TOWN OF BLUFFTON
PLANNING COMMISSION MEETING AGENDA
ELECTRONIC MEETING
Wednesday, August 26, 2020, 6:00 PM

This meeting can be viewed on the Town of Bluffton's Facebook page (https://www.facebook.com/TownBlufftonSC/)

I. **CALL TO ORDER**

II. **ROLL CALL**

III. **NOTICE REGARDING ADJOURNMENT**
The Planning Commission will not hear new items after 9:30 P.M. unless authorized by a majority vote of the Commission Members present. Items which have not been heard before 9:30 P.M. may be continued to the next regular meeting or an additional meeting date as determined by the Commission Members.

IV. **NOTICE REGARDING PUBLIC COMMENTS***

V. **ADOPTION OF THE AGENDA**

VI. **ADOPTION OF MINUTES** – July 22, 2020

VII. **PUBLIC COMMENTS FOR ITEMS NOT ON THE AGENDA***

VIII. **OLD BUSINESS**

IX. **NEW BUSINESS**

1. **FOR ACTION**

A. **New River Forest (Street Naming):** A request by Thomas Hurley of Atlas Surveying on behalf of Richard Schwarz with Village Park Homes for approval of a Street Naming Application for streets within the New River Forest Development Plan The project consists of 113 single family homes with an Amenity Center. The property is zoned New Riverside PUD and is identified by tax map number R610 036 000 1318 000 located north and west of the intersection of New Riverside Road and Wheel House Way

(DP-07-20-014384) (Staff - Will Howard)

X. DISCUSSION

1. For Discussion Only – No Action

   A. **Stormwater Design Manual Workshop**: Discussion and direction on amendments to the Town of Bluffton Code of Ordinances, Chapter 23 – Unified Development Ordinance related to adopting the Southern Lowcountry Post Construction Stormwater Ordinance and Stormwater Design Manual (Staff – Bryan McIlwee, Director of Engineering)

XI. ADJOURNMENT

*Public Comments may be submitted electronically via the Town's website at (https://bit.ly/TOBPublicComment) or by emailing your comments to the Growth Management Coordinator at dmclain@townofbluffton.com. Comments will be accepted up 2 hours prior to the scheduled meeting start time. All comments will be read aloud for the record and will be provided to the Planning Commission Board.

NEXT MEETING DATE: Wednesday, September 23, 2020

"FOIA Compliance – Public notification of this meeting has been published and posted in compliance with the Freedom of Information Act and the Town of Bluffton policies."

In accordance with the requirements of Title II of the Americans with Disabilities Act of 1990 ("ADA"), the Town of Bluffton will not discriminate against qualified individuals with disabilities on the basis of disability in its services, programs, or activities. The Town of Bluffton Council Chambers are ADA compatible. Any person requiring further accommodation should contact the Town of Bluffton ADA Coordinator at 843.706.4500 or adacoordinator@townofbluffton.com as soon as possible but no later than 48 hours before the scheduled event.

*Please note that each member of the public may speak at one public comment session and a form must be filled out and given to the Chairperson of the Commission. Public comment must not exceed three (3) minutes.

TOWN OF BLUFFTON PLANNING COMMISSION
Electronic Meeting

Wednesday, July 22, 2020, Minutes

Present: Chairman, Josh Tiller; Vice Chairman, Terry Hannock; Dan Keefer, Trey Griffin, Charlie Wetmore, Amanda Jackson, Ronald Williams

Staff: Kevin Icard, Planning & Community Development Manager; Darby McLain, Growth Management Coordinator; Brie Giroux, Special Projects & Programs Administrator

I. CALL TO ORDER

Chairman Tiller called the meeting to order at 6:00 p.m.

II. ROLL CALL

III. NOTICE REGARDING ADJOURNMENT

The Planning Commission will not hear new items after 9:30 P.M. unless authorized by a majority vote of the Commission Members present. Items which have not been heard before 9:30 P.M. may be continued to the next regular meeting or an additional meeting date as determined by the Commission Members.

IV. NOTICE REGARDING PUBLIC COMMENTS

Every member of the public who is recognized to speak shall address the Chairman and in speaking, avoid disrespect to the Commission, Town Staff, and other members of the meeting. State your name and address when speaking for the record. UNLESS OTHERWISE AMENDED BY THE PLANNING COMMISSION, COMMENTS ARE LIMITED TO THREE (3) MINUTES.

V. ADOPTION OF THE AGENDA

Commissioner Jackson made a motion to adopt the Wednesday, July 22, 2020 Planning Commission Meeting Agenda. Commissioner Griffin seconded the motion, all were in favor and the motion passed.

VI. ADOPTION OF MINUTES – JUNE 24, 2020

Commissioner Wetmore made a motion to approve the adoption of the June 24, 2020 minutes, Commissioner Keefer second the motion. Chairman Tiller & Commissioner Jackson abstained due to being absent from the last meeting. All were in favor & the motion passed.

VII. PUBLIC COMMENTS FOR ITEMS NOT ON THE AGENDA

No Public Comments

VIII. OLD BUSINESS

DRAFT

No old business.

IX. NEW BUSINESS

No new business.

I. DISCUSSION

Saint Gregory the Great Annexation (Workshop – Discussion Only):** Consideration of a Request submitted by Walter Nester of Burr, Forman, McNair on behalf of the Bishop of Charleston for a request for the annexation of approximately 61.093 acres located at 323 Fording Island Road and identified by Beaufort County Tax Map Nos. R600 022 000 0125 0000 and R600 022 000 1120 0000, into the Town of Bluffton corporate limits (ANNX-07-19-13330) (Staff – Kevin Icard)

Saint Gregory the Great Zoning Map Amendment (Workshop – Discussion Only):** Consideration of a Request by Walter Nester of Burr, Forman, McNair on behalf of the Bishop of Charleston for a Zoning Map Amendment for approximately 61.093 acres located at 323 Fording Island Road and identified by Beaufort County Tax Map Nos. R600 022 000 0125 0000 and R600 022 000 1120 0000 to rezone the subject property to Buckwalter Planned Unit Development (PUD) subject to a new Saint Gregory the Great Land Use Tract to be established through a Buckwalter PUD Text Amendment. (ZONE-07-19-13331) (Staff – Kevin Icard)

Staff Members Kevin Icard and Brie Giroux presented the staff report for the proposed annexation of Saint Gregory the Great located at 323 Fording Island Road, which is incorporated into the minutes.

Commissioner Wetmore would like a capacity study done to determine what usage the county would allow versus what the town will allow.

Vice Chairman Hannock asked if the applicant has thought about including workforce housing with the expansion. The Applicant, Walter Nester, replied it is not part of the application but if the board is making including workforce housing as part of the ask, that is something that can be discussed.

Chairman Tiller asked who decides what entity decides which uses are permitted in each zoning district in Beaufort County (e.g. is it the Board of Zoning Appeals, Town Council, UDO etc.) Staff member Kevin Icard said he would investigate that.

Mr. Nester said that if the development rights that are being requested (commercial acreage and residential dwelling units) are not able to fit on the St. Gregory the Great tract, they will not be transferable. Commissioner Wetmore asked if they were nontransferable & non-sellable. Mr. Nester confirmed that this will be the case.

Chairman Tiller asked if the applicant had any interest in connecting with Eagles Pointe to the North side of the property. Mr. Nester said he was not certain if the interconnectivity could be made there due to the golf course maintenance facility.

Chairman Tiller asked if there was an additional discussion.

Vice Chairman Hannock is concerned about entrances and exits, especially with that density and wanted to reiterate the need for workforce housing.

Staff member Brie Giroux pointed out there are already entrances & exits to both the West & the East.

Chairman Tiller asked for a traffic study to be included when the master plan is presented the commission.

Chairman Tiller asked if there were any more questions.

Commissioner Griffin had no further comment.

Commissioner William's asked that the town comes up with more clear answers to the commission's question before this goes before Town Council.

Staff member Kevin Icard reminded the commission that both items are coming back before the commission next month.

Commissioner Jackson-Denmark stated that she is concerned about the traffic. With the amount of traffic, we are already experiencing in that area, we need to make sure we have efficient entries & exits.

Commissioner Wetmore also voiced his concerns about the traffic. He also requested that we involve The Fire Department in this decision since they are directly affected. Wetmore also pointed out the applicant is likely to receive push back from Berkley Hall residents.

Mr. Nester pointed out the entrance and exit roads already in place are owned by Beaufort County, not the Town of Bluffton.

Commissioner Jackson-Denmark asked if the road will become property of The Town of Bluffton if annexed in. Staff member Kevin Icard replied that the road would remain Beaufort County's.

II. ADJOURNMENT

Vice Chairman Hannock made a motion to adjourn The July 22, 2020 Planning Commission meeting, adjourned at 7:18pm.

DRAFT

PLANNING COMMISSION

STAFF REPORT

DEPARTMENT OF GROWTH MANAGEMENT

MEETING DATE:	August 26, 2020
PROJECT:	STR 07-20-014384 New River Forest - New Street Name Application
PROJECT MANAGER:	Will Howard – Principal Planner

REQUEST: A request by Thomas Hurley of Atlas Surveying on behalf of Richard Schwarz with Village Park Homes for approval of a Street Naming Application.

INTRODUCTION: The Applicant is requesting approval of the following new street names:

1. Kelsey Lane
2. Kenwood Drive

BACKGROUND: This application is for approval of new street names for the approved New River Forest Development Plan, a residential development consisting of 113 single family homes with an amenity center. The property is zoned New Riverside PUD and is identified by tax map number R610 036 000 1318 000 located north and west of the intersection of New Riverside Road and Wheel House Way.

PLANNING COMMISSION ACTIONS: As granted by the powers and duties set forth in Section 2.2.6.C.5 of the Unified Development Ordinance, the Planning Commission has the authority to take the following actions with respect to this application:

1. Approve the application as submitted by the Applicant;
2. Approve the application with conditions; or
3. Deny the application as submitted by the Applicant.

REVIEW CRITERIA & ANALYSIS: Town Staff and the Planning Commission are required to consider the criteria set forth in Section 3.15.3 of the Unified Development Ordinance in assessing an application for the New Street Name. These criteria are provided below followed by a Staff Finding(s) based upon review of the application submittals to date.

1. Section 3.15.3.A Does not already exist within Beaufort County;

2. Section 3.15.3.B Are not street types with the same primary name, such as Smith Street and Smith Boulevard;

3. Section 3.15.3.C Are not name(s) which sound alike or which might be confused with one another;

4. Section 3.15.3.D Does not use frivolous or complicated words, or unconventional spellings;

5. Section 3.15.3.E Are not numbers (such as 1st Street) or alphabetical letters (such as A Street);

6. Section 3.15.3.F Could not be perceived as offensive;

7. Section 3.15.3.G Are simple, logical, easy to pronounce, clear and brief;

8. Section 3.15.3.H Are associated with the history of Bluffton or the character of the Lowcountry when possible;

9. Section 3.15.3.I May represent a common theme within residential developments; and

10. Section 3.15.3.J The application must comply with applicable requirements in the Applications Manual.

Finding. Town Staff finds that the proposed new streets names are acceptable and meet the requirements of Article 3 of the Unified Development Ordinance as stated above.

STAFF RECOMMENDATION: Staff finds that the requirements of Section 3.15.3 have been met and recommends that the Planning Commission approve the New Street Name application as submitted by the Applicant.

ATTACHMENTS:
1. New Street Name Application
2. Site Plan

TOWN OF BLUFFTON
NEW STREET NAME APPLICATION

Growth Management Customer Service Center
20 Bridge Street
Bluffton, SC 29910
(843)706-4522
www.townofbluffton.sc.gov
applicationfeedback@townofbluffton.com

Applicant	Property Owner
Name: Thomas W Hurley	Name: RICHARD SWARTZ
Phone: 843-645-9277	Phone: 704-208-7521
Mailing Address: 49 BROWNS COVE RD. SUITE #5, RIDGELAND, SC29936	Mailing Address: 4454 BLUFFTON PARK CRESCENT SUITE 101, BLUFFTON, SC 29910
E-mail: thurley@atlassurveying.com	E-mail: rschwartz@villageparkgroup.com
Town Business License # (if applicable): LIC-05-17-023210	

Project Information

Proposed Street Name (in order of preference):

1. KELSEY LANE
2. KENWOOD DRIVE
3. PAYTON DRIVE

Street Location:	Tax Map Number(s):
NEW RIVER FOREST SUBDIVISION	R614 036 000 1318 0000

Minimum Requirements for Submittal

- ☒ 1. One (1) original plat and digital file showing the streets, proposed name of each, and a list of the proposed street name(s).
- ☐ 2. Project Narrative and digital file describing reason for application and compliance with the criteria in Article 3 of the UDO.
- ☐ 3. An Application Review Fee as determined by the Town of Bluffton Master Fee Schedule. Checks made payable to the Town of Bluffton.

Disclaimer: **The Town of Bluffton assumes no legal or financial liability to the applicant or any third party whatsoever by approving the plans associated with this permit.**

I hereby acknowledge by my signature below that the foregoing application is complete and accurate and that I am the owner of the subject property. As applicable, I authorize the subject property to be posted and inspected.

Property Owner Signature:	Date: 6/25/20
Applicant Signature: Thomas W. Hurley	Date: 6/25/20

For Office Use

Application Number:	*Date Received:*
Received By:	*Date Approved:*

TOWN OF BLUFFTON
MAJOR SUBDIVISION APPLICATION
PROCESS NARRATIVE

The following Process Narrative is intended to provide Applicants with an understanding of the respective application process, procedures and Unified Development Ordinance (UDO) requirements for obtaining application approval in the Town of Bluffton. While intended to explain the process, it is not intended to repeal, eliminate or otherwise limit any requirements, regulations or provisions of the Town of Bluffton's Unified Development Ordinance. Compliance with these procedures will minimize delays and assure expeditious application review.

