning's n value from **Figure 6-5** or calculated from Equation 6.6.2.3.

6) Using Manning's Equation, calculate the flow velocity in the vegetated channel by using the trial hydraulic radius (Rtrial) calculated in Step 2, the known channel slope, and the Manning's n value calculated in Step 5.

$$V_{calc} = \frac{1.49}{n} R_{trial}^{\frac{2}{3}} \quad S^{\frac{1}{2}}$$

Where:

**$V_{calc}$** = Calculated velocity (ft/sec),
**$R_{trial}$** = Trial hydraulic radius (ft.) from Step 2,
**n** = Manning's n determined from Step 4, and
**S** = Slope of channel (ft/ft).

7) Compare the velocity values calculated in Step 3 and Step 6. If the values do not match within ± 0.1, return to Step 1 and repeat the process. When the values do match, the matching value must be less than the permissible velocity (Vp) to be acceptable. If the matching velocity value is greater than the permissible velocity (Vp), then the channel bottom width and/or side slopes must be adjusted accordingly.

If the final trial depth is greater than the allowable depth of the channel, the channel dimension must be altered so the vegetated channel has enough capacity to handle the peak flow rate (**Q**).

### 6.6.2.5 Capacity Design

Once the design for stability has been completed, the channel must be checked to see if it has enough capacity to handle flows when the vegetation moves into a different Retardance Class. The following steps shall be executed:

1. Assume a trial depth ($d_t$) that is greater than the final flow depth calculated from the Stability Design in Section 6.6.2.4.

2. Knowing the channel dimensions, calculate the corresponding trial hydraulic radius (Rtrial) for this assumed depth using:

$$R_{trial} = \frac{bd_t + Zd_t^2}{b + 2d_t\sqrt{Z^2 + 1}}$$

Where:

**$R_{trial}$** = Hydraulic radius (ft.)
**b** = Known bottom width of channel (ft.)
**Z** = Known side slopes of channel
**$d_t$** = Trial depth of flow in channel (ft.)

3. Divide the known design flow rate (Q) by the vegetated channel cross sectional area to obtain a velocity (v).

4. Multiply the velocity (v), calculated in Step 3, by the trial hydraulic radius (Rtrial) calculated in Step 2 to obtain a value for vR.

5. Select the desired Retardance Class for the vegetation from Tables 6-6 and 6-7. It is recommended that the minimum Retardance Class utilized for capacity design be Retardance class C.

6. Using the calculated vR value in Step 4, and the known Retardance Class of the vegetation, read the corresponding Manning's n value from **Figure 6-5** or calculate it using Equation 6.6.2.3.

7. Using Manning's Equation, calculate the flow velocity in the vegetated channel by using the trial hydraulic radius (Rtrial) calculated in Step 2, the known channel slope, and the Manning's n value from Step 6.

8. Compare the velocity values calculated in Step 3 and Step 7. If the values do not match, return to Step 1 and repeat the process. If the trial depth is determined to be greater than the depth of the channel, the channel dimension must be altered so the vegetated channel has enough capacity to handle the peak flow rate (Q).

**Table 6-5. Maximum Permissible Velocities for Vegetated Channels**

| | Permissible Velocity (ft./sec.)* | | | | | |
|---|---|---|---|---|---|---|
| | Erosion Resistant Soils % Slope | | | Easily Eroded Soils % Slope | | |
| **Cover** | **0-5** | **5-10** | **> 10** | **0-5** | **5-10** | **> 10** |
| Bermuda Grass | 8 | 7 | 6 | 6 | 5 | 4 |
| Bahia<br>Buffalo Grass<br>Blue Gamma<br>Centipede Grass<br>Tall Fescue<br>Kentucky Bluegrass<br>Red Canary Grass | 7 | 6 | 5 | 5 | 4 | 3 |
| Grass-legume Mixture | 5 | 4 | NR | 4 | 3 | NR |
| Lespedeza Sericea<br>Weeping Lovegrass<br>Kudzu<br>Alfalfa<br>Small Grains<br>Temporary Vegetation | 3.5 | NR | NR | 2.5 | NR | NR |

* Allow velocities over 5 ft/sec only where good cover and maintenance will be provided. If poor vegetation exists due to shade, climate, soils or other factors, the permissible velocity shall be reduced by 50 percent

NR = Not Recommended

Sources: Elementary Soil and Water Engineering, Shwab et. al.
Design Hydrology and Sedimentology for Small Catchments, Hann et. al., 1995

**Table 6-6. Vegetated Retardance Classes based on Vegetation**

| Retardance Class | Vegetation | Condition |
|---|---|---|
| A | Red Canary Grass<br>Weeping Lovegrass<br>Yellow Bluestem Ischaetum | Excellent stand, tall (average 36-inches)<br>Excellent stand, tall (average 30-inches)<br>Excellent stand, tall (average 36-inches) |
| B | Bermuda Grass<br>Native grass mixtures<br>Tall fescues<br>Lespedeza Sericea<br>Grass-legume Mixture<br>Red Canary Grass<br>Alfalfa<br>Weeping Lovegrass<br>Kudzu<br>Blue Gamma | Good stand, tall (average 12-inches)<br>Good stand, uncut<br>Good stand, uncut (average 18-inches)<br>Good stand, not woody, tall (average 19-inches)<br>Good stand, uncut (average 20-inches)<br>Good stand, mowed (average 12- to 15-inches)<br>Good stand, uncut (average 11-inches)<br>Good stand, uncut (average 13-inches)<br>Dense growth, uncut<br>Good stand, uncut (average 13-inches) |
| C | Bahia<br>Crabgrass<br>Bermuda Grass<br>Common Lespedeza<br>Grass-legume Mixture<br>Centipede Grass<br>Kentucky Bluegrass | Good stand, uncut (6- to 8-inches)<br>Fair stand, uncut (10- to 48-inches)<br>Good stand, mowed (average 6-inches)<br>Good stand, uncut (average 11-inches)<br>Good stand, uncut (6- to 8-inches)<br>Very dense cover (average 6-inches)<br>Good stand, headed (6- to 12-inches) |
| D | Red Fescue<br>Bermuda Grass<br>Common Lespedeza<br>Buffalo Grass<br>Grass-legume Mixture<br>Lespedeza Sericea | Good stand, uncut (3- to 6-inches)<br>Good stand, cut to 2.5-inches<br>Excellent stand, uncut (average 4.5-inches)<br>Good stand, headed (12- to 18-inches)<br>Good stand uncut (4- to 5-inches)<br>Very good stand, mowed (2-inches) |
| E | Bermuda Grass<br>Bermuda Grass | Good stand, cut to 1.5-inches<br>Burned Stubble |

**Table 6-7. Vegetated Retardance Classes based on Stand and Vegetation Height**

| Stand | Height of Vegetation (inches) | Retardance Class |
|---|---|---|
| Good | > 30<br>11-24<br>6-10<br>2-6<br>< 2 | A<br>B<br>C<br>D<br>E |
| Fair | > 30<br>11-24<br>6-10<br>2-6<br>< 2 | B<br>C<br>D<br>D<br>E |

Source: Soil Conservation Service Engineering Field Manual, 1979

# Chapter 7. STORM WATER DETENTION DESIGN AND DOWNSTREAM ANALYSIS

This chapter provides policies and technical procedures for analyzing storm water facilities required for land disturbance activities in Greenville County. The design methods and criteria outlined in this chapter shall be used in the design and evaluation of detention systems utilized for storm water quantity control.

## 7.1. Hydrologic and Hydraulic Design Criteria

All designs of detention systems utilized for storm water quantity control shall be submitted with a design summary report when applying for a Storm Water Management Permit. The following design criteria shall be implemented for water quantity control unless a waiver is granted on a case-by-case basis.

- Post-development discharge rates from the entire development area shall not exceed pre-development discharge rates for the 2-, 10- and 25-year frequency 24-hour duration storm events.
  - Multi-stage control structures may be required to control the 2-, 10- and 25-year storm events.
  - The same hydrologic procedures shall be used in determining both the pre-development and post-development peak flow rates.
- Post-development discharge velocities in receiving channels shall be non-erosive flow velocities or shall be equal to or less than the pre-development 10-year, 24-hour storm event flow velocities.
- Emergency spillways shall be designed to safely pass the post-development 100-year 24-hour storm event without overtopping any dam structures.
- All dry detention basin volumes shall be drained from the structures from 48 to 72 hours.
- Watersheds that have well documented water quantity problems may have more stringent or modified design criteria as determined from master plan studies by Greenville County including but are not limited to:
  - Post-development discharge rates from the entire development area not exceeding pre-development discharge rates for storm frequencies greater than the 25-year frequency 24-hour duration storm event.
  - Post-development discharge volumes from the entire development area not exceeding pre-development discharge volumes.
  - Reduction of peak flow rates from pre-development to post-development.
  - Reduction of total volume released from pre-development to post-development.
  - Downstream channel, culvert or property improvements.
- A project may be eligible for a waiver from the storm water management requirements for water quantity control if the applicant can justly verify that:
  - The proposed project will not create any significant adverse effects on the receiving natural waterway downstream of the property.
  - The imposition of peak flow rate control for storm water management would create, aggravate, or accelerate downstream flooding.

### 7.1.1 Accepted Detention Structural Controls

Detention structural controls are used for providing water quantity control and are typically used downstream of other minor structural controls. These structures are designed to provide channel protection, overbank flood protection, and any adverse downstream impacts that are related to the increase in peak flow rates and flow volumes from development. Detention structural storm water controls can be classified into several categories as shown in Table 7-1.

**Table 7-1. Detention Structural Controls**

| General Structural Control | Description |
| --- | --- |
| **Dry Detention/Dry Extended Basins** | Dry detention basins and dry extended detention basins are surface storage facilities intended to provide temporary storage of storm water runoff and releasing it at a designed flow rate to reduce downstream water quantity impacts. These structures are designed to completely drain to a dry condition within 72 hours. |
| **Wet Storm Water Detention Basins**<br>• Wet Pond<br>• Wet Extended Detention Pond<br>• Micropool Extended Detention Pond<br>• Multiple Pond System | Wet detention basins are constructed storm water basins that have a permanent pool or micropool of water. Runoff from each rain event is detained above the permanent pool and released at a designed flow rate to reduce downstream water quantity impacts. |
| **Multi-purpose Detention Areas** | Multi-purpose detention areas are used for one or more specific activities such as parking areas and rooftops. These areas are used to provide temporary storage of runoff. Some of the multi-purpose area such as infiltration trenches or bio-retention areas may also be used for water quality purposes. |
| **Underground Detention** | Underground detention is used as an alternative to surface dry-detention basins. They are used in areas that are space-limited where there is not enough adequate land to provide the required detention volume. The underground storage utilizes tanks, vaults, and buried pipes to supply the required storage volume. |

## 7.2. Design Procedures

This section provides the general design procedures for the design of storm water quantity structures. The following items shall be required for the design of these structures, and routing flows through them.

- Compute the inflow hydrograph for the structure.
- Compute a stage-storage relationship for the proposed structure. A stage storage-curve defines the relationship between the depth of water and storage volume within the detention facility.
- Compute stage-discharge relationship of the outlet control structures.
- Perform routing calculations for the 2-, 10-, 25- and 100-year 24-hour storm events. These may be done by hand, or may be done by using a storage routing computer model.

- Evaluate the control structure outlet flow velocity and provide velocity control or channel stabilization if needed.

Routing of hydrographs is critical to the proper design of storm water quantity control structures. Storage design procedures have been formulated without using routing, but the use of these methods in designing storm water quantity structures has not produced acceptable results for the Southeastern United States.

Hand calculations are available for routing hydrographs through detention structures, however they are time consuming and inefficient when multiple designs are required to be evaluated. For this chapter, it is assumed that the design professional will be using one of the many computer software packages available to perform storage routing calculations. Input parameters typically required for computer software packages include:

- Hydrological parameters of the development site
  - Area
  - Curve Numbers
  - Time of concentration

- Hydraulic parameters of detention structures
  - Stage-storage relationship
  - Stage-discharge relationship

## 7.2.1 Stage-Storage Calculations

A stage storage curve defines the relationship between the depth of water and storage volume within the detention facility. The stage storage relationship is calculated by utilizing known surface area values at known elevations within the basin. The areas used for this calculation are obtained by either field survey data or using known geometric relationships within the basin. Two of the most common methods of calculating stage storage relationships are the double end area method, and the pyramid frustum method.

### 7.2.1.1 Double End Area Method

The double end area method is expressed as:

$$V_{1,2} = \left[\frac{(A_1 + A_2)}{2}\right] d$$

Where:

**$V_{1,2}$** = Storage volume ($ft^3$) between elevation 1 and 2.
**$A_1$** = Surface area ($ft^2$), at elevation 1.
**$A_2$** = Surface area ($ft^2$), at elevation 2.
**D** = Change in elevation between stations 1 and 2.

### 7.2.1.2 Pyramid Frustum Method

The pyramid frustum method is expressed as:

$$V = \frac{d}{3}\left[\frac{(A_1 x A_2)^{0.5} + A_1 A_2}{3}\right]$$

Where:

**$V_{1,2}$** = Volume of frustum of a pyramid ($ft^3$) between elevation 1 and 2.
**d** = Change in elevation between stations 1 and 2.
**$A_1$** = Surface area ($ft^2$), at elevation 1.
**$A_2$** = Surface area ($ft^2$), at elevation 2.

### 7.2.2 Stage-Discharge Calculations

A stage discharge curve defines the relationship between the depth of water within a storage structure and the outflow from the structure. This relationship shall be determined by utilizing the flow equation from Section 6.2.

### 7.2.3 Detention Structure Design Parameters

The construction of detention structures usually requires excavation or the placement of earthen embankments to obtain a required storage volume. This section discusses the design criteria of detention structures to ensure the long term function of the structure while minimizing the maintenance responsibilities.

#### 7.2.3.1 General Design Criteria

1. Basins on Slopes: When basins are created by cutting and filling a slope, care should be taken that the seasonal groundwater table on the slope above the basin is not exposed, thus creating a seasonal spring. Controlling the groundwater flow or spring flow into a basin may be accomplished by the proper installation of a subsurface interceptor drainage system. To prevent destabilization from groundwater seepage, riprap may be needed.

2. Inlet and Outlet Locations: The inlets and outlet should be as far apart as possible, with a minimum of a 2:1 ratio of length to width between inlet and outlet. Runoff should have to travel the longest distance possible thorough the basin before being discharged. The shallow and narrow end of the basin should be located near the inlet and the deeper and wider end near the outlet.

3. Inlet Design: The inlet must be designed with riprap or other energy dissipater, such as a baffle below the inflow structure to reduce erosive forces and pretreatment to remove sediment. Sediment fore bays will be required on all ponds for post construction water quality and shall be designed with a minimum length to width ratio of 2:1.

4. Relationship to Groundwater: The basin bottom should be located above the seasonal high groundwater table to avoid standing water in the basin.

5. Scour: Prevention of scour at the inlet is necessary to reduce maintenance problems and prevent damage to basin floor vegetation. The velocities of flow through the inlet sediment control structure and basin should not exceed 2.5 feet per second. Energy dissipation should be provided at the inlet and outlet to prevent scour and reduce the velocity of storm water.

6. Access:

- Maintenance access shall be planted with grass and at least 10 feet wide with a maximum slope of 15% and a maximum cross slope of 3%. Sufficient land areas for equipment access for the basin maintenance should be provided. This access shall extend to the fore bay, micropool and outlet structure. It should never cross the emergency spillway, unless the spillway has been designed for that purpose and to the extent feasible, be designed to allow for vehicle turnaround. An easement may be required.
- Provide a flat maintenance shelf/berm with a minimum width of 10-foot around the perimeter of the basin. The pond berm must provide load bearing capability for industrial maintenance mowers.

7. Outlet Protection: Outflow from the basin must be directed to a stable channel.

8. Minimum Buffer/ Setback: Minimum buffer/setback for the detention structure shall be 25 feet from the basin easement to any dwelling

9. Safety Fence: A safety fence or vegetative barrier is required where a detention structures interior side slopes are steeper than 3H:1V or when the impoundment is a wall greater than 24 inches in height. If the wall is adjacent to a walkway or street a railing may be required instead of a fence.

### 7.2.3.2 Surface Detention Basin Criteria

1. Basin Side Slopes: Vegetated embankments shall be less than 15-feet in height and shall have side slopes no steeper than 3H:1V. Embankments protected with Erosion Control Blankets or Turf Reinforcement Matting shall be no steeper than 2H:1V. In this case, at a minimum, one interior side slope must be 3H:1V to provide easier access into the basin. Geotechnical slope stability analysis is required for slopes greater than 10-feet in height and embankments that have steeper slope than those indicated above

2. Basin Shape: Provide a long and narrow basin shape, with a minimum length to width ration of 2:1, 3:1 is best. Length to width ratio can be increased by designing an irregularly shaped basin or by using baffles to create a longer path of flow. The allowable dead storage space of a basin is limited to a maximum of 20%.

3. Dry Detention Bottom Slopes: The bottom of detention structures shall be graded towards the outlet structure to prevent standing water conditions and be stabilized to prevent scour. A low flow or pilot channel constructed across the facility bottom from the inlet to the outlet is required to prevent standing water conditions when the pond bottom may be subject to non-storm flow from groundwater, footing drainage, storm sewer acting as under drain and sump discharge. A minimum 2 percent bottom slope is recommended for both cross slope and longitudinal slope.

4. Under Drains: If the 2% grade can not be obtained an acceptable alternative is to install an under drain. The under drain shall be constructed in the following manner:

   - The under drain shall be one of the last items to be installed to eliminate any sediment build-up that would cause the under drain to not function properly.
   - A non-woven geotextile fabric shall be laid in the excavated trench first.
   - The perforated drainpipe shall be covered with washed stone.
   - Both stone and drain shall then be wrapped with the non-woven geotextile and backfilled with sandy porous material.

5. Permanent Pool Detention: The maximum depth of permanent storage facilitates shall be determined by site conditions, design constraints, and environmental needs. The facility should provide a permanent pool of water with a depth sufficient to discourage weed growth without creating undue potential for anaerobic bottom conditions. A depth of 6 to 8 feet is reasonable unless fishery requirements dictate otherwise. Aerating may be required for permanent pools to prevent anaerobic conditions. Wildlife experts shall be contacted where aquatic habitat is required.

6. Emergency Spillways: Emergency spillways shall be designed to covey the routed runoff of the 100-year 24-hour design storm while maintaining at least one foot of freeboard between the high water elevation and the top of the embankment crest. Overflow must discharge to a stable channel or established wetland area.

   - Location: Emergency spillways must be located on undisturbed, non-fill soil wherever possible. If the spillway must be located on fill soils, then it must be horizontally offset at least 20 feet from the principal outlet and be designed with some type of lining (i.e.: riprap, reinforced turf, or non-flexible lining).

   - Exit channel grade: The maximum grade of the spillway's exit channel may not exceed 20% unless a non-flexible lining is used to control erosion with the channel. All linings must be evaluated for stability at the channel grade chosen (Flexible linings include vegetation, reinforced turf, riprap and modular blocks).

7. Safe Dams Act: A dam is defined as being an artificial barrier that impounds water to a depth of 15-feet or greater and has a maximum storage volume of 10-acre-feet or greater; therefore, impoundment depths greater than 15-feet are subject to the requirements of the Safe Dams Act unless the facility is excavated. Several exemptions are allowed from the Safe Dams Act and any questions concerning specific design application should be addressed by SCDHEC.

8. Principal Spillways:
   - Trash Racks: All basin outlets must have a trash rack to control clogging by debris and to provide safety to the public. The surface area of each rack must be at least four times the outlet opening it is protecting. The spaces between rack bars must be no more than six inches or one-half the dimension of the smallest outlet opening behind it, whichever is less. Trash racks should be inclined to be self-cleaning.
   - Seepage Control: All pipes that extend though an embankment should have anti-seep collars or filter diaphragms to control the migration of soil materials and, so prevent potential embankment failure from "piping" within the backfill soil along the conduit. All smooth outlet pipes greater than eight inches and all corrugated outlet pipes great than 12 inch must have seepage controls to prevent the migration of soil along the outside of the pipe.
   - Anti-floatation: All outlets employing a riser structure must be designed to prevent the riser floating.

### 7.2.3.3 Subsurface Detention Basin Criteria

1. Emergency Spillways: Overflow must discharge to a stable channel.

2. Pretreatment: All subsurface systems must include pretreatment for the removal of sediments prior to entering the detention structure.

3. Observation Wells: Subsurface detention systems must have an observation port for monitoring sediment and debris levels and determining when rehabilitation is necessary. This should be installed to the bottom of the system.

4. Access Port: Access to the subsurface system must be provided to allow for the removal of accumulated sediment and debris.

#### 7.2.3.4 Landscaping Criteria

In order to ensure that the ponds' engineering function is protected the following criteria for a landscaping plan near storm water ponds has been established:

1. Do not place landscaping within 10 feet of inlet or outlet pipes or other manmade structures such as spillways.
2. Do not place trees on berms that impound water, only shrubs that have fibrous roots may be planted on berms.
3. Do not plant trees on steep slopes or berms in order to prevent damage from blowdowns that can lead to failure of the dam/berm.
4. Side slopes and berms should be built no steeper than 3H:1V so that standard riding mowers can be used to maintain them.
5. Ensure that there is enough space between plantings and structures to allow room for an industrial mower to maneuver (a minimum of six foot is needed for the mower).
6. Use drought tolerant species or assure watering from the HOA if non-drought tolerant perennials, trees, shrubs or vines are a part of the design.
7. Plant in clumps or "landscaping islands" rather than rows. Clustering allows for mowing around clusters but not necessarily within them.
8. Avoid planting perennials where committed care is not guaranteed. Perennials may look like meadow weeds and be accidentally mowed if not cared for.
9. Provide ongoing maintenance to keep weeds at bay until any ground cover or cluster planting become well established.
10. Avoid planting berms with thick, shrubby ground cover which could mask rodent activity that could weaken the berm, piping of water along living or dead roots that lead to dam failure.
11. Plant on cut slopes which pose little threat in blowdown or piping conditions.
12. Use good soil by amending native soil with at least 2" of compost tilled into the subgrade to a depth of at least six inches to ensure the plants succeed.
13. Trees or shrubs with a mature height over 4 feet tall may not be planted on the embankment or allowed to grow within 15 feet of the toe of the embankment and 24 feet from the principal spillway structure of wet ponds.
14. On wet ponds side slopes along the shoreline of the pond should be three to one (3H:1V) or flatter to facilitate maintenance and to reduce public risk of slipping and falling into the water.
15. A shallow water bench, which is home to most of the aquatic plant life, should be established around the perimeter of the permanent pool to promote the growth of emergent vegetation along the shoreline and deter individuals from wading.

## 7.3. Simplified Detention

### 7.3.1 Purpose

The purpose of the Simplified Urban Drainage System (SUDS) model is to emulate a more complex model, such as HEC-1, for use on smaller watershed such as those in Greenville County. It will also reduce most of the trial and error work done by designers and yield more uniform designs.

A simplified design procedure, as used in this context, is a design procedure for small catchments where hydrologic computational procedures can be greatly simplified using regionalized constants. The computations should be based on selected simple parameters such as watershed area and percent impervious. The design that results will be right sized in some cases and conservative in all others.

Simplified detention design procedures are desirable for a number of reasons. First computations are simple, making for a reduced design time. Second, there will be more uniformity in design which should make the review process simpler, less time consuming and more consistent across reviewers. Third, very little data is required for more simplified design procedures. Finally, designs are right sized in some cases and conservative in most cases. Thus, if a developer is willing to use a conservative design, he or she can trade engineering design cost for construction cost. In all cases, the option of using a more complex model such as HEC-1 for design should be available.

The main difference with the SUDS model is that a triangular hydrograph is being assumed. This is something that was not previously allowed in the IDEAL model.

### 7.3.2 Benefits of Simplified Detention

The Simplified Detention Design Aid design procedure is defined as a design procedure for small catchments where hydrologic computational procedures can be greatly simplified using regionalized constants. The computations are based on selected simple parameters such as watershed area and percent impervious. The resulting detention designs are correctly sized in some cases and conservative in all others. The SUDS model is available on the Greenville County Website along with documentation.

Simplified detention design procedures are desirable for a number of reasons:

1. They result in reduced design time,
2. Designs will be more uniform in general which makes the review process simpler, less time consuming, and more consistent across reviewers,
3. Very little data is required for some simplified design procedures, and
4. Designs are right sized in some cases and conservative in most cases.

## 7.4. Downstream Analysis

Downstream analysis shall be required for all development sites unless a waiver or variance is granted from this analysis. When water quantity controls are implemented, an off-site analysis waiver may not be required, provided that all required design criteria of the Design Manual are met.

In some cases the design professional may verify that storm water quantity controls may adversely impact downstream conditions. Therefore, downstream analysis shall be performed prior to sizing storm water quantity control structures to determine the extent of the controls to be implemented. Downstream analysis may show that more stringent controls need to be implemented to effectively prevent any adverse downstream impacts.

A downstream peak flow analysis which includes the assumptions, results and supporting calculations to show safe passage of post-development design flows downstream. The analysis of downstream conditions in the report shall address each and every point or area along the project site's boundaries at which runoff will exit the property. The analysis shall focus on the portion of the drainage channel or watercourse immediately downstream from the project. This area shall extend downstream from the project to a point in the drainage basin where the total area of the development comprises ten percent (10%) of the total basin area. In calculating runoff volumes and discharge rates, consideration may need to be given to any planned future upstream land use changes.

### 7.4.1 Downstream Analysis Limits

Hydrologic and hydraulic engineering analysis shall be implemented to determine the downstream effects from any development activity. This analysis shall extend downstream to a specific point of concern. The point of concern may be identified by the Director in certain situations. The following are typical points of concern:

- The point where the development represents less than 10 percent of the total drainage of the watershed to that point. This is the minimum set by the ordinance.

- The first downstream road crossing

- Downstream residential lots.

- Location of known existing flooding, drainage, or erosion problems.