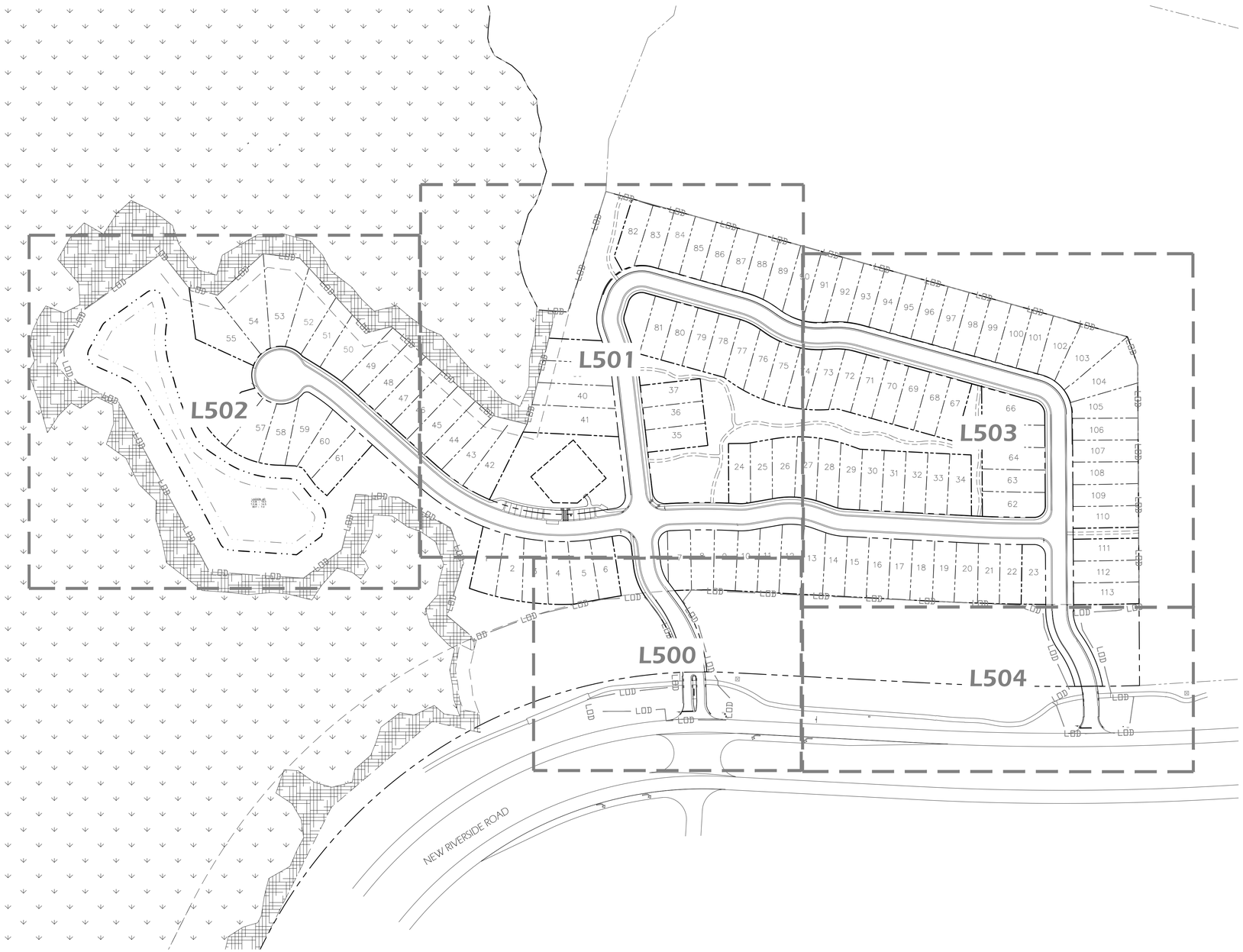
Step 1. Pre-Application Meeting	**Applicant & Staff**
Prior to the filing of a Major Subdivision Application, the Applicant is required to consult with the UDO Administrator or their designee at a Pre-Application Meeting for comments and advice on the appropriate application process and the required procedures, specifications, and applicable standards required by the UDO.	
Step 2. Application Check-In Meeting	**Applicant & Staff**
Upon receiving input from Staff at the Pre-Application Meeting, the Applicant shall submit the Major Subdivision Application and required submittal materials during a mandatory Application Check-In Meeting where the UDO Administrator or designee will review the submission for completeness.	
Step 3. Review by UDO Administrator & Development Review Committee	**Staff**
If the UDO Administrator determines that the Major Subdivision Application is complete, it shall be forwarded to the Development Review Committee (DRC). The DRC shall review the application and prepare written comments for review with the Applicant.	
Step 4. Development Review Committee Meeting	**Applicant & Staff**
A public meeting shall be held with the Applicant to the review the DRC Staff Report and discuss the application. The Applicant will be directed to address any comments, if any, and resubmit the application materials. If applicable, upon resubmittal, the application materials will be reviewed for compliance with the DRC Staff Report and, if all comments are addressed, the application is placed on the next available Planning Commission (PC) Meeting agenda.	
Step 5. Planning Commission Meeting	**Applicant, Staff & Planning Commission**
The PC shall review the Major Subdivision Application for compliance with the criteria and provisions in the UDO. The PC may approve, approve with conditions, or deny the application.	
Step 6. Issue Subdivision Plat	**Staff**
If the PC approves the Major Subdivision Application, the UDO Administrator shall issue the approved Subdivision Plat.	

ATTACHMENT 2

NEW RIVER FOREST

PARCEL 4A-1

TAX MAP NUMBER: PORTION OF R614 036 000 1318 0000



PROJECT TEAM

CLIENT

VILLAGE PARK HOMES

LANDSCAPE ARCHITECTS

WITMER JONES KEEFER, LTD.
BLUFFTON, SOUTH CAROLINA
843-757-7411

CIVIL ENGINEER

CAROLINA ENGINEERING CONSULTANTS
BEAUFORT, SOUTH CAROLINA
843-322-0553

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Witmer Jones Keefer Ltd.
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www.wjkled.com
53 Promenade Street, Suite 201 | Bluffton, South Carolina | 29910 | ph 843.757.7411

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THIS SHEET TO SCALE AT: 24"X36"

SITE DEVELOPMENT PLANS
FOR
NEW RIVER FOREST
PARCEL 4A-1
BLUFFTON, SOUTH CAROLINA

DATE:	OCT 8, 2019
PROJECT NO.:	19057.01
DRAWN BY:	KJ
CHECKED BY:	DK

SUBMITTAL PLAN, NOT FOR CONSTRUCTION

REVISIONS:

DRAWING TITLE

COVER SHEET

DRAWING NUMBER

CS

MEMORANDUM

TO: Planning Commission

FROM: Bryan McIlwee, P.E., Director of Engineering
Kim Jones, CEPSCI, Watershed Mngt. Division Manager

RE: Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual

DATE: 8/26/20

CC: Heather Colin, AICP, Director of Growth Management
Kevin Icard, AICP, Planning & Community Development Manager

REQUEST – For information only.

BACKGROUND – Staff is providing information on the development of the Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual in preparation for a formal recommendation from Planning Commission on 9/23/20 regarding proposed amendments to the Unified Development Ordinance (UDO).

Elected officials from City of Hardeeville, Towns of Bluffton, Ridgeland, and Hilton Head Island, Beaufort County, and Jasper County re-established the Southern Lowcountry Regional Board (SoLoCo) on 8/29/17. The Mission of SoLoCo is "to create a regional think tank that will identify the problems and opportunities that face the entire southern Lowcountry, as defined by the members and regardless of municipal or county boundaries; to discuss the zoning, housing, employment, quality of life and social issues; and to propose action plans to the appropriate legislative bodies."

SoLoCo prioritized the need for a uniform set of stormwater standards and design guidelines to meet the goal of protecting the region's sensitive environment, residents' quality of life, and future economic development opportunities. On 8/29/17, SoLoCo requested each jurisdiction assign a staff member to a subcommittee to investigate current stormwater standards and bring forth a recommendation for standardization. Understanding the importance of the regional approach, SoLoCo-represented staff members invited staff from other jurisdictions not part of the SoLoCo, namely the City of Beaufort and Town of Port Royal, to also participate in the evaluation.

The subcommittee delivered a report on 12/5/17 that compared the eight (8) different stormwater ordinance standards. Recognizing that existing standards may not be current with State of the Knowledge for stormwater management, the subcommittee recommended procuring a consultant team to more efficiently and expeditiously write a regional, unified stormwater

ordinance and manual to meet SoLoCo's goal. The scope of work for procurement included the following:

- Benchmark the region among similar communities in South Carolina and the southeast coast.

- Define stormwater design standards that are consistent with the goal of protecting quality of life, environment, and economic development.

- Engage stakeholders before, during, and after the standards are developed.

Following the recommendation of the subcommittee, SoLoCo voted on 3/27/18 to recommend that each SoLoCo member, as well as the City of Beaufort and Town of Port Royal, hire a consultant and cost-share in funding the project as part of their FY19 budgets. During that meeting, the Towns of Ridgeland and Hilton Head Island stated they would not be participating in the project. The Town of Bluffton's consolidated FY19 budget included this project and prioritized it in the Strategic Plan Fiscal Years (FY) 2019 – 2020 under Focus Area "May River & Surrounding Rivers and Watersheds" with the May River Watershed Action Plan (Action Plan) Update. A component of the Action Plan Update consists of updating "Article 5.10 Stormwater" of the Unified Development Ordinance (UDO), last amended in 2011, to align stormwater design requirements with current State of the Knowledge practices.

SoLoCo recommended on 6/26/18 that Center for Watershed Protection, with support from McCormick Taylor, be awarded the contract in the amount of $179,554 to be cost-shared based upon population. Town Council unanimously adopted a Resolution on 9/11/18 to enter into a Memorandum of Agreement with Beaufort County regarding the financing and production of the regional stormwater ordinance and design manual. Jasper County, Town of Port Royal, City of Beaufort, and City of Hardeeville each entered into their own Memorandums of Agreement with Beaufort County to participate in and fund the project.

The consultant team and project partners received local stakeholder input from the project's outset and garnered feedback from the professional design community during statewide, regional, and national presentations. The resulting Southern Lowcountry Post Construction Stormwater Ordinance (Stormwater Ordinance) and Design Manual are unique in that they accomplish the following:

- Regional collaboration for consistent, effective management of stormwater at the watershed scale.

- The Stormwater Ordinance and Design Manual unify current diversity of municipality requirements due to MS4 permits, need, and community dynamics:
    - Allows for "Special Watershed Protection Area" designations and requirements

  - Establishes post-construction criteria for volume control (quantity and quality) and design standards
  - Provides enforcement for current design through life of the development

- Stormwater Design Manual is watershed-based approach, not by jurisdiction
  - Incorporates green infrastructure/low impact development
  - Protects existing natural areas & incorporates open space in new development
  - Provides water quality and quantity credit for thirteen (13) Best Management Practices (BMPs)

ANTICIPATED UNIFIED DEVELOPMENT ORDINANCE SECTIONS AFFECTED – Staff anticipates the following sections of the UDO may be edited as part of the Southern Lowcountry Post Construction Stormwater Ordinance and Design Manual adoption process and will be discussed further during the 9/23/20 Planning Commission meeting:

- UDO Article 1 – Introduction
  - Section 1.1.13 – Severability

- UDO Article 3 – Application Process
  Changes may be required related to the stormwater permit and process,
  - Section 3.10 – Development Plan
  - Section 3.13 – Development Surety and
  - Section 3.14 – Certificate of Construction Compliance process changes.

- UDO Article 5 – Design Standards
  - Section 5.3 – Natural Resources, Tree Conservation, Planting & Landscaping
  - Section 5.10 – Stormwater, For clarity and consistency with partner jurisdictions, the majority of Article 5.10 Stormwater will be struck through, except for Illicit Discharge Detection and Elimination, and reference the regional Stormwater Ordinance as Appendix "X." The Stormwater Ordinance will reference the Design Manual as Exhibit "Y."

- UDO Article 9 – Definitions and Interpretation

PROJECT TIMELINE

- 12/2018 – Project initiated by Center for Watershed Protection seeking design community input on existing stormwater ordinances.
- 1/2019 – 12/2019 – Subcommittee and consultant team technical meetings.
- 11/7/2019 – Key elements of draft Ordinance and Manual presented at SC Association of Stormwater Managers quarterly meeting.

- 1/6/2020 – 2/27/2020 – Draft Ordinance and Manual available online for Public Comment.
- 1/23/2020 – Jasper County and City of Hardeeville Public Meeting.
- 1/28/2020 – Beaufort County, City of Beaufort, and Town of Port Royal Public Meeting.
- 1/30/2020 – Town of Bluffton Public Meeting.
- 3/6/2020 – Staff and Consultant review of Public Comments.
- 3/20/2020 – 2nd meeting for Staff and Consultant review of Public Comments.
- 3/31/2020 – Final documents provided to all partners.
- 4/14/2020 – Key elements of draft Ordinance and Manual presented at National Watershed and Stormwater Conference.
- 4/24/2020 – Key elements of draft Ordinance and Manual presented at Southeast Stormwater Association Regional Spring Meeting.
- 6/25/2020 – Internal review and legal review of documents.
- 7/28/20 – Staff update provided to SoLoCo for adoption schedules.
- 8/26/2020 – Planning Commission Workshop
- 8/27/2020 – May River Watershed Action Plan recommendation to Planning Commission
- 9/23/2020 – Planning Commission Public Hearing and recommendation to Town Council
- 10/20/2020 – Town Council Workshop
- 11/7/2020 – Town Council First Reading
- 12/8/2020 – Public Hearing and Town Council Second Reading
- 1/1/2021 – Implementation of SoLoCo Regional Stormwater Ordinance & Design Manual

ATTACHMENTS:

1. Southern Lowcountry Stormwater Post Construction Stormwater Ordinance
2. Southern Lowcountry Stormwater Design Manual

Southern Lowcountry Post Construction Stormwater Ordinance

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Post-Construction Stormwater Management Ordinance for the Southern Lowcountry Region

Description: This ordinance addresses post-construction stormwater management in the Southern Lowcountry Region, defined as the jurisdictional boundaries of Beaufort County, Jasper County, City of Beaufort, Town of Bluffton, City of Hardeeville, and Town of Port Royal. The ordinance establishes requirements for stormwater plans that are to be submitted before land development, redevelopment or major substantial improvement commences. The plans document how post-construction stormwater runoff quality and quantity will be effectively managed according to performance criteria described in the Ordinance and Southern Lowcountry Design Manual. Guidelines for inspection, maintenance, and violations are also included and these requirements are hereby incorporated herein. The ordinance incorporates by reference the *Southern Lowcountry Stormwater Design Manual* and technical specifications for stormwater system design.