- Any point as directed by Greenville County.

The primary areas of analysis shall be done for:

- The development area,
- All drainage exit points from the property,
- The receiving channel at the exit points, and
- Each component of the downstream system including:
    - Channels
    - Pipes
    - Culverts
    - Bridges
    - Overbank areas
    - Overbank structures

### 7.4.2 Downstream Analysis Design Storm Events

All downstream analysis studies shall be done using the 2, 10, 25, and 100-year 24-hour storm events.

### 7.4.3 Downstream Analysis Criteria

The downstream analysis shall determine whether the design storm events of interest cause or increase flooding, drainage, or erosion impacts to downstream properties or road crossings. The analysis criteria shall include but is not limited to:

- Existing land use curve numbers shall be used for developed areas upstream. Where areas upstream are known to be developed the Director may require these areas to be considered developed in a future land use condition.

- The weighted curve number for the proposed development site shall be used for all undeveloped upstream areas.

- Existing land use for downstream areas of interest may be used, but future land use, when applicable, is recommended for conservative results.

- Routing of flows using an accepted hydrologic and hydraulic method from Chapters 5, and 6.

- Hydraulic step-backwater calculations (Corps of Engineer's HEC-2 or HEC-RAS models or equivalent) shall be performed to determine flood elevations of any downstream impacted areas.
- The effects of any upstream and proposed storm water quantity or quality structures.

## 7.4.4 Improvement Options

If the downstream analysis determines that the development of a particular site does contribute to flooding, drainage, or erosion problems, then at least one the following improvements shall be implemented:

- On-site Water Quantity Control
- Off-site Water Quantity Control
- Improvements to the Downstream Storm Water Conveyance System

### 7.4.4.1 On-Site Water Quantity Control

The design professional may select to implement on site water quantity control structures designed according to the criteria in Section 7.1. These structures may consist of nonstructural controls such as swales, natural drainageways, wetlands, and low areas within the site terrain. These structures may also consist of structural approaches such as engineered detention facilities.

### 7.4.4.2 Off-Site Water Quantity Control

The design professional may use an off-site publicly or privately owned facility to prevent adverse downstream impacts. The use of off-site facilities must meet the following requirements:

- The facility to be used must be functional,

- The owner/entity has agreed to accept runoff from the proposed development site,

- The owner has an implemented maintenance agreement for the facility,

- The facility is sized to effectively handle increased flow rates and flow volumes, and

- There are no significant adverse impacts between the outlet from the proposed development site and the inlet to the off-site facility.

### 7.4.4.3 Improvements to the Downstream Storm Water Conveyance System

The design professional may perform and provide supporting calculations that indicate that the best solution is to upgrade the downstream system. This option may be implemented under the following requirements,

- The downstream property owner of the facilities to be improved has granted temporary construction easements,
- The downstream improvements are economically feasible, and
- The improvement will not cause any other significant problems downstream.

# Chapter 8. EROSION AND SEDIMENT CONTROL

## 8.1. Introduction

Natural erosion has been occurring since the earth was formed. This process, which generally occurs at a relatively slow rate, has shaped and molded the earth's surface in the form we recognize today. Man-made erosion, on the other hand, occurs at a quicker rate.

Man-made erosion caused by inappropriate management of storm water runoff from development sites contributes greatly to urban land breakdown and water pollution. It is estimated that erosion on unprotected construction sites may average up to 30 tons per acre per year. Construction-generated storm water runoff often contains sediment, toxic chemicals, oil and grease, pesticides (herbicides, insecticides, or rodenticides), trace metals, and other contaminants which serve as a significant source of water pollution and threatens public health, fish and other wildlife. Nutrients from fertilizers containing nitrogen, phosphorous, and potassium are carried by eroded sediment. These nutrients fuel weed and algae growth, and make outdoor water areas unattractive for swimming and other recreational activities. The resulting water and environmental damage caused by construction-related erosion is often extensive, long-term, costly and time consuming to correct.

### Erosion

In Greenville County, water is the primary cause of most of the erosion experienced. Water has an affinity for sediment; therefore, most streams transport a bedload of sediment. This sediment is deposited, detached and transported over and over again. Studies have found that the bedload can harbor fecal matter and reproduction occurs in the bedload. Once a storm event occurs the fecal is released into the water column as the bedload is re-suspended.

Through proper management, the impacts from land disturbance activities can be reduced. Construction site disturbances are typically for development to improve the quality of life and to produce income. It is imperative that these disturbances are controlled and their impacts to water quality of Waters of the State are minimized. Therefore, the implementations of erosion prevention techniques are very critical to meeting this objective.

Erosion on most disturbed sites occurs in the following forms:

- Sheet
- Rill and interrill
- Gully

There are two concepts that must work together to begin the erosion process. The first is detachment. As raindrops fall and strike the ground, energy is released in the collision. This energy is transferred to the soil particles and they are moved. When the water flows over the surface it will transport these soil particles to a point downstream. This is the second part of the process known as transport. The flowing water also has energy that will dislodge soil particles. It is important to note that clear water has a greater affinity for sediment than does sediment-laden flow. Also remember that runoff and resulting transport does not occur until rainfall intensities exceed infiltration rates of the soil media.

Sheet erosion is a result of overland flow from disturbed areas. As this flow concentrates, interrills and rills begin to form. Once the flow concentrates into a single point, a gully may begin to form. Usually, sheet erosion is found on flatter slopes with rills and interrills forming as the slope increases. Then often times gully erosion is formed on the steeper sections of the slope.

There are two primary means to prevent erosion from occurring on sites that are disturbed. The most desirable alternative but, not always possible, is source protection. This protection encompasses a wide range of techniques most of which are management issues. The other approach is to provide flow control. This is a structural engineering solution. Often times it translates to diverting flow away from disturbed areas. From an application standpoint a combination of these to solutions can be very effective in reducing erosion.

## Sedimentation

Since it is impossible to prevent all soil erosion, it is necessary to develop sediment control techniques. Soil erosion is a result of detachment and transport of the soil particles. Sediment does not accumulate until deposition occurs. Deposition occurs because velocities decrease and soil particles in the flow are heavy enough to settle. Once runoff starts, the quantity and size of the material transported increases with the velocity of the flow. Eventually the runoff will reach a point where the velocity will decrease and the transport capacity will also decrease. Any factor that reduces velocity in a flow segment increases deposition.

In general, larger sized particles and aggregates will settle at higher flow velocities while smaller sized particles will require a much lower flow velocity to settle out. Therefore, the particle size distributions of the soil have an enormous effect on the trapping efficiency of a sediment control structure. Typically civil engineers develop particle size distributions by using a dispersing agent. When considering the erosion and sedimentation phenomena the eroded particle size distribution (EPSD) should be used. The eroded particle size distribution has a direct effect on the required settling velocities. This in turn has a direct effect on the required detention area and detention time. Eroded sediment will be deposited starting first with the larger particles and aggregates, while smaller particles will be carried further downstream until their required settling velocity is reached. Therefore, the eroded particle size distribution and aggregate composition of a particular soil has a major impact on the soil erosion-deposition process.

The eroded particle size distribution of a particular soil is not the same as the primary particle size distributions. The primary particle sizes are based on the soil in a dry condition and represent the percentages of sand, silt and clay in the soil. Since sediment from eroded soils includes both primary soil particles and aggregates, eroded particle size distributions can not be accurately inferred from primary particle distributions, but can be estimated from the primary distributions.

Extensive research has been done on primary particle size distributions of soils. Primary particle distributions can be used in empirical equations to determine the eroded particle size distributions of the soil. Equations used in the CREAMS (Chemicals, Runoff and Erosion in Agricultural Management Systems) model are one set of equations designed to convert primary particle sizes into eroded particle sizes. The eroded particle size distributions listed in Appendix B were determined using the CREAMS based equations and primary particle sizes from Greenville County soils surveys. If site specific data is available, it should be used.

The critical shear stress or critical tractive force determines a soil's resistance to the shearing forces of concentrated flows. When the shearing forces of the water flow exceed the critical tractive force of the soil, erosion takes place. For non-cohesive soils, Shields diagram is commonly used to determine the critical tractive force for individual soil particles. For cohesive soils, the critical tractive force has been related to the following:

- Soil shear strength,

- Soil salinity,
- Moisture content,
- Percent clay,
- Mean particle size,
- Dispersion ratio,
- Vane shear strength ,
- Percent organic matter,
- Cation Exchange Capacity (CEC),
- Calcium-Sodium ratio, and
- Plasticity index.

Soil erosion by water is measured by the soil lost from a given area, usually described on a per unit area basis. Sediment yield is the amount of sediment that passes a certain point in a watershed. The ratio between soil loss and the sediment yield is the delivery ratio. Most often we consider two delivery ratios. Delivery ratio one is the amount of sediment delivered from the overland flow, delivery ratio two is the amount of sediment delivered to the sub-watershed outlet by concentrated flow.

Typical erosion prediction models like the USLE (universal soil loss equation) and RUSLE (revised universal soil loss equation) do not include delivery ratios or channel erosion. Both of the models determine soil loss over an extended period of time such as months and years in units of weight measure. Another useful model is MUSLE (modified universal soil loss equation) which estimates sediment yield for single storm events. This approach does account for delivery ratio one but does not include delivery ratio two or channel erosion. Acceptable computerized versions of these models include but are not limited to SEDIMOTII (University of Kentucky) and SEDCAD4 (Civil Software Design, Ames, Iowa). Greenville County has developed SEDIMOTIV and it is available to users in Greenville County.

These models are used to determine the amount of sediment that will enter an erosion control structure. The design sediment storage volume is directly related to the amount of soil lost from the site during the design life of the structure. The use of these models also helps in determining the cleaning schedule of the sediment control structure. The models will be able to predict the amount of sediment entering the structure over a given period of time. When this amount equals the design sediment storage, the structure must be cleaned free of the stored sediment.

Sediment control structures are designed to keep eroded soils from having adverse off-site impacts that includes adjacent properties and Waters of the State. There are three major types of sediment control structures:

- Detention structures that provide enough surface area and storage volume to slow the flow of the sediment-laden runoff and allow the desired particle sizes to settle out so a desired trapping efficiency is met.

- Structures that filter out eroded sediment particles, and

- Structures that add chemical agents that promote particle flocculation and settling.

Most all of the BMPs employed today function primarily by Stokes Law of quiescent settling. Filtering is not an efficient control because of the particle size variations and the filter media clogging and becoming ineffective. Chemical treatment is the least desirable due to the impacts to the impacted water pH variations.

## 8.2. Purpose

This chapter of the Design Manual provides the user with the tools to meet the requirements of the Greenville County Storm Water Management Ordinance. Some of the information contained in this chapter, such as the application forms and checklists are available in digital format and can be downloaded from the Greenville County Webpage.

This chapter also establishes requirements to be used when preparing plans for minimizing soil erosion and sedimentation during and after construction of any land development, improvement or retrofit project. Guidelines on how to select and design EPSC BMPs for specific construction activities have been developed in accordance with several references from across the country. Suggested uses for EPSC and Storm Water Control BMPs are summarized in Appendix E. An EPSC BMP selection flowchart is provided in Appendix E.

## 8.3. Erosion Protection and Sediment Control Requirements

The Greenville Storm Water Ordinance requires that an EPSC plan be developed and approved, prior to initiating construction on land disturbing activities that are in excess of 5,000 square feet or require a building permit or as directed by a General Permit.

The Ordinance also establishes standards for the design of EPSC plans to minimize the adverse impact and off-site degradation that may result from construction site runoff.

### 8.3.1 EPSC Development Standards

EPSC plans shall be developed to achieve an **80 percent** design removal efficiency of total suspended solids (TSS) goal. Simply applied, when a site is completely denuded of vegetation, the structural and nonstructural EPSC measures are designed to trap 80 percent of the TSS that are generated by the site. The design storm event associated with this level of control is the **10-year 24-hour SCS Type II storm event**.

SCS procedures should be used to determine runoff amounts. It is important to note that when a BMP is designed for the 10-year 24-hour storm event, the BMP will have a greater trapping efficiency for more frequent events such as the 2-year 24-hour storm event.

Each EPSC Plan must delineate the following elements:

- All Sensitive Features (including steep slopes 30%)
- Sources of sediment that may potentially leave the site
- The location and depth of all structural and nonstructural BMPs necessary to achieve the 80 percent design removal efficiency goal to protect receiving water bodies, off-site areas and all Sensitive Features
- Installation and maintenance of required BMPs
- The sequencing of construction activities to be utilized on the project

The following nonstructural site management practices shall be utilized on the plans where applicable:

- Minimize site disturbance to preserve and maintain existing vegetative cover.
- Limit the number of temporary access points to the site for land disturbing activities.
- Phase and sequence construction activities to minimize the extent and duration of disturbed soil exposure.
- Locate temporary and permanent soil disposal areas, haul roads and construction staging areas to minimize erosion, sediment transport and disturbance to existing vegetation.

Detailed EPSC plans shall comply with the following specific standards and review criteria:

- Sediment Tracking Control. Stabilized construction entrances shall be located and utilized at all points of ingress/egress on a construction site. The transfer of soil, mud and dust onto public rights-of-ways shall be prevented.
- Crossings of waterways during construction should be minimized and must be approved by the Greenville County Storm Water Plan Review Agency. Encroachment into stream buffers, riparian areas and wetlands should be avoided when possible.
- Topsoil shall be stockpiled and preserved from erosion or dispersal both during and after site grading operations when applicable.
- Temporary Stabilization Measures. Where construction or land disturbance activity will or has temporarily ceased on any portion of a site, temporary site stabilization measures shall be required as soon as practicable, but no later than 14 calendar days after the activity has ceased.
- Final Stabilization. Final Stabilization of the site shall be required within 14 calendar days of construction completion.
- Temporary Structural Controls installed during construction shall be designed to accomplish maximum stabilization and control of erosion and sedimentation, and shall be installed, maintained, and removed according to the specifications set forth in the Design Manual, Standard Specifications and Standard Drawings. All temporary structural controls shall be designed to control the peak runoff resulting from the storm event identified in the Design Manual, Standard Specifications and Standard Drawings.
- All Permanent Structural Controls, including drainage facilities such as channels, storm sewer inlets, and detention basins, shall be designed according to the standards set forth in the Design Manual, Standard Specifications and Standard Drawings.

### 8.3.2 Alternative Erosion Prevention and Sediment BMPs

To encourage the development and testing of innovative alternative EPSC BMPs, alternative management practices that are not included in the Design Manual, Standard Specifications and Standard Drawings may be allowed upon review and approval. To use an alternative BMP, the design professional shall submit substantial evidence that the proposed measure will perform at least equivalent to currently approved BMPs contained in the Design Manual, Standard Specifications and Standard Drawings. Evidence may include, but is not limited to:

- Supporting hydraulic and trapping efficiency calculations.
- Peer-review by a panel of licensed professional engineers.
- Research results as reported in professional journals.
- Manufacturer literature.

To justify the efficiency of innovated EPSC BMPs, the owner may be required to monitor the trapping efficiency of the structure. If satisfactory results showing that trapping efficiencies of greater than 80 percent are obtained, the innovative BMP may be used and no other monitoring studies shall be required. If monitoring shows that a certain BMP is not sufficient or if Greenville County finds that a BMP fails or is inadequate to contain sediment, other upstream and downstream BMPs shall be implemented to reach the required efficiency.

### 8.3.3 Basic Design Procedures

Control of sedimentation from construction sites may be accomplished through the utilization of a variety of erosion and sediment control BMPs. The complexity of the erosion and sediment control plan will vary depending on the individual site conditions. The goal of implementing the erosion control plan is to limit the quantity of sediment being eroded from, and leaving a construction site. This may be partially accomplished through the implementation of sediment control BMPs. However, these sediment trapping controls typically only remove a small portion of the clay particles eroded from the site. The best protection is provided by a combination of practices including temporary and permanent stabilization, flow diversions, and streambank protection, all which minimize the amount of soil that is eroded from the site.

All land development shall be planned in such a way to control and limit erosion and sediment discharge from construction sites using, but not limited to, the BMPs listed in this chapter. The goal of these erosion and sediment control BMPs shall be to:

- Minimize the extent and duration of disturbed soil exposure.
- Protect off-site and downstream locations, drainage systems and natural waterways from the impacts of erosion and sedimentation.
- Limit the exit velocities of the flow leaving the site to non-erosive or pre-development conditions.
- Design and implement an ongoing inspection and maintenance plan.

## 8.4. Erosion Prevention Measures

Erosion prevention measures shall be used during and after construction site preparation in order to safely convey clean water to storm drains or adequate watercourses. One or more measures and BMPs should be utilized as appropriate during the project's construction phase. Such measures may include phasing and construction sequencing.

In addition to site-specific erosion control measures, the grading plan should include the following general measures as a minimum:

- The finished cut and fill slopes to be vegetated should not be steeper than 3H:1V. The finished grades of cut and fill slopes to be vegetated with vines and/or groundcovers should not be steeper than 1H:1V.
- Cuts or fills should not be so close to property lines as to endanger adjoining property without adequately protecting such properties against erosion, sedimentation, slippage, settlement, subsidence, or other damages.
- Subsurface drainage should be provided in areas having a high water table to intercept seepage that would affect slope stability, bearing strength or create undesirable wetness.
- No fill shall be placed where it can slide or wash onto another property.
- Fill shall not be placed adjacent to channel banks where it can create bank failure, reduce the capacity of the stream, or result in downstream sediment deposition.
- All borrow and disposal areas should be included as part of the grading plan.
- Adequate channels and floodways should be provided to safely convey increased runoff from the developed area to an adequate outlet without causing significant channel degradation, or increased off-site flooding.

Greenville County technical specification and details for Erosion Prevention Measures are located Appendix F and include:

- EC-01 Surface Roughening
- EC-02 Bench Terracing
- EC-03 Seeding (Temporary and Permanent Stabilization, Sod, Mulch)
- EC-04 Rolled Erosion Control Products (RECPs)
- EC-05 Hydraulic Erosion Control Products (HECPs)
- EC-06 Riprap or Aggregate
- EC-07 Outlet Protection
- EC-08 Dust Control
- EC-09 Transition Mats
- EC-10 Slope Interruption Devices
- EC-11 Compost
- EC-12 Biological Growth Stimulant

## 8.4.1 RECP Design

### Designing RECPs Example

| | | |
|---|---|---|
| **Given:** | Peak flow rate carried by channel: | 80 cfs |
| | Bottom width of design channel $B_o$: | 4-feet |

| | |
|---|---|
| Manning's n of matting: | 0.025 |
| Side slopes of design channel: | 2:1 |
| Channel bed slope (ft/ft): | 0.01 |

**Find:** Temporary Erosion Control Blanket (ECB) that will meet the maximum shear stress requirements with no establishment of vegetation.

**Solution:** The normal depth of flow in the channel ($d_n$ ) shall be calculated.

- Manning's Equation can be utilized to determine the normal flow depth, or
- The graphical procedure outlined in Section 6.1.8 may be used.

Solve for $AR^{2/3}$

$$AR^{2/3} = \frac{(Q*n*)}{b_o^{8/3} * S^{1/2}} = \frac{(80*0.025)}{4^{8/3}*(.01)^{1/2}} = 0.50$$

For Side Slopes 2:1, **Figure 6-1**. Reads: $d_n/B_o = 0.43$

Solve for $d_n = (0.43 * B_o) = (0.43 * 4) =$ 1.72-feet.
The maximum shear stress is then calculated.

Solve for $\tau = \gamma\, d_n\, S = (62.4* 1.72 * .01) = 1.1\ (\#/ft^2)$

Select an appropriate ECB or TRM for the design conditions.

Select a Erosion Control Blanket that can handle a maximum shear stress of 1.1 pounds/ square foot from the list of ECBs and TRMs.

## 8.4.2 Design of Riprap Channel Linings

Design of erosion protection within the channel should be accomplished using the FHWA Tangent Flow Method presented below. This method is applicable to both straight and curved channel sections where flows are tangent to channel bank. The Tangent Flow Method determines a stable rock size for straight and curved channel sections using known shape flow depth and channel slope dimensions. A stone size is chosen for the maximum depth of flow. If the sides of the channel are steeper than 3H:1V the stone size must be modified. The final design size will be stable on both the sides and bottom of the channel.

### 8.4.2.1 Straight Channel Sections:

1. Enter the graph of **Figure 8-1** with the maximum flow depth (feet) and channel slope (ft/ft). Where the two lines intersect, choose the $d_{50}$ stone size. (Select $d_{50}$ for diagonal line above the point of intersection)
2. If the channel side slopes are steeper than 3H:1V, continue with Step 3; if not, the procedure is complete.
3. Enter the graph in **Figure 8-2** with the side slope and the base width to maximum depth ratio (B/d).

Where the two lines intersect, move horizontally left to read K1.

4. Determine from the graph in **Figure 8-3** the angle of repose for the d50 stone size and the channel side slope. (Use an angle of 42o for d50 >10-inches. Do not use riprap on slopes steeper than the angle of repose for the stone size.)

5. Enter graph in **Figure 8-4** with the side slope of the channel and the angle of repose for the d50 stone size. Where the two lines intersect, move vertically down to read K2.

6. Compute d50 x K1/K2 = d50 to determine the correct size stone for the bottom and side slopes of straight sections of channel.

### 8.4.2.2 Curved Channel Sections:

1. Enter the graph of **Figure 8-1** with the maximum flow depth (feet) and channel slope (ft/ft). Where the two lines intersect, choose the $d_{50}$ stone size. (Select $d_{50}$ for diagonal line above the point of intersection.)

2. Determine the radius of the curved section (RO) in feet.

3. Calculate the top width of the riprap at the design water surface (BS) in feet.

| | | |
|---|---|---|
| $B_S$ | = | $B_O + 2(Z*D)$ |
| $B_O$ | = | Bottom width of channel (feet) |
| Z | = | Channel sides slopes defined as ZH:1V |
| D | = | Depth of riprap (feet) |

4. Calculate the Ratio $B_S / R_O$

5. Knowing the value of the BS/RO ratio from step 4, use the graph in **Figure 8-5** and read the corresponding value of K3.

6. Compute (d50 x K3) = d50 to determine the correct size stone for the bottom and side slopes of curved channel sections.

### 8.4.2.3 Straight Channel Section Design Example

**Given:** A trapezoidal channel has a depth (D) of 3-feet, a bottom width ($B_o$) of 8-feet, side slopes (Z) 2:1, and a 2 percent slope.

**Find:** A stable riprap size for the bottom and side slopes of the channel.

**Solution:**

1. From **Figure 8-1**, for a 3-foot-deep channel over a 2 percent grade,
   Read $d_{50}$ = 0.75-feet or 9-inches.

2. Since the side slopes are steeper than 3:1, continue with step 3

**If side slopes were less than 3:1, the process would be complete.

3. From **Figure 8-2**, BO/d = 8/3 = 2.67, Side slopes Z = 2,
   Read $K_1$ = 0.82.

4. From **Figure 8-3**, for d50 = 9-inches,
   Read Angle of Repose = 41

5. From **Figure 8-4**, side slopes Z = 2, and Angle of Repose = 41 ,
   Read $K_2$ = 0.73.

6. Stable Riprap = $d_{50}$ x ($K_1/K_2$) = 0.75 x (0.82/0.73) = 0.84-feet or 10-inches

#### 8.4.2.4 Curved Channel Section Design Example

**Given:** The preceding straight channel example has a curved section with a radius of 50-feet.

**Find:** A stable riprap size for the bottom and side slopes of the curved channel section.

**Solution:**

1. $R_O$ = 50-feet.

2. Calculate Channel Top Width of Water Surface
   $B_S = B_O + 2(Z*D) = 8 + 2(2*3) = 20$-feet.

3. Calculate the Ratio $B_S / R_O$
   = 20/50 = 0.40

4. From **Figure 8-5**, for $B_S / R_O$ = 0.40

Read $K_3$ = 1.1

5. $d_{50}$ x $K_3$ = (0.84-ft. x 1.1) = 0.92-feet or 11-inches.

### 8.4.3 Outlet Protection Design Example

**Given:** An 18-inch pipe discharges 24 cfs at design capacity onto a grassy slope (no defined channel)

**Find:** The required length, width and median stone size ($d_{50}$) for riprap lined protection.

**Solution:**

1. Since the pipe discharges onto a grassy slope with no defined channel, a **Minimum Tailwater Condition** is assumed. Figures for design of outlet protection for Minimum and Maximum Tailwater Conditions are provided in **Figure 8-6** and **Figure 8-7**

2. From **Figure 8-6**, the intersection of a discharge of 24 cfs and a pipe diameter (d) of 18-inches,

Gives a protection length ($L_a$) of 20-feet.

3. From **Figure 8-6**, the intersection of a discharge of 24 cfs and a pipe diameter (d) of 18-inches.

   Gives a median stone size ($d_{50}$) of 0.8-ft.

4. The upstream protection width equals 3 times the pipe diameter (3Do)

   = 3 x 1.5-feet = 4.5-feet

5. The downstream protection width equals the apron length + the pipe diameter;

   = 20-feet + 1.5-feet = **21.5-feet**

# 8.5. Temporary Sediment Control Measures

Greenville County emphasizes erosion prevention in EPSC plans. However there are always instances where erosion cannot be prevented. For these situations temporary sediment controls and BMPs must be implemented to control the migration of eroded sediment off site. The following sediment control measures are applicable as temporary practices for use during construction. One or more of the measures and BMPs should be utilized as appropriate during the project's construction phase. A discussion of the planned measures will be required during the Preliminary Plan Review phase for sites containing sensitive features.