***Formatting Notes**: Summary boxes precede many sections of the ordinance and provide a descriptive overview and regulatory intent of the section. Language that is italicized in brackets may be altered or removed to suit the needs of the local jurisdiction. Language italicized in sharp brackets should be changed to match the terminology used by the local jurisdiction or to include data specific to the jurisdiction.*

Section 1. General Provisions

1.1. Findings of Fact

It is hereby determined that:

1) Land development or redevelopment activities can alter the hydrologic response of local watersheds by increasing:
    a. stormwater runoff rates, volumes, and pollutant loads;
    b. flooding;
    c. channel erosion;
    d. pollutant transport and deposition in rivers and streams, wetlands, and estuaries;
    e. fluctuations in salinity concentrations and productivity in estuaries; and
    f. beach contamination and subsequent serious threats to human health.
2) Land development or redevelopment activities can alter the hydrologic response of local watersheds, increasing stormwater runoff rates and volumes, and, consequently, decreasing the amount of rainfall that is available to recharge shallow groundwater aquifers;
3) Without proper mitigation in place, some discharges which end up in stormwater management systems are not stormwater discharges and can carry with them harmful metals and other contaminants;
4) The negative impacts of land development or redevelopment activities on local aquatic resources can adversely affect the health, safety and general welfare of the general public;
5) The negative impacts of land development or redevelopment can be controlled and minimized through the regulation of stormwater runoff rates, volumes, and pollutant loads on development and redevelopment sites;

6) Communities within the *Southern Lowcountry* Region are required to comply with a number of State and Federal regulations that require the adverse impacts of stormwater runoff rates, volumes and pollutant loads to be controlled and minimized;
7) Therefore, the *<local jurisdiction>* has determined that it is in the public interest to control and minimize the adverse impacts of land development or redevelopment activities and has established this set of stormwater management provisions to regulate post-construction stormwater runoff rates, volumes and pollutant loads on development and redevelopment sites.

1.2. Purpose and Intent

The purpose of this ordinance is to protect and maintain the integrity of local aquatic resources, and, consequently, the health, safety and welfare of the general public, by establishing minimum stormwater management provisions that control and minimize the adverse impacts of land development or redevelopment activities. This ordinance seeks to meet that purpose through the following objectives:

1) Establish decision-making processes surrounding land development or redevelopment activities that protect the integrity of local aquatic resources;
2) Establish minimum post-development stormwater management standards and design criteria in the *Southern Lowcountry Stormwater Design Manual* that will reduce flooding, channel erosion, and pollutant transport and deposition in local aquatic resources;
3) Establish minimum post-development stormwater management standards and design criteria in the *Southern Lowcountry Stormwater Design Manual* that will help preserve existing hydrologic conditions on development and redevelopment sites;
4) Establish design criteria in the *Southern Lowcountry Stormwater Design Manual* for structural and nonstructural stormwater management practices that can be used to meet the minimum post-development stormwater management standards and design criteria;
5) Establish that Better Site Design (BSD) and site planning has been incorporated, documented, and presented in the development/redevelopment design process.
6) Maintain structural and nonstructural stormwater management practices to ensure that they continue to function as designed and pose no threat to public safety; and,
7) Streamline administrative procedures for the submission, review, approval and disapproval of stormwater management plans and for the inspection of approved land development projects.
8) If any of the stormwater management standards, as defined in this Ordinance and in the *Southern Lowcountry Stormwater Design Manual* cannot be attained on the site (due to impractical site characteristics or constraints), a Maximum Extent Practicable analysis shall be prepared and submitted by the applicant for review, discussion, and ultimate approval of the jurisdiction. Any uncontrolled post-development stormwater quantity or quality volume shall be intercepted and treated in one or more off-site stormwater management practices or a fee-in-lieu shall be required.
9) The stormwater management practices of approved plans shall provide volume control and at least an eighty (80) percent reduction in total suspended solids loads, thirty (30) percent reduction of total nitrogen load, and sixty (60) percent reduction in bacteria load.

1.3. Applicability and Exemptions

1) This ordinance shall be applicable to any new development or redevelopment activity that meets one or more of the following criteria, unless exempt pursuant to Section 1.3.2 below:
    a. New development that involves the creation of 5,000 square feet of impervious surface or that involves other land disturbing activities of one acre or more.
    b. Redevelopment that involves the creation, addition or replacement of 5,000 square feet or more of impervious surface or that involves other land disturbing activities of one acre or more.
    c. New development or redevelopment, regardless of size, that is part of a larger common plan of development, even though multiple, separate and distinct land disturbing activities may take place at different times and on different schedules.
    d. A major substantial improvement of an existing property.
2) The following activities are exempt from this ordinance:
    a. Any maintenance, alteration, renewal, or improvement as approved by *<local jurisdiction>* which does not alter existing drainage pattern, does not result in change or adverse impact on adjacent property, or create adverse environmental or water quality impacts, and does not increase the temperature, rate, quality, or volume or location of stormwater runoff discharge.
    b. Projects that are exclusively for agricultural or silvicultural activities within areas zoned for these agricultural and silvicultural uses;
    c. Agricultural activity not involving relocation of drainage canals;
    d. Redevelopment that constitutes the replacement of the original square footage of impervious cover and original acreage of other land development activity when the original development is wholly or partially lost due to natural disaster or other acts of God occurring after *<date of adoption>*; and,
    e. Work by agencies or property owners required to mitigate emergency flooding conditions. If possible, emergency work should be approved by the duly appointed officials in charge of emergency preparedness or emergency relief. Property owners performing emergency work will be responsible for any damage or injury to persons or property caused by their unauthorized actions. Property owners will stabilize the site of the emergency work within 60 days, or as soon as reasonable, following the end of the emergency period.

1.4. Designation of Ordinance Administrator

The *<administrator>* is hereby appointed to administer and implement the provisions of this ordinance.

1.5. Compatibility with Other Regulations

This ordinance is not intended to interfere with, modify or repeal any other ordinance, rule, regulation, or other provision of law. The requirements of this ordinance should be considered minimum requirements, and where any provision of this ordinance imposes restrictions different from those imposed by any other ordinance, rule, regulation, or other provision of law, whichever provision is more restrictive or imposes higher protective standards for human health or the environment shall control.

1.6. Severability

If the provisions of any section, subsection, paragraph, subdivision, or clause of this ordinance shall be adjudged invalid by a court of competent jurisdiction, such judgment shall not affect or invalidate the remainder of any section, subsection, paragraph, subdivision, or clause of this ordinance.

1.7. Stormwater Management Manual

The *<local jurisdiction>* will utilize the standards, criteria, and information presented in the latest edition of the *Southern Lowcountry Stormwater Design Manual or applicable addendums, appendices, technical memorandums, and/or applicable revisions that may be directly applied* for the proper implementation of this ordinance. This Manual may be updated and expanded periodically, based on improvements in science, engineering, monitoring, local experience, and state or federal water quality requirements.

The procedures and standards set forth in this Stormwater Management Ordinance, and the policies, procedures, and design data specified in the *Southern Lowcountry Stormwater Design Manual* provide the minimum standards to be adhered to by land development and redevelopment activities under the jurisdiction of *<local jurisdiction>*.

The *Southern Lowcountry Stormwater Design Manual* identifies Special Watershed Protection Areas that have standards and criteria specific to land development or redevelopment in the areas.

Section 2. Definitions

"Administrator" means the person appointed by each jurisdiction to execute the requirements of this Ordinance and Stormwater Design Manual.

"Applicant" means a property owner or other responsible person who has submitted an application for a post-development stormwater management permit.

"Best management practice" (BMP) -– Structural or non-structural practice that minimizes the impact of stormwater runoff on receiving waterbodies and other environmental resources, especially by reducing runoff volume and the pollutant loads carried in that runoff.

"Better Site Design" means site design techniques that can be used during the site design process to minimize the creation of new impervious cover and reduce a site's impact on the watershed. Better site design techniques include reduced clearing and grading limits, roadway lengths and widths, and parking lot and building footprints.

"Better Site Planning" means site planning techniques that can be used during the site planning process to protect and conserve natural areas that are critical in preserving pre-development site hydrology and reducing a site's impact on the watershed. Better site planning techniques include conserving significant stands of trees and other vegetation, natural drainage features, and riparian buffers.

"Building" means any structure, either temporary or permanent, having walls and a roof, designed for the shelter of any person, animal, or property, and occupying more than 100 square feet of area.

"Channel" means a natural or artificial watercourse with a definite bed and banks that conducts continuously or periodically flowing water.

"Dedication" means the deliberate appropriation of property by its owner for general public use.

"Detention" means the temporary storage of stormwater runoff in a stormwater management practice for the purpose of controlling the peak discharge.

"Developer" means a person who undertakes land development or redevelopment activities.

"Development" is a term that means the physical improvement of land by land disturbing activities or construction of infrastructure, buildings and structures allowed through site plan, development plan or subdivision approval.

"Drainage Easement" means an easement appurtenant or attached to a tract or parcel of land allowing the owner of adjacent tracts or other persons to discharge stormwater runoff onto the tract or parcel of land subject to the drainage easement.

"Easement" means a legal right granted by a land owner to a grantee allowing the use of private land for conveyance or treatment of stormwater runoff and access to stormwater management practices.

"Erosion and Sedimentation Control Plan" means a plan that is designed to minimize the accelerated erosion and sediment runoff at a site during land development or redevelopment activities.

"Evapotranspiration" means the loss of water to the atmosphere by both evaporation and transpiration, through the uptake of water by plants.

"Existing Conditions" means land use and land cover conditions at the time of a land development or redevelopment permit application.

"Extreme Flood Protection" means measures taken to prevent adverse impacts from large low-frequency storm events with a return frequency of 100 years or more.

"Fee-in-lieu" means a payment collected by approval of a local jurisdiction as an alternative to meeting the requirements of onsite stormwater control facilities.

"Flooding" means a volume of surface water that is too great to be confined within the banks or walls of a conveyance or stream channel and that overflows onto adjacent lands.

"Greenspace" or "**Open Space**" means permanently protected areas of the site that are preserved in a natural state.

"Hydrologic Soil Group (HSG)" means a Natural Resource Conservation Service classification system in which soils are categorized into four runoff potential groups. The groups range from group A soils, with high permeability and little runoff produced, to group D soils, which have low permeability rates and produce much more runoff.

"Impaired Waters" means those streams, rivers and lakes that currently do not meet their designated use classification and associated water quality standards and as identified in the Clean Water Act Section 303(d) list by the South Carolina Department of Health and Environmental Control.

"Impervious Cover" means a surface composed of any material that impedes or prevents the passive, natural infiltration of water into soil. Impervious surfaces include, but are not limited to, rooftops, buildings, streets, roads, and compacted stone or gravel, except those designed specifically to provide active, engineered infiltration.

"Infill Development" means land development that occurs within designated areas based on local land use, watershed, and/or utility plans where the surrounding area is generally developed, and where the site or area is either vacant or has previously been used for another purpose.

"Infiltration" means the process of percolating stormwater runoff into the subsoil.

"Infiltration Practice" means any stormwater management practice designed to provide active, engineered infiltration of retained water to the subsurface. These stormwater management practices may be above or below grade.

"Inspection and Maintenance Agreement and Covenant" means a written agreement and covenant providing for the long-term inspection and maintenance of stormwater management facilities and practices on a site or with respect to a land development or redevelopment project, which when properly recorded in the deed records constitutes a restriction on the title to a site or other land involved in a development project.

"Land Development" means any change in land cover, including, but not limited to, clearing, digging, grubbing, stripping, removal of vegetation, dredging, grading, excavating, filling, and paving, that alters the hydrologic response of local watersheds.

"Land Development Activities" means those actions or activities that comprise, facilitate, or result in land development.

"Land Development Project" means a discrete land development undertaking.

"Larger Common Plan of Development" means a common plan for development or sale. It identifies a site where multiple separate and distinct construction activities (areas of disturbance) are occurring on contiguous areas. Such sites may have one operator or owner or several operators and owners. Construction activities may take place at different times on different schedules, in separate stages, and/or in separate phases, and/or in combination with other construction activities. Each developer, operator or owner for each site or project determined to be a part of a larger common plan of development are subject to land development approval and permitting requirements as defined herein and the Southern Lowcountry Design Manual.

"Low Impact Development" means small-scale, distributed stormwater management practices that can be used during the site design process to replicate existing hydrologic conditions, help offset the creation of new impervious cover, and reduce a site's impact on the watershed.

"Major Substantial Improvement" is a renovation or addition to a structure that meets both of the following cost and size thresholds: a) construction costs for the building renovation/addition are greater than or equal to 50% of the pre-project assessed value of the structure as developed using current Building Valuation Data of the International Code Council, and b) combined footprint of structure(s) exceeding the cost threshold and any land disturbance is greater than or equal to 5,000 square feet.

"Maximum Extent Practicable (MEP)" refers to the extent of efforts to comply with local post-construction stormwater management requirements. Elements of MEP indicate serious intent to comply and include selecting and implementing design elements to address site restrictions. Maximum extent practicable is defined as the following:

- Proponents of redevelopment projects have made all reasonable efforts to meet the applicable *Southern Lowcountry Stormwater Design Manual*;
- They have made a complete evaluation of possible stormwater management measures including environmentally sensitive site design that minimize land disturbance and impervious surfaces, low impact development techniques, and stormwater best management practices (BMPs); and,

- If not in full compliance with the applicable Standards, they are implementing the highest practicable level of stormwater management.

"New Development" means a land development activity on a previously undeveloped site.

"Nonpoint Source Pollution" means a form of water pollution that does not originate from a discrete point, such as a sewage treatment plant or industrial discharge, but involves the transport of pollutants, such as sediment, fertilizers, pesticides, heavy metals, oil, grease, bacteria, nutrients, organic materials, and other contaminants from land to surface water and groundwater via mechanisms such as precipitation, stormwater runoff and leaching. Nonpoint source pollution is a by-product of land use practices, such as agriculture, silviculture, mining, construction, subsurface disposal, suburban and urban runoff.

"Nonstructural Stormwater Management Practice" or **"Nonstructural Practice"** means any natural or planted vegetation or other nonstructural component of the stormwater management plan that provides for or enhances stormwater quantity and/or quality control or other stormwater management benefits and includes, but is not limited to, riparian buffers, open and greenspace areas, overland flow filtration areas, natural depressions, and vegetated channels.

"Off-Site Facility" means a stormwater management facility located outside the boundaries of the site.

"On-Site Facility" means a stormwater management facility located within the boundaries of the site.

"Overbank Flood Protection" means measures taken to prevent an increase in the frequency and magnitude of out-of-bank flooding (i.e. flow events that exceed the capacity of the channel and enter the floodplain) and that are intended to protect downstream properties from flooding for the 2-year through 25-year frequency storm events.

"Owner" means the legal or beneficial owner of a site, including, but not limited to, a mortgagee or vendee in possession, receiver, executor, trustee, lessee or other person, firm, or corporation in control of the site.

"Permit" means the permit issued by the <*local jurisdiction*> to the applicant, which is required for undertaking any land development or redevelopment activity.

"Person" means, except to the extent exempted from this ordinance, any individual, partnership, firm, association, joint venture, public or private corporation, trust, estate, commission, board, public or private institution, utility, cooperative, city, county or other political subdivision of the State, any interstate body, or any other legal entity.

"Post-development" refers to the time period or the conditions that may reasonably be expected or anticipated to exist, after completion of the land development or redevelopment activity on a site.

"Pre-development" refers to the time period or the conditions that exist, on a site prior to land development. For the purpose of determining pre-development surface runoff conditions, it is assumed that predevelopment is meadow conditions.

"Project" means a land development or redevelopment project.

"Recharge" means the replenishment of groundwater aquifers.

"Redevelopment" means a change to previously existing, improved property, including but not limited to the building of structures, filling, grading, paving, or excavating, but excluding ordinary maintenance

activities, remodeling of buildings on the existing footprint, resurfacing of paved areas, and exterior changes or improvements that do not materially increase or concentrate stormwater runoff or cause additional nonpoint source pollution..

"Regional Stormwater Management Facility" or **"Regional Facility"** means stormwater management facilities designed to control stormwater runoff from multiple properties, where the owners or developers of the individual properties may assist in the financing of the facility and the requirement for on-site controls in the contributing drainage area is either eliminated or reduced.

"Riparian Buffer" means an area of land at or near a streambank, wetland, or waterbody that has intrinsic water quality value due to the ecological and biological processes it performs or is otherwise sensitive to changes which may result in significant degradation of water quality.

"Runoff" means stormwater runoff.

"Runoff Reduction" means the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainwater harvesting, engineered filtration, or extended filtration.

"Site" means the parcel of land being developed, or the portion thereof on which the land development or redevelopment project is located.

"Special Watershed Protection Area" means a watershed or drainage catchment designated by the <*local jurisdiction*> to provide specific stormwater management requirements beyond those established in the *Southern Lowcountry Stormwater Design Manual* for the general three watershed protection areas of the Southern Lowcountry.

"Stop Work Order" means an administrative order that requires development activity on a site to be stopped. The extent of the stop work order is determined by the <*local jurisdiction*> and is identified in accompanying details of each Order.

"Stormwater Hotspot" means an area where land use or activities generate highly contaminated runoff with concentrations of pollutants in excess of those typically found in stormwater runoff. The following operations are examples of, but not limited to, stormwater hot spots in this ordinance: car washes, industrial sites, auto repair shops, parking garages, vehicle fueling and storage areas, golf courses, marinas, and transportation equipment repair facilities.

"**Stormwater Management Practice**" means structural and nonstructural practices that control stormwater runoff and provide for or enhance stormwater quantity and/or quality control or other stormwater management benefits.

"Stormwater Management" means the collection, conveyance, storage, treatment, and disposal of stormwater runoff in a manner intended to prevent increased flood damage, streambank channel erosion, habitat degradation, and water quality degradation and to enhance and promote the public health, safety, and general welfare.

"Stormwater Management Facility" means any infrastructure that controls or conveys stormwater runoff.

"Stormwater Management Plan" means a document describing how existing runoff characteristics will be affected by a land development or redevelopment project and containing measures for complying with the provisions of this ordinance.

"Stormwater Management System" means the entire set of structural and nonstructural stormwater management practices that are used to capture, convey, and control the quantity and quality of the stormwater runoff.

"Stormwater Retrofit" means a stormwater management practice designed for an existing development site that previously had either no stormwater management practice in place or a practice inadequate to meet the requirements of the *Southern Lowcountry Stormwater Design Manual*.

"Stormwater Runoff" means the flow of surface water resulting from precipitation.

"Structural Stormwater Management Practice" means a structural stormwater management facility or device that controls stormwater runoff and changes the characteristics of that runoff including, but not limited to, the quantity and quality, the period of release, or the velocity of flow of such runoff.

"Subdivision" means the division of a parcel of land resulting in one or more new lots or building sites for the purpose, whether immediately or in the future, of sale, transfer of ownership, or land development or redevelopment, and includes divisions of land resulting from or made in connection with the layout or development of a new street or roadway or a change in an existing street or roadway.

"Violation" means to transgress conditions of a permit, development plan, maintenance agreement, or local or state statutes.

"Watercourse" means a permanent or intermittent stream or other body of water, either natural or man-made, which gathers or carries surface water.

"Watershed Management Plan" means a document, usually developed cooperatively by government agencies and other stakeholders, to protect, restore, and/or otherwise manage the water resources within a particular watershed or subwatershed. The plan commonly identifies threats, sources of impairment, institutional issues, and technical and programmatic solutions or projects to protect and/or restore water resources.

"Watershed Protection Area" means a watershed or drainage catchment designated in the *Southern Lowcountry Stormwater Design Manual* with specific stormwater management requirements that are intended to enhance the quality of development, protect and enhance stormwater quality and management, protect aquatic resources from the negative impacts of land development process, address water quality impairments or a total maximum daily load, as identified by the South Carolina Department of Health and Environmental Control (DHEC), or address localized flooding issues.

Section 3. Permit Procedures and Requirements

3.1 Permit Application Requirements

No owner or developer shall perform any land development or redevelopment activity without first meeting the requirements of this ordinance and the *Southern Lowcountry Stormwater Design Manual* and having been issued a permit from the *<local jurisdiction>*. Unless specifically exempted by this ordinance, any owner or developer proposing a land development or redevelopment activity shall submit to the *<local jurisdiction>* a permit application and accompanying items as dictated in the *Southern Lowcountry Stormwater Design Manual* and *<local jurisdiction>* for that purpose.

The *<Administrators>* shall use the criteria, and information, including technical specifications and standards, in the *Southern Lowcountry Stormwater Design Manual* as the basis for decisions about

stormwater plans and about the design, implementation and performance of structural and non-structural stormwater systems. The *Southern Lowcountry Stormwater Design Manual* standards shall describe in detail how post-development stormwater runoff will be controlled and managed, the design of all stormwater facilities and practices, the components of a project plan necessary to meet the requirements of this Ordinance and post-construction maintenance and inspection requirements.

3.2 Maximum Extent Practical Guidelines and Process

Maximum extent practicable, or "MEP," is the language of the Clean Water Act that sets the standards to evaluate efforts pursued to achieve pollution reduction to the waters of the United States. It is the determination of this Ordinance that all proposed development and redevelopment sites meet the requirements of the Southern Lowcountry Stormwater Design Manual to achieve reduction of pollution to the waters of the Southern Lowcountry. If it is technically infeasible to do so, the applicant shall document and provide such information to <*local authority*> for review. Information provided shall demonstrate how a combination of several iterations of Better Site Design and post development stormwater management design scenarios fail to meet the minimum requirements of the Southern Lowcountry Stormwater Design Manual and justification of their determination of infeasibility. Cost is not a viable justification.

The MEP process defined by the Southern Lowcountry Stormwater Design Manual shall be the basis of submittals for plan approval under this Ordinance. The MEP submittal must provide documentable evidence of the process the applicant has performed that demonstrates the restrictions to the use and implementation of BMPs to meet the requirements of this Manual in whole or in part. The consideration for a waiver of this Ordinance's requirements will rely on the MEP submittal and <*Administrator*> review.

3.3 Performance Bonds

Bonding for the cost of stormwater facilities approved for the proposed development shall be provided in accordance with the <*local jurisdiction*> performance bond and permit issuance process. The <*local jurisdiction*> shall require from the developer a surety or cash bond, irrevocable letter of credit, or other means of security acceptable to the <*local jurisdiction*> prior to the issuance of any building, grading and/or stormwater permit for any land development, redevelopment or major substantial improvement activity requiring a permanent stormwater management system. The bond required in this Section shall include provisions relative to forfeiture for failure to complete work specified in the approved stormwater management design plan, compliance with all of the provisions of this ordinance, other applicable laws and regulations, and any time limitations.

3.4 Waivers

Individuals seeking a waiver from the requirements of this Ordinance may submit to the *(administrator)* a request for a waiver in accordance with the Southern Lowcountry Stormwater Design Manual.

3.5 Fee-in-Lieu

A fee-in-lieu process shall be established by <*local jurisdiction*> for development projects when none or only partial stormwater requirements can be met. The intent of the fee-in-lieu is to perform or construct future stormwater management BMP projects to mitigate impacts resulting from the development

project. The fee-in-lieu may apply in both a waiver and non-waiver development and redevelopment review process.

Section 4. Post-Construction Stormwater Management Criteria

All development and redevelopment sites shall utilize structural and nonstructural stormwater management practices to control and minimize the increased stormwater runoff rates, volumes, and pollutant loads caused by land development in accordance with the criteria presented in the *Southern Lowcountry Stormwater Design Manual*.

For structural and nonstructural stormwater management practices not included in the *Southern Lowcountry Stormwater Design Manual*, or for which pollutant removal and runoff reduction rates have not been provided, the effectiveness of the structural or nonstructural stormwater management practice must be documented through prior studies, literature reviews, or other means and receive approval from the *<local jurisdiction>* before being included in the design of a stormwater management system. In addition, if the site is located in a Watershed Protection Area or a Special Watershed Protection Area the *<local jurisdiction>* may impose additional requirements as deemed necessary, which are located in the *Southern Lowcountry Stormwater Design Manual*.

4.1 Stormwater Volume Control

Some portion of the stormwater runoff generated on a development or redevelopment site shall be captured and retained, reused, or otherwise reduced in order to preserve and/or replicate pre-development site hydrology, recharge shallow groundwater aquifers, promote baseflow to on-site and downstream aquatic resources, and minimize the water quality impacts of land development. Applicants shall follow the runoff reduction, peak flow and extreme flood requirements in the *Southern Lowcountry Stormwater Design Manual*.

4.2 Stormwater Conveyance Systems

Stormwater conveyance systems, which may include but are not limited to culverts, stormwater drainage pipes, catch basins, drop inlets, junction boxes, headwalls, gutters, swales, channels, ditches, and energy dissipaters, shall be provided when necessary for the protection of public right-of-way and private properties adjoining development and redevelopment sites and/or public right-of-ways. Stormwater conveyance systems that are designed to convey stormwater runoff from more than one parcel shall meet the following requirements:

1. Methods used to calculate stormwater runoff rates and volumes shall be in accordance with the latest edition of the *Southern Lowcountry Stormwater Design Manual*;

2. All culverts, pipe systems, and open channel flow systems shall be sized in accordance with the stormwater management design plan using the methods included in the latest edition of the *Southern Lowcountry Stormwater Design Manual*; and,

3. Planning and design of stormwater conveyance systems shall be in accordance with the criteria and specifications found in the latest edition of the *Southern Lowcountry Stormwater Design Manual.*

4. Off-site discharge points in the final approved stormwater plan submission must be identified and the receiving conveyance system must be determined and certified by the Applicant

Engineer to be adequate by the applicant/engineer to convey the 25-year storm and not have negative impact on downstream properties.

4.2.1 Overbank Flood Protection

All stormwater management systems shall be designed to control the post-development peak discharge generated by the overbank flood protection storm event, as defined in the latest edition of the *Southern Lowcountry Stormwater Design Manual*, to prevent an increase in the frequency and magnitude of damaging overbank flooding and safely convey the design storms. A stormwater management system complies with this requirement if:

1) It provides overbank flood protection in accordance with the criteria and information provided in the latest edition of the *Southern Lowcountry Stormwater Design Manual*; and,

2) Appropriate structural and nonstructural stormwater management practices have been selected, designed, constructed, and maintained in accordance with the standards, criteria, and information presented in the latest edition of the *Southern Lowcountry Stormwater Design Manual*.

Off-site discharge points in the final approved stormwater plan submission must be identified and the receiving conveyance system must be determined and certified by the Applicant Engineer to be adequate by the applicant/engineer to convey the 2- to 25-year, 24-hour storm and not have negative impact on downstream properties.

4.2.2 Extreme Flood Protection

All stormwater management systems shall be designed to control and/or safely convey the post-development peak discharge generated by the extreme flood protection storm event, as defined in the latest edition of the *Southern Lowcountry Stormwater Design Manual*, to protect downstream properties from flood damage, maintain the boundaries of existing floodplains, and protect the physical integrity of downstream stormwater conveyance features and flood control facilities. A stormwater management system complies with this requirement if:

- It provides extreme flood protection in accordance with the criteria and information provided in the latest edition of the *Southern Lowcountry Stormwater Design Manual*;

- Appropriate structural and nonstructural stormwater management practices have been selected, designed, constructed, and maintained in accordance with the standards, criteria, and information presented in the latest edition of the *Southern Lowcountry Stormwater Design Manual*; and

- Adequate 100 year flow overflow path (as documented in the 10% analysis submission) from the site to adjacent properties is identified and determined to not have a negative impact on existing downstream receiving conveyance system(s), adjacent properties, and/or structures; this overflow path must be certified by a professional engineer.

4.3 Structural Stormwater Management Practices

All structural stormwater management practices shall be selected, designed, constructed, and maintained in accordance with the standards, criteria, and information presented in the latest edition of

the *Southern Lowcountry Stormwater Design Manual* and any relevant addenda. Applicants shall consult the latest edition of the *Southern Lowcountry Stormwater Design Manual* for guidance on selecting structural stormwater management practices that can be used to satisfy the post-construction stormwater management criteria.

Section 5. Construction of Stormwater Management Systems

The <*local jurisdiction*> is authorized under this Ordinance to require performance bonds for construction of stormwater management systems, as detailed in the *Southern Lowcountry Stormwater Design Manual*.

The <*local jurisdiction*> is authorized under this Ordinance to perform construction inspections including, but not limited to, preconstruction, preclearing, and construction sequence inspections as detailed in the *Southern Lowcountry Stormwater Design Manual*.

The <*local jurisdiction*> is authorized under this Ordinance to perform final construction inspections and require "as built" plans for all permanent stormwater management practices as detailed in the *Southern Lowcountry Stormwater Design Manual*.

Section 6. Ongoing Inspection and Maintenance of Stormwater Management Systems

The <local jurisdiction> is authorized under this Ordinance to perform and require ongoing inspections and maintenance of stormwater management systems as detailed in the *Southern Lowcountry Stormwater Design Manual*.

Section 7. Violations, Enforcement, and Penalties

The <*local jurisdiction*> is authorized under this Ordinance to enforce the provisions of this ordinance as described in <*local jurisdiction*> violations, enforcement and penalties process. Any action or inaction that violates the provisions of this ordinance or the requirements of an approved stormwater management design plan, stormwater management inspection and maintenance agreement and plan, or permit may be subject to the enforcement actions. Any such action or inaction that is continuous with respect to time is deemed to be a public nuisance and may be abated by injunctive or other equitable relief.