Greenville County technical specifications and details for Temporary Sediment Control Measures are located Appendix F and include:

- SC-01 Surface Outlet and Baffle Sediment Basin / Multipurpose Basins
- SC-02 Temporary Sediment Trap
- SC-03 Silt Fence
- SC-04 Rock Ditch Check
- SC-05 Sediment Tube Ditch Check
- SC-06 Stabilized Construction Entrances
- SC-07 Storm Drain Inlet Protection
- SC-08 Rock Sediment Dikes
- SC-09 Construction DeWatering
- SC-10 Floating Skimmer
- SC-11 Porous Baffles
- SC-12 Perimeter Control for Small Sites
- SC-13 Polymer/ Flocculant / Coagulant for Sediment Control

## 8.5.1 Sediment Storage Volumes and Maintenance Schedules

Calculating the appropriate sediment storage volume is very important un sediment basin and sediment trap design. This volume is the storage occupied by the sediment deposited over the given design period. Design periods may be the life of the basin, or the time between scheduled clean outs. Using computed sediment yields from the Universal Soil Loss Equation (USLE), along with the sediment bulk density, the sediment storage volume can be calculated by

$$V_S = \frac{Y_D}{W * 43{,}560}$$

Where $\mathbf{V_S}$ is the sediment storage volume (acre-feet), $\mathbf{Y_D}$ is the sediment deposited over the design period (pounds), and **W** is the weight density (bulk density) of the deposited sediment (lbs./ft$^3$). **W** can be found from soil survey data (usually given in grams/cm$^3$) or by the equation

$$W = W_c P_c + W_m P_m + W_s P_s$$

Where $W_c$, $W_m$, and $W_s$ are unit weights of clay, silt, and sand in (lbs./ft$^3$) taken from Table 8-1, and $P_c$, $P_m$, and $P_s$ are the primary soil matrix percent clay, silt, and sand as listed in soil survey (used as a decimal).

**Table 8-1. Unit Weight Values of Basin Sediment**

| Type of Basin Operation | Wc (#/ft$^3$) | Wm (#/ft$^3$) | Ws (#/ft$^3$) |
|---|---|---|---|
| Sediment always submerged (Wet Pond) | 26 | 70 | 97 |
| Basin normally empty (Dry Pond) | 40 | 72 | 97 |

### 8.5.1.1 R Factors and EI Values

When designing for sediment storage volume, the sediment deposited over the design period $\mathbf{Y_D}$, must be calculated. This value can be obtained by converting the sediment yield calculated by the Universal Soil Loss Equation (USLE) into pounds of sediment.

One of the variables used in the USLE is the R factor. R is the factor in the USLE that accounts for the damaging effects of rainfall. The R factor indicates the erositivity of the rainfall, not the average annual precipitation in a locality. The R factor is defined as the number of erosion index (EI) values in a normal year's rain. The EI index value of a given storm is equal to the kinetic energy of the storm (hundreds of foot-tons per acre) multiplied by its maximum 30-minute intensity (inches/hour). The EI values of individual storms may be summed to get an EI value for a month, six months, or for any period of time. When EI values are summed and averaged over a period of years, they become R factors.

The distribution of EI values become important when soil losses need to be calculated for a period of time less than one year, such as a construction season. The distribution of the EI values over a known period of time is used to calculate an R factor for that time period. Table 8-2 of this chapter shows the distribution of EI values for Greenville County as a percentage of the R factor for Greenville County. This design procedure shall require a minimum EI value of 50 for any construction period.

**Table 8-2. Average Example Distribution of Rainfall Erosion Index (EI Curves) for Greenville County**

| Date | Percent of EI Value |
|---|---|
| January 1 | 0.0 |
| January 15 | 1.0 |
| February 1 | 3.0 |
| February 15 | 5.0 |
| March 1 | 7.0 |
| March 15 | 9.0 |
| April 1 | 12.0 |
| April 15 | 15.0 |
| May 1 | 18.0 |
| May 15 | 21.0 |
| June 1 | 25.0 |
| June 15 | 29.0 |
| July 1 | 36.0 |
| July 15 | 45.0 |
| August 1 | 56.0 |
| August 15 | 68.0 |
| September 1 | 77.0 |
| September 15 | 83.0 |
| October 1 | 88.0 |
| October 15 | 91.0 |
| November 1 | 93.0 |
| November 15 | 95.0 |
| December 1 | 97.0 |
| December 15 | 99.0 |
| January 1 | 100.0 |

**The minimum EI value for any construction period shall be 50.**

**The annual R factor value for Greenville County is 300.**

### 8.5.1.2 Factors and EI Value Example Problem

- The annual R factor value for Greenville County is **300**.
- If construction of a particular site is scheduled to take place for 5 months from January 1 to June 1, the EI Curve value would be,
- 25.0 – 0.0 = **25.0**
- The corresponding R factor for this time period is calculated to be

  0.25 * 300 = **75.0.**

- If construction of a particular site is scheduled to take place for 5 months from March 1 to August 1, the EI Curve value would be,

  56.0 – 7.0 = **49.0**

- The corresponding R factor for this time period is calculated to be

  0.49 * 300 = **147.0**

### 8.5.1.3 Calculating Sediment Storage Volumes

The following steps are used to determine the storage volume for a sediment trapping structure. All Universal Soil Loss Equation input values are found in Appendix B of this Design Manual.

1. Determine the sediment yield from the site using the Universal Soil Loss Equation

$$A = R \bullet K \bullet LS \bullet CP$$

Where :

**A** = Average soil loss per unit area (tons/acre/specified design period),
**R** = Rainfall erosive index (100-ft-tons/acre x in/hr)
(EI Value for given design period * average annual R Value)
**K** = Soil erodibility factor (tons/acre per unit R),
**LS** = Length-slope steepness factor (length is the slope distance from the point of origin of overland flow to the point of concentrated flow or until deposition occurs (dimensionless), and
**CP** = Control practice factor (dimensionless).

2. Determine the weight density **(W)** of the specific soil.

- Use the equation from Section 8.5.1, or
- Soil bore test and/or the Greenville County Soil Survey provide a soil bulk density usually given in grams/$cm^3$
- Convert (grams/$cm^3$) to (lbs/ $ft^3$) by multiplying by 62.43

**W** = (bulk density in grams/$cm^3$) x (62.43) = lbs/$ft^3$

3. Convert sediment yield from (tons/acre) to acre-feet of sediment storage.

- Determine the total disturbed area **DA** (acres)
- Determine the sediment yield in tons,

  Calculated by Multiplying **A** from step 1. * **DA** from step 3. (tons/acre * Acres = tons)

- Convert tons to pounds to get YD
  (**$Y_D$** = (tons) * (2000 lbs/ ton) = pounds)

$$V_S = \frac{Y_D}{W * 43{,}560} \quad = acre - feet$$

4. The design professional can now determine what level the required sediment storage corresponds to, and require a clean out marking stake to be installed at this elevation. The contractor shall be

required to clean out the basin or trap when this level is reached. Or the designer can simply state that based on the calculations, the basin or trap will be required to be cleaned out on a time period basis such as weeks, months or years.

#### 8.5.1.4 Sediment Storage Volume Example

**Given:** A 60-acre construction site is to be cleared to a bare soil condition and developed. The contributing runoff slope length is 400-feet with a 2.5 percent slope. The primary soil is Cecil Sandy Loam. A sediment basin is to be designed to be the primary sediment control structure on the site. Determine the required sediment storage volume if construction is to take place between March 1 and September 1

1. Determine the sediment yield form the site using the Universal Soil Loss Equation

$$A = R \bullet K \bullet LS \bullet CP$$

**R** = from Table 8-2, EI for September 1 = 77.0, and EI for March 1 = 7.0
(77.0 – 7.0) = 70% of 300 **= 210**
**K** = 0.28 for Cecil sandy loam soil
**LS** = 0.365 for 400 ft slope length with 2.5%
**CP** = 1.0 for a bare soil condition
**A** **= (210) x (0.28) x (0.365) x (1.0) = 21.5 tons/acre**

2. Determine the weight density (W) of the Cecil sandy loam soil.

- Soil boring tests give an average soil bulk density of 1.40 grams/cm3 for Cecil sandy loam soil
- Convert 1.40 (grams/cm3) to (# / ft3) by multiplying by 62.43

**W** = (1.40) x (62.43) = $\underline{87.4\ \#/ft^3}$

3. Convert sediment yield from (tons/acre) to acre-feet of sediment storage.

- Determine the total disturbed area (acres)
- Determine the sediment yield in tons

21.5 (tons/acre) * 60 (acres) = **1290 tons**

- Convert tons to pounds to get $\mathbf{Y_D}$
$\mathbf{Y_D}$ = (1290 tons) * (2000 # / ton) = 2,580,000 pounds

$$V_S = \frac{Y_D}{W * 43{,}560} = \frac{2{,}580{,}000}{87.4. \times 43{,}560} = 0.68\ acre - feet$$

## 8.6. Runoff Control and Conveyance Measures

The following flow control measures are applicable as temporary and/or permanent practices for use during construction. Greenville County technical specification and details for Runoff Control Measures are located Appendix F and include:

- RC-01 Pipe Slope Drains
- RC-02 Subsurface Drains
- RC-03 Runoff Conveyance Measures
- RC-04 Stream Crossings

## 8.6.1 Runoff Control and Conveyance Measures Design Example Problems

See **Figure 8-8**, **Figure 8-9** and **Figure 8-10** for Subsurface Drain Capacity for the given Manning's n value

**Given:** An interceptor subsurface drain is to be installed on a 1.0% grade, 700-feet in length, using corrugated plastic pipe.

**Find:** The required size of the drain pipe.

**Solution:**

- The required capacity of the drain pipe is 1.50 cfs per 1000-feet.
- The design capacity for this situation can be calculated by:

$$\text{Capacity} = \frac{700}{1000}\, x\, 1.50\ \ cfs = \ 1.05\ \ cfs$$

- The Manning's n value for corrugated plastic pipe is 0.015.
- From **Figure 8-9**, with the hydraulic gradient of 0.01 and a flow capacity of 1.05 cfs, read a pipe size of 8-inches.

**Given:** A relief drain system is designed to have a gridiron pattern of 8 laterals, 500-feet long, on a 0.50 percent grade spaced 50-feet on center, connected to a main pipe 400-feet in length on 0.50 percent grade. Smooth PVC pipe shall be used.

**Find:** The required size of the drain pipe.

**Solution:**

Lateral Design:

- The drainage area (DA) for each lateral is 25-feet on either side of the pipe multiplied by the length:

$$\text{DA} = \frac{(25ft + 25ft)\ x\ 500ft.}{43{,}560\ ft^2/acre} = \ 0.57\ acres$$

- From Section 8.6.6.2, relief drains in a uniform pattern shall remove 1-inch of water in 24-hours (0.042 cfs/acre):

$$0.042\ cfs\ x\ 0.57\ acres\ =\ 0.02\ cfs$$

- The Manning's n value for PVC pipe is 0.013.

- From **Figure 8-8**, with the hydraulic gradient of 0.005 and a flow capacity of 0.02 cfs, read a pipe size of 4-inches for each lateral.

**Main Pipe Design:**

- The drainage area (DA) of the main pipe will only drain 25-feet opposite the laterals:

$$\mathrm{DA} = \frac{(25\,ft)\ x\ 400\,ft.}{43{,}560\ \ ft^2/} \ =\ 0.23\ acres$$

- The drainage area from the 8 laterals (DAL) is calculated to be:

$$\mathrm{DAL} = 8\ x\ 0.57\ acres\ =\ 4.56\ acres$$

- The total drainage area (TDA) to the main is:

$$\mathrm{TDA} = 0.23 acres\ +\ 4.56\ acres\ =\ 4.79\ acres$$

- Relief drains in a uniform pattern shall remove 1-inch of water in 24-hours (0.042 cfs/acre):

0.042 cfs x 4.79 acres = **0.20 cfs**

- The Manning's n value for PVC pipe is 0.013.

- From **Figure 8-8**, with the hydraulic gradient of 0.005 and a flow capacity of 0.2 cfs, read a pipe size of 5-inches for the main.

# 8.7. Engineering Design Aids and Design Guidelines for Sediment Controls

This section presents design aids that were developed for use in designing four types of sediment control structures; sediment basins, sediment traps, silt fences, and rock ditch checks for Greenville County South Carolina. Each of these design aids will be briefly described and then examples will be used to demonstrate their use in realistic problems. First however a common feature of each design aid settling velocity will be discussed.

## 8.7.1 Characteristic Settling Velocity and Eroded Particle Size

A common feature of each of the design aids is that a characteristic settling velocity for the eroded soil must be obtained. For Greenville County conditions, this velocity corresponds to an eroded size such that 15 percent of the sediment has particles smaller than the size specified. The procedure for empirically estimating eroded size distributions is best described by Hayes et. al (1996). The characteristic settling velocity corresponds to an eroded particle diameter that is referred to as $D_{15}$. This diameter represents the point on the eroded particle size distribution curve where 15 percent of the particles (by weight) are equal to or smaller than this size. Estimated eroded size distributions for Greenville County soils using an adaptation of the method described by Foster et al. (1985) were developed. The procedure uses the primary particle size information reported by the USDA Soil Conservation Service (SCS) as part of county soil surveys. This procedure may be used with USDA Soil Survey Data or site specific soil boring data. Other procedures are given by Haan et. al. (1994) for physically based estimating procedures. If $D_{15}$ is less than 0.01 mm, then settling velocity based upon a simplified form of Stokes Law is:

$$\mathbf{V_s = 2.81d^2}$$

Where $V_s$ is settling velocity in ft/sec and $d$ is diameter in mm. If $D_{15}$ is greater than or equal to 0.01 mm, then settling velocity should be found using:

$$\mathbf{\log_{10}V_s = -0.34246\ (\log_{10}d)^2 + 0.98912\ (\log_{10}d) - 0.33801}$$

Where $V_s$, is settling velocity in ft/sec and d is particle diameter in mm (Wilson et al., 1982). The characteristic settling velocity can be obtained using **Figure 8-11** and the eroded particle size ($D_{15}$) for soils found in Greenville County is provided in Appendix D.

It is important to remember that the eroded size distribution is the most critical parameter in sizing sediment controls. The eroded size distributions vary greatly from primary particle size distributions that are often determined as a result of soil strength investigations for construction purposes. Primary particle sizes will yield erroneous results and should not be used. The user should note that $D_{15}$ is often smaller for coarse textured (more sandy soils) because of the reduced clay content and the lack of aggregation.

**Table 8-3. Soil Classification by Texture**

| Greenville County Soil Classification by General Texture | | | |
|---|---|---|---|
| Texture | Coarse | Medium | Fine |
| Soil Type | Sandy Loam | Silt Loam | Clay Loam |

## 8.7.2 Sediment Basin Design Aids

The Sediment Basin Design Aids are designed for soils classed as either coarse (sandy loam), medium (silt loam), or fine (clay loam). The design ratio should be less than or equal to the curve value at any given trapping efficiency. The sediment basin Design Aids have been developed for the following two separate conditions:

- Basins **not** located in low lying areas and/or not having a high water table, and
- Basin located in low lying areas and/or having a high water table.

#### 8.7.2.1 Sediment Basin Design Aid Ratio

$$\text{Basin Ratio} = \frac{q_{po}}{A V_{15}}$$

Where:

| | | |
|---|---|---|
| $q_{po}$ | = | Peak outflow rate from the basin for the 10-year 24-hour storm event (cfs), |
| **A** | = | Surface area of the pond at riser crest (acres), |
| $V_{15}$ | = | Characteristic settling velocity (fps) of the characteristic $D_{15}$ eroded particle (mm). |

Constraints for use of Sediment Basin Design Aids:

- Watershed area less than or equal to 30 acres
- Overland slope less than or equal to 20 percent
- Outlet diameter less than or equal to 6-feet

Basin Ratios above the design curves are not recommended for any application of the design aids. If the basin ratio $q_{po}/AV_{15}$ intersects the curve at a point having a trapping efficiency less than the desired value, the design is inadequate and must be revised.

A basin **not** located in a low lying area and not having a high water table, has a basin ratio equal to **2.20 E5** at 80 percent trapping efficiency as shown in **Figure 8-12**.

A basin that **is** located in a low lying area or in an area that has a high water table, has a basin ratio equal to **4.70 E3** at 80 percent trapping efficiency as shown in **Figure 8-13**.

#### 8.7.2.2 Sediment Basin Example Problems

**Given:**

A sediment basin is to be constructed on a 14-acre (0.0219 $mi^2$) disturbed site.

Peak discharge is to be limited to that of the current land use, established grass.

A pond site is available with an area at the riser crest of 0.75 ac. Soil in the area is an Edisto.

a) Estimate the basin's trapping efficiency for a 10-year, 24-hour storm if time of concentration is approximately 20 minutes.

b) If the desired trapping efficiency is 80 percent and the eroded diameter D15 equals 0.01mm, what is the required peak discharge for basin areas of 0.33, 0.50, 0.67, 0.75 and 1.0 acres

**Solution:**

**Part (a)**

1. Estimate the peak runoff allowed. The SCS curve number is found for a hydrologic soil group C with established grass as 74. Using a 10-year, 24-hour design storm of 6.0-inches, with this curve number yields a runoff volume of 3.2-inches using the SCS curve number method.

2. Using the SCS graphical method to estimate peak flow, the $I_a/P$ ratio computes to approximately 0.12. Combining this and an estimated time of concentration equal to 0.33 hrs yields a $q_u$ = 650 csm/in for a Type II storm distribution.

3. The peak discharge allowed is calculated by multiplying $q_u$ times the runoff volume times the disturbed area in $mi^2$ and is approximately 46 cfs.

4. $D_{15}$ for an Edisto sub-soil 0.0128. Using this diameter, $V_{15}$ can be estimated as 3.7E-4 ft/sec.

5. The sediment basin ratio can now be calculated by calculating

   $q_{po} / (AV_{15}) = 46 / [(0.75)(3.7E\text{-}4)] = 1.70\ E5$

6. Going to the Sediment Basin Design Aid (**Figure 8-12**) with this sediment basin ratio, read across to the curve and then turn down to the x-axis. The trapping efficiency is estimated to be **81%.**

7. If the desired trapping efficiency was not obtained, the process would need to be repeated with a larger basin or decreased discharge until the desired trapping efficiency was found.

**Part (b)**

1. Determine the Sediment Basin Ratio. From the Sediment Basin Design Aid (**Figure 8-12**), the ratio for a design trapping efficiency of 80 percent is **2.20 E5 $ft^2$/acre.**

2. Determine the ratio of qpo/A required. Substituting the results from step 1 into equation 3,

   $Basin\ Ratio = 2.2x10^5 = q_{po}/A/V_{15}$

3. With D15 equal 0.01 mm, the corresponding V15 is **2.8E-4 ft/sec**. Hence,

   $2.2x10^5\ V_{15} = q_{po}/A = (2.2x10^5)(2.8x10^{-4})$ = **62 cfs /acre of pond.**

4. Determine $q_{po}$ and $A$ values. The following results can be tabulated for the acreage shown:

   $q_{po}$ = 62 cfs/acre * (0.33 ac.) = **20.5 cfs.**

Continuing this calculation for basin areas of 0.67 and 1.0 acres, we have:

| Pond Area (acres) | $q_{po}$ (cfs) |
|---|---|
| 0.33 | 20.5 |
| 0.50 | 31.0 |
| 0.67 | 41.5 |
| 0.75 | 46.5 |
| 1.00 | 62.0 |

Each of these combinations will give the desired 80 percent trapping efficiency for the specified eroded size. The depth will depend on the expected volume of sediment to be deposited during the life of the structure.

## 8.7.3 Rock Ditch Check Design Aids

Design aids for rock ditch checks were developed similarly to those for ponds. Again, the $D_{15}$ eroded particle size is used for the calculation of the characteristic settling velocity. The ratio for ditch checks is defined by:

The Rock Ditch Design Aids have been designed for the following soil classifications:

- Coarse (sandy loam),
- Medium (silt loam), and
- Fine (clay loam).

The design ratio should be less than or equal to the curve value at any given trapping efficiency.

### 8.7.3.1 Rock Ditch Check Design Aid Ratio

$$\text{Ditch Check Ratio} = \frac{Sq^{(1-b)}}{aV_{15}}$$

Where:

**S** = Channel slope (%),
**q** = Unit width flow through the check for the 10-year 24-hour storm event (cfs/ft),
$\mathbf{V_{15}}$ = Characteristic settling velocity (fps), of the characteristic $D_{15}$ eroded particle (mm).

Coefficients a and Exponent b can be interpolated from tables

Constraints for the use of Rock Ditch Check Design Aids:

- Watershed area is less than or equal to 5 acres
- Overland flow length is less than or equal to 500-feet
- Overland slope is less than or equal to 15 percent
- Maximum depth of the ditch is less than or equal to 6-feet

Ditch Check Ratios above the design curves are not recommended for any application of the design aids.

If the ditch check ratio intersects the curve at a point having a trapping efficiency less than the desired value, the design is inadequate and must be revised.

A ditch check located on coarse soils has a ditch check ratio equal to **1.10 E3** at 80 percent trapping efficiency as shown in **Figure 8-14**.

A ditch check located on medium soils has a ditch check ratio equal to **5.80 E3** at 80 percent trapping efficiency as shown in **Figure 8-15**.

A ditch check located on fine soils has a ditch check ratio equal to **1.20 E4** at 80 percent trapping efficiency as shown in **Figure 8-16**.

#### 8.7.3.2 Rock Ditch Check Example Problem

**Given:** A rock ditch with a channel slope of 1.0 percent is to be installed on an area having Cecil sandy loam soils. The eroded size distribution is for a medium texture soil since it is a sandy loam.

The runoff coefficient "C" for the rational method is estimated as 0.4 with an intensity of 6.75 in/hr for the design storm.

Drainage area to the ditch check is 4.4 ac.

Average rock diameter of the ditch check is 0.10 m (4 in.).

Average width (perpendicular to flow) is 6.7 ft and ditch check length is one meter (refer to Section 6.4 for procedures to calculate flow through a ditch check).

**Find:**

The trapping efficiency for the rock ditch check.

**Solution:**

A Cecil $D_{15}$ topsoil is 0.0066 mm, and the settling velocity is found to be $V_{15}$ = 1.2 E-4 fps.

Peak flow can be estimated from the given information by substituting into the rational formula so that

$q_p = C\ i\ A = 0.4\ (6.75)(4.4) = 11.9$ cfs

1. The flow rate should be converted to flow per unit width by dividing the peak flow by the check width to obtain the design q as

$$q = 11.9\ \text{cfs}/6.7\ \text{ft} = 1.78\ \text{cfs/ft}$$

2. Appropriate values of the coefficients a and b can be interpolated from Table 8-4.

- Rock diameter of 0.10 m
- Flow length of 1.0 m

a = 4.13

b = 0.6651.

Substitute all values and calculate the ditch check ratio

$$Sq^{(1-b)} / a V_{15} = (1.0)(1.78^{(1-0.6651)})/(4.13)(1.2E-4) = 2448$$

3. Enter the Rock Ditch Check Design Aids for medium texture soil (**Figure 8-15**) on the y-axis with Ditch Check Ratio = 2.5E3, go to line and turn to the x-axis to read trapping efficiency.

Trapping efficiency equals **86%.**

Note: The ditch check must also be checked for overtopping since this is a common occurrence and results in total failure of the check. If the check overtops, the trapping efficiency is assumed to be zero. See Section 6.4 entitled Stage Discharge Equations for Rock Structures.

**Table 8-4. Stone Flow Coefficient *a* and Exponent *b***

| Stone Diameter(m) | Exponent b | Coefficient a dl= 1m | Coefficient a dl = 2m | Coefficient a dl = 3m |
|---|---|---|---|---|
| 0.01 | 0.6371 | 9.40 | 6.05 | 4.60 |
| 0.02 | 0.6540 | 7.40 | 4.65 | 3.55 |
| 0.03 | 0.6589 | 6.40 | 4.08 | 3.08 |
| 0.04 | 0.6609 | 5.85 | 3.65 | 2.80 |
| 0.05 | 0.6624 | 5.40 | 3.35 | 2.60 |
| 0.06 | 0.6635 | 5.05 | 3.15 | 2.40 |
| 0.08 | 0.6644 | 4.50 | 2.85 | 2.20 |
| 0.09 | 0.6648 | 4.28 | 2.70 | 2.10 |
| 0.10 | 0.6651 | 4.13 | 2.60 | 2.05 |
| 0.20 | 0.6662 | 3.20 | 2.05 | 1.57 |
| 0.30 | 0.6664 | 2.80 | 1.75 | 1.30 |
| 0.40 | 0.6665 | 2.50 | 1.55 | 1.16 |
| 0.50 | 0.6666 | 2.30 | 1.40 | 1.08 |

**$D_{50}$ = rock ditch check average stone diameter in meters.**

***dl* = average flow length through the rock ditch check in meters.**

Source: Haan et. al. (1994) pg. 151.

## 8.7.4 Silt Fence Design Aids

This design aid for applies to silt fences placed in areas down slope from disturbed areas where it serves to retard flow and cause settling. Two conditions must be met for satisfactory design.

- Trapping efficiency must meet the desired level of control.
- Overtopping of the fence must not occur.

### 8.7.4.1 Silt Fence Design Aid Ratio

The silt fence design aid is a single line grouping all soil textures together. A similar procedure was used for development of the ratio as used for the ponds and rock checks. For the silt fence, the ratio is:

$$\text{Silt Fence Ratio} = \frac{q_{po}}{V_{15} P_{area}}$$

Where:

| | | |
|---|---|---|
| $q_{po}$ | = | Peak outflow through the fence for the 10-year 24-hour storm event (cfs), |
| **V15** | = | Characteristic settling velocity (fps), of the characteristic D15 eroded particle (mm), |
| $P_{area}$ | = | Potential ponding area up slope of the fence ($ft^2$). |

The ponding area can be estimated by using the height of the fence available for flow through and extending a horizontal line from the fence to an intersection with the ground surface upslope of the fence. The unit available area is calculated by multiplying the fence height by the ground slope. Multiply this unit area by the available fence length for ponding to obtain the potential ponding area.

Using the calculated ponding area, calculate the ratio and enter the value to **Figure 8-17** to determine the efficiency. Once an acceptable trapping efficiency is determined, a calculation for overtopping must be performed. The overtopping calculation must be performed using the slurry flow rate through the fence. This rate must be checked against the incoming flow to determine if enough storage exist behind the fence to prevent overtopping.