ATTACHMENT 2

Southern Lowcountry Stormwater Design Manual

Stormwater Best Management Practices

Prepared by

Center for Watershed Protection

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Acronym Definitions

Acronym/Abbreviation	Definition
ARC	Antecedent Runoff Condition
BMP	Best Management Practice
BSD	Better Site Design
CDA	Contributing Drainage Area
CN	Curve Number
C-SWPPP	Construction Stormwater Pollution Prevention Plan
EGL	Energy Grade Line
EPA	United States Environmental Protection Agency
ESC	Erosion and Sediment Control
FHWA	Federal Highway Administration
GI	Green Infrastructure
HDS	Hydraulic Design Services
HGL	Hydraulic Grade Line
HUC	Hydrologic Unit Code
IWS	Internal Water Storage
LID	Low-Impact Development
LOD	Limits of Disturbance
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
NC DEQ	North Carolina Department of Environmental Quality
NEH	National Engineering Handbook
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PROW	Public Right-of-Way
PUD	Planned Unit Development
SC DHEC	South Carolina Department of Health and Environmental Control
SC DOT	South Carolina Department of Transportation
SDA	Site Drainage Area
SWMP	Stormwater Management Plan
SWRv	Stormwater Retention Volume

Chapter 1. Introduction, Background, Purpose, and Administration

1.1 Introduction

Upon passage of the Southern Lowcountry Stormwater Ordinance as amended and adopted by <*local jurisdiction*>, participating municipalities/jurisdictions will follow the design and permitting requirements of the *Southern Lowcountry Stormwater Design Manual*. The Ordinance directs residents, land developers, redevelopment, and government permit applicants to submit details and plans that comply with this Manual. It is the intent of the Ordinance that all proposed development, redevelopment, and major substantial improvement shall provide stormwater quality control for the stormwater retention volume (SWRv) for Watershed Protection Areas and/or Special Watershed Protection Areas. In the following chapters, Better Site Design (BSD) practices, green infrastructure/low impact development practices (GI/LID), and stormwater best management practices (BMPs) are described in detail to support the stormwater retention requirements. Through in-line and off-line application of these practices, the cumulative impact is reduction of the runoff and the retention on site of design storms.

This Manual and the design criteria presented within represent good engineering practice and should be used in the preparation of stormwater management plans. The criteria are intended to establish requirements, minimum standards, and methods for a sound planning, design, and review process. It is intended to guide the stormwater design review of proposed work done by developers, private parties, and governmental agencies.

1.2 Background

The U.S. Environmental Protection Agency (EPA) recommends that the Phase II Small Municipal Separate Storm Sewer System (MS4) permit require the permittee to adopt a planning process that identifies the municipality's program goals (e.g., minimize water quality impacts resulting from post-construction runoff from new development and redevelopment), implementation strategies (e.g., adopt a combination of structural and/or non-structural BMPs), operation and maintenance policies and procedures, and enforcement procedures. In developing the program, EPA states that the permit should also require the permittee to assess existing ordinances, policies, programs and studies that address stormwater runoff quality. These policy assessments should include the following:

- Policies and ordinances that:
    - provide requirements and standards to direct growth to identified areas,
    - protect sensitive areas such as wetlands and riparian areas,
    - maintain and/or increase open space (including a dedicated funding source for open space acquisition),
    - provide buffers along sensitive water bodies,
    - minimize impervious surfaces, and
    - minimize disturbance of soils and vegetation;
- Policies or ordinances that encourage infill development in higher density urban areas and areas with existing infrastructure;
- Education programs for developers and the public about project designs that minimize water quality impacts; and
- Measures such as minimization of percent impervious area after development and minimization of directly connected impervious areas (81 Federal Register 237).

1.3 Purpose

This Manual's purpose is to provide a framework for designing a stormwater management system to:

- Improve water quality through runoff reduction to the maximum extent practicable (MEP);
- Prevent downstream stream bank and channel erosion;
- Reduce downstream overbank flooding; and
- Safely pass or reduce the runoff from extreme storm events.

This Manual presents a unified approach for sizing stormwater best management practices (BMPs) in the Southern Lowcountry to meet pollutant removal goals, reduce peak discharges, and pass extreme floods. Additionally, it follows a watershed approach for their size and specification. Based on the site's watershed, stormwater design criteria specific to each must be met for development permit approval.

1.4 Applicability and Exemptions

1.4.1 Applicability

Design criteria in this Manual are applicable to any new development or redevelopment activity that meets one or more of the following criteria, or is a major substantial improvement, unless exempt pursuant to Section 1.4.2 below:

1. New development that involves the creation of 5,000 square feet of impervious surface or that involves other land disturbing activities of one acre or more.
2. Redevelopment that involves the creation, addition, or replacement of 5,000 square feet or more of impervious surface or that involves other land disturbing activities of one acre or more.
3. New development or redevelopment, regardless of size, that is part of a larger common plan of development, even though multiple, separate and distinct land disturbing activities may take place at different times and on different schedules.
4. A major substantial improvement of an existing property, which is defined as a renovation or addition to a structure that meets both of the following cost and size thresholds: a) construction costs for the building renovation/addition are greater than or equal to 50% of the pre-project assessed value of the structure as developed using current Building Valuation Data of the International Code Council, and b) project size where the combined footprint of structure(s) exceeding the cost threshold and any land disturbance is greater than or equal to 5,000 square feet.

The design criteria are applicable for infill development of platted lots, whether they are new development or redevelopment sites if the work involves creation, addition or replacement of 5,000 square feet or more of impervious surface or that involves other land disturbing activities of one acre or more.

1.4.2 Exemptions

The following activities are exempt from the permitting requirements of this Manual:

1. Any maintenance, alteration, renewal, or improvement as approved by *<local jurisdiction>* which does not alter existing drainage pattern, does not result in change or adverse impact on adjacent property, or create adverse environmental or water quality impacts, and does not increase the temperature, rate, quality, volume, or location of stormwater runoff discharge.
2. Projects that are exclusively for agricultural or silvicultural activities within areas zoned for these agricultural and silvicultural uses;
3. Agricultural activity not involving relocation of drainage canals;

4. Redevelopment that constitutes the replacement of the original square footage of impervious cover and original acreage of other land development activity when the original development is wholly or partially lost due to natural disaster or other acts of God occurring after <*date of adoption*>; and,
5. Work by agencies or property owners required to mitigate emergency flooding conditions. If possible, emergency work should be approved by the duly appointed officials in charge of emergency preparedness or emergency relief. Property owners performing emergency work will be responsible for any damage or injury to persons or property caused by their unauthorized actions. Property owners will stabilize the site of the emergency work within 60 days, or as soon as reasonable, following the end of the emergency period.

1.5 Administration

1.5.1 Approval Requirements

Before the <*local jurisdiction*> may issue a stormwater permit for any project requiring stormwater management, the <*local jurisdiction*> must approve a Stormwater Management Plan (SWMP) meeting the requirements of the Southern Lowcountry Stormwater Ordinance and receive all fees required by the <*local jurisdiction*> for site and building development plans.

A complete SWMP submittal includes a completed engineer's certification statement, a submittal checklist, plans and design that are signed and sealed by a registered professional engineer licensed in South Carolina. Erosion and sediment control for sites below the South Carolina Department of Health and Environmental Control (SC DHEC) National Pollutant Discharge Elimination System (NPDES) General Permit for Stormwater Discharges from Construction Activities (SCR100000) thresholds must obtain permit coverage under this stormwater permit. All construction stormwater permit applications above the SC DHEC thresholds are reviewed by the DHEC Office of Coastal Resources Management, or the reviews are delegated to the <*local jurisdiction*> to determine compliance with the requirements of SCDHEC's NPDES General Permit for Stormwater Discharges from Construction Activities (SCR100000) and of the Construction Stormwater Pollution Prevention Plan (C-SWPPP). These permit applications must be approved, issued, and provided to <*local jurisdiction*> prior to the issuance of the stormwater management plan approval.

1.5.2 Fees

An applicant is responsible for paying fees that provide for the cost of review, administration, and management of the stormwater permitting process and inspection of all projects subject to the requirements of <*the local jurisdiction*>. These fees are posted by the <*local jurisdiction*>.

Chapter 2. Design, Review, & Permitting Process

2.1 Satisfying the Stormwater Management, Site Planning, & Design Criteria

2.1.1 Overview

This chapter presents a comprehensive set of site planning and design and post-construction criteria that must be applied to new development and redevelopment activities occurring within the Southern Lowcountry region. Satisfying these criteria promotes the systematic development of acceptable stormwater management plans, and a successful integration of natural resource protection and stormwater management through the site planning and design process (Figure 2.1).

Through the use of Better Site Design, as described in detail below, the integration of natural resource protection and stormwater management can be achieved by:

- Identifying and protecting valuable natural resources;
- Limiting land disturbance, new impervious cover, and disturbed pervious cover; and
- Reducing and managing post-construction stormwater runoff rates, volumes, and pollutant loads.

This approach involves the use of two distinct but complementary groups of natural resource protection and stormwater management techniques:

- Green Infrastructure Practices: Natural resource protection and stormwater management practices and techniques (i.e., better site planning and design techniques, low impact development practices) that can be used to help prevent increases in post-construction stormwater runoff rates, volumes and pollutant loads.
- Stormwater Management Practices: Stormwater management practices (e.g., wet ponds, swales) that can be used to manage post-construction stormwater runoff rates, volumes and pollutant loads.

Natural resource protection and stormwater management techniques help control and minimize the negative impacts of the land development process while retaining and, perhaps, even enhancing a developer's vision for a development site. When applied during the site planning and design process, they can be used to create more natural and aesthetically pleasing development projects and create more cost-effective post-construction stormwater management systems (ARC, 2001). The use of these techniques, particularly the green infrastructure practices, can even reduce overall development costs while maintaining or increasing the resale value of a development project (MacMullan and Reich, 2007; US EPA, 2007; Winer-Skonovd et al., 2006).

2.1.2 Better Site Design in the Planning Process

Better Site Design (BSD) refers to planning land development using certain principles to minimize stormwater impacts. Integral to low impact development design, proper application of BSD principles can allow for smaller required stormwater BMP storage and retention volumes, and can help provide significant reductions in post-construction peak flows and pollutant loads. These principles include reduction/restoration of impervious cover, conservation of natural cover areas, stream restoration, and integration of both structural and non-structural stormwater management within site design. The principles of Better Site Design are referenced in the sections below.

Fundamental to the application of Better Site Design is the correlation between impervious surface area in a watershed and negative impacts on receiving water resources. On a national level, the Impervious

Cover Model (ICM) estimates stream quality based on percentage of impervious cover (Schueler and Fraley-McNeal, 2009). This model demonstrates that streams follow a continuous gradient of degradation in response to increasing impervious cover in a watershed. Local studies have supported this paradigm, and report that changes in the rate and volume of stormwater runoff were primary causes of ecological impairment in headwater tidal creeks, such as those found in Beaufort and Jasper Counties. These studies have shown that physical and chemical characteristics such as altered hydrography, increased salinity variance, increased chemical contaminants, and increased fecal coliform loadings of tidal creeks were negatively impacted with as little as 10 to 20% impervious cover. When impervious cover exceeded 30% of the watershed, measurable impacts to living resources were observed, indicating the ecological processes in the creek ecosystems were impaired (Holland et al., 2004).

Such findings are of consequence to Beaufort and Jasper Counties. Increasing pressure for development in response to population growth, and land development practices of the Lowcountry result in significant tree removal and loss of vegetative cover from land grading and storm pond construction and increases in impervious surfaces. According to the NOAA C-CAP Land Cover Analysis (https://coast.noaa.gov/ccapatlas/), from 1996 to 2010, the percent net increase in impervious surface area was 60% for Beaufort County and 59% for Jasper County. Table 2. 1 below summarizes the findings of this NOAA report. Although the percentage of total wetlands lost is relatively low for both counties, the actual wetland types have been converted from palustrine forested wetlands to palustrine scrub/shrub and palustrine emergent wetlands, which may alter ecosystem processes and hydrology in these areas.

Table 2.1. Summary of land cover changes in Southern Lowcountry from 1996 to 2010.

	Beaufort County[1]			Jasper County[1]		
Land Cover %	**1996**	**2010**	**% Change**	**1996**	**2010**	**% Change**
Development	3.87	6.16	+59.12	1.62	2.52	+55.15
Forested Area	25.28	21.5	-14.98	62.50	48.37	-22.60
Wetlands	33.85	33.20	-1.93	45.24	44.74	-1.11

[1] Percent of County under each land cover type.

Given the rapid growth the Southern Lowcountry experienced in the past 20 years, the goals of Better Site Design should resonate with those charged with managing stormwater and its release into the area watersheds. Succinctly, the goals of Better Site Design include the following:

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

The Center for Watershed Protection's Better Site Design Handbook outlines 22 model development principles for site design that act to reduce impervious cover, conserve open space, prevent stormwater pollution, and reduce the overall cost of development (CWP, 2017). The principles can provide notable

reductions in post-construction stormwater runoff rates, volumes and pollutant loads (ARC, 2001). Better Site Design across the country is implemented through review of existing planning and development codes, and streets, parking and stormwater engineering criteria. Within the context of a stormwater management document and this Manual, the Better Site Design techniques of greatest application include protection of existing natural areas, incorporation of open space into new development, effective sediment and erosion control practices, and stormwater management that mimics natural systems. The following sections apply Better Site Design to the Southern Lowcountry Watershed Protection Areas and Special Watershed Protection Areas to help mitigate the effects of development to the watersheds. Therefore, the conservation principles below are part of an overall watershed approach to stormwater management and will complement the Watershed Protection Area approach in this Manual. Their application is subject to *<local jurisdiction>* requirements and/or standards.

2.1.3 Natural Resources Inventory

The first step to conserve natural resources is properly documenting existing assets. An up-to-date natural resources inventory map can provide geospatial information for water resources, soils, sensitive natural resource areas, critical habitats, and other unique resources (Ellis et al., 2014).

An application for new development requires a natural resources inventory prior to the start of any land disturbing activities. A natural resources inventory prepared by a qualified person shall be used to identify and map the most critical natural resources identified on the property that would be best to preserve, such as those listed in Table 2.2, as they exist predevelopment. Qualified persons include individuals with a working knowledge of hydrology, wetlands, plant taxonomy, and field survey methods. Qualified individuals include but are not limited to licensed foresters, professional wetland scientists, and geographic information professionals. A thorough assessment of the natural resources, both terrestrial and aquatic, found on a development site shall be submitted in the development application.

Table 2.2. Resources to be identified and mapped during the Natural Resources Inventory.

Resource Group	Resource Type
General Resources	• Topography • Natural Drainage Divides • Natural Drainage Patterns • Natural Drainage Features (e.g., Swales, Basins, Depressional Areas) • Soils • Erodible Soils • Steep Slopes (e.g., Areas with Slopes Greater Than 15%) • Trees and Other Existing Vegetation
Freshwater Resources	• Rivers • Perennial and Intermittent Streams • Freshwater Wetlands
Estuarine Resources	• Tidal Rivers and Streams • Tidal Creeks • Coastal Marshlands • Tidal Flats • Scrub-Shrub Wetlands
Marine Resources	• Near Coastal Waters • Beaches
Groundwater Resources	• Groundwater Recharge Areas • Wellhead Protection Areas
Terrestrial Resources	• Dunes • Maritime Forests • Marsh Hammocks • Evergreen Hammocks • Canebrakes • Bottomland Hardwood Forests • Beech-Magnolia Forests • Pine Flatwoods • Longleaf Pine-Wiregrass Savannas • Longleaf Pine-Scrub Oak Woodlands
Other Resources	• Shellfish Harvesting Areas • Floodplains • Aquatic Buffers • Other High Priority Habitat Areas as described by South Carolina Department of Natural Resources

2.1.4 Conservation Development

Conservation development, also known as open space development or cluster development, is a site planning and design technique used to concentrate structures and impervious surfaces in a small portion of a development site, leaving room for larger conservation areas and managed open spaces elsewhere on the site (Figure 2.1). Alternative lot designs are typically used to "cluster" structures and other impervious surfaces within these conservation developments.

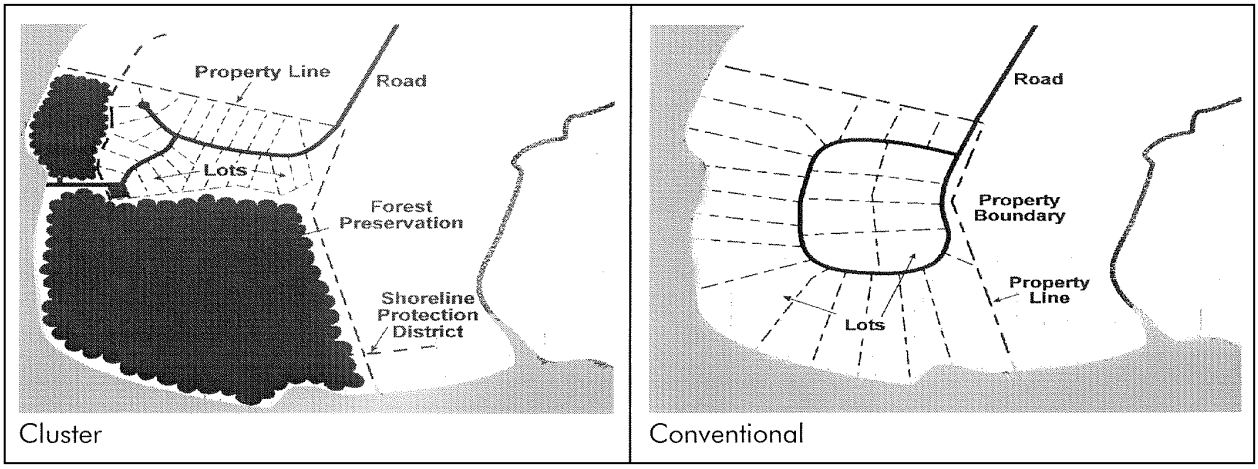

Figure 2.1. Conservation (i.e., cluster) development versus conventional development.

Conservation development projects provide a host of environmental benefits that are typically more difficult to achieve with conventional site design techniques. They provide for better natural resource protection on development sites and inherently limit increases in site imperviousness, sometimes by as much as 40 to 60 percent (CWP, 1998). Reduced site imperviousness results in reduced post-construction stormwater runoff rates, volumes and pollutant loads, which helps better protect both on-site and downstream aquatic resources from the negative impacts of the land development process. Reduced stormwater runoff rates, volumes and pollutant loads also help reduce the size of and need for storm drain systems and stormwater management practices on development sites.

As a number of recent studies have shown (MacMullan and Reich, 2007; US EPA, 2007; Winer-Skonovd et al., 2006), conservation development projects can also be significantly less expensive to build than more conventional development projects. Most of the cost savings can be attributed to the reduced amount of infrastructure (e.g., roads, sidewalks, post-construction stormwater management practices) needed on these development projects. And while these projects are frequently less expensive to build, developers often find that the lots located within conservation developments command higher prices and sell more quickly than those located within more conventional developments (ARC, 2001).

Table 2. 3 provides suggestions for Better Site Design techniques that will help protect valuable resources such as buffers, trees, wetlands, and open space.

Table 2.3. Better Site Design principles for conservation.

Principle	Description
Vegetated Buffer System	Create a variable width, naturally vegetated buffer system along all streams that also encompasses critical environmental features such as the 100-year floodplain, steep slopes, and freshwater wetlands. *Recommended buffer widths are included in Table 3.2-4 in Ellis et al., 2014*
Buffer Maintenance	The riparian buffer should be preserved or restored with native vegetation that can be maintained through delineation, plan review, construction, and occupancy stages of development.
Clearing and Grading	Clearing and grading of forests and native vegetation should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.
Tree Conservation	Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native plants. Wherever practical, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas to promote natural vegetation.
Land Conservation	Open space development should be encouraged to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, off-site mitigation consistent with locally-adopted watershed plans should be encouraged.
Stormwater Outfalls	New stormwater outfalls should not discharge unmanaged into jurisdictional wetlands, sole-source aquifers, or sensitive areas.

2.1.5 Residential Streets & Parking Lots

Up to 65% of the total impervious cover in a watershed can be the attributed to streets, parking lots, and driveways (CWP, 1998). Table 2.4 describes Better Site Design principles related to techniques to reduce the impervious surfaces associated with these hardscapes.

Table 2.4. Better Site Design principles for streets and parking to meet *<local jurisdiction>* requirements.

Principle	Description
Street Width	Design residential streets for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicles.
Street Length	Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.
Right-of-Way Width	Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, the sidewalk, and vegetated open channels. Utilities and storm drains should be located within the pavement section of the right-of-way wherever feasible.
Cul-de-sacs	Minimize the number of residential cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.
Vegetated Open Channels	Where density, topography, soils, and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.
Parking Ratios	The required parking ratio governing a particular land use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance, taking into account local and national experience to see if lower ratio is warranted and feasible.
Parking Lots	Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in spillover parking areas.
Structured Parking	Utilize structured (e.g., parking garage) and shared parking to reduce impervious surface area.
Parking Lot Runoff	Wherever possible, provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.

2.1.6 Lot Development Principles to Meet Requirements

Development of lots follows similar guidelines for reducing impervious cover and protecting natural areas, such as open space. Table 2. 5 summarizes Better Site Design principles for lot development. Preserving open space is critical to maintaining water quality at the regional level. Compared to traditional development, open space development can reduce the annual runoff volume from a site by 40%–60%, nitrogen loads by 42%–81%, and phosphorus loads by 42%–69% (CWP, 1998). Large, continuous areas of open space reduce and slow runoff, absorb sediments, serve as flood control, and help maintain aquatic communities. Open space can be provided by minimizing lot sizes, setbacks, and frontage distances.

Table 2. 5. Better Site Design principles for lot development.

Principle	Description
Open Space Development	Utilize open space development that incorporates smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.
Setbacks and Frontages	Consider minimum setbacks allowed by <*local jurisdiction*>. Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.
Sidewalks	Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.
Driveways	Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.
Rooftop Runoff	Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and avoid routing rooftop runoff to the roadway and the stormwater conveyance system.
Open Space Management	Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.

For more detailed descriptions of these techniques, please reference *Better Site Design: A Handbook for Changing Development Rules in Your Community* (CWP, 1998) and Chapter 3 of *Low Impact Development in Coastal South Carolina: A Planning and Design Guide* (Ellis et al., 2014).

2.1.7 Site Planning & Design Process

Figure 2.2 depicts the site planning and design process that is captured in *Low Impact Development in Coastal South Carolina: A Planning and Design Guide* (Ellis et al., 2014) and is applicable to the *<local jurisdiction>*. The site planning and design checklist of the Southern Lowcountry Design Manual does not make each of the phases of the process a submittal requirement. The checklist, however, gives the *<local jurisdiction>* the opportunity to ask whether each of these steps have been considered. The actual document submittal begins with the preliminary plan when considered in context of the planning process below:

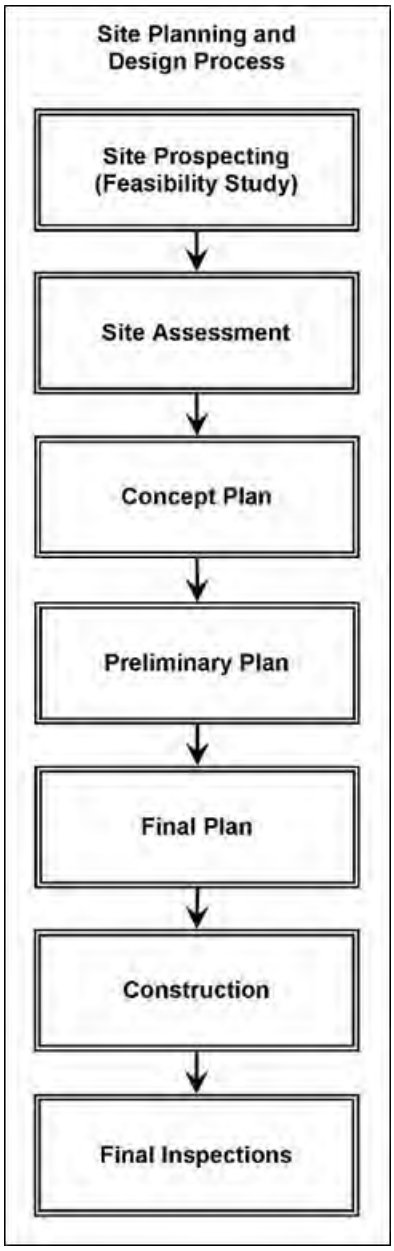

Figure 2.2. Site planning & design process (source: Center for Watershed Protection, Inc.)

- Site Prospecting: During the site prospecting phase, some basic information is used to evaluate the feasibility of completing a development or redevelopment project. A *feasibility study* is typically used to evaluate the many factors that influence a developer's decision about whether or not to move forward with a potential development project. Factors that are typically evaluated during a *feasibility study* include information about site characteristics and constraints, applicable local, state and federal stormwater management and site planning and design requirements, adjacent land uses and access to local infrastructure (e.g., water, sanitary sewer).
- Site Assessment: Once a potential development or redevelopment project has been deemed feasible, a more thorough assessment of the development site is completed. The site assessment, which is typically completed using acceptable site reconnaissance and surveying techniques, provides additional information about a development site's characteristics, its natural resource inventory and constraints. Once the assessment is complete, a developer can identify and analyze the natural, man-made, economic and social aspects of a potential development project, define the actual buildable area available on the development site and begin making some preliminary decisions about the layout of the proposed development project.
- Concept Plan: The results of the site assessment are typically used to create a concept plan (also known as a *sketch plan*) for the proposed development project. A concept plan is used to illustrate the basic layout of the proposed development project, including lots and roadways,

and is usually reviewed with the local development review authority before additional resources are used to create a more detailed plan of development. During this phase, several alternative concept plans can be created and compared with one another to craft a plan of development that best "fits" the character of the development site (Figure 2.3, Figure 2.4, and Figure 2.5). It is at this point in the planning and design process that a Maximum Extent Practicable demonstration described in Section 3.9 is required for development projects that will seek a waiver from requirements of this Manual.

- Preliminary Plan: A preliminary plan presents a more detailed layout of a proposed development project. It typically includes information about lots, buildings, roadways, parking areas, sidewalks, conservation areas, utilities and other infrastructure, including the post-construction stormwater management system. After the preliminary plan has been reviewed and approved by the local development review authority, a final plan may be prepared. There may be several iterations of the preliminary plan between the time that it is submitted and the time that it is approved by the local development review authority.
- Final Plan: The final plan adds further detail to the preliminary plan and reflects any changes to the plan of development that were requested or required by the local development review authority. The final plan typically includes all of the information that was included in the preliminary plan, as well as information about landscaping, pollution prevention, erosion and sediment control and long-term operation and maintenance of the site's post-construction stormwater management system. There may be several iterations of the final plan between the time that it is submitted and the time that it is approved by the local development review authority.
- Construction: Once the final plan has been reviewed and approved, performance bonds are set and placed, contractors are retained, and construction begins. During the construction phase, a development project may be inspected on a regular basis by the local development review authority to ensure that all roadways, parking areas, buildings, utilities and other infrastructure, including the post-construction stormwater management system, are being built in accordance with the approved final plan and that all primary and secondary conservation areas have been protected from any land disturbing activities.
- Final Inspections: Once construction is complete, final inspections take place to ensure that all roadways, parking areas, buildings, utilities and other infrastructure, including the post-construction stormwater management system, were built according to the approved final plan. As-built plans are also typically prepared and executed during this phase. If a development project passes all final inspections, an occupancy permit may be issued for the project.

Figure 2.3. Conventional Site Design (source: Merrill et al., 2006).

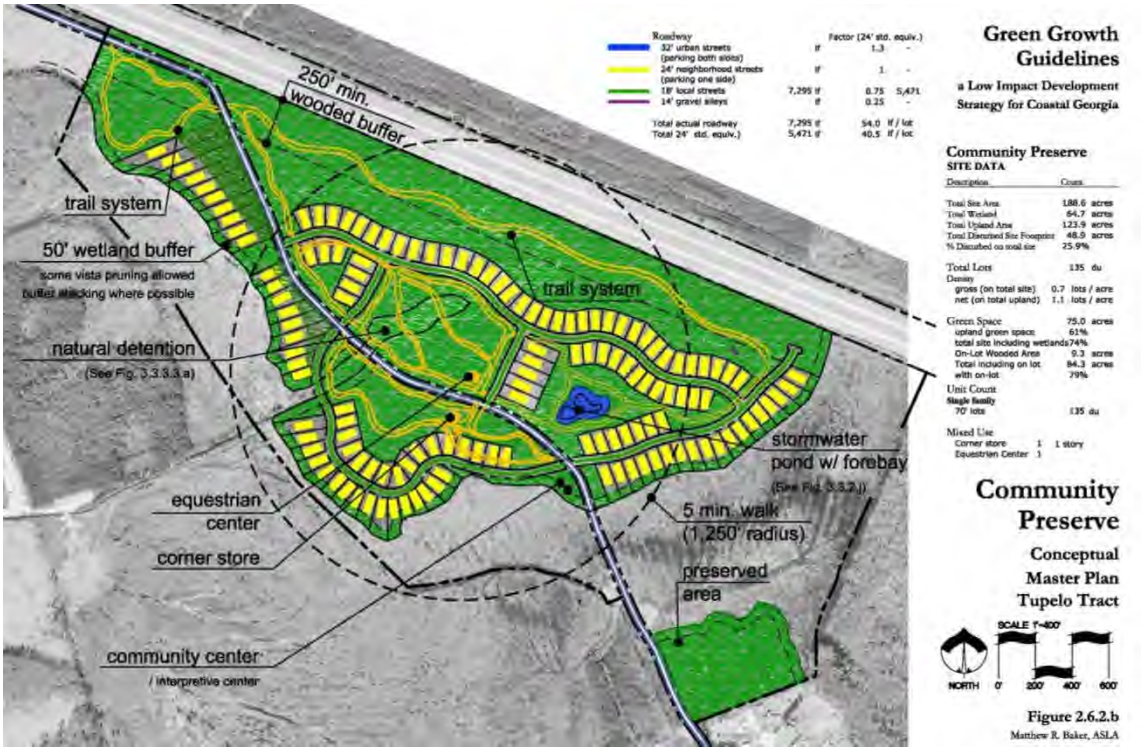

Figure 2.4. Conservation Site Design (source: Merrill et al., 2006).