Constraints for the use of Silt Fence Design Aids:

- Watershed area is less than or equal to 5 acres
- Overland flow length is less than or equal to 500-feet
- Overland slope is less than or equal to 6 percent
- Slurry flow rate through the fence is less than or equal to 10 gpm / ft
- Maximum height of the silt fence is less than or equal to 3-feet

Silt Fence Ratios above the design curves are not recommended for any application of the design aids. If the silt fence ratio intersects the curve at a point having a trapping efficiency less than the desired value, the design is inadequate and must be revised.

A silt fence ratio equal to **0.23** has an 80 percent trapping efficiency as shown in **Figure 8-17**.

### 8.7.4.2 Silt Fence Example Problem

**Given:**

A wire-backed silt fence is to be built from 2.5 ft wide, silt fence fabric at the toe of a 2.0 percent slope draining a linear construction site.

Topography will cause runoff to drain through 400-feet of total fabric length.

Peak flow from the 1.0-acre upslope area is estimated at 2.5 cfs using the rational equation with "C" equal to 0.25 and intensity equal to 10.0 iph.

Freeboard allowance and installation will reduce the usable height of the fence from 2.5- to 1.5-feet that is usable above ground.

Slurry flow rate for the filter fabric is 10 gpm/ft$^2$ of fabric according to manufacturer specifications or other source.

**Find:**

A. The trapping efficiency if the soil is Lakeland Sand with an eroded size distribution having a $D_{15}$ equal to 0.0463 mm.

B. The trapping efficiency if the soil is Cecil with an eroded size distribution having a D15 equal to 0.0066 mm.

**Solution:**
**A:**
1. The settling velocity of the $D_{15}$ particle (0.0463 mm) can be estimated as $V_{15}$ equal to 5.1 E-3 ft/sec.

2. The ponded area can be estimated using the geometry at the installation site. With a fence length of 400 ft, maximum depth equal to 1.5 ft based on the usable width of the fabric, and slope upstream of the fence equal to 2.0 percent, there will be ponded area of 75 ft$^2$/linear ft of fabric for a total ponded area of

   $$P_{area} = (75\ ft^2/ft)\ (400\ ft) = 30{,}000\ ft^2$$

   Based on this ponding calculation, a tie back of 75-feet is required to provide an adequate ponding area.

3. The filter fence ratio is calculated as

   $$\text{Silt Fence Ratio} = q_{po} / (V_{15}\ P_{area}) = 2.5/[(5.1E\text{-}3)(30{,}000)] = 0.017$$

4. Reading the trapping efficiency from the Silt Fence Design Aid (**Figure 8-17**) with the ratio equal to 0.017, the trapping efficiency is approximately 94 percent.

   - The fence must be checked for its ability to pass the design flow without overtopping.

5. Convert the peak flow from cfs to gpm so that

   $$q_{po} = (2.5\ ft^3/sec)(7.48\ gal/ft^3)(60\ sec/min) = 1122\ gpm$$

6. Required length of fabric to carry this flow can be found by dividing the peak flow rate by the effective height (1.5-ft) and the slurry flow rate of 10 gpm/ft2 of fabric. Hence, the length of fence required to carry the peak flow without overtopping is

   $$L = (1122)/\ (1.5)\ (10) = 75\ ft$$

7. Since 75 ft is less than the 400 ft available, the fence as designed should not overtop if it is properly maintained. Note: This analysis does not account for concentration of flows or strength of the posts, wire mesh, or fabric.

**B.**

1. A Cecil $D_{15}$ topsoil is 0.0066 mm, and the settling velocity is found to be $V_{15}$ = 1.2 E-4 fps.

2. The filter fence ratio is calculated as:
   Silt Fence Ratio = $q_{po}$ /($V_{15}$ $P_{area}$) = 2.5/[(1.2E-4)(30,000)] = **0.70**

3. Reading the trapping efficiency from the Silt Fence Design Aid (**Figure 8-17**) with the ratio equal to 0.70, the trapping efficiency is approximately **70%.**

## 8.7.5 Sediment Trap Design Aids

Sediment traps, for the purposes of this document, are small excavated ponds with rock fill outlets. Their outlet hydraulics are different from a drop inlet structure, thus the Design Aid is slightly different with the area defined as being the area at the bottom of the outlet structure. Trapping efficiencies for sediment traps are plotted in **Figure 8-18** as a function of the sediment trap ratio:

### 8.7.5.1 Sediment Trap Design Aid Ratio

The sediment trap design aid is a single line grouping all soil textures together. A similar procedure was used for the development of the ratio as used for basins. For the sediment trap, the ratio is:

$$\text{Sediment Trap Ratio} = \frac{q_{po}}{A\,V_{15}}$$

Where

| | | |
|---|---|---|
| $q_{po}$ | = | peak outflow for the 10-year 24-hour storm event (cfs), |
| **A** | = | surface area at the elevation equal to the **bottom** of the rock fill outlet (acres), |
| $V_{15}$ | = | characteristic settling velocity (fps), of the characteristic $D_{15}$ eroded particle (mm). |

Constraints for the use of Sediment Trap Design Aids are:

- Watershed area less than or equal to 5 acres
- Overland slope less than or equal to 20 percent
- Rock fill diameter greater than 0.2-feet and less than 0.6-feet
- Rock fill height less than 5-feet
- Top width of rock fill between 2- and 4-feet
- Maximum Side slopes 1:1 to 1.5:1.

Sediment Trap Ratios above the design curves are not recommended for any application of the design aids. If the sediment trap ratio intersects the curve at a point having a trapping efficiency less than the desired value, the design is inadequate and must be revised.

A sediment trap ratio equal to **9.0 E4** has an 80 percent trapping efficiency

Storm flows shall be routed through the sediment trap to calculate the required depth and storage volume of the trap.

A sediment storage volume shall be calculated and provided below the bottom of the rock fill outlet structure.

### 8.7.5.2 Sediment Trap Example Problem

**Given:**

A sediment trap designed for a 10-year, 24-hour storm is to be constructed on a development site as a temporary sediment control measure for a 3-acre drainage area that is totally disturbed.
The outlet is to be a rock fill constructed of rock with a mean diameter of 0.5-feet.

The soil is a Cecil sandy loam, the slope of the watershed is 5 percent, and the time of concentration is 6 minutes.

a) If the desired trapping efficiency is 80 percent, what is the required peak discharge for trap areas of 0.10, 0.25, and 0.50 acres.

**Solution:**

1. Determine the Sediment Trap Ratio. From the Sediment Trap Design Aid (**Figure 8-18**), the ratio for a design trapping efficiency of 80 percent is 9.0E4 $ft^2$/acre.

2. Determine the ratio of qpo/A required from the Sediment Trap Ratio,

   *Sediment Trap Ratio* $= 9.0x10^4 = qpo/A*V15$

3. The D15 for a Cecil soil is 0.0066 mm, and the corresponding V15 for a Cecil sandy loam soil is 1.2E-4 ft/sec. Hence,

   $9.0x10^4\ V_{15} = qpo/A = (9.0x10^4)(1.2x10^{-4}) = 11$ *cfs /acre of pond.*

4. Determine qpo/A values. The following results can be tabulated for the acreage shown:

| Sediment Trap Bottom Area (acres) | qpo Through Rock Fill (cfs) |
|---|---|
| 0.10 | 1.1 |
| 0.25 | 2.8 |
| 0.50 | 5.5 |

Each of these combinations will give the desired resulting 80 percent trapping efficiency.

The rock fill outlet structure must be designed to convey a peak flow of that shown in column two of the table above. See Section 6.4 for design details. If the check rock fill overtops, the trapping efficiency is assumed to be zero.

Storm flows shall be routed through the sediment trap to calculate the required depth and storage volume of the trap.

A sediment storage volume shall be provided below the bottom of the rock fill outlet structure.

## 8.8. Report Development

Specific requirements for the erosion and sediment control section of the Storm Water Management Permit Application shall include, but is not limited to the following items:

- The plans shall contain a description and location of the predominant soil types on the site.
- The plans shall show the location and delineation of vegetative covers that are not to be disturbed.
- The plans shall contain the location and dimensions of all storm water drainage and natural drainage systems on, and adjacent to the development site.
- The plans shall contain both existing and planned site topography.
- The plans shall contain the location and dimensions of all land disturbing activities.
- If applicable, the plans shall contain the potential location for soil stock-piles and the related stabilization structures or techniques for these stock piles.
- The plans shall include details, dimensions and descriptions of all temporary and permanent erosion and sediment control measures.
- Notes contained in the erosion and sediment control plan shall state that all erosion and sediment controls be inspected at least once every seven calendar days, or after any storm event the produces greater than ½-inches of rainfall during any 24-hour period.
- Notes contained in the erosion and sediment control plan shall state that when construction or land disturbance activities have temporarily ceased on any portion of a site, temporary site stabilization measures shall be required as soon as practicable, but no later than 14 calendar days after the activity has ceased.
- Notes contained in the erosion and sediment control plan shall state that final stabilization of the site shall be required within 14 calendar days of the completion of construction.
- Specifications for a sequence of construction operations shall be contained on all plans describing the relationship between the implementation and maintenance of sediment controls including permanent and temporary stabilization and the various phases of earth disturbance and construction. The specifications for the sequence of construction shall contain, at a minimum, the following:
  - Clearing and grubbing for those areas necessary for installation of perimeter controls
  - Installation of sediment basins and traps
  - Construction of perimeter controls
  - Remaining clearing and grubbing
  - Road grading
  - Grading for the remainder of the site
  - Utility installation and whether storm drains will be used or blocked until the completion of construction
  - Final grading, landscaping, or stabilization
  - Removal of sediment control structures.
- Design computation for all erosion and sediment control structures.
  - List of the trapping efficiency of each sediment control structure.
  - Calculation of required sediment storage volumes.

- Explanation of any computer models or software used with highlights of the output data.
- Description of required clean-out frequencies and maintenance schedules.

# Chapter 9. WATER QUALITY

## 9.1. Water Quality Background and Calculations

The selection and design guidelines set forth in this chapter of the Design Manual for water quality controls are provided to aid the design professional in planning and designing appropriate water quality BMPs relative to target pollutants, function, ease of maintenance, aesthetics, and safety. The design professional is responsible for designing water quality BMPs to function properly for each specific site. It is important to understand the types of pollutants that are present in urban runoff as well as their potential impacts on receiving water bodies. It is equally important to locate the source of these pollutants so source controls can be applied to eliminate these pollutants from entering receiving water bodies. Table 9-1 lists typical urban storm water runoff pollutants and their sources, and the list is by no means exhaustive.

**Table 9-1 Pollutants and Sources in the Urban Landscape**

| Pollutant Source | Pollutant of Concern |
|---|---|
| **Erosion** | Sediment and attached soil nutrients, organic matter, and other adsorbed pollutants. |
| **Atmospheric Deposition** | Hydrocarbons emitted from automobiles, dust, metals, and other chemicals released from industrial and commercial activities. |
| **Construction Materials** | Metals, paint, and wood preservatives. |
| **Manufactured Products** | Heavy metals, phenols and oils from automobiles, Zinc and Cadmium from tire wear. |
| **Landscape Maintenance** | Fertilizer and pesticides. Generally as impervious area increases, nutrients build up on surfaces and runoff transport capacities rise resulting in high loads. |
| **Plants and Animals** | Plant debris, animal excrement. |
| **Septic Tanks** | Coliform bacteria, nitrogen, $NO_3$. |
| **Non-Storm Water Connections** | Sanitary sewage, industrial wastewater, commercial discharge, and construction activities. |
| **Accidental Spills** | Pollutants of concern depend on the nature of the spill. |
| **Animal Waste Management** | Fecal coliform, nitrates and phosphorus. |
| **Pesticide Applications** | Pollutants of concern depend on the pesticide being used and the type of crop. |
| **Land Disturbance Agriculture** | Sediment and attached soil nutrients, organic matter, and other adsorbed pollutants. |
| **Fertilizer Applications** | Nitrogen and phosphorus. |

Source: U.S. Environmental Protection Agency, June 1992.

## 9.1.1 Characterization of Urban Storm Water Runoff Quality

### 9.1.1.1 Suspended Solids

The most prevalent form of storm water pollution is the presence of suspended matter that is either eroded by storm water or washed off paved surfaces by storm water. Suspended solids increase the turbidity of the receiving water, thereby reducing the penetration of light, resulting in decreased activity and growth of photosynthetic organisms. Also, elevated concentrations of suspended sediment alters stream nutrient biogeochemistry which impacts nutrient adsorption and desorption, processes very important to control over primary production and overall ecosystem health (Lee, 1996; Dent and Henry, 1999). The increased turbidity also detracts from the aesthetics of natural waters. In addition, the clogging of fish gills has been attributed to the presence of suspended solids. Combined sewer overflows typically contain high suspended solids concentrations. The solids that settle in the receiving water pose long-term threats resulting from their oxygen demand and gradual accumulation of toxic substances (Moffa, 1990). Sedimentation and other forms of physical separation are often an effective means of removing suspended solids from storm water.

Sediment is derived from a variety of sources, including erosion from disturbed areas, washoff of sediment deposited on impervious areas, and detachment of sediment due to the increased stream power that comes from increased flow rates and flow durations with urbanization. A significant number of

models are available to predict total suspended solids (TSS) contributions from “clean” sediment, but few of the models have parameters specific to urbanized areas. Most of the models were developed to deal with agricultural soils, and their application to urban areas is limited.

Models that do have capabilities that have been used for predicting urban clean sediment include SWMM and the SEDIMOT models. For the models to be effectively utilized in sizing BMPs, predictions must be made of time varying quantities as well as the size distribution. Those distributions must be of the aggregated particles, not the primary particles.

### 9.1.1.2 Oxygen Demanding Matter and Bacteria

Sufficient levels of dissolved oxygen (DO) in the water column are necessary to maintain aquatic life, growth, and reproductive activity, as well as to maintain aerobic conditions. The introduction of storm water containing oxygen-demanding organic matter can impair the receiving water quality by reducing the DO levels such that it is unable to sustain certain forms of aquatic life and can further cause the water to become foul. Bacteria enter the storm water drainage system typically from the washoff of animal feces and organic matter from the catchment surface. Occasionally, bacteria may enter the drainage system through residential sanitary lateral connections and industrial or commercial drains, although such practices are typically illegal. Organic matter, usually in the form of vegetation and detritus, is carried through the conveyance system by the storm water. Pathogenic bacteria and viruses in storm water discharges pose human health threats. The removal of pathogenic bacteria is achieved primarily through the process of biological decay and physical-chemical disinfection where practiced.

### 9.1.1.3 Nutrients

Nitrogen and phosphorus are plant nutrients that promote the growth of plants and protista such as algae, and are the second leading stressor of impaired rivers and streams and the leading stressor of impaired lakes (US EPA, 1997). Such nutrients contribute to the eutrophication of water bodies resulting in the list of associated liabilities such as decreased oxygen supply, alteration of aquatic life, decreased recreational value (Novotny,1985).

Nutrients are typically derived from agricultural runoff as well as runoff from chemicals applied to lawns in urbanized areas, runoff from industrial sites, municipal wastewaters (of more concern for combined sewer overflows), or dry fall onto impervious surfaces that is later washed into storm water. Model studies indicate that the increase in nutrient loading due to increased imperviousness will be dramatic. For example, the increase in the Maryland Chesapeake Bay watershed due to increased urbanization is expected to range from 2 to 20 times the current load, depending on whether residential development is highly restricted or unrestricted (Houlahan, 1992). Nutrients can be removed from storm water prior to discharge through biological uptake such as by plantings in storm water quality control ponds.

Most models of nutrient loadings that have an extensive data base included have been based on agricultural and forest operations. These have applicability to washoff from fertilized lawns and forested areas but not to the impervious areas. Models of nutrient loading in urban runoff are typically based on washoff type calculations or user-defined loadings and concentrations, all of which require user-defined constants. Estimating the water quality loading for nutrients is difficult to accomplish without local data.

### 9.1.2 Pollutant Loading

Estimating the pollutant load for a particular development site is commonly calculated based on the general land use category of the site. Primary land use contributors are streets, roads, highways, residential areas, commercial areas, industrial areas, and sites under development.

The control of urban runoff can be classified in two categories:

- Runoff quantity control, and
- Runoff quality control.

Quantity control techniques are well established and are based on the physical laws of conservation and momentum. Such measures seek to attenuate peak runoff flow rates and to reduce hydrograph volumes to mitigate flooding and the potential for erosion downstream.

A much more difficult task is the water quality control of urban runoff. This problem is confounded by the intermittent nature of rainfall, the variability of rainfall characteristics, such as volume and intensity, and the variability of constituent concentrations.

Tables 9-2 through 9-6 list several published pollutants loads based on urban land use.

### Table 9-2. Urban "C" Values For Use With the Simple Method (mg/l)

| Pollutant | New Suburban NURP Sites (Wash DC) | Older Urban Areas (Baltimore) | Central Business District (Wash DC) | National NURP Study Average | Hardwood Forest (Virginia) | National Urban Highway Runoff |
|---|---|---|---|---|---|---|
| **Phosphorus** | | | | | | |
| Total | 0.26 | 1.08 | --- | 0.46 | 0.15 | --- |
| Orhto | 0.12 | 0.26 | 1.01 | --- | 0.02 | --- |
| Soluble | 0.16 | --- | --- | 0.16 | 0.04 | 0.59 |
| Organic | 0.10 | 0.82 | --- | 0.13 | 0.11 | --- |
| **Nitrogen** | | | | | | |
| Total | 2.00 | 13.6 | 2.17 | 3.31 | 0.78 | --- |
| Nitrate | 0.48 | 8.9 | 0.84 | 0.96 | 0.17 | --- |
| Ammonia | 0.26 | 1.1 | --- | --- | 0.07 | --- |
| Organic | 1.25 | --- | --- | --- | 0.54 | --- |
| TKN | 1.51 | 7.2 | 1.49 | 2.35 | 0.61 | 2.72 |
| **COD** | 35.6 | 163.0 | --- | 90.8 | > 40.0 | 124.0 |
| **BOD (5-day)** | 5.1 | --- | 36.0 | 11.9 | --- | --- |
| **Zinc** | 0.037 | 0.397 | 0.250 | 0.176 | --- | 0.380 |
| **Lead** | 0.018 | 0.386 | 0.370 | 0.180 | --- | 0.550 |
| **Copper** | --- | 0.105 | --- | 0.047 | --- | --- |

Source: Schueler (1987)

### Table 9-3. Concentrations For Use With the Simple Method (mg/l)

| Pollutant | Residential | Mixed | Commercial | Open/Non-urban |
|---|---|---|---|---|
| **BOD (5-day)** | 10.0 | 7.8 | 9.3 | --- |
| **COD** | 73 | 65 | 57 | 40 |
| **TSS** | 101 | 67 | 69 | 70 |
| **Total P** | 0.383 | 0.263 | 0.201 | 0.121 |
| **Soluble P** | 0.143 | 0.560 | 0.800 | 0.250 |
| **TKN** | 1.900 | 1.288 | 1.179 | 0.965 |
| **Nitrate** | 0.736 | 0.558 | 0.572 | 0.543 |
| **Copper** | 0.144 | 0.114 | 0.104 | 0.030 |
| **Lead** | 0.033 | 0.027 | 0.029 | --- |
| **Zinc** | 0.135 | 0.154 | 0.226 | 0.195 |

Source: NURP (U.S. Environmental Protection Agency, 1983)

**Table 9-4. Event Mean Concentrations in mg/l for Simple Method for Greenville, S.C. Area**

| Pollutant | Open / Ag | Residential | Office | Woods | Industrial | Commercial |
|---|---|---|---|---|---|---|
| TSS | 185 | 138 | 308 | 119 | 133 | 99 |
| TDS | 79 | 58 | 85 | 41 | 57 | 48 |
| Total-P | 0..22 | 0.41 | 0.24 | 0.15 | 0.11 | 0.19 |
| Dissolved-P | 0.04 | 0.10 | 0.06 | 0.01 | 0.02 | 0.08 |
| Total-N | 2.49 | 2.19 | 2.14 | 0.79 | 1.43 | 1.61 |

Source: Greenville County Annual Report for NPDES Phase I MS4 Permit Prepared by Woolpert Inc. (Woolpert 2007)

**Table 9-5. Estimated Pollutant Loading for Various Land Uses (mg/l)**

| | Estimated Pollutant Loading (mg/l) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Land Use | BOD | COD | TSS | TDS | TP | DP | TKN | NO2 / NO3 | Pb | Cu | Zn | Cd |
| Forest/ Rural Open | 3 | 27 | 51 | 415 | 0.11 | 0.03 | 0.94 | 0.80 | 0.000 | 0.000 | 0.000 | 0.000 |
| Urban | 3 | 27 | 51 | 415 | 0.11 | 0.03 | 0.94 | 0.80 | 0.014 | 0.000 | 0.040 | 0.001 |
| Agricultural/ Pasture | 3 | 53 | 145 | 415 | 0.37 | 0.09 | 1.92 | 4.06 | 0.000 | 0.000 | 0.000 | 0.000 |
| Low Density Residential | 38 | 124 | 70 | 144 | 0.52 | 0.27 | 3.32 | 1.83 | 0.057 | 0.026 | 0.161 | 0.004 |
| Medium Density Residential | 38 | 124 | 70 | 144 | 0.52 | 0.27 | 3.32 | 1.83 | 0.180 | 0.047 | 0.176 | 0.004 |
| High Density Residential | 14 | 79 | 97 | 189 | 0.24 | 0.08 | 1.17 | 2.12 | 0.041 | 0.033 | 0.218 | 0.003 |
| Commercial | 21 | 80 | 77 | 294 | 0.33 | 0.17 | 1.74 | 1.23 | 0.049 | 0.037 | 0.156 | 0.003 |
| Industrial | 24 | 85 | 149 | 202 | 0.32 | 0.11 | 2.08 | 1.89 | 0.072 | 0.058 | 0.671 | 0.005 |
| Highways | 24 | 103 | 141 | 294 | 0.43 | 0.22 | 1.82 | 0.83 | 0.049 | 0.037 | 0.156 | 0.003 |
| Water/ Wetlands | 4 | 6 | 6 | 12 | 0.08 | 0.04 | 0.79 | 0.59 | 0.011 | 0.007 | 0.003 | 0.001 |

Adapted from NURP (1983), Horner et. al (1994), and Cave at. Al. (1994)

**Table 9-6. Estimated Pollutant Loading for Various Land Uses (lbs/ac-yr)**

| | Estimated Pollutant Loading (lbs/ac-yr) | | | | | |
|---|---|---|---|---|---|---|
| **Land Use** | **TSS** | **Total Phosphorus** | **Total Nitrogen** | **Pb** | **Zn** | **Cu** |
| **Road** | 447 | 0.95 | 2.14 | 0.70 | 0.28 | 0.05 |
| **Commercial** | 717 | 0.71 | 4.63 | 2.79 | 2.94 | 1.90 |
| **Single-Family, Low Density** | 178 | 0.49 | 3.56 | 0.05 | 0.12 | 0.16 |
| **Single-Family, High-Density** | 287 | 0.58 | 4.57 | 0.09 | 0.20 | 0.27 |
| **Multi-Family Residential** | 395 | 0.62 | 5.01 | 0.62 | 0.30 | 0.30 |
| **Forest** | 77 | 0.10 | 1.75 | 0.02 | 0.02 | 0.02 |
| **Grass** | 301 | 0.12 | 3.71 | 0.06 | 0.09 | 0.03 |
| **Pasture** | 305 | 0.12 | 3.71 | 0.09 | 0.09 | 0.03 |

Source: Terrene Institute, 1994

| | | | | | |
|---|---|---|---|---|---|
| BOD | = | Biochemical Oxygen Demand | TKN | = | Total Kjeldahl Nitrogen |
| COD | = | Chemical Oxygen Demand | $NO_2/NO_3$ | = | Nitrates / Nitrites |
| TSS | = | Total Suspended Solids | Pb | = | Lead |
| TDS | = | Total Dissolved Solids | Cu | = | Copper |
| TP | = | Total Phosphorus | Zn | = | Zinc |
| DP | = | Dissolved Phosphorus | Cd | = | Cadmium |

## 9.2. Calculating Pollutant Loads Using the Simple Method

Schueler (1987) presented a constant concentration method of determining pollutant loads commonly known as the Simple Method. This method multiplies flows by a constant pollutant concentration based on land use. This method is based on an extensive database obtained in Washington, D.C. for the National Urban Runoff Program (NURP). The Simple Method estimates pollutant loads from urban development by the following equation:

$$L = 0.227(P \quad P_j \; R_v \; C \; A)$$

Where:

**L** = Pollutant load in pounds per desired time interval
**P** = Rainfall depth over the desired time interval in inches
$\mathbf{P_j}$ = Fraction of rainfall events over the time interval that produce runoff
$\mathbf{P_j}$ = 1 for a single event
$\mathbf{P_j}$ = 0.9 for larger time intervals (months, years)
$\mathbf{R_v}$ = Volumetric runoff coefficient expressing the fraction of rainfall converted to runoff
**C** = Event mean pollutant concentration in mg/l (taken from local field data or tables)
**A** = Total area of site in acres (areas < 640 acres are recommended)

The most important factor affecting the volumetric runoff coefficient ($\mathbf{R_v}$) is the imperviousness of the watershed, **I**, in percent. An empirical relationship was developed that relates $\mathbf{R_v}$ and I as:

$$R_v = 0.05 + 0.09(I)$$

Event mean pollutant concentrations, **C,** should be obtained from local data. For situations where they are not available, values of **C** can be approximated from Tables 9-2, 9-3, and 9-4.

# 9.3. Calculating Pollutant Loads Using the Greenville IDEAL Model

## 9.3.1 Background

The intent of legislation such as the South Carolina Storm Water Management and Sediment Reduction Act is that developments in South Carolina will not negatively impact water quality and downstream habitats. The potential for problems present challenges to engineers and developers to design and install best management practices that will not cause the state's waters to be impaired by pollutants such as nutrients, sediment, or bacteria. Simplified methods and the IDEAL (Integrated Design and Assessment for Environmental Loadings) Model for calculating pollutant removal efficiency of BMPs and treatment systems will assist designers and regulators in meeting state and federal requirements.

The IDEAL Model provides Greenville County specific design methods that give reasonable assurance that effluent meets desired performance without the lengthy design process typically associated with designs developed to meet a performance standard. The use of area specific design methods provides a means of achieving control without the steep learning curve associated with simulation techniques. For large-scale developments or in sensitive areas, it is still anticipated that site specific data and other procedures such as modeling be used for detailed evaluation of controls.

## 9.3.2 Approach

The IDEAL Model includes estimation of performance of detention/retention ponds, extended detention ponds, sand filters, and riparian buffers. The performance of each control is modeled using Greenville County specific conditions (including soils, topography, and climate) and compared with removal efficiency. For each structure, spreadsheet modeling was developed that is consistent with performance standards.

Effectiveness of control, or removal efficiency, is commonly determined by either a water quality design standard or a performance standard. A water quality performance standard dictates a maximum acceptable level (i.e., concentration) in the effluent. The control is designed such that this level is not exceeded. On the other hand, a water quality design standard establishes a standard specification based on a given drainage area or similar criterion. There are obvious benefits associated with each method. Performance standards offer site specific water quality control, but require considerable on-site collection of information for design purposes and are much more difficult to design and review. Structures designed for performance standards have a higher design cost than structures designed for water quality design standards. However construction costs tend to be considerably less, since design standards are inherently conservative. Design standards, on the other hand, are more easily employed and complied with but often entail risk that the structure is either grossly over designed, resulting in added installation costs, or grossly under designed so that the measure may not perform satisfactorily, particularly in sensitive areas. A preferable alternative to these methods is to provide a design procedure that can meet a desired performance without incurring excessive design costs. To achieve this, the design is typically expected to be slightly conservative, but considerably less conservative than if developed from a design standard.

The IDEAL Model is based on site visits at numerous construction locations throughout South Carolina in order to see innovative BMPs, as well as areas needing improvement. Cooperation with regulatory personnel included discussions as to what specific BMPs should/should not be considered for evaluation.

It is recognized that there are a large number of potential post construction BMPs that can potentially be used.

Evaluation of existing modeling capabilities led to the development of a new spreadsheet model known as IDEAL. The IDEAL Model, a model for hydrology, sedimentology, and water quality, contains much detail and ties water quality modeling together with physical, chemical, and biological relationships to provide a much more realistic description of reactions that are taking place in the real world.

It should be recognized that selection of an appropriate water quality model to allow evaluation of a wide range of pollutant control technologies in a seamless manner depends on the user's application. This process led to some modifications in the program to account for selected BMPs, treatment trains, topography, soil properties, and climate. Data bases of rainfall records for three Greenville County locations were analyzed to simplify user data requirements and simplify input for spreadsheets.

Since the method selected for accomplishing the simulation is critical, several items were considered.

- Combine hydrologic, and hydraulic routines with accepted pollutant removal routines.
- Impact on channels or ponds on adjacent wetlands.
- Consider each of the pollutants of interest (nutrients, sediment, and bacteria indicator).

Each of these tasks was accomplished, and the results analyzed to produce spreadsheets that can be used as an aid for designing BMPs based on pollutant removal. It should be recognized that aids such as these are developed for typical conditions. More detailed evaluation methods should be utilized if the situation is environmentally sensitive or hazardous. In all cases, good engineering judgment should be considered as an essential ingredient in design.

### 9.3.3 The IDEAL Model

The IDEAL Model assists in streamlining the storm water permitting application process for new development and provides consistent water quality protection from all storm water runoff, in addition to traditional storm water management and erosion control requirements. These design aids provide a reasoned and uniform approach to evaluating the effect on water quality of storm water runoff.

The IDEAL Model is not rules or regulations promulgated by the agency, but is guidance for evaluation and implementation of BMPs for storm water design. The IDEAL Model was developed by means of a comprehensive literature review and then use of best available science and valid scientific principles. State environmental agencies and the EPA have traditionally used guidance documents to provide preferred methodology to assist its staff with consistent application and to provide information and guidance to persons outside the agency to allow them to more effectively and efficiently implement program requirements. Because the IDEAL Model is not binding rules, alternative approaches, methodologies and solutions are allowed; however, it is incumbent on one proposing an alternative to adequately demonstrate both the effectiveness and equivalency of that alternative. IDEAL is available on the Greenville County website along with documentation.

## 9.4. Water Quality Regulations

Water quality control consists of post-development controls to help reduce the impacts of development on the water quality of the receiving downstream water bodies. The following minimum design criteria are established for water quality control unless a waiver is granted on a case-by-case basis.

**State Rules**

- Permanent water quality ponds and detention structures having a permanent pool elevation shall be designed to store and release the first ½-inch of runoff from the site over a minimum period of 24-hours. The water quality storage volume of these water quality structures shall be designed to accommodate at least ½-inch of runoff from the entire site.
- Permanent water quality structures **not** having a permanent pool elevation shall be designed to store and release the first 1-inch of runoff from the site over a minimum period of 24-hours.
- Permanent water quality infiltration practices shall be designed to accommodate at a minimum the first 1-inch of runoff from impervious areas located on the site.
- When existing wetlands are intended to be water quality structures, the Storm Water Management Permit shall not be implemented until all necessary Federal and State permits have been obtained.

**Greenville County Ordinance – Minimum Water Quality Requirements**

- All storm water runoff generated from a site shall be adequately treated before discharged. It will be presumed that a storm water management system complies with this requirement if:
    - Preferred method is to size water quality capture devices to trap 85% of total suspended solids (TSS) based on annual loading.

      (Note: The Greenville County IDEAL Model or another model such as the USEPA overflow model may be used to design BMPs to meet this criteria. The updated IDEAL Users Manual available on the Greenville County website describes how to use the model to design several BMPs to this standard)
    - An alternative as a default criteria, the devices may be sized to capture the first inch of runoff from the impervious area of the site and discharge it over a 24-hour period.
- Appropriate structural storm water controls or non-structural practices are selected, designed, constructed or preserved, and maintained according to the specific criteria in this manual;
- The Director has discretion to require more stringent controls for water quality where the Director determines the minimum standards are not adequate. Areas where more stringent controls may apply include outstanding resource waters, trout waters, wetlands, steep slopes, TMDLs, or other sensitive areas.
- All development and redevelopment projects and portions of redevelopment projects disturbing one acre or more that will result in more than one cubic foot per second increase in peak runoff rate shall meet the requirements of this section even though there is not a change in land use.

Water Quality control BMPs can be classified into two major classifications:

- Non-structural Controls, and
- Structural Controls

## 9.5. First Flush Water Quality Volume

The water quality volume is the storage needed within a water quality control BMP to control the "first flush" of runoff during a storm event. Studies have shown that the highest pollutant concentrations are found in the initial runoff period known as the "first flush." For Greenville County, this "first flush" volume has been designated to be:

- The preferred method is to size the water quality capture device to trap 85% of TSS based on annual loading (The Greenville County IDEAL Model or another model such as the USEPA overflow model may be used to design BMPs to meet this criteria. The updated IDEAL User's Manual available on the Greenville County website describes how to use the model to design several BMPs to this standard).

- As an alternative as a default criteria, the device may be designed to capture the first inch of runoff from the impervious area of the site and discharge it over a twenty-four (24) hour period.

# 9.6. Water Quality Pollutant Removal Mechanics

The removal of pollutants from urban runoff by BMP facilities such as storm water management ponds and filter strips can occur in a number of ways which include:

- Sedimentation
- Decay and biological uptake
- Filtration
- Adsorption
- Nitrification/Denitrification
- Plant uptake, and
- Microbial degradation

Pollutant removal in storm water management ponds and detention facilities occurs primarily through the sedimentation of suspended solids. Pollutant removal by decay or biological uptake may also occur under long detention times and favorable environmental conditions.

## 9.6.1 Sedimentation

### 9.6.1.1 Quiescent Settling

Quiescent settling is associated with sedimentation in an ideal sedimentation basin which consists of four zones:

- Inlet zone, in which the pollutant concentration of the influent water is dispersed uniformly over the vertical cross section of the tank and the influent water is transformed into uniform horizontal flow;

- Sedimentation zone, where particles settle out of suspension by gravity;

- Sludge zone, where settled particles are removed from the water column; and

- Outlet zone.

Several simplifying assumptions are implicit in the formulation of sedimentation efficiency of an ideal basin. These assumptions are that quiescent settling of discrete particles is the only mechanism governing sedimentation, the concentration of suspended solids of each particle size entering the sedimentation zone is uniform over the vertical cross section, and a particle that strikes the sludge zone is permanently removed (Fair and Geyer, 1954).

It is clear that these assumptions may be violated. For urban runoff control systems, it is very difficult, if not impossible, to achieve completely quiescent conditions within a storage reservoir, due primarily to the intermittent and random nature of rainfall which results in fluctuations in storage level and variable inflow /outflow rates. For surface detention facilities, wind action and temperature-induced density currents may further affect the quiescent removal of suspended particles. As a result of these limitations, only the permanent pools of storm water management ponds are considered to approximate quiescent conditions in the inter event period.

Properly designed storage facilities, such as ponds with long, circuitous flow paths, enhance the sedimentation of suspended solids from the water column; however, it is difficult to ensure a completely mixed and uniformly dispersed concentration of pollutants in the influent runoff. In this regard, deep forebays in storm water management ponds may be used to reduce the potential for preferential flow paths and dead zones which are induced primarily by the momentum of the influent runoff. In reality, particles that settle out of suspension during one runoff event may be resuspended by a subsequent runoff event, especially for storage facilities which are able to drain completely between runoff events, such as extended detention dry ponds. This resuspension violates the assumption that particles that strike the bottom (or sludge zone) are removed permanently. Again, properly designed facilities with proper inlet protection should minimize such effects.

### 9.6.1.2 Dynamic Settling

Storage facilities for urban runoff control, which drain within and between storm events, operate in an unsteady mode with varying inflow and outflow rates, and therefore their removal efficiencies cannot be modeled assuming quiescent settling conditions. Since there is fluid turbulence in such storage facilities, the removal of total suspended solids (TSS) is assumed to occur by dynamic settling.

The pond settling performance factor or turbulence factor, n, is meant to reflect the degree of turbulence and short-circuiting in the flow through the pond (or basin), which is, in turn, affected by the pond geometry (e.g., length-to-width ratio, area-to-depth ratio, inlet and outlet configuration).

## 9.6.2 Decay and Biological Uptake

Some dissolved pollutants and pathogenic bacteria in urban runoff may be removed from the water column by decay or die-off. Other dissolved pollutants may be removed through biological uptake (e.g., nutrients such as organic nitrogen and orthophosphate ion), by means of vegetation in storm water management ponds and wetlands. The removal efficiencies of these pollutants are often approximated using first-order kinetics.

Most urban BMPs rely heavily on gravitational settling as a primary pollutant removal pathway. There are upper limits to the amount of pollutant removal that can be achieved in this pathway. Most removal occurs in the first six to twelve hours.

## 9.6.3 Filtration

Many particulate pollutants are physically strained out as they pass through the filter bed of sand, soil, or organic matter, and are trapped on the surface or among the pores of the filter media. The effect of filtration can be very strong. For example, Pitt et al. (1995) report that as much as 90 percent of small particles commonly found in urban runoff (6 to 41 microns) are trapped by an 18-inch layer of sand, and presumably an even greater percentage of larger particles.

The filtration pathway is not effective in removing soluble pollutants and the smallest particles upon which pollutants are often attached. In addition, the importance of the filtration pathway is a function of the media used in the filter. In relatively tight media, such as soil or sand, filtration is very important, whereas, in more porous media such as compost or peat, the filtration effect is comparatively weak.

### 9.6.4 Adsorption

The ability of a filtering system to remove soluble nutrients, metals, and organic pollutants is often due to the adsorption pathway, in which ions and other molecules attach to binding sites on filter media particles. In general, the adsorption potential of a filtering system increases when the filtering media has a high content of organic matter or clay, a high cation exchange capacity (CEC), and a neutral to alkaline pH.

Each of the media used for filtering systems exhibit sharply different adsorption potentials. Pure sand, for example, initially has little or no organic matter, clay or cation exchange capacity, and therefore, little potential for adsorption. Over time, most sand filters develop a thin layer of organic matter and fine particles at the surface layer of the filter media as a result of sediment deposition, thereby increasing the adsorption potential. Organic filter media such as soil, peat and compost, on the other hand, have a much greater potential for adsorption, if the pH of the media is in the optimum range.

### 9.6.5 Nitrification / Denitrification

Nitrification is an important nitrogen removal pathway as organic matter is gradually decomposed. Microbes break down organic nitrogen into ammonia, which is then transformed into soluble nitrate-nitrogen. The nitrification process generally requires an aerobic (oxygen-rich) environment which is characteristic of many filtering systems. As a result, nitrification occurs rapidly in many filtering systems, resulting in the export of low concentrations of ammonia.

Denitrification is the final step in the nitrogen cycle. It is the conversion of soluble nitrate into nitrogen gas that is returned to the atmosphere. To proceed, the denitrification process requires a moist, anaerobic environment, an abundant supply of both organic carbon and nitrate, and the presence of denitrifying bacteria. These conditions are not always met in most filtering systems. Consequently, most filtering systems actually export more soluble nitrate than they receive. In recent years, designers have attempted to create suitable conditions for denitrification within filtering systems, and have demonstrated a capability to remove nitrate.

### 9.6.6 Plant Uptake

Several filtering systems incorporate plants, such as algae, emergent wetlands or grass to improve removal rates. Examples included vegetated open channels (grass), sand or organic filters (that have a grass cover crop), bioretention, filter strips, and gravel wetland filters (algae, wetland plants). Plants can increase pollutant removal in several ways. During periods of stormflow, for example, grass and emergent wetland plants provide resistance to flow, thereby reducing runoff velocities. Slower runoff velocities translate into more time for other pollutant pathways to work (such as settling, filtering, infiltration and adsorption). In addition, the roots of grass and emergent plants help bind up the filter media, preventing loss of sediments and attached pollutants via erosion.

The growing plants also create a continual supply of thatch, or detritus, which provide the organic matter needed for greater adsorption. During periods of growth, the plants also take up nutrients and metals from the filter bed and incorporate it into their biomass. If plant biomass is harvested or mowed, pollutants are removed. Taken together, however, the use of plants in a filtering system is usually of secondary importance as a pollutant removal pathway in comparison to the other five pathways.

# 9.7. Non-Structural Water Quality Controls

## 9.7.1 Open Vegetated Conveyance Systems

Open vegetated conveyances can be designed and installed as an alternative to curb and gutter and hard piping storm water conveyance systems. Open vegetated conveyances improve water quality by providing partial pollutant removal as water is filtered by the vegetation and by the opportunity to infiltrate into the soil. Open vegetated conveyances also can be designed to reduce flow velocities when compared to hard piping systems.

Open vegetated conveyance systems can be incorporated into moderate to low density development sites where land is available and where the land surface is gently sloping (less than 5 percent). The soil must be able to withstand the design tractive forces and flow velocities of the open conveyance, or an applicable Turf Reinforcement Mat or Erosion Control Blanket shall be designed to protect the open conveyance. A dense cover of strong rooted vegetation, such as tall fescue, shall be called for on the plans.

For maximum water quality benefits, vegetated open conveyance shall be designed to promote shallow low velocity flow.

## 9.7.2 Water Quality Stream Buffers

A water quality stream buffer is an area along a shoreline, wetland or stream where development is restricted or prohibited. The primary function of the buffer is to physically protect and separate a stream, lake, or wetland from future disturbance or encroachment.

## 9.7.3 Disconnected Rooftop Drainage to Pervious Areas

Disconnected rooftop drainage can reduce the runoff flow rates from developed areas. The disconnection involves directing storm water runoff from rooftops towards pervious areas where it is allowed to filter through vegetation and other landscaped material and infiltrate into the soil. This practice is applicable and most beneficial in low-density residential or commercial developments having less than 50 percent impervious area. Disconnection is not applicable to large buildings where the volume of runoff from the rooftops will cause erosion or degradation to receiving vegetated areas.

The disconnection of rooftop drainage has the following benefits:

- Increase the time of concentration by disconnecting runoff from any structural storm water drainage systems.

- Provide water quality benefits by allowing runoff to infiltrate into the soil. Downspouts from rooftops should discharge to gently sloping, well-vegetated areas, vegetated filter strips, or bio-retention areas. Erosion control devices such as splash blocks or level spreaders may be required at the downspout discharge point to transfer the flow from concentrated flow to sheet flow.

## 9.7.4 Cluster Development to Conserve Natural Areas

Cluster development practices concentrate development away from environmentally sensitive areas such as streams, wetlands, and mature wooded areas. The clustering of development in one area reduces the amount of roadways, sidewalks, and drives required when compared to development sprawled over the entire land area.

Clustering and conservation of natural area practices shall be installed at least to some extent on all development sites not only to reduce the impacts to natural resources by minimizing disturbance and impervious areas, but also to maintain some of the natural beauty of the site.

Reducing the amount of disturbed area and impervious area reduces the amount of runoff volume treated for water quantity and water quality control. Concentrating development away from environmentally sensitive areas will also reduce the amount of time and expenses to get federal and state permits for impacting jurisdictional waters.

Development should be concentrated on the flattest part of the development parcel away from environmentally sensitive areas such as steep slopes, streams, and wetlands. This will not only reduce the impacts to these areas, but may reduce the amount of earth moving necessary for the development.

## 9.7.5 Grass Paving or Alternative Paving Surfaces

Grass paving technology allows for the reduction of paved areas by implementing grass paving in areas that are infrequently used such as fire lanes and overflow parking where applicable. A variety of grass paving materials are available on the market. Grass paving units are designed to carry vehicular loading and may be composed of different types of materials. The pavers are typically covered with sod to make the areas indistinguishable from other grassed areas. Grass pavers allow water quality benefits by allowing storm water to infiltrate into the underlying soils and by the filtering of storm water as it flows through the grass.

Grass pavers provide a more aesthetically pleasing site and reduce the impact of complete asphalt surfaces. Grass pavers should not be used for frequently traveled or parked in areas.

Grass pavers can reduce the runoff volume and extend the time of concentration for a particular site. Some pavers may provide enough infiltration to be considered a pervious area.

## 9.7.6 Natural Infiltration

Natural infiltration is a method in which an undisturbed land area covered with natural vegetation accepts runoff from new development and infiltrates the runoff into the soil. Natural infiltration areas should only be used where the soils are suitable. The area should be in a forested condition with the land surface covered by leaves, pine needles, and other forest floor organic materials and should only be designated for passive recreation such as biking.

A natural infiltration area may be used as a storm water quality control if it meets the design criteria of this section.

The size of a natural infiltration area can be calculated using the following equation:

$$A = \frac{(K\ T\ I)}{[(cd) - K]}$$

Where:

| | | |
|---|---|---|
| **A** | = | Natural infiltration area required (acres) |
| **K** | = | Runoff volume to infiltrate (inches) |
| **T** | = | Total site area or total drainage area (acres) |
| **I** | = | Built upon area ratio (Built upon area / T) |
| **c** | = | Effective water capacity (in/in), shall be determined from site-specific soil samples. |
| **d** | = | Depth of soil A horizon (inches), shall be determined from site-specific soil samples. |

The runoff from the areas to be treated by natural infiltration shall enter the infiltration area as sheet flow with a non-erosive velocity. The areas draining to the Natural Infiltration area shall be stabilized and vegetated a minimum of 20-feet in length.

The natural infiltration area shall have the following characteristics:

- Appropriate soils that have a minimum infiltration rate of 0.3-inches per hour, low erosion potential, and good drainage (not in a wetland or floodplain).
- Mature forest cover (if the natural infiltration area (A) is not located in a mature forest, then the area shall be double of that calculated by the equation above).
- Slopes less than 10 percent.
- The natural infiltration area shall remain permanently undisturbed.

The limitations of natural infiltration areas include:

- Not suitable for soils that have greater than 30 percent clay content or greater than 40 percent clay and silt content.
- Not suitable in areas with high water tables or shallow depth to highly impervious strata such as bedrock or clay layers.
- High sediment loadings or lack of maintenance clogs the surface layer therefore inhibiting any water infiltration into the soil.

## 9.8. Structural Controls

Structural water quality control structures are recommended for use with a wide variety of land uses and development types. These controls have demonstrated the ability to effectively treat runoff volume to reduce the amounts of pollutants discharged to the downstream system. Structural storm water quality controls are classified into the following categories:

- General Application Controls
  - WQ-01 Dry Storm Water Detention Ponds
  - WQ-02 Wet Storm Water Detention Ponds
  - WQ-03 Storm Water Wetlands

- WQ-04 Gravel Wetlands
- WQ-05 Bioretention Areas
- WQ-06 Sand Filtration Facilities
- WQ-07 Infiltration Trenches
- WQ-08 Enhanced Dry Swales
- WQ-09 Infiltration Basins
- WQ-10 Stormwater Manufactured Treatment Devices (MTDs)

- Limited Application Controls
  - WQ-11 Permanent Water Quality Stream Buffers
  - WQ-12 Vegetated Filter Strips
  - WQ-13 Level Spreaders

Greenville County technical specifications and details for these Post Construction Water Quality BMPs are located Appendix G.

### 9.8.1 General Application Controls

General application structural controls are recommended for use in a wide variety of application situations. These structural controls have demonstrated the ability to effectively treat water quality volumes and are presumed to be capable of removing 80 percent of the total suspended solids (TSS) load typically found in urban post development runoff. The general storm water controls can be classified into several categories as shown in Table 9-7.

**Table 9-7. Structural Controls**

| General Structural Control | Description |
|---|---|
| **Dry Ponds** | A dry detention basin does not maintain a permanent pool and is intended to manage both the quantity and quality of stormwater runoff before discharging off-site. |
| **Wet Ponds** | Wet storm water ponds are constructed storm water basins that have a permanent pool or micropool of water. Runoff from each rain event is detained and treated in the pool, and released at a designed rate. |
| **Storm Water Wetlands** | Storm water wetlands are constructed wetland systems used for storm water management. Storm water wetlands consist of a combination of shallow marsh areas, open water and semi-wet areas above the permanent water surface. |
| **Gravel Wetland Systems** | Gravel wetlands use wetland plants in a submerged gravel or crushed rock media to remove storm water runoff pollutants. Use these in mid- to high- density environments where other structural controls will be utilized. |
| **Bioretention Areas** | Bioretention Areas are shallow storm water basins or landscaped area that utilize engineered soils and vegetation to capture and treat storm water runoff. Runoff may be returned to the conveyance system or partially exfiltrate into the soil. |

| General Structural Control | Description |
|---|---|
| **Sand Filters** | Sand filters are multi-chamber structures designed to treat storm water runoff through filtration, using a sand bed as its primary filter media. Filtered runoff may be returned to the conveyance system or partially exfiltrate into the soil. |
| **Infiltration Trench** | An infiltration trench is an excavated trench filled with stone aggregate used to capture and allow infiltration of storm water runoff into the surrounding soils from the bottom and sides of the trench. |
| **Infiltration Basin** | Infiltration Basins are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. The size and shape can vary and designs can use one large basin, or multiple smaller basins throughout a site. |
| **Enhanced Grassed Swales** | Enhanced swales are vegetated open channels that are explicitly designed and constructed to capture and treat storm water runoff within dry or wet cells formed by check dams or other structures. |
| **Stormwater Manufactured Treatment Devices (MTDs)** | MTDs use the movement of storm water runoff through a specially designed structure to remove target pollutants. They are typically used on smaller commercial sites and urban hotspots. There are numerous commercial vendors of these structures, but there is limited data on the performance of these structures. These structures may require monitoring to verify specific pollutant removal efficiencies. |

### 9.8.1.1 Comparative Pollutant Removal Capability

Several generalizations can be made about the overall performance of storm water filtering systems. In general, they exhibit a high capability to remove suspended sediments and a moderate ability to remove total phosphorus and nitrogen (although low or negative with respect to soluble nutrient forms). The storm water pollutant whose performance cannot easily be generalized is fecal coliform with some designs showing a high capability to remove bacteria, and others showing none.

Tables 9-9 and 9-10 provide a general comparison of expected pollutant removal rates based on monitoring data, theory and best professional judgement. As can be seen, most filtering designs have a high capability to remove sediment. Phosphorus removal rates range more widely with the highest rates reported for gravel fitters, dry swales and perimeter sand filters, and the lower rates for grass channels, wet swales and filter strips. Nitrogen removal typically ranges from 30 to 50 percent. Most filtering systems, however, have a zero or negative removal rate for soluble nitrate (with the exception of dry swales, wet swales and gravel fitters). Most filtering systems have a high capability to remove bacteria with the exception of open channel options such as drainage channels and grass channels.
Table 9-10 presents a very generalized comparison of the comparative pollutant removal capability four groups of BMPs (actual removal rates for a particular design within a BMP group, however, may be higher or lower than those shown in the Table, and are presented only for rough technology comparison).

When the four groups of BMP systems are compared, it is evident that there is not a great deal of difference in their capability to remove sediment or total phosphorus. Greater differences in pollutant removal are noted for nitrogen (especially nitrate). There are not enough data available to assess if there are any differences in bacteria removal among the four groups of BMPs. It should also be noted that the removal rates indicated for infiltration BMPs are projections only since very few of these systems have actually been monitored. In summary, it appears that the removal capability of most BMP systems is similar for most pollutants of concern when they are designed and maintained properly and incoming pollutant levels are higher than the irreducible concentration.