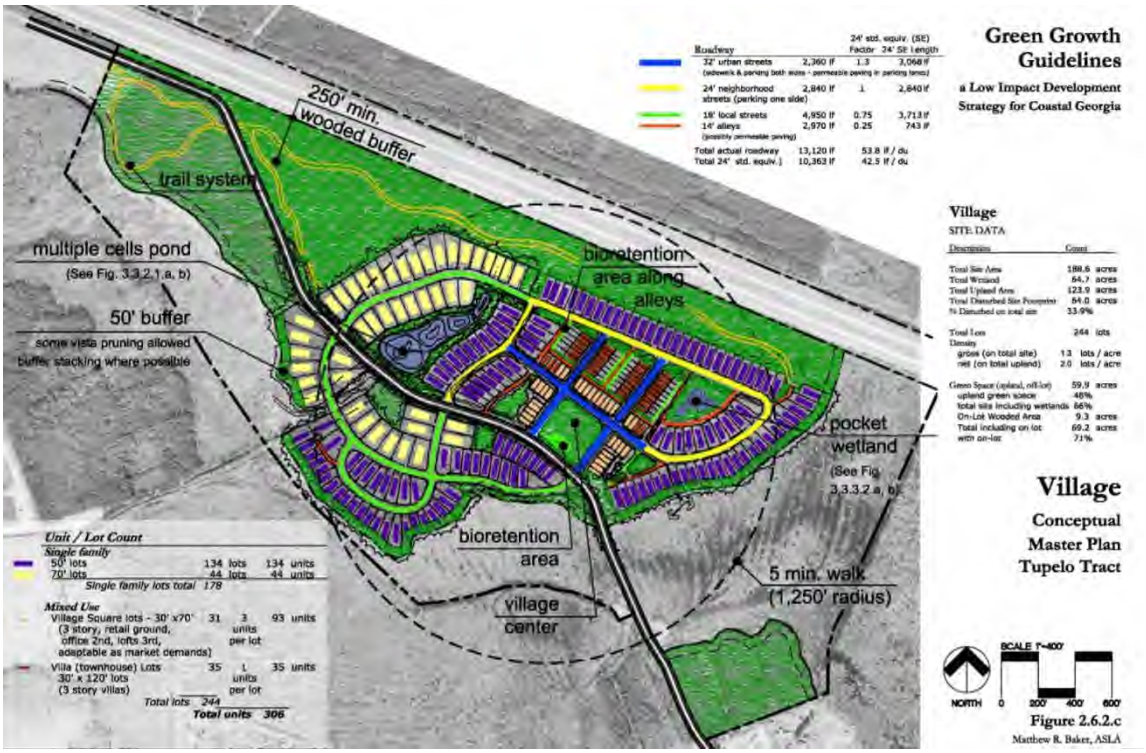

Figure 2.5. New Urbanist Site Design (source: Merrill et al., 2006).

2.1.8 Integrating Natural Resource Protection & Stormwater Management with the Site Planning & Design Process

In order to successfully *integrate* natural resource protection and stormwater management with the site planning and design process, site planning and design teams are encouraged to consider following questions at the beginning of the process:

- What valuable natural resources, both terrestrial and aquatic, can be found on the development site?
- How can better site planning techniques be used to protect these valuable natural resources from the direct impacts of the land development process?
- How can better site design techniques be used to minimize land disturbance and the creation of new impervious and disturbed pervious cover?
- What low impact development practices can be used to help preserve pre-development site hydrology and *reduce* post-construction stormwater runoff rates, volumes and pollutant loads?
- What stormwater management practices can be used to *manage* post-construction stormwater runoff rates, volumes and pollutant loads?
- Are there any site characteristics or constraints that prevent the use of any particular low impact development or stormwater management practices on the development site?

Although answering these questions is no easy task, they can be readily obtained within the context of the six-step *stormwater management planning and design process* outlined in Figure 2.6, and the steps are described in more detail below.

- **Step 1: Pre-Application Meeting**

It is recommended that a pre-application meeting between the applicant's site planning and design team and the *<local jurisdiction>* development review authority occur at the very beginning of the stormwater management planning and design process. This meeting, which should occur during the site prospecting phase of the overall site planning and design process (Figure 2.6), helps establish a relationship between the site planning and design team and the *<local jurisdiction>* development review authority. The pre-application meeting also provides an opportunity to discuss the local site planning and stormwater management design criteria that will apply to the proposed development project, which increases the likelihood that the remainder of the site planning and design process will proceed both quickly and smoothly.

- **Step 2: Review of Local, State, and Federal Stormwater Management, Site Planning, & Design Requirements**

Once a pre-application meeting has been completed, it is recommended that the site planning and design team review the local, state and federal requirements that will apply to the proposed development project. This review should occur during the site prospecting phase of the overall site planning and design process (Figure 2.6), while the feasibility study is still being completed.

During their review of stormwater management and site planning and design requirements, the applicant's site planning and design teams should also investigate opportunities and incentives for land conservation, and opportunities and incentives for conservation development as illustrated earlier in Figure 2.1.

- **Step 3: Natural Resources Inventory**

Once the potential development or redevelopment project has been deemed feasible, acceptable site reconnaissance and surveying techniques must be used to complete a thorough assessment of the natural resources, both terrestrial and aquatic, found on the development site. The identification and subsequent preservation and/or restoration of these natural resources helps reduce the negative impacts of the land development process "by design." The natural resources inventory should be completed during the site assessment phase of the overall site planning and design process (Figure 2.6). A map that is created to illustrate the results of the natural resources inventory, known as a site fingerprint, should be used to prepare a stormwater management concept plan for the proposed development project.

Once the natural resources inventory has been completed and a site fingerprint has been created, the site planning and design team should have a better understanding of a development site's characteristics and constraints. This information can be used to identify primary and secondary conservation areas (Figure 2.7) and define the actual buildable area available on the development site. Along with information about adjacent land uses and available infrastructure (e.g., roads, utilities), the site fingerprint can also be used to make some preliminary decisions about the layout of the proposed development project and to guide the creation of the stormwater management concept plan.

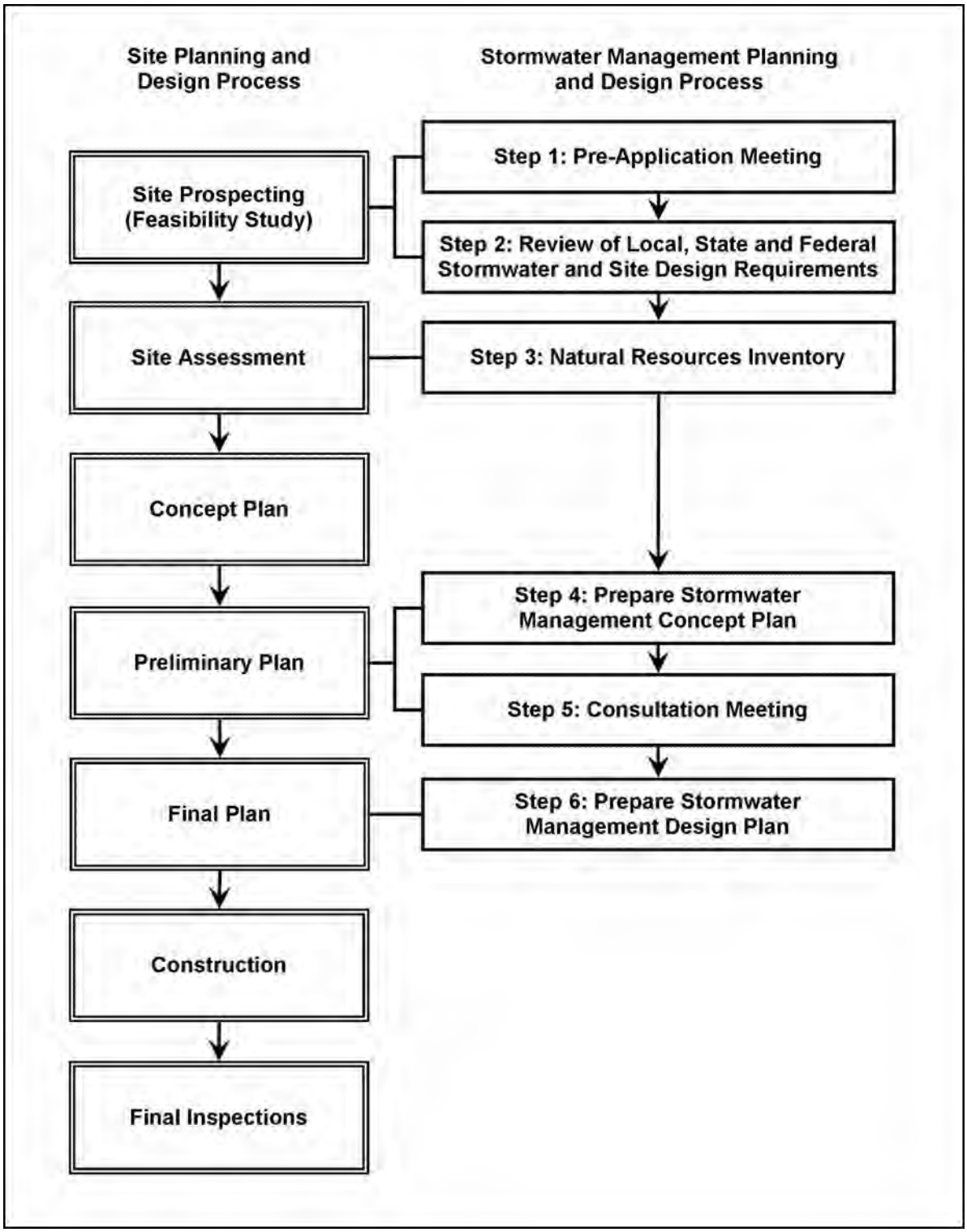

Figure 2.6. Integrating Natural Resource Protection & Stormwater Management with the Site Planning & Design Process (source: Center for Watershed Protection, Inc.).

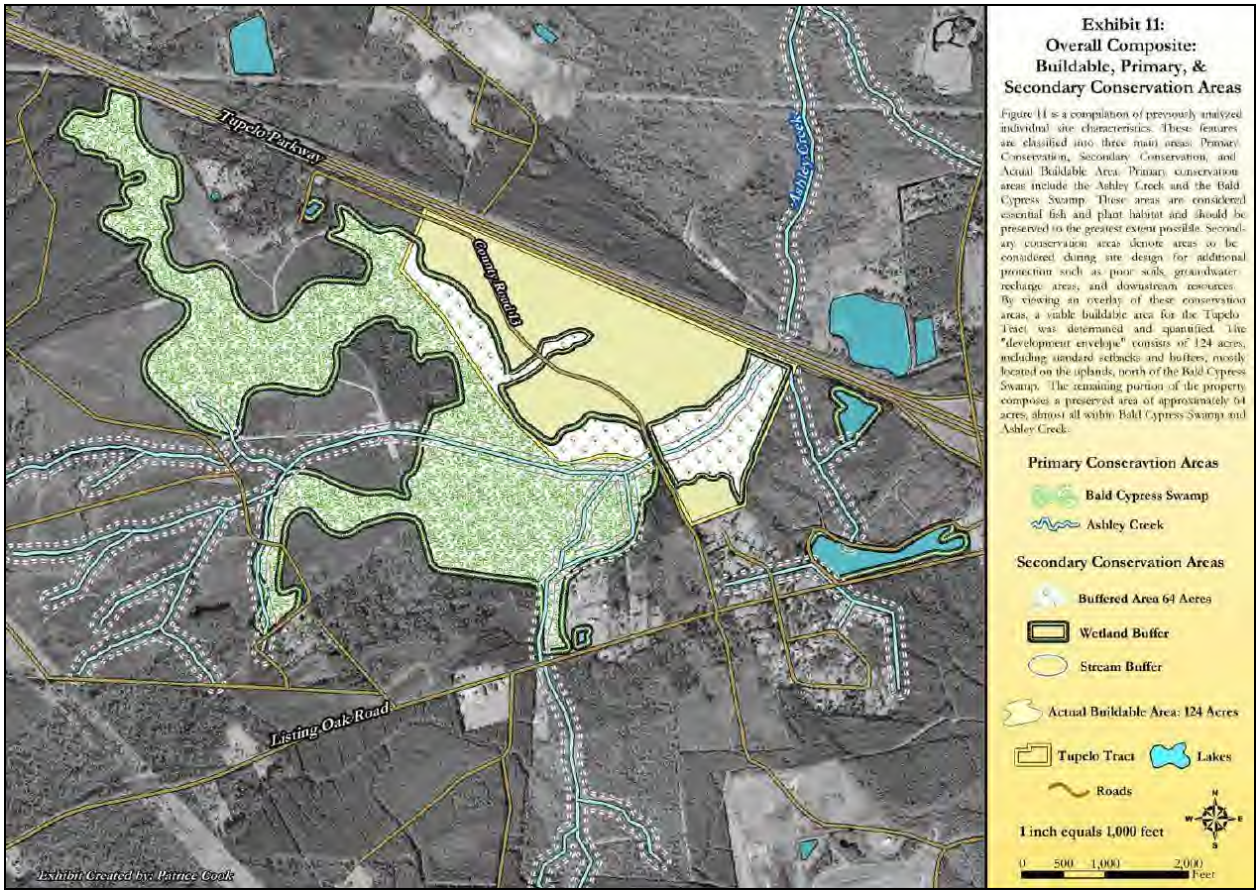

Figure 2.7. Buildable Area and Primary/Secondary Conservation Areas (source: Merrill et al., 2006).

- **<u>Step 4: Prepare Stormwater Management Concept Plan</u>**

After the natural resources inventory has been completed, it is recommended that the site fingerprint be used to develop a stormwater management concept plan for the proposed development project. The stormwater management concept plan should illustrate the layout of the proposed development project and should show, in general, how post-construction stormwater runoff will be managed on the development site.