**Table 9-8. Estimated Pollutant Removal Capability of General Storm Water Filter Systems**

| | Estimated Pollutant Removal Efficiency % | | | | | |
|---|---|---|---|---|---|---|
| **BMP** | **Monitoring** | **TSS** | **TP** | **TN** | **Nitrate Nitrogen** | **Other** |
| **Surface Sand Filters** | Yes | 85 | 55 | 35 | Neg | Bacteria 40-80<br>Metals 35-90 |
| **Dry Enhanced Swales** | Yes | 90 | 65 | 50 | 80 | Metals 80-90 |
| **Wet Enhanced Swales** | Yes | 80 | 20 | 40 | 50 | Metals 40-70 |
| **Vegetated Drainage Channel** | Yes | 65 | 25 | 15 | Neg | Hydrocarbons 65<br>Metal 20-50<br>Bacteria Neg |
| **Vegetated Filter Strip** | Yes | 70 | 10 | 30 | 0 | Metals 40-50 |

**Table 9-9. General Application Pollutant Removal Efficiencies**

| | Estimated Pollutant Removal Efficiency % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **BMP** | **TSS** | **TP** | **TN** | **Nitrate Nitrogen** | **Metals** | **Bacteria** | **Cu** | **Pb** | **Zn** |
| **Dry Ponds** | 61 | 19 | 31 | 9 | 26-54 | --- | --- | --- | --- |
| **Wet Ponds** | 67 | 51 | 33 | 43 | 24-73 | 70 | 57 | 73 | 66 |
| **Shallow Marsh Wetlands** | 51-83 | 40-43 | 26-49 | 49-73 | 36-85 | 76 | --- | --- | --- |
| **Extended Detention Wetland** | 69 | 39 | 56 | 36 | 0-63 | --- | --- | --- | --- |
| **Pond / Wetland System** | 35-71 | 35-56 | 19-29 | 40-68 | 0-57 | --- | --- | --- | --- |

| | Estimated Pollutant Removal Efficiency % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **BMP** | **TSS** | **TP** | **TN** | **Nitrate Nitrogen** | **Metals** | **Bacteria** | **Cu** | **Pb** | **Zn** |
| **Gravel Wetland** | 83 | 64 | 19 | 81 | 21-83 | 78 | --- | --- | --- |
| **Bioretention Areas** | --- | 65-87 | 49 | 15-16 | --- | --- | 43-97 | 70-95 | 64-95 |
| **Sand Filters** | 87 | 51 | 44 | -13 | 34-80 | 55 | --- | --- | --- |
| **Infiltration Basins** | 75 | 60-70 | 55-60 | --- | 85-90 | 90 | --- | --- | --- |
| **Infiltration Trenches** | 80 | 65-75 | 60-70 | 82 | 85-95 | 98 | 95 | 95 | 95 |
| **Enhanced Swales** | 81 | 28-83 | 40-92 | 31-90 | 14-55 | --- | 11-70 | 67 | 33-86 |

Source: US EPA Post-Construction Storm Water Management BMP Manual, 2001.
Georgia Storm Water Manual, Volume 2: Policy Guidebook, First Edition, Atlanta Regional Commission, March 2001.

The removal rates shown are for comparison only. Actual removal rates can very widely based on the extent of the design

**Table 9-10. Pollutant Removal Capability of Four Types of BMP Systems**

| | Pollutant Removal Efficiency % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **BMP** | **TSS** | **Organic Carbon** | **TN** | **Nitrate Nitrogen** | **TP** | **Cu** | **Pb** | **Zn** | **Hydrocarbons** |
| **Pond System** | 80 | 65 | 35 | 60 | 65 | 50 | 85 | 65 | 80 |
| **Wetland System** | 75 | 15 | 25 | 60 | 50 | 30 | 75 | 50 | 80 |
| **Infiltration System** | 90 | 90 | 50 | 50 | 60 | 60 | 90 | 90 | --- |
| **Filtering System** | 85 | 50 | 35 | Neg | 60 | 45 | 85 | 75 | 85 |

Source: Current Assessment of Urban BMPs, Design of Storm Water Wetlands

**Table 9-11. Pollutant Removal Capability of Storm Water Quality BMPs**

| | Estimated Pollutant Removal Efficiency % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **BMP** | **TSS** | **TP** | **TN** | **Bacteria** | **Cu** | **Pb** | **Zn** | **COD** |
| **Infiltration System** | 75 | 50 | 40 | --- | 25 | 50 | 65 | 65 |
| **Dry Ponds** | 20-60 | 10-30 | 10-20 | 20-40 | 10-40 | 20-60 | 10-50 | 10-50 |
| **Extended Dry Pond** | 30-80 | 15-40 | 10-40 | 20-60 | 10-50 | 20-70 | 10-60 | 10-60 |
| **Wet Ponds** | 50-90 | 30-80 | 30-60 | 20-80 | 20-80 | 30-90 | 30-90 | 30-90 |
| **Bioretention Areas** | 50-85 | 20-40 | 0-40 | 10-60 | 30-60 | 40-80 | 30-80 | 30-80 |
| **Constructed Wetlands** | 60-90 | 30-85 | 30-80 | 20-80 | 20-80 | 50-90 | 30-90 | 30-90 |
| **Sand Filters** | 60-85 | 30-75 | 30-60 | 40-80 | 30-60 | 50-80 | 30-80 | 30-80 |

Source: Operation, Maintenance and Management of Storm Water Management, US EPA 1997

## 9.8.2 Limited Application Controls

Limited application structural controls are those that are recommended only for limited use for special site or design conditions. Generally, these practices cannot alone achieve 80 percent TSS removal goal and are intended for hotspots for specific land use constraints or conditions. Limited application controls may be used within a system of water quality controls and are very effective pre
treatment structures for the General Application Controls listed in Section 9.8.1. Limited application structural controls should be designed and used only in development situations where regular maintenance is guaranteed. The limited storm water controls can be classified into several categories as shown in Table 9-12.

**Table 9-12. Limited Structural Control**

| Limited Structural Control | Description |
|---|---|
| **Water Quality Stream Buffers** | A stream buffer is an area along a shoreline, wetland or stream where development is restricted or prohibited with the primary function to physically protect and separate a stream, lake, or wetland from future disturbance or encroachment. |

| Limited Structural Control | Description |
|---|---|
| **Vegetated Filter Strips** | Vegetated filter strips provide filtering of storm water runoff as it flows across the vegetation. However, by themselves these controls do not consistently obtain an 80% TSS removal. Vegetated filter strips are best used as pretreatment measures or part of a treatment system approach. |
| **Grassed Channels and Swales** | Grassed swales provide filtering of storm water runoff as it flows across vegetation. However, by themselves these controls do not consistently obtain an 80% TSS removal. Grassed swales are best used as pretreatment measures or part of a treatment system approach. |
| **Porous Paver Systems** | Porous paver systems consist of open void paver units laid on gravel subgrade to promote storm water infiltration. Porous pavers provide water quality and quantity benefits, but has high maintenance requirements. |

### 9.8.2.1 Innovative Technologies

Innovative technologies are encouraged and shall be accepted providing there is sufficient documentation as to the effectiveness and reliability of the proposed structure. To justify the efficiency of innovated water quality control structures, the owner may be required to monitor the pollutant removal efficiency of the structure. If satisfactory results are obtained, the innovative water quality structure may be used and no other monitoring studies shall be required. If the control is not sufficient, other onsite and/or downstream controls shall be designed to trap the required pollutants.

## 9.9. Anti-degradation Rules for Impaired Waters

This section of the Design Manual provides information to ensure that Anti-degradation Rules are implemented for activities that contribute nonpoint source pollution to adjacent waterbodies. The Anti-degradation Rules are specifically formulated to ensure that no new activities will further degrade waterbodies that are not presently meeting water quality standards. The involvement in the Anti-degradation Rules shall occur though the Greenville County Storm Water Permitting, Section 401 Water quality Certificate, Critical Area Planning, and State Navigable Water Permitting. Greenville County shall implement the Anti-degradation Rules when issuing NPDES permits for point source and nonpoint source loadings into impaired waters. The activities of primary concern are land development projects that are immediately adjacent to and discharge runoff of storm water into impaired waters. These projects may also be required to obtain a Special Pollution Abatement Permit as discussed below in Section 9.10.

### 9.9.1 Impaired Waterbodies

Every two years SCDHEC is required by Section 303(d) of the Clean Water Act to identify waterbodies that are not meeting water quality standards despite the implementation of technology based controls. The listing of the impaired waters lists each waterbody by name monitoring station number hydrologic unit and basin. The impairment and cause shall also be identified for each waterbody.

## 9.9.2 Applicability

Large scale development projects with more than 25 acres of disturbed land which have storm water discharges directly into an impaired body via structures or ditches must have assurance that storm water runoff will not cause or contribute to degradation to the receiving waterbody. Also, there may be certain projects that are less than 25 acres adjacent to ecologically important or sensitive areas that shall require assurance that storm water runoff will not cause or contribute to degradation to the receiving waterbody. The concern of water quality pertains to runoff during construction and runoff after the project is finished and stabilized.

## 9.9.3 Water Quality Impairment

Design professionals shall determine whether runoff from the proposed land disturbance contains pollutants that are already causing impairment of the adjacent waterbody. These pollutant discharges will vary from site to site. If storm water runoff from the proposed land development will contribute pollutants that already cause water quality impairment, the design professional must provide assurance that measures and controls will be implemented to prevent further problems to the impairment.

The techniques and controls discussed in Chapter 9 shall be utilized to provide the removal of any harmful pollutants. There is not a specific methodology that must be followed in determining the BMPs selected and utilized to follow the Anti-degradation Rules. However, the calculations and descriptions must show that the water quality BMPs to be installed will ensure that runoff from the site will not cause or contribute to further degradation of the impaired waterbody.

In an effort to aid the design community as well as to provide the County quantifiable assurances for meeting MS4 permit goals, the County has developed and made available the IDEAL computer program. With the IDEAL model, designers can calculate the annual loading for the pollutant of concern for the pre-developed condition as a baseline and the developed condition (with no increase) for impaired waters discharge compliance.

For pollutants causing impairment for which a numeric water quality standard has been adopted (fecal coliform, pH, metals), calculations shall be performed and submitted showing that the pollutants in the runoff from the development site will not exceed the applicable in-stream water quality standards. The runoff discharged through the last water quality BMP shall have a water quality level equal to or better than the in-stream standard. The design professional shall provide insurance in a different manner when the water quality impairment is not a pollutant itself, but is affected by a pollutant that can be regulated such as dissolved oxygen levels are affected by biochemical demand. In these situations, a reasonable approach to show that runoff will not further degrade the adjacent impaired waterbody is to show that the post-development loading of a particular pollutant is less than or equal to pre-development loading. This insures that there will be no net increase of loading of that particular pollutant and no further lowering of the water quality standard.

In most cases, the effectiveness of the designed water quality BMPs will not require water quality sampling. However, for certain situations, it may be required for the applicant or landowner to collect monitoring data to confirm the effectiveness of the BMPs.

## 9.9.4 Total Maximum Daily Loads (TMDLs)

A TMDL is the total amount of pollutant a waterbody can receive from all sources and still meet the required water quality standard. For some waterbodies DHEC and Greenville County will develop a TMDL that includes recommended limits or loads for both point sources and nonpoint sources. For other waterbodies the identified load may be only for nonpoint sources or for point sources only.

A standard policy has been developed in anticipation of TMDLs that apply to the Greenville County MS4. The Waste Load Allocation (WLA) percent reduction from the first impaired station downstream of a proposed project will be applied to the land disturbance Permit requirements. The applicant will have to demonstrate (with IDEAL) that the annual pollutant of concern loading for the site in a developed condition will be reduced by the respective amount as compared to the pre-developed condition.

## 9.10 Special Pollution Abatement Permit

A Special Pollution Abatement Permit is required when development or re-development occurs within a watershed that drains to a waterbody listed as impaired by SCDHEC or has an established TMDL developed and implemented for a pollutant(s) of concern to ensure that effective BMPs are used to control water quality for these waterbodies. A Special Pollution Abatement Permit will be valid for a period of five (5) years, at which point it must be renewed. At the time of renewal, any deficiencies in the control of the targeted pollutants or management method must be corrected. Any development that occurs without a required permit shall be a violation of Division 9 of the Greenville County Storm Water Management Ordinance.

Development in other areas known to have particular adverse water quality pollutant impacts may be required to comply with this requirement at the discretion of the Director. Areas that qualify have been identified by sampling and monitoring results and are given as priority areas for water quality treatment. Outstanding resource waters may also qualify for compliance with this requirement for protection of their classification.

All special pollution abatement permit requests shall include as a minimum the following information:

- Name of the development.
- Physical location of the development.
- Name of impaired waterbody that receives storm water discharge from the development.
- Pollutant(s) of concern that is responsible for the designated impairment.
- Supporting information for the permit request, including:
  - Name of contact person for permit compliance.
  - Site map (minimum scale of 1"=50') of development with buildings, parking, drives, other impervious surfaces, ditches, pipes, catch basins, drainage basin limits, acreage of offsite water draining onto the development, discharge points to "Waters of the United States" or "Waters of the State," and locations of storm water treatment facilities and BMPs.
- Storm water treatment facilities and BMPs including manufacturer, model, flow rates of runoff draining to each facility or BMP for the 1-year and 10-year 24-hour storms, and the verified

treatment and bypass flows for each facility and BMP.

- Inspection and maintenance program and schedule for each facility or BMP.

- Certification by the engineer of record that the storm water treatment facility or BMP will address the pollutants listed in the TMDL or on the impairment for the waterbody on the 303(d) and meets the requirements in the TMDL for the subject waterbody.

- Certification by the person responsible for the land disturbing activity that the facility or BMP will be maintained and inspected according to the inspection and maintenance program detailed in the permit request. Certified quarterly reports shall be submitted to the Director by the operator of the facility or as the Director requires as given in the permit conditions. Sampling and monitoring may be required to verify the performance of the facility and compliance with the requirements in the Special Pollution Abatement Permit.

# Chapter 10. LOW IMPACT DEVELOPMENT

A number of "green" building initiatives have been developed to mitigate the effects of urban development on the health of people and the environment. Whether it is installing a green roof atop a city school, reducing a building's energy consumption by using natural lighting or driving on porous pavement in a neighborhood, these practices all represent green initiatives. Green initiatives use holistic planning to reduce the "footprint" of a site's impervious areas (buildings, parking lots, etc.).

Whether you are talking about the Smart Growth initiative, which encourages mixed land use to promote urban renewal and conservation, Leadership in Energy and Environmental Design (LEED) promoting energy efficiency and sustainability or Low-Impact Development (LID) which uses better site design techniques to maintain the natural hydrology of a site from its pre- to post-developed state, these initiatives all promote environmental sustainability and conservation. Designing sites to use less energy, be sustainable, and have a low-impact on the surrounding environment can have positive impacts on the health of both the public and the environment. These initiatives create healthier work and living environments, increase the health of our rivers lakes and streams, conserve natural resources, help reduce $CO_2$ emissions and help create a sustainable community. This chapter describes the design methodology of LID related to storm water management.

## 10.1 Low Impact Development (LID) Concepts

A site incorporating LID design generally produces a much smaller peak rate and volume of runoff than traditional storm water management methods. In a traditional design, the increased rate and volume of runoff is concentrated into pipes conveyed and detained in a single large structure at the "end-of-pipe". In an LID approach, storm water runoff is managed near the source ("source-controlled") in a number of small, landscape features. These features encourage infiltration and lengthen time of concentration as well as retaining flow to create a hydrologic landscape functionally equivalent to the pre-development conditions. These source treatment structures should ideally connect to natural drainage ways. The goal of LID is to combine this hydrologically functional site design with pollution prevention integrated management practices (IMPs) to reduce the impacts of development on the quality and quantity of runoff. The term IMP is used in place of BMP or best management practices as IMPS are integrated throughout the development providing source treatment as well as landscape amenities. Some examples of LID site planning considerations are listed below:

To assess the hydrologic functionality of a site, designers use the curve number (CN), time of concentration (Tc), and other factors. By maintaining the pre-development values of these metrics; a developed site will behave similarly to its pre-developed state; meeting storm water management requirements; as well as, preserving natural habitats and features, reducing thermal, flow and pollutant shocks to downstream environments, and utilizing runoff to supply groundwater recharge and landscaped areas. Figure 10-1 illustrates a layout of a single family residential lot using LID.

- Maintain natural drainage patterns
- Direct runoff to depressed areas for infiltration
- Preserve existing trees
- Reduce impervious areas
- Locate IMPs in soils with the highest permeability
- Disconnect impervious area from one another
- Limit clearing and grading as much as possible
- Locate impervious areas on less permeable soils

- Maintain the existing natural terrain and avoid construction of or in steep slope areas (>15%)
- Use "site fingerprinting" techniques to preserve tree canopy and natural vegetative buffers
- Re-vegetate cleared and graded areas
- Avoid concentrating flow into pipes or channels

## 10.1.1. Curve Number

The CN is used to determine the volume of runoff from a site. Developed LID sites try to maintain the same volume of runoff as their pre-developed condition, in essence maintaining the same curve number.

Changes in land cover can increase the amount of runoff from a site by reducing infiltration. Therefore, reduction of land cover changes is the first step in limiting changes to the CN. There are a number of ways to reduce changes in land cover, including:

- Reduce the size of cleared area (i.e. preserve as much woodland as possible) and increase reforestation areas
- Locate cleared/graded areas outside permeable soils and vegetated areas
- Design roads, sidewalks, and parking areas to minimize land cover impacts
- Reduce or disconnect site imperviousness

### 10.1.1.1 Reduce Limits of Clearing and Grading

The limits of clearing and grading refer to the area of the site to which development is directed. This development area will include all impervious areas such as roads, sidewalks, rooftops, graded lawn areas and open drainage IMPs. To reduce the change in land cover and minimize hydrologic impact to the existing site, the development area should be located where impact on the predevelopment CN is less sensitive (e.g., on barren C and D type soils which will have less impact than developing forested A and B type soils). At a minimum, placing the development area outside of stream and lake buffer areas or increasing these buffer areas will lead to a reduction in land cover changes.

### 10.1.1.2 Site Fingerprinting

Site fingerprinting refers to a number of minimal disturbance techniques which can be used to further reduce the limits of clearing and grading. Site fingerprinting identifies the smallest possible site area that must be disturbed and clearly delineates this on the site. Techniques that can be used to minimize disturbance and preserve pre-development land cover (i.e. CN) include the following:

- Minimizing the size of construction easements, materials storage areas, and sighting stockpiles within the development envelope to the minimum needed to build the structures and move equipment. Significant compaction can be caused by construction traffic and is the leading cause of death or decline of mature trees in developed areas (Hinman, 2005).
- Careful sighting of lots and home layout, clearing and grading to avoid steep slopes, avoiding the removal of existing trees and excessive grading.
- If steep slopes cannot be avoided, use of mitigation practices such as rainwater harvesting or dry wells should be implemented to attenuate the flow.
- Roof rainwater harvesting is essential to LID in high density projects located on soils with low infiltration capacity.

- Minimize imperviousness by reducing paved surfaces on private areas. Examples are shared driveways, permeable pavements, or a driveway with just wheel strips.
- Design homes on crawl spaces or basements that conform to natural grades without creating a flattened pad for slab construction; thus saving clearing and grading costs.
- Flag the smallest site disturbance area possible to minimize soil compaction on site. Install construction fencing and tree protection areas where necessary to protect root structures along the limits of encroachment during the construction phase.
- Re-vegetate cleared and graded areas to provide an effective way to decrease post-development CN. When minimal disturbance techniques are impossible or impractical, re-vegetation can be used to connect bioretention facilities to natural drainage ways, increase soil permeability, and mitigate land cover changes caused by development.

#### 10.1.1.3 Preserve Permeable Soils and Vegetated Areas

Addition of impervious surfaces and compaction due to construction traffic over soils creates the greatest possible change in infiltration (e.g. CN) between pre- and post-development conditions. Therefore the preservation of existing soils should be promoted in all unpaved areas throughout the site. Areas with well drained soils are generally good sites for bioretention areas and help sustain groundwater recharge and stream base flows.

Preservation of woodland areas can help reduce impacts on existing land cover. Woodland areas promote infiltration, distribute flow, reduce velocities, provide wildlife habitat, and help maintain stream bank and bed stability. Saving existing trees on a development site is a cost-effective and quality-enhancing practice. Expansion of vegetated areas adds to the benefits of preservation by further reducing CN changes. Trees and other native species should be kept in groups large enough to maintain soil moisture, sunlight, wind and other growth characteristics. Retaining mature trees of a single species is seldom successful (Hinman, 2005). For best results flag tree preservation area at least 3-ft outside of the existing edge of canopy.

#### 10.1.1.4 Alternative Roadway Designs

Roadways, sidewalks, driveways, and parking areas are the greatest contributors to increasing CN and the size of the required detention/ retention structure. The increase in CN due to impervious areas and the associated land clearing increase both the amount and rate of runoff over pre-development conditions. LID designs minimize the effective imperviousness of roadways and parking areas by using minimal grading and clearing techniques, minimizing impervious areas, and using open drainage sections. The following features can be incorporated into a roadway design to minimize land cover impacts:

<u>Narrow road sections</u>: Small sections reduce impervious area and clearing and grading impacts. Reducing pavement widths from 26' to 20' reduces pavement area by 30%. A 40' cul-de-sac with an interior bioretention area of 20' in diameter decreases impervious area by 1300 $ft^2$ over a standard 40' cul-de-sac while still allowing adequate room for emergency vehicles to turn around. Other traffic calming techniques can also be used to minimize pavements while maintaining safety. Porous pavers may also be used where appropriate. Using queuing streets or pull-out parking in parking lots with porous pavers in peak overflow areas can reduce the size of parking lots.

<u>Open Drainage Sections</u>: Grassed swales and infiltration trenches can be used in place of curb and gutter

where allowed to distribute and attenuate the flow as well as enhance water quality and result in reduction of drainage pipes and associated infrastructure.

Road Layouts: Local and collector streets with curves and alignment changes allow the roadway to fit into existing topography, minimizing earthwork and hydrologic impacts. Curvilinear road layouts must meet current AASHTO design requirements. Looped road layouts provide open areas in the center for bioretention as well as a visual break for houses facing the street. Minimizing frontage widths and providing green streets or open space pathways between homes for walking and biking will also reduce impervious areas.

Reduced Sidewalk Applications: Reducing sidewalk widths (44" ADA recommended minimum), using porous pavers, or only building sidewalks on one side of the street, where allowed, decrease site imperviousness.

#### 10.1.1.4.1 Design of Roadways on Steep Slopes

LID designs generally avoid construction on steep slopes. However in mountainous or hilly areas, this situation cannot be avoided especially in the case of roadway drainage. Roads on steep slopes most often consist of a series of switchbacks cut into the hillside. These roadways typically have no crown and drain towards the hillside into a ditch or open conveyance. In curves or other areas a pipe or culvert will convey the water from the ditch under the road and down the hillside. In order to provide adequate storm water treatment and lower the impact for these roadways, a number of practices have been developed or adapted from existing practice.

One such practice is the addition of a filtration area beneath the open ditch with an under-drain to provide separation and limited treatment for the WQV. Designed in a similar manner to a traditional infiltration trench, a steep slope trench must account for much faster velocities due to the increased slope (up to 15%). This may require the bottom of the trench to be rip-rap, concrete or another material with high erosion resistance. In order to provide infiltration with the use of concrete or rip-rap channel liners, the under-drain may have standpipes capped with grates every few hundred feet or as needed. Periodic outlet pipes should be installed to pass underneath the roadway to an outlet sufficiently protected from erosion. The object of the rock media is not to infiltrate water into the hillside soils as this can reduce the stability of the slope and increase the risk of landslides. The object is to provide filtration and detention while conveying the WQV to an appropriate outlet point.

On the down slope side of the roadway, practices such as relief drains can be used to capture and convey water to an appropriate outlet. These drains also intercept groundwater seepage in the slope increasing slope stability. **Figure 10-2** from Washington Dept. of Ecology shows a diagram of a relief drain.

Other down slope practices are staggered crescent benches which are staggered pockets to hold plantings, and chimney drains which are vertical drains through the hill which have an outlet at the toe of the slope. A number of geosynthetics are also available. If retaining walls are present weep gardens may also be appropriate.

### 10.1.1.5 Retention Storage

In an LID design after following careful site planning guidelines and implementing practices to minimize changes in CN there will most likely still be a need for additional retention storage to maintain the CN. This storage should be provided in source control IMPs. These IMPs are small scale and distributed strategically throughout the site close to the origin of the runoff that they treat. When the need arises additional detention basins may be required.

#### 10.1.1.5.1 Residential

Residential lots must be laid out to distribute retention storage volume as much as possible throughout the site. It is important to allocate enough area to provide for needed storm water retention storage. In most cases, adequate space is available, but situations may arise on small lots (1/4-acre or less) where the storage requirements can not be accommodated while allowing for reasonable use of lawn and/or open space area. Retention storage in residential areas can be incorporated onto individual lots or common areas. Due to maintenance concerns, locating IMPs in common areas dispersed throughout the site is recommended. However, guidelines for locating on-lot retention storage areas on residential LID sites include the following:

- Locate swales and bioretention IMPs (rain gardens) where they can provide a green space connection between existing wooded or natural areas;
- Bioretention practices must be located outside a road or utility right-of-way to avoid conflict with underground utilities;
- Infiltration or enhanced swales may be used in public right-of-way;
- Keep all LID storm water IMPs outside sensitive areas and respective buffers; and,
- Insure that the contributing drainage area to the site is stabilized prior to bioretention installation.

#### 10.1.1.5.2 Commercial/Industrial

For commercial/ industrial LID sites, retention storage planning is focused on two areas, (1) perimeter buffer areas and (2) green areas located within parking lots. On site retention storage can be provided as interior bioretention, located within required landscape islands, or as cistern or rain barrel facilities. If the available green space in the parking area is insufficient, bioretention within the landscaped buffer area located on the perimeter of the site can be used. Existing minimum green space requirements plus the size of perimeter buffers and parking requirements will dictate the feasibility of providing all required storage within surface swales, terraces, or bioretention facilities.

#### 10.1.1.5.3 Additional Methods

The following LID practices can be used for detention within residential or commercial/ industrial sites:

- Swales, check dams, and diversion structures
- Restricted drainage pipe and inlet entrances
- Wider swales and terraces
- Rain barrels, cisterns, dry wells
- Rooftop and Parking lot Storage
- Terraces designed for and used as detention
- Infiltration trenches
- Retention or Irrigation ponds
- Use 4:1 slopes for roadway swales outside of public right-of-way to minimize disturbance and preserve trees. Stabilizing these slopes with fiber mats and planting perennials, wild flowers or

other dense ground cover or woody shrubs will enhance infiltration and increase time of concentration.

- Locate on-lot swales where they can provide green space connection to existing wooded or natural areas

In summary, a Site CN is very important in determining the amount of runoff that will be produced from a rain event. LID techniques help to reduce changes in CN caused by site development. Table 10-1 summarizes which LID techniques affect the factors governing the CN.

**Table 10-1. LID Planning Techniques to Reduce the Post-Development LID CN**

| Suggested Options Affecting Curve Number | Reduce Length And Width of Roads and Driveways | Conserve Natural Resources Areas | Minimize Limits of Clearing and Grading | Preserve Permeable Soils | Preserve Natural Depressions | Use Transition Zones | Use Vegetated Swales | Provide For Bioretention |
|---|---|---|---|---|---|---|---|---|
| Land Cover Type | | X | X | | | X | X | X |
| Percent of Imperviousness | X | | | | | X | | |
| Hydrologic Soils Group | | X | | X | | | | |
| Hydrologic Condition | | X | X | X | | | | |
| Disconnectivity of Impervious Area | X | | | | | | | |
| Storage and Infiltration | | | | | X | | | X |

*Adopted from (MDDNR, 1999)

### 10.1.2. Time of Concentration

Time of concentration (Tc) describes the time it takes for runoff to flow from a site's most hydrologically remote point to the outlet. A sites time of concentration in conjunction with the CN determines the peak discharge rate for a storm event. The time of concentration is a function of flow velocity which in turn is affected by:

- Travel distance (flow path)
- Slope of the ground and/or water surface
- Ground surface roughness
- Channel shape and pattern

These factors can then be manipulated to modify the Tc of an LID site by modifying the following aspects of the flow:

- Maximize sheet flow
- Modify/ lengthen flow path
- Site and lot slopes
- Open swale IMP geometry
- Site and lot vegetation (roughness)

Sheet Flow: The site should be graded to maximize overland sheet flow distance and minimize the disturbance of woodlands along the Tc flow path. Where graded areas flow to natural drainage ways, velocities should not exceed 1-ft/sec to the extent practicable, as faster velocities may provide insufficient contact time for settlement of suspended solids. The installation of a stable, level spreader along the upland edge of the natural drainage way buffer, or flat grassy area about 30-ft wide upland of the buffer will allow the runoff to spread out.

Flow Path: Increasing the flow path or travel distance will increase the time of concentration and allow more time for infiltration reducing not only the peak flow but the total volume of runoff as well. In residential areas, rooftop and driveway runoff can be permanently infiltrated or stored within infiltration trenches, dry wells, or cisterns strategically located to capture the runoff prior to it reaching the lawn. Strategic lot grading can increase both the surface roughness and the travel length of the runoff lengthening the time of concentration along that particular flow path.

Site and Lot Slopes: Flatten lot slopes to approach a minimum of 1%. This will increase infiltration and travel time. While codes may require a positive drainage perimeter around the building, lot areas outside the pad should contain at least 1% positive slope. Also, soil compaction of original soils (not fill) in the lot should be avoided to maximize infiltration.

Open Swales: Open drainage conveyances are preferred in LID designs over conventional storm drainage structures. To alleviate flooding problems, vegetated or grassed open drainage IMPs should be provided as the primary means of conveying surface runoff between lots and along roadways. Swales can be made wider and flatter to decrease velocity and increase $T_c$. Infiltration and terraces can be used to reduce the quantity of the surface runoff as the need arises. The site should be graded as to minimize the quantity and velocity of surface runoff within the open drainage IMPs.

Site and Lot Vegetation: Revegetate and/ or plant areas to promote natural retention and increase travel time. Re-vegetating graded areas or preserving existing vegetation can reduce peak discharge by increasing surface roughness. Connecting vegetated buffer areas with existing vegetation or forest allows designers to avoid “paved areas” as the $T_c$ flow path for the “shallow concentrated flow” part of the Tc calculation. The benefits of these practices minimize the need for bioretention facilities.

In summary, a site $T_c$ is very important in determining the peak rate of runoff that will occur during a rain event. LID techniques help to reduce $T_c$. Table 10-2 summarizes which LID techniques affect the factors governing the $T_c$.

**Table 10-2. LID Planning Techniques to Maintain Pre-development Tc**

| LID Objective | Disconnect Impervious Areas | Wider and Flatter Swales | Maintain Sheet Flow | Clusters of Trees and Shrubs in Flow Path | Provide Tree Conservation Zones | Minimize the Use of Storm Drain Pipes | Preserve Existing Topography | Provide for Bioretention |
|---|---|---|---|---|---|---|---|---|
| **Minimize disturbance** | X | | X | X | X | X | X | |
| **Flatten grades** | | X | X | | | X | X | X |
| **Reduce height of slopes** | | | | | | X | X | |
| **Increase flow path** | X | X | X | X | | X | | |
| **Increase roughness** | x | | x | x | x | x | | x |

*Adopted from (MDDNR, 1999)

## 10.2 LID Hydrologic Analysis

The goal of LID is to create a post-development landscape that has similar hydrologic functionality to the pre-developed site. This is done by maintaining the pre-development CN, Tc, as closely as possible and using a number of small scale retention structures near sources of increased runoff to make up the difference in runoff volume and peak rate between the pre- and post-developed conditions. The LID design approach focuses on the following hydrologic analysis and design components:

CN: Minimizing change in the post-development CN by reducing impervious areas, preserving trees, meadows and well drained areas to reduce storage requirements.

$T_c$: Maintaining the pre-development Tc to minimize the increase in peak runoff rate by lengthening flow paths and reducing the length of conveyance systems

Retention: Providing retention storage for volume, peak and water quality control, near the source of increased runoff.

Detention: Providing additional detention storage, if required, to maintain peak runoff control and prevent flooding.

Table 10-3 provides a summary of LID techniques that can be used to manipulate the above design and analysis components.

### Table 10-3. LID Techniques for use with Design and Analysis Components

| LID Hydrologic Design and Analysis Components | Flatten Slope | Increase Flow Path | Increase Sheet Flow | Increase Roughness | Minimize Disturbance | Flatten Slopes On Swales | Infiltration Swales | Vegetative Filter Strips | Constricted Pipes | Disconnected Impervious Areas | Reduce Curb And Gutter | Rain Barrels And Cisterns | Rooftop Storage | Bioretention | Revegetation | Vegetation Preservation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lower Post-development CN** | | | | | X | | X | X | | X | X | | | X | X | X |
| **Increase Tc** | X | X | X | X | | X | | X | X | X | X | X | X | X | X | X |
| **Retention** | | | | | | | X | X | | | | X | X | X | X | X |
| **Detention** | | | | | | X | | | X | | | X | X | | | |

*Adopted from (MDDNR, 1999)

## 10.2.1 Process and Computations for LID Hydrologic Analysis

The LID hydrologic analysis procedure is used to determine the post-development CN, Tc, retention, detention and water quality requirements of the site (MDDNR, 1999). The analysis process is illustrated by the flow chart shown in **Figure 10-3**. The hydrologic evaluation steps are performed using an iterative process. Numerous site planning and management configurations may need to be evaluated to identify the optimum solutions. The concept of low-impact development is to emphasize the simple and cost-effective solutions. Use of hydrologic evaluations can assist in identifying these solutions prior to detailed design and construction costs.

The basic information used to develop the LID site plan and used to determine CN and Tc for the pre- and post-development conditions is the same as that needed for traditional storm water management. A variety of models are available to simulate the rainfall-runoff processes for watersheds. The selection of the appropriate modeling technique will depend on the level of detail and rigor required for the application and the amount of data available for setup and testing of the model results.

## 10.2.2 Data Collection

The basic information used to develop the LID site plan and used to determine CN and Tc for the pre- and post-development conditions is the same as that needed for traditional storm water management. A variety of models are available to simulate the rainfall-runoff processes for watersheds. The selection of the appropriate modeling technique will depend on the level of detail and rigor required for the application and the amount of data available for setup and testing of the model results.

## 10.2.3 Determining the LID Runoff Curve Number

The determination of CN requires careful evaluation of each land cover type within the site. By preserving natural vegetation and infiltration areas while minimizing and disconnecting impervious areas, the designer can minimize the need for retention IMPs and take full advantage of infiltration characteristics. The first step in determining the CN is to determine the percentage of each land use/cover on the site. The site should be analyzed in discrete unites to determine the CN. Curve numbers can be found in TR-55 (SCS, 1986). Because LID focuses on minimal disturbance and retaining areas with high storage and infiltration potential, overlying the site with SCS HSG boundaries can be used to develop the LID CN. Calculating the composite CN without considering disconnectivity of impervious areas is done using the following equation:

$$CN_c = \frac{CN_1 A_1 + CN_2 A_2 + \ldots + CN_n A_n}{A_1 + A_2 + \ldots + A_n}$$

Where, $CN_c$ is the composite curve number, $A_j$ is the area of each land cover type, and $CN_j$ is the curve number for each land cover.

When the impervious areas are less than 30% of the total site area, the percentage of unconnected impervious areas within the watershed influences the calculation of the CN (SCS, 1986). Disconnected impervious areas are impervious areas without any direct connection to a drainage system or other impervious surface. Roof drains from homes directed to lawn areas where sheet flow occurs are an example of a disconnected impervious area. Disconnecting impervious areas from one another reduces the volume of runoff. The $CN_c$ for sites with disconnected impervious areas less than 30% of the total site area is given by the following equation:

$$\mathrm{CN_c} = \mathrm{CN_p} + \left(\frac{\mathrm{P_{imp}}}{100}\right)\cdot\left(98 - \mathrm{CN_p}\right)\cdot\left(1 - 0.5\mathrm{R}\right)$$

Where, R is the ratio of unconnected impervious area to total impervious area, $CN_p$ is the composite pervious CN, and $P_{imp}$ is the percentage of impervious site area.

## 10.2.4 Determining Time of Concentration

The determination of $T_c$ using LID is performed in the same manner as in conventional storm water management. In LID however, the pre-development Tc should be greater than or equal to the post-development $T_{c.}$ The procedure for determining Tc can be found in Section 5.2.3 of this manual.

## 10.2.5 Storm Water Management Requirements

In order to fulfill the objectives of an LID design, a post development site must store runoff in order to maintain the pre-development volume, pre-development peak runoff rate, and frequency and meet water quality requirements. Once the CN and Tc have been determined for the pre- and post-development conditions, storage requirements can be calculated. Of those requirements, the one which requires the largest volume to maintain will control the design. A series of design charts have been developed to estimate the surface area required to control the increase in runoff volume, rate and frequency. These design charts are based on an arbitrary depth of 6-inches for all storage structures, as this is the recommended depth for LID bioretention basins. The charts also neglect any reduction in direct runoff from infiltration. The results of the design charts may be transformed to a depth other than 6-inches and to include the effects of infiltration by using the following equations, respectively:

$$\%\ \text{Site Area for BMP} = \frac{\%\ \text{Site Area for BMP at 6 inch depth} \cdot 6\,\text{inch}}{\text{alternative storage depth}}$$

$$\%\ \text{Site Area for BMP} = \frac{\text{Initial}\ \%\ \text{Site Area for BMP} \cdot (100 - x)}{100}$$

Where, x is the percentage of the storage volume infiltrated. The value of x should be minimal (< 10%).

In order to meet storm water management requirements, the appropriate IMPs or combinations of IMPs (treatment trains) must be selected to satisfy the surface area and volume requirements as calculated from the design charts. The design charts to be used to evaluate these requirements are:

- Chart Series A: Percentage of Site Area Required to Maintain the Pre-development Runoff Volume Using Retention Storage
- Chart Series B: Percentage of Site Area Required to Maintain the Pre-development Peak Runoff Rate Using 100% Retention
- Chart Series C: Percentage of Site Area Required to Maintain the Pre-development Peak Runoff Rate Using 100% Detention

The design charts are based on the following general conditions, and can be found in Appendix J:

- The land uses for the development are relatively homogeneous throughout the site
- The storm water management measures are evenly distributed across the development, to the greatest extent possible
- The percent of site area is based on 1-inch runoff increments. Use linear interpolation for determining intermediate values.

The procedure to determine the IMP requirements is outlined in the following steps. It should be noted that the practical and reasonable use of the site must be considered and IMPs must not restrict this use.

<u>Step 1</u>: **Determine storage volume required to maintain pre-development volume or CN using retention storage.** Use Chart Series A. The IMPs must not restrict the use of the site. The storage area, expressed as a percent of the entire site area, is for volume control only; additional storage may be required for water quality or peak rate control. The charts are incremented by inches of rainfall. Linear interpolation between charts may be necessary to capture the appropriate design storm.

**<u>Step 2</u>: Determine storage volume required for water quality control.** This volume is translated to a percent of the site area by assuming a storage depth of 6-inches. The volume requirement for storm water management water quality control is the first 1-inch of runoff from impervious areas. The surface area required for water quality volume control is shown in the following equation:

$$\%\ \text{Site Area for Water Quality BMP} = \frac{\text{Site Area} \cdot P_{imp} \cdot 1-\text{inch}}{\text{Site Area} \cdot \text{BMP Depth}}$$

**<u>Step 3</u>: Determine storage volume required to maintain peak storm water runoff rate using 100**

**percent retention.** The percentage of site area or amount of storage required to maintain the pre-development peak runoff rate is based on Chart Series B. This chart series is based on the relationship between storage volume, $V_s/V_r$, and discharge, $Q_0/Q_i$, to maintain the pre-development peak runoff rate. Where $V_s$ is the volume of storage needed to maintain the pre-development peak runoff rate using 100% retention, $V_r$ is the post development peak runoff volume, $Q_0$ is the peak outflow discharge rate, and $Q_i$ is the peak inflow discharge rate.

<u>Step 4</u>: **Determine whether additional detention storage is required to maintain the pre-development peak runoff rate.** The percentage of the site required to maintain the pre-development volume using retention, as calculated in Step 1, may not be adequate to maintain both the pre-development volume and peak runoff rate. As CNs diverge between pre- and post-development conditions, the storage requirement to maintain the volume is greater than the storage required to maintain the peak runoff rate. As the CN converge or remain similar, the storage required to maintain the peak runoff rate is greater than that required to maintain the volume. If the percentage of the site required to maintain the pre-development runoff volume (Step 1) is less than the percentage of the site required to maintain the pre-development peak runoff rate using 100% retention (Step 3), then additional detention storage will be required.

The combination of retention and detention practices is defined as a hybrid IMP. The procedure for determining the percentage of site area required for the hybrid approach is given in Step 5. **Note: Steps 5 through 7 are only required if additional detention storage is needed (as determined by Step 4).**

<u>Step 5</u>: **Determine storage required to maintain pre-development peak runoff rate using 100 percent detention.** The percentage of site area required to maintain the pre-development peak runoff rate using 100% detention is given by Chart Series C. This chart series should only be used when hybrid design is necessary or where site limitations prevent the use of retention storage. Sites which may prevent the use of retention storage may have severely limited soils for infiltration or retention practices. The procedure to determine the site area is the same as that of Step 3.

Using Chart Series B and Chart Series C, the following assumptions apply:

- The $T_c$ for the post-development condition is equal to the $T_c$ for the pre-development condition.
- The depth of storage for the detention structure is 6-inches. For other depths use the following equation:

$$\%\ \text{Site Area for BMP} = \frac{\%\ \text{Site Area for BMP at 6 inch depth} \cdot 6\,\text{inch}}{\text{alternative storage depth}}$$

- The surface area, is for peak flow control

<u>Step 6</u>: **Use hybrid facility design.** When the percentage of site area for peak rate control exceeds that for volume control, a hybrid approach must be used. While retaining all of the volume will automatically control the peak rate, controlling the peak rate will not necessarily retain the entire excess volume. Therefore, a hybrid approach calculates the necessary site area to satisfy both criteria. To determine the hybrid area needed, the ratio of retention to total storage must be determined using the following equation:

$$x = \frac{50}{V_{R100} - V_{D100}} \cdot \left(-V_{D100} + \sqrt{V_{D100}^2 + 4 \cdot \left(V_{R100} - V_{D100}\right) \cdot VR}\right)$$

This value can then be used to determine the additional amount of site area, above that required for volume control, needed to maintain the pre-development peak runoff rate with the following equation:

$$H = VR \cdot \left(\frac{100}{x}\right)$$

Where VR is the large of the two area values in percent obtained from Step 1 (Chart A) and Step 2, $V_{R100}$ is the value obtained from Chart B, in Step 3, $V_{D100}$ is the value obtained from Chart C, Step 5, x is the ratio of retention storage to total storage, and H is the hybrid area expressed as a percentage of the total site area.

**Step 7: Determine hybrid amount of IMP site area required to maintain peak runoff rate with partial volume attenuation (required when retention area is limited).** This step should be used when a site conditions or physical constraints limit the amount of site area which can be used for retention practices but a hybrid approach is still needed. When this occurs, the amount, or percentage of area available for retention IMPs is less than the percent required to maintain the volume. A variation of the hybrid approach is used to maintain the peak runoff rate while attenuating as much of the increased runoff volume as possible based on input from the designer. The designer should determine the appropriate percentage of the site available for volume control (VR') by analyzing site constraints. This percentage is then put into the equations above in place of VR for determining the ratio of retention to total storage, "x", in place of VR. Note that VR' should at least equal the water quality volume from Step 2.

## 10.3 Low-Impact Development Integrated Management Practices (LID IMPs)

Low-impact development uses distributed source control techniques to achieve the desired post-development hydrologic conditions. The previous sections highlight how site planning and design techniques can be used to minimize hydrologic effects of development; as well as, asses the need for storage due to increases in runoff volume, or peak rate. LID IMPs are used to satisfy these storage volume requirements. The design goal is to locate the IMPs at the source or lot, ideally on level ground within individual lots of the development or providing a green space connection to existing woodlands. Management practices that are suited to low-impact development include:

- LID-01 Green Roofs
- LID-02 Rain Barrels, Cisterns, & Dry Wells
- LID-03 Pervious Pavement
- LID-04 Planter Box
- LID-05 Stormwater Alley
- LID-06 Driveways
- LID-07 Mountainous LID Steep Slope Sites
- LID-08 Vegetated Swales
- LID-09 Full Dispersion
- LID-10 Urban LID Applications
- LID-11 Stormwater Courtyards
- LID-12 Disconnect Impervious and Green Space Preservation

## 10.3.1 LID IMP Selection Process

The selection and design process begins with the control goals identified in section 2. A set of simple steps, shown in **Figure 10-4** can help guide the designer through the selection process. These steps are iterative and may be repeated many times to optimize the design to the hydrologic control objectives and other design objectives. More than one design may meet all the constraints and design considerations and it is up to the developer/ designers judgment to decide which design is the most appropriate for their particular site and land use.

**Step 1: Define Hydrologic Controls Required**. The hydraulic controls required are those needed to maintain the pre-development runoff volume, peak runoff rate, and frequency. Because of the nature of LID, when the design parameters were quantified for the pre-development conditions, they define or quantify the hydrologic controls required for the developed site. These objectives were defined and addressed in the previous sections. Hydrologic functions such as infiltration, frequency and volume of discharges, and groundwater recharge become essential considerations when identifying and selecting IMPs.

**Step 2: Evaluate Site Opportunities and Constraints.** In this step, the site should be evaluated for opportunities and constraints. Opportunities are locations where physical conditions like available space, infiltration characteristics and slopes are amenable to IMP installations. These same conditions might also constrain the use of IMPs. Table 10-4 provides a summary of potential site constraints for various IMPs.

**Table 10-4. Site Constraints of LID IMPs**

| | Bioretention | Dry Well | Filter/ Buffer Strip | Swales: | Rain Barrels | Cistern | Infiltration Trench |
|---|---|---|---|---|---|---|---|
| Space Required | Minimum surface area range: 50 to 200 ft² Minimum width: 5 to 10 ft Minimum length: 10 to 20 ft Minimum depth: 2 to 4 ft | Minimum surface area range: 8 to 20 ft² Minimum width: 2 to 4 ft Minimum length: 4 to 8 ft Minimum depth: 4 to 8 ft | Minimum length of 15 to 20 ft | Bottom width: 2 ft minimum, 6 ft maximum | Not a factor | Not a factor | Minimum surface area range: 8 to 20 ft² Minimum width: 2 to 4 ft Minimum length: 4 to 8 ft |
| Slopes | Usually not a limitation, but a design consideration | Usually not a limitation, but a design consideration. Must locate down gradient of building and foundations | Usually not a limitation, but a design considerations | Swale side slopes: 2:1 or flatter Longitudinal slope: 1.0% minimum; 5% maximum based on permissible velocities | Usually not a limitation, but a design consideration for location of barrel outfall | Not a factor | Usually not a limitation, but a design consideration. Must locate down gradient of buildings and foundations |
| Water Table/ Bedrock | 3ft clearance above water table/ bedrock recommended | 2 to 4 ft clearance above water table/ bedrock recommended | 2ft clearance above water table/ bedrock recommended | 2ft clearance above water table/ bedrock recommended | Generally not a constraint | | 4 ft clearance above water table/ bedrock recommended |
| Proximity to build foundations | Minimum distance of 10 ft down gradient from buildings and foundations recommended | Minimum distance of 10 ft down gradient from buildings and foundations recommended | Minimum distance of 10 ft down gradient from buildings and foundations recommended | Minimum distance of 10 ft down gradient from buildings and foundations recommended | Not a factor | | Minimum distance of 10 ft down gradient from buildings and foundations recommended |
| Max. Depth | 2 to 4 ft depth depending on soil type | 6 to 10 ft depth depending on soil type | Not applicable | Not applicable | Not applicable | | 6 to 10 ft depth depending on soil type |
| Maintenance | Low requirement, property owner can include in normal site landscape maintenance | Low requirement | Lower requirement, routine landscape maintenance | Low requirement, routine landscape maintenance | Low requirement | | Moderate to high |

*Adopted from (MDDNR, 1999)

**Step 3: Screen for Candidate Practices.** Based on the evaluation of site opportunities and constraints, a comparison with the available practices is made. IMPs that are inappropriate or infeasible for the specific site are excluded. The screening should consider the hydrologic functions, size, water quality contribution and other factors. Screening is not simply a matter of selecting from a menu of available IMPs but an integrated planning and design process.

**Step 4: Evaluate Candidate IMPs in various configurations.** After the candidate IMPs are identified, they are deployed as appropriate throughout the site and the hydrologic methods described previously are applied to determine if the mix of IMPs satisfies the hydrologic control objectives. Typically on the first attempt, the hydrologic control objectives are not met. Design iterations may be necessary, adjusting the number and size of IMPs until the hydrologic control and design objectives are optimized.

**Step 5: Select Preferred Configuration and Design.** The iterative design process typically identifies a number of potential configurations and mixes of IMPs. Design factors such as space requirements, aesthetics, cost and other factors can all be factored into the process to arrive at an optimum or preferred configuration and mix of IMPs that provide the identified level of hydrologic control at a reasonable cost.

**Step 6: Design Conventional Controls if Necessary.** If for any reason the hydrologic control objectives cannot be achieved using LID IMPs, it may be necessary to add so conventional controls. Sometimes site constraint such as a high water table, low-permeability soils or intensive land uses such as commercial or industrial sites preclude the use of sufficient LID IMPs to satisfy the hydrologic design objectives. In this case it is recommended that LID IMPs be used to the extent possible and conventional controls, such as detention or retention practices (i.e. ponds), be used to satisfy the remaining objectives.

### 10.3.2 Other Environmentally Sensitive IMPs

Low-Impact Development is a relatively new concept. It is anticipated that over the next few years many additional best management practices and improvements to the LID approach will be introduced as local agencies and designers begin to experiment with the use of the practice.

One such example of an additional developing practice is rooftop greening. This technique consists of the use of pre-cultivated vegetation mats. This practice has the following benefits:

- Improve air quality (up to 85% of dust particles can be filtered out of the air).
- Cooler temperatures and higher humidity through natural evaporation.
- 30-100% of annual rainfall can be stored, relieving storm drains.

Innovative technologies are encouraged and shall be evaluated on a case by case basis providing there is sufficient documentation as to the effectiveness and reliability of the proposed structure. To justify the efficiency of innovated practice, the owner may be required to monitor the hydrologic and water quality function of the practice. If satisfactory results are obtained, the practice may be used and no other monitoring studies shall be required. If the control is not sufficient, other on-site and/or downstream controls shall be designed to satisfy the hydrologic and water quality requirements.

## CHAPTER 10 REFERENCES:


Maryland Department of Environmental Resources (MDDNR) (1984), *Low-Impact Development: An Integrated Design Approach*, Department of Environmental Resources, Prince George's County, MD, Programs and Planning Division.

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Texas Water Development Board (TWDB) (2005). The Texas Manual on Rainwater Harvesting 3rd Ed. http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf,

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# Chapter 11. STREAM PROTECTION AND RESTORATION

## 11.1. Structural Streambank Stabilization

Streambank stabilization is used to prevent streambank erosion from high velocities and quantities of storm water runoff. Typical methods include the following:

- Riprap - Large angular stones placed along the streambank or lake.
- Gabion - Rock filled wire cages that are used to create a new streambank.
- Reinforced Concrete - Concrete bulkheads and retaining walls that replace natural streambanks and create a non-erosive surface.
- Grid Pavers – Pre-Cast or poured-in-place concrete units that are placed along streambanks to stabilize the streambank and create open spaces where vegetation can be established.
- Cribb Walls- Logs with vegetation used to create new streambanks.