The creation of a stormwater management concept plan allows the applicant's site planning and design team to make some preliminary decisions about the layout of the proposed development project. If it is submitted to the local development review authority prior to the preparation and submittal of the stormwater management design plan, it can also be used to solicit early feedback on the project and on the green infrastructure and stormwater management practices that will be used to manage post-construction stormwater runoff on the development site.

During the creation of the stormwater management concept plan, most of the site layout, including the layout of lots, buildings, roadways, parking areas, sidewalks and green infrastructure and stormwater management practices, will be completed. Therefore, it is very important that natural resource protection and stormwater management be considered throughout this part of the stormwater management planning and design process.

- **Step 5: Consultation Meeting**

Once a stormwater management concept plan has been created, it is recommended that the applicant's site planning and design team hold a consultation meeting with the *<local jurisdiction>* development review authority. This meeting, which should occur right after completion of the stormwater management concept plan, provides an opportunity to discuss the proposed development project and the approach that was used to satisfy the stormwater management and site planning and design criteria that apply to the development site. It may be advantageous for the consultation meeting to take place on the development site after the concept plan submittal, but prior to approval. This meeting can be used to verify site conditions and feasibility of the proposed stormwater management concept plan.

- **Step 6: Prepare Stormwater Management Design Plan**

Subsequent to review and approval of the stormwater management concept plan, the site planning and design team should prepare a stormwater management design plan. The stormwater management design plan should detail how post-construction stormwater runoff will be managed on the development site and should include maps, narrative descriptions and design calculations (e.g., hydrologic and hydraulic calculations) that show how the stormwater management and site planning and design criteria that apply to the development project have been met. The stormwater management design plan should be submitted to the local development review authority for review and approval.

2.2 Submittal & Review Process of Stormwater Management Plans

The Stormwater Management Plan (SWMP) consists of the entire submittal package and includes the following components:

- Project description and narrative;
- Description of selected stormwater management systems;
- Erosion and sediment control plans;
- Sufficient information to evaluate the environmental characteristics of the affected areas, the potential impacts of the proposed development on water resources, the effectiveness and acceptability of stormwater best management practices (BMPs), and land covers for managing stormwater runoff;
- Supporting computations and drawings; and
- Construction, inspection, and maintenance schedules.

All SWMPs must include the Stormwater submittal checklist (Appendix D) and calculations summary. The plans must include the calculated stormwater retention volume (SWRv) for each BMP and for the overall project, the pre and post development peak flow comparison, extreme flood requirements, and any off-site retention or detention volume obligation.

The SWMP and accompanying documentation may be submitted electronically according to the *<local jurisdiction>* process, but the applicant must also submit one paper copy of the SWMP carrying the stamp of a registered professional engineer licensed in the State of South Carolina with all supporting documentation to *<local jurisdiction>*.

Upon acceptance of a complete application (which includes payment of filing fees), the *<local jurisdiction>* will review the SWMP and make a determination to approve, approve with conditions, or disapprove the SWMP. Relatively large and/or complicated projects tend to require a longer review

time than smaller and less complicated projects. A written response of approval or disapproval will be provided to the applicant. If it is determined that more information is needed or that a significant number of changes must be made before the SWMP can be approved, the applicant must resubmit the applications with the revisions required and certified by the registered professional engineer according to the plan resubmittal process of the *<local jurisdiction>*.

When a SWMP approval is granted, a final submission package is required, including the following:

- One PDF copy of the SWMP, certified by a registered professional engineer licensed in the State of South Carolina,
- A declaration of covenants that has been approved for legal sufficiency by the *<local jurisdiction>*, and
- All supporting documents specified within this Manual or as requested during the review process according to the *<local jurisdiction>* requirements.

2.2.1 Components of a Stormwater Management Plan

As itemized in the SWMP checklist in Appendix D Design Checklists, a SWMP includes the following:

Site Plan

The following information must be formatted to print as a standard drawing size of 24 by 36 inches. The site drawing will provide details of existing and proposed conditions:

- A cover page that contains a blank space measuring 7 inches wide by 9.5 inches high. The blank space must be located 1 inch below the top edge and 1 inch from the left edge of the page;
- A plan showing property boundaries and the complete address of the property;
- Lot number or property identification number designation (if applicable);
- North arrow, scale, and date;
- Property lines (include longitude and latitude);
- Location of easements (if applicable);
- Existing and proposed structures, utilities, roads, and other paved areas;
- Existing and proposed topographic contours;
- Soil information for design purposes;
- Area(s) of soil disturbance;
- Drainage area(s) within the limits of disturbance (LOD) and contributing to the LOD;
- Contributing drainage area (CDA) to each BMP;
- Location(s) of BMPs, marked with the BMP ID Numbers to agree with the BMP design summary list;
- Delineation of existing and proposed land covers including natural cover, compacted cover, and impervious surfaces. Consult Appendix G Compliance Calculator Instructions for details;
- Natural resources inventory with site fingerprint map;
- All plans and profiles must be drawn at a scale of 1 in. = 10 ft, 1 in. = 20 ft, 1 in. = 30 ft, 1 in. = 40 ft, 1 in. = 50 ft, or 1 in. = 100 ft. Although, 1 in. = 10 ft, 1 in = 20 ft, and 1 in. = 30 ft, are the most commonly used scales. Vertical scale for profiles must be 1 in. = 2 ft, 1 in. = 4 ft, 1 in. = 5 ft, or 1 in. = 10 ft;
- Drafting media that yield first- or second-generation, reproducible drawings with a minimum letter size of No. 4 (1/8 inch);
- Location and size of existing utility lines including gas lines, sanitary lines, telephone lines or poles, electric utilities and water mains;

- A legend identifying all symbols used on the plan;
- Applicable flood boundaries and FEMA map identification number for sites lying wholly or partially within the 100-year floodplain;
- Site development plan and stormwater management narrative;
- Assess potential application of green infrastructure practices in the form of better site planning and design techniques. Low impact development practice should be used to the maximum extent practicable during the creation of a stormwater management concept plan. A demonstration of better site planning is required. The following site information and practices shall be considered:
    - Soil type (from Soil Study);
    - Depth of ground water on site;
    - Whether the type of development proposed is a hotspot as defined by the Ordinance and Design Manual and address how this influences the concept proposal;
    - Protection of primary and secondary conservation areas;
    - Reduced clearing and grading limits;
    - Reduced roadway lengths and widths;
    - Reduced parking lot and building footprints to minimize impervious surface;
    - Soil restoration;
    - Site reforestation/revegetation;
    - Impervious area disconnection;
    - Green roof (for redevelopment, infill and major substantial improvement projects); and
    - Permeable pavements.
- Stormwater Pollution Prevention Plan (SWPPP) or Erosion and Sediment Control narrative (for projects disturbing over an acre);
- Information regarding the mitigation of any off-site impacts anticipated as a result of the proposed development;
- Construction specifications;
- Design and As-Built Certification, including the following:

  Certification by a registered professional engineer licensed in the State of South Carolina seal that the site design, land covers, and design of the BMPs conforms to the standard of care applicable to the treatment and disposal of stormwater pollutants and that the Facility has been designed in accordance with the specifications required under the stormwater ordinance of the *<local jurisdiction>.*

  Submission one set of the As-Built drawings sealed by a registered professional engineer licensed in the State of South Carolina within 21 days after completion of construction of the site, all BMPs, land covers, and stormwater conveyances.

  For a project consisting entirely of work in the public right-of-way (PROW), the submission of a Record Drawing certified by an officer of the project contracting company is acceptable if it details the as-built construction of the BMP and related stormwater infrastructure.
- Maintenance sheet for stormwater BMPs, including the following:
  - i A maintenance plan that identifies routine and long-term maintenance needs and a maintenance schedule;
  - ii A maintenance agreement and schedule for all post construction best management practices in a form and manner that meets the *<local jurisdiction>* requirements.
  - iii For applicants using Rainwater Harvesting, submission of third-party testing of end-use water quality may be required at equipment commissioning as determined by the requirements in Appendix J Rainwater Harvesting Treatment and Management

Requirements. Additional regular water quality reports certifying compliance for the life of the BMP may also be required in Appendix J Rainwater Harvesting Treatment and Management Requirements.

Stormwater Retention Volume Computations

The following summary calculations must be included on the plan set. Supporting documentation and the South Carolina DHEC C-SWPPP are not in the plan set but provided separately.

- Calculation(s) of the required SWRv for the entire site within the LOD and each site drainage area (SDA) within the LOD;
- Calculation(s) for each proposed BMP demonstrating retention value towards SWRv in accordance with Chapters 2 and 4;
- For Rainwater Harvesting BMP, calculations demonstrating the annual water balance between collection, storage, and demand, as determined using the Rainwater Harvesting Retention Calculator;
- For proprietary and non-proprietary BMPs follow the guidance in Chapter 4.13 to identify/receive approval or denial to use these practice(s); and
- Off-site stormwater volume requirement.

Pre-/Post-Development Hydrologic Computations

Include in the plan set a summary of the pre-/post-runoff analysis with the following information at a minimum:

- A summary of soil conditions and field data;
- Pre- and post-project curve number summary table;
- Pre and post construction peak flow summary table for the 2-, 10-, 25- and 50-year 24-hour storm events for each SDA within the project's LOD; and
- Flow control structure elevations.

Hydraulic Computations

Hydraulic computations for the final design of water quality and quantity control structures may be accomplished by hand or through the use of software using equations/formulae as noted in Chapters 3 and 4. The summary of collection or management systems will include the following:

- Existing and proposed SDA must be delineated on separate plans with the flow paths used for calculation of the times of concentration;
- Hydraulic capacity and flow velocity for drainage conveyances, including ditches, swales, pipes, inlets, and gutters. Plan profiles for all open conveyances and pipelines, with energy and hydraulic gradients for the 25-year and 100-year, 24-hour storms;
- The proposed development layout including the following:
    - Location and design of BMP(s) on site, marked with the BMP ID Numbers;
    - Stormwater lines and inlets;
    - A list of design assumptions (e.g., design basis, 2 through 50-year return periods);
    - The boundary of the CDA to the BMP;
    - Schedule of structures (a listing of the structures, details, or elevations including inverts); and

- Manhole to manhole profile, listing of pipe size, pipe type, slope, (i.e., a storm drain pipe schedule) computed velocity, and computed flow rate, energy grade line (EGL) and hydraulic grade line (HGL).

Supporting Documentation

Provide a written report with the following supporting documentation:

- Pre- and post-project curve number selection
- Time of concentration calculation;
- Travel time calculation;
- Hydrologic computations supporting peak discharges assumed for each SDA within the project's LOD for the 2-, 10-, 25-, and 100-year, 24-hour storm events;
- SC DHEC's Construction Stormwater Pollution Prevention Plan (C-SWPPP).

A professional engineer registered in the State of South Carolina must also submit the following:

1. Elevation and topographic data illustrating changes in topography and drainage;
2. Impacts upon local flood flows (25- and 100-yr storm events;
3. Identify areas where stormwater flows are discharged off-site or off-property;
4. For proposed off-site/property discharge points, perform analysis of receiving off-site conveyance systems to confirm safe conveyance from the proposed developed property, no negative impact to adjacent properties, and adequacy of the receiving, existing conveyance system for 25-yr storm flows. Such analysis shall be taken to point where the 25-yr storm conveyance is determined to be adequate in the public stormwater conveyance/infrastructure system; and
5. Documentation supporting safe passage of the 100-yr post development flow according to the 10% Rule (see Section 3.8);

2.2.2 Resubmission of Stormwater Management Plans

If changes occur in the design or construction of an accepted SWMP, the applicant may be required to resubmit the SWMP for approval. Examples of changes during design and construction that will require SWMP resubmission for review include the following:

1. Revision to the property boundary, property size, or LOD boundaries that may require redesigning BMPs;
2. Any change to SWRv through land cover designation change;
3. Change in compaction or infiltration rates due to construction activities;
4. Encountering contaminated soil or other underground source of contamination;
5. Changes to floodplain designation or requirements;
6. Changes in any component of the BMP that may adversely affect the intended capacity of the approved BMP, such as the following:
    a. Modification to approved BMP selection, dimensions, or location
    b. Modification to approved material specification
    c. Changes to the size, invert, elevation, and slopes of pipes and conveyances
    d. Installation of new drains and conveyance structures
    e. Need for a new storm sewer outlet connection to the sanitary/storm sewer main
    f. Changes to the amount of off-site requirements
    g. Changes to the CDA to a BMP
7. Revision to the approved grading and drainage divides and that may require redesigning BMPs;

8. Relocation of an on-site storm sewer or conveyance; or
9. Abandonment, removal, or demolition of a BMP.

If the applicant resubmits an SWMP after making changes, the resubmission must contain a list of the changes made and may be in the form of a response to comments. The resubmittal plans and calculations must include the stamp of the registered professional engineer in South Carolina.

However, if any of the following minor changes are made to the SWMP, resubmission is not required. These minor changes may be made anytime during inspection or at the as-built submittal by the *<local jurisdiction>*.

1. Changes to SWM components that do not adversely affect BMP capacity while in consultation with the *<local jurisdiction>*. The inspector should review the appropriate manufacturer's documentation to his/her satisfaction before approving such a change and should ensure that such changes are recorded as red line changes or deviations in the as-built plans. These changes include the following:
    a. Changes to parts type of similar function (e.g. dewatering valve)
    b. Change in hole pattern or size of underdrain pipe perforations
    c. Change in project address, ownership, permit status, or zoning

2.2.3 Design Certifications

The engineer shall certify that this Plan satisfies all requirements of the Southern Lowcountry Ordinance and Stormwater Design Manual. The following statement with engineer's seal is required in the Plan submittal.

> The engineering features of all stormwater best management practices (BMPs), stormwater infrastructure, and land covers (collectively the "Facility") have been designed/examined by me and found to be in conformity with the standard of care applicable to the treatment and disposal of stormwater pollutants. The Facility has been designed in accordance with the specification required under Ordinance XXX of *<local jurisdiction>.*

2.2.4 Performance Bonds

Bonding for the cost of stormwater facilities approved for the proposed development shall be provided in accordance with the *<local jurisdiction>* bonding and permit issuance process. It is recommended that the bond be in the amount of 125% of the approved estimated cost (labor, equipment, material and incidentals) for construction/installation of the approved stormwater management facilities. The *<local jurisdiction>* shall require from the developer a surety or cash bond, irrevocable letter of credit, or other means of security acceptable to the *<local jurisdiction>* prior to the issuance of any building and/or grading permit for any land development or redevelopment activity requiring a permanent stormwater management system. The bond required shall include provisions relative to forfeiture for failure to complete work specified in the approved stormwater management design plan, compliance with all of the provisions of this ordinance, other applicable laws and regulations, and any time limitations. The bond shall not be fully released without a final inspection of the completed work by the *<local jurisdiction>*, a recorded inspection and maintenance agreement and plan, and submission of "as-built" plans