### 11.1.1 Applications

Structural streambank stabilization is used where vegetative stabilization practices are not practical and where the streambanks are subject to heavy erosion from increased flows or disturbance during construction. Stabilization should occur before any land development in the watershed area. Stabilization can also be retrofitted when erosion of a streambank occurs. All applicable Federal Army Corps of Engineers and State DHEC Regulations, including Section 404 of the Clean Water Act that regulates the placement of fill-in wetlands, must be met while working in the stream.

An important design feature of structural streambank stabilization methods is the foundation of the structure; the potential for the stream to erode the sides and bottom of the channel should be considered to make sure the stabilization measures will be supported properly. Structures can be designed to protect and improve natural wildlife habitats; for example grid pavers can be designed to keep vegetation. Permanent structures should be designed to handle expected flood conditions. A well-designed layer of stone can be used in many ways and in many locations to control erosion and sedimentation. Riprap protects soil from erosion and is often used on steep slopes built with fill materials that are subject to harsh weather or seepage. Riprap can also be used for flow channel liners, inlet and outlet protection at culverts, streambank protection, and protection of shore lines subject to wave action. It is used where water is turbulent and fast flowing and where soil may erode under the design flow conditions. It is used to expose the water to air as well as to reduce water energy. Riprap and gabion (wire mesh cages filled with rock) are usually placed over a filter blanket (i.e., a gravel layer or filter cloth). Riprap is either a uniform size or graded (different sizes) and is usually applied in an even layer throughout the stream. Reinforced concrete structures may require positive drainage behind the bulkhead or retaining wall to prevent erosion around the structure. Gabion and grid pavers should be installed according to manufacturers' recommendations.

Streambank stabilization structures should be inspected regularly and after each large storm event. Structures should be maintained as installed. Structural damage should be repaired as soon as possible to prevent further damage or erosion to the streambank.

### 11.1.2 Design Criteria

Since each reach of channel requiring protection is unique, measures for streambank protection should be installed according to a unique plan and adapted to the specific site. Design should be developed according to the following principles:

- Bottom scour should be controlled, by either natural or structural means, before any permanent type of bank protection can be considered feasible.

- Specific attention should be given to maintaining and improving habitat for fish and wildlife.

- Structural measures must be effective for the design flow and be capable of withstanding greater flow without serious damage.

Refer to Section 8.4.2 for the design of riprap lined channels.

### 11.1.3 Maintenance

- Inspections should be made regularly and after each large storm event. Repairs should be made as quickly as possible after the problem occurs.

- All temporary and permanent erosion and sediment control practices should be maintained and repaired as needed to assure continued performance of their intended function. All maintenance and repair should be conducted in accordance with an approved manual.

## 11.2. Bioengineering Streambank Stabilization

Bioengineering systems are installed to establish vegetation on bank slopes, provide soil protection, control erosion and reinforce the outer layers of the bank slope. In general terms, eroded streambank slopes are reshaped to a workable shape and live cuttings of woody native plants are installed into the slope during the dormant season. The cuttings develop root systems and flourish to provide a dense vegetation growth. All applicable federal U.S. Army Corps of Engineers and SCDHEC Regulations, including Section 404 of the Clean Water Act that regulates the placement of fill in wetlands, must be met while working in the stream.

### 11.2.1 Applications

Vegetative streambank stabilization is used on sections of streambanks subject to erosion from excess runoff. This practice is generally applicable where bankflow velocities do not exceed 6 ft/sec and soils are erosion resistant. When velocities are above 6 ft/sec, geotextiles, or structural measures are generally required.

Structural streambank measures are expensive to build and to maintain. Without constant upkeep, natural agents expose them to progressive deterioration. The materials used often prevent the reestablishment of native plants and animals. Very often these structural measures destroy the aesthetics of the stream.

In contrast, the utilization of living plants instead of or in conjunction with structures has many advantages. Vegetated measures provide a habitat for fish and wildlife and are aesthetically pleasing. The degree of protection, which may be low to start with, increases as the plants grow and spread. Repair and maintenance is unnecessary where self-maintaining streambank plants are established. In addition, planting vegetation is less damaging to the environment than installing structures, therefore vegetation should always be considered first.

## 11.2.2 Plant Zones

At the edge of all natural watercourses, plant communities exist in a characteristic succession of vegetative zones. The following zones are a guide for locating plant groups for successful establishment;

- Aquatic plant zone,
- Reed bank zone,
- Shrub zone, and
- Tree zone.

A typical annual curve of the water levels correlated with these typical vegetated zones is shown in **Figure 11-1**.

### 11.2.2.1 Aquatic Plant Zone

The aquatic plant zone is normally submerged and is inhabited by plants such as pond weeds and water lilies. The roots of these plants help to bind the soil, and they further protect the channel from erosion because the water flow tends to flatten them against the banks and the bed of the stream.

### 11.2.2.2 Bank Zone

The lower part of the reed bank zone is generally submerged for about half the time and is inhabited by rushes, reeds, grasses, cattails, and other water plants which bind the soil with their roots rhizomes and shoots and slow the water's flow rate by friction.

### 11.2.2.3 Shrub Zone

The shrub zone is flooded only when flow exceeds the average high water level. The shrub zone is inhabited by trees and shrubs with high regenerative capacities such as willow, alder, dogwood, and viburnum. These plants hold the soil with their root systems and slow water speed by friction. Shrub zone vegetation is recommended for the impact bank of stream meander where maximum scouring occurs.

### 11.2.2.4 Tree Zone

The tree zone is flooded only during periods of very high water.

## 11.2.3 Two-Stage Channels

Two-staged channels are constructed water courses consisting of a smaller channel within a larger channel. A two-staged channel is designed to meet conveyance requirements while minimizing environmental impacts and taking advantage of naturally stable geometry. Two-staged channels shall be used where:

- Channel relocation is unavoidable and a new stream channel must be constructed.
- The conveyance efficiency of an existing channel must be increased to alleviate flooding.
- The depth of an existing channel must be increased to accommodate increasing flow rates and volumes from upstream development.
- Stream restoration would benefit a previously modified or heavily impacted channel.

Typical specifications for two-staged channels are shown in **Figure 11-2**. Two-staged channels are designed to have a low-flow channel section and an overflow channel section.

#### 11.2.3.1 Low-Flow Channel

Low flow-channels shall be designed using the following criteria:

- The capacity shall be able to carry 50 percent (1/2) of the 2-year 24-hour storm event.
- Stream stability, water quality, and habitat enhancement features shall be added in the design such as meanders, eddy rocks, pools, and riffles.
- The base of the channel shall consist of natural soil, sand, and rocks.

#### 11.2.3.2 Overflow Channel

Flood channels shall be designed using the following criteria:

- The capacity of the overflow channel shall be designed to carry the 10-year 24-hour storm event.
- The minimum bottom width of the overflow channel shall be at least three times the top width of the low-flow channel.
- Proper vegetation shall be incorporated into the overflow channel to benefit water quality, bank stability, and wildlife.

### 11.2.4 Bioengineering Streambank Stabilization Design Criteria

Bioengineering streambank stabilization applications usually employ plant materials in the form of live woody cuttings or poles of readily sprouting species, which are inserted deep into the bank or anchored in various other ways. This serves the dual purposes of resisting washout of plants during the early establishment period, while providing some immediate erosion protection due to the physical resistance of the stems. Plant materials alone are sufficient on some streams or some bank zones, but as erosive forces increase, they can be combined with other materials such as rocks, logs or brush, and geotextile matting. The evaluation of the erosion potential of streambanks should be made considering;

- Frequency of bank-full flow based on anticipated watershed development;
- Channel slope and flow velocity, by design reaches;
- Soil conditions;
- Present and anticipated channel Manning's "n" values;
- Channel bend and bank conditions; and
- Identification of stable area and troubled spots.

Preliminary site investigations and engineering analysis must be completed to determine the mode of bank failure and the feasibility of using vegetation as a component of streambank stabilization work. In addition to the technical analysis of flows and soils, preliminary investigations must include consideration of access, maintenance, urgency, and availability of materials.

Cuttings, pole/post plantings, and live stakes taken from local species that sprout readily (e.g., willows) are more resistant to erosion and can be used lower on the bank. In addition, cuttings and pole plantings can provide moderation of velocities when planted in high densities. Often, they can be planted deep enough to maintain contact with adequate soil moisture levels and eliminate the need for irrigation. The reliable sprouting properties, rapid growth, and availability of cuttings of willows and other pioneer species makes them appropriate for streambank stabilization. There are different planting methods to consider when designing bioengineering systems.

### 11.2.4.1 Pole/Post Plantings

Pole /posts typically are typically 3- to 5-inches in diameter and 5- to 7-feet long, but may be 12-feet long or more if required for a particular situation. Large dormant posts offer the most initial bank structure stability. They are useful on steep overhanging banks that are expected to continue to erode. Posts should be large enough to remain in place without breaking or being buried if some additional erosion takes place. On potentially dry streambanks where water availability may be a problem, longer posts can be planted deep enough to intercept water.

Large posts offer resistance and dissipate high flow energies within the stream. The resistance of large posts may not be desirable where high conveyance efficiencies are required.

Heavy equipment may be required to install very large posts. A backhoe fitted with a ramrod is an effective tool for creating the holes required for planting the posts. Post ranging from 5- to 7-feet in length may be driven into streambanks using a hand-held fence-post driver.

### 11.2.4.2 Live Stakes

Live stakes are typically 1- to 3-inches in diameter and 1.5- to 3-feet long. Live stakes are adequate for stable streambanks that may experience minor erosion, but will not solely rely on the live stakes for stability and erosion protection.

Live staking involves the installation of single plant cuttings large and long enough to be pushed into the ground in the form of stakes. A sledgehammer is typically sufficient for driving live stakings into streambanks. In some instances, pilot will be required to initiate the driving of the stakes.

### 11.2.4.3 Seedlings

Seedlings shall not be planted on actively eroding streambanks and do not offer any initial bank stability. Seedlings are typically planted with shovels and is labor intensive but easily accomplished by a crew of several workers.

### 11.2.4.4 Planting Combinations

Several techniques are available that employ large numbers of cuttings arranged in layers or bundles that can be secured to streambanks and be partially buried. Depending on the arrangement of these systems, they can provide direct protection from erosive flows, prevent erosion from upslope water sources, promote trapping of sediments, and quickly develop dense roots and sprouts.

- Joint planting makes use of live stakes installed between previously placed natural rocks within the channel and along the bank slopes.

- Brush mattresses and woven mats are typically used on the face of a bank and consist of cuttings laid side by side and interwoven or pinned down with jute cord or wire held in place by stakes.

- Brush layers are cuttings laid on terraces dug into the bank, then buried so that the branches extend from the bank.

- Live fascines, revetments, wattles and rootwads are bundles of cuttings tied together, placed in shallow trenches arranged horizontally on the bank face, partially buried, and staked in place. The dormant plantings may be installed alone or with dead woody cuttings to provide protection for the live plants.

- These structures decrease erosion and promote silt and sand to be deposited along the bank and within the structure. The deposited materials form a good environment for new cuttings and a good seedbed for natural species to grow. These structure provide excellent fish and wildlife cover.

- Reed Rolls consist of burlap rolls filled with soil, root material and rooted shoots that are partially buried and staked to establish herbaceous species in appropriate habitats.

- Natural fibers are used in “fiber bio-logs” which are sold specifically for streambank applications. These are cylindrical fiber bundles that can be staked to a bank with cuttings or rooted plants inserted through or into the material.

- Geotextiles can be used for erosion control in combination with seeding, or with plants placed through slits in the fabric. The typical streambank use for these materials is in the construction of vegetated geogrids where the fill soils between layers of cuttings are encased in fabric, allowing the bank to be constructed of successive “lifts” of soil.

- The addition of vegetation to structural applications is also effective. This involves the placement of stakes and poles between riprap and stones of existing stabilization. Timber cribwalls may also be constructed with cuttings or rooted plants extending through the timbers from the backfill soils.

In most cases, streambank stabilization projects use combinations of the techniques described above in an integrated approach. Toe protection often requires the use of riprap, but the amounts can be reduced if vegetative practices are used along the bank. Likewise, stone blankets on the bank face can be replaced with geotextiles and geogrids supplemented with plantings and cuttings. Most upper bank areas can usually be stabilized with vegetation alone although anchoring systems may be required. Refer to **Figure 11-3** and **Figure 11-4** for typical soil bioengineering streambank stabilization methods.

### 11.2.4.5 Maintenance

Vegetated streambanks are always vulnerable to new damage, and repairs may be needed periodically. Check banks after every high water event and fix gaps in the vegetative cover with geotextiles or new plants mulched. Fresh cuttings from other plants on the bank may be used, or they can be taken from motherstock plantings. Apply a complete fertilizer annually until the desired density of vegetation is reached. Protect new plantings from grazing livestock or wildlife where this is a problem.

# Chapter 12. INSPECTION AND ENFORCEMENT PROCEDURES

This chapter establishes inspection and enforcement guidelines to be followed for inspections of storm water management and water quality facilities.

## 12.1. Storm Water Management Inspector Authority

Storm Water Management Inspectors are authorized by Greenville County to inspect and enforce the requirements of this Design Manual. The inspectors shall be:

- Authorized to conduct inspections and file reports for periodic inspections as necessary during construction of storm water systems to assure compliance with the approved plans.
- Authorized to furnish the permittee or agent the results of inspection in a timely manner after the completion of each required inspection.
- Authorized to issue a Correction Order to the permittee or agent when any portion of the work does not comply with the approved plans.
- Authorized to issue a Notice of Violation (NOV) to the permittee or agent when any portion of the work does not comply with the approved plans.
- Authorized to Issue a Stop Work Order as the result of unsafe conditions, working without a permit, unsatisfactory work, progress, or other non-compliance.
- Authorized to issue a Civil Citation as a result of unsafe conditions, non-compliance with a Stop Work Order, unsatisfactory work, progress or other non-compliance.
- Authorized to perform a final inspection upon the completion of the storm water system to determine if the completed work is constructed in accordance with the approved storm water design plan, approved "As-built" plan certified by the permittee's registered professional engineer.

## 12.2. Storm Water Management Inspector Responsibility

Greenville County Inspectors shall conduct periodic site inspections on all land disturbing activities and sites that have post-development permanent water quality BMP facilities. The person responsible for the land disturbing activity shall notify the Greenville County Inspector before the initiation of construction and upon project completion when a final inspection shall be conducted to ensure compliance with the approved Storm Water and Sediment Control Permit.

Greenville County Inspectors shall enforce the following inspection items:

- Ensure that the approved storm water management and erosion prevention and sediment control plans are on the project site and are properly being followed and implemented.
- Ensure that active construction sites are inspected for compliance with the approved plans on a regular basis.
- Provide the person financially responsible for the land disturbing activities a written report after every inspection describing:

- Date and location of the site inspection,
- Whether the approved plans have been properly implemented and maintained,
- Approved plan or practice deficiencies, and
- Action taken.

- Notify the person financially responsible for the land disturbing activities in writing within 15 working days when violation are observed including:

  - Nature of the violations,
  - Proposed penalty,
  - Required corrective actions, and
  - The time period for adequately correcting the violations.

### 12.2.1 Inspection During Construction

Storm Water Management Inspectors shall conduct inspections for each storm water management BMP shown on the specific plans for the project site during the construction phase of a project:

- Every seven calendar days and within 24-hours after each rainfall event that produces ½-inches or more of precipitation,

- At the request of Greenville County,

- At the request of the permittee, and

- Due to a complaint of any construction impacts.

The Inspector also has the freedom to make unscheduled inspections to assure compliance with the plans.

If an imminent hazard exists and the owner fails to comply with the required maintenance activities, Greenville County shall employ the necessary labor and materials to perform the required work as expeditiously as possible. The owner shall be assessed the costs of the inspection, labor, materials and equipment. The costs shall be collected from any bonds that are in place and sufficient to cover the costs, or shall become a lien on the property, and shall be collected in the same manner as County taxes.

Third party inspections, by a qualified individual who is independent of the owner, may be required at the discretion of the Director at sites that have compliance problems and at sites where storm water discharges to environmental sensitive waters (such as waters classified as Trout Waters, Outstanding Resource Waters, Shellfish Harvesting Waters, etc.).. Inspections must be done by qualified professionals as outlined in the SCDHEC's Construction General Permit (SCR-100000) Inspection reports shall be submitted to the County every two weeks or 30 days if the site has been temporarily stabilized and approved by the County showing results of inspections, weather conditions, corrective actions and other information as may be required by the Director.

### 12.2.2 Permanent Structure Maintenance Inspections

The purpose of maintenance inspections is to ensure that permanent storm water management and erosion and sediment control BMP structures are working properly and remain functional.

At least one preventative maintenance inspection shall be performed on permanent storm water management BMPs during the first year of operation. After the first year of operation, these BMPs shall be inspected at least one time every three years or be inspected as stipulated in the maintenance agreement.

- The owner of the facility shall be contacted prior to maintenance inspections and the inspection shall be conducted at reasonable times.
- If the owner can not be contacted, the inspection shall be performed and a report shall be sent to the owner.

- Upon refusal by any property owner to permit an inspector to enter or continue an inspection, the inspector shall terminate the inspection or confine the inspection to areas where no objection is raised. The inspector shall immediately report the refusal and grounds to the Director. The Director shall promptly seek the appropriate compulsory process.

- In the event where it is believed that discharges from the property may cause imminent and substantial threat to human health or the environment, the inspection may take place at any time without notice.

- Inspection Reports shall be maintained in a permanent file located in the Directors office.

- A Correction Order and/or Notice of Violation shall be issued for any required maintenance needed.

- After a notice to comply is given in writing, a specified period of time shall be allocated for the owner/permittee to begin the required maintenance activities.

If an imminent hazard exists and the owner fails to comply with the required maintenance activities, Greenville County shall employ the necessary labor and materials to perform the required work as expeditiously as possible. The owner shall be assessed the costs of the maintenance labor and materials. The costs shall become a lien on the property and shall be collected in the same manner as County taxes.

## 12.3. Correction Orders

The purpose of the correction order is to notify the owner/permittee and or contractor/developer of deficiencies noted during specific inspections. Correction Orders shall be submitted in writing, and a verbal notice may be given if it shall result in immediate compliance as the work is being completed. The Director shall give written notice to the violator within 15 working days of the inspection.

Correction Orders are to be issued when the permittee or contractor is required to make changes to storm water management controls and procedures that satisfy the storm water design plans and specifications. The notice shall specify: the nature of the violation, the potential penalty, if applicable, the corrective action required, which may include restoration of impact to offsite land and waters, and the amount of time in which to correct deficiencies, if appropriate.

All Correction Orders, verbal or written, shall be noted in the project file. A compliance date and mailing address for sending needed information shall be supplied.

Correction Orders may be issued in such cases as:

- Failure to comply with the storm water design plans. Incorrect measurements, improper materials, improper installation or failing to follow proper procedures.

- Failure to provide certification for completed storm water structures. The Inspector shall issue a Correction Order to the permittee/developer requesting certification and/or "As-built."

- Failure to properly maintain permanent storm water structures.

Any person violating any of the provisions of the Storm Water Management Ordinance shall be required to comply with the Director's notice. Where a violation has not been corrected by the violator within the applicable time period for correction, Greenville County, or its contractor, may enter upon the lot or parcel of land and correct the violation, including offsite impact, and the costs incurred as a result of such action (including inspection, administration, labor and equipment costs) shall be collected from the letter of credit or other means of security in place and sufficient to cover such costs, or shall become a lien upon the property and shall be collected in the same manner as County taxes are collected. These costs shall be assessed in addition to any other penalty or injunctive relief authorized under the Ordinance.

## 12.4. Notice of Violation and Stop-Work Orders

The purpose of issuing Stop Work Orders and Notice of Violations is to gain compliance with Correction Orders issued and/or gain compliance with the Greenville County Storm Water Ordinance.

### 12.4.1 Issuing Violations

The Storm Water Management Inspector or Director shall issue a Notice of Violation to a permittee/owner and/or contractor/developer or agent upon non-compliance of the Greenville County Storm Water Ordinance. In most cases, a Correction Order is used for the first offense. Subsequent non-compliance with the Ordinance or failure to complete the items on the Correction Order within a specified time period may result in a Notice of Violation or Stop Work Order.

For violations that do not involve the safety of life, or an imminent threat of serious damage to the environment and public or private property, Stop Work Orders and Notice of Violations may be issued for, but is not limited to the following:

- Failure to notify the Greenville Storm Water Department before beginning work on the next phase of a development project.
    - Any work that has been placed without a required inspection approval shall be certified in writing by a registered design professional before the next phase of construction shall begin.
    - Greenville County reserves the right to require inspection on all un-inspected facilities at the sole expense of the permittee/owner. Any deficiencies that need to be corrected before work shall start again shall be listed and given a compliance date. The permittee shall be notified to call for future inspections.
- Failure to have work inspected and approved before continuing work on the project.

- Failure to call for final inspection.
    - The final inspection shall list all deficiencies that must be corrected before the development project is complete.
    - The final inspection shall provide compliance date, and request a letter of certification or "As-built." The permittee/owner or contractor/developer shall contact a Greenville County Inspector to request a re-inspection after completing the corrections of the initial final inspection.
- Failure to provide certification for completed storm water structures. If an engineer's certification or "As-built" is not received by the compliance date as requested by a previously issued Correction Order, a Notice of Violation to the permittee/owner and/or contractor/developer will be sent requesting the certification.
- Failure to have erosion and sediment controls in place, improper installation, and/or improper maintenance. If excavation has been initiated and no erosion and sediment control BMPs are in place, or are not working to protect sediment from the leaving the development site, a Notice of Violation shall be sent with a directive to install the BMPs or correct them immediately or face a Stop Work Order for the entire site.
- Construction not in accordance with the approved plans.
    - First, a Correction Order stating the activities to be corrected and a compliance date shall be issued.
    - If the correction work hasn't been completed by the compliance date, a Notice of Violation shall be issued stating:

      A Stop Work Order may be issued,<br>
      Permits for the site may be suspended or revoked ,<br>
      Bonds may be recalled if the work is not completed by a new compliance date.
- Working without grading, building, or other applicable permits.
    - Stop Work Order shall be issued directing the owner to obtain the required permits.
    - The Stop Work Order shall state that failure to comply may result in the suspension or revocation of any remaining permits issued for the site and/or civil citations being issued.
- Failure to properly maintain permanent storm water structures.

### 12.4.2 Non-Compliance with Stop Work Orders

A Notice of Violation shall be issued warning the violator that the grading, storm water, and/or building permit for the site may be suspended or revoked, bond recalled, or civil citation issued if any work continues on the development site.

Any development in violation of a Stop Work Order is subject to impoundment of any and all equipment on the property, and payment of all fees, bonds, penalties and payment of impoundment charges prior to retrieving the equipment.

## 12.5. Working without a Permit

Any person that proceeds with development work on a site that requires a Site Development Plan without first submitting a plan or obtaining a permit where applicable shall automatically have a Stop Work Order placed on the development. This Stop Work Order shall require a fee of $200 double the normal amount of applicable bond and fees and payment of any other applicable penalties prior to lifting the Stop Work Order. The Stop Work Order may allow or require correction of violations but no other project activities. Any development in violation of a Stop Work Order is subject to impoundment of any and all equipment on the property and payment of all fees bonds penalties and payment of impoundment charges prior to retrieving the equipment.

## 12.6. Civil Citations

The issuance of Civil Citations by the Inspector may be made for the following situations:

- When a Notice of Violation and/or Stop Work Order has not been complied with or there has not substantial progress in complying with the Notice of Violation and/or Stop Work Order.
- On abandoned sites where no work has been taking place, and continued non-compliance with a Notice of Violation may result in the issuance of repeat citations.
- When a Stop Work Order has been issued, and work still continues in defiance of the order. Under such circumstances, the Civil Citation shall be issued for the storm water management violation.
- When repeated, reoccurring violations take place at the same development site or when repeated reoccurring violations take place by the same responsible party. Each day that a violation remains uncorrected constitutes a separate applicable violation.

In addition to or in lieu of the criminal penalties authorized by the Storm Water Management Ordinance, the County has the authority to assess a civil penalty of not more than seven thousand five hundred dollars ($7,500.00) per violation against any person who has violated any provision of the ordinance. Each separate day of a violation constitutes a new and separate violation. A person assessed a civil penalty may appeal the assessment to the magistrate, who may waive, modify, or affirm the civil penalty. All civil fines collected pursuant to the provisions of the Ordinance shall be directed to fund the costs associated with storm water education, correcting violations and/or enforcing the provisions of the ordinance.

Citations shall be hand delivered when possible. When it is not possible, the Citation shall be sent by Certified Mail. Owners, agents, permittees, lessees, builders, contractors, developers, firms, corporations, or partnerships listed on permit application or tax record may be cited under this provision.

## 12.7. Consent Process

Upon determination that a violation of any of the provisions of the Storm Water Management Ordinance or the SWMP have occurred, the County may choose to pursue in magistrate court action for criminal and/or civil fines and penalties to the maximum extent allowed by law. The County may also choose at its sole discretion, to proceed with a consent process. The first step for the consent process is for the County's enforcement officer to hold a fact finding meeting with the violator. Second, the enforcement officer develops a draft consent decree that contains corrective actions and penalties based on the facts found. This draft consent decree is presented to the violator and may be negotiated for a mutually agreeable action. If the parties fail to agree on the consent action the enforcement officer will present an administrative order to be enforced on the violator. In cases where the violator refuses to comply with the administrative order the County will pursue criminal and/or civil penalties for violations as authorized by this ordinance.

The County Attorney may institute injunctive, mandamus or other appropriate action or proceedings at law or equity, including criminal proceedings, for the enforcement of the Storm Water Management Ordinance or to correct violations of the Ordinance, and any court of competent jurisdiction shall have the right to issue restraining orders, temporary or permanent injunctions, mandamus or other appropriate forms of remedy or relief.

## 12.8. Criminal Penalties

The County has the authority to charge any person violating any provision of this ordinance with a misdemeanor punishable within the jurisdictional limits of magistrate's court. Each day of a violation shall constitute a new and separate offense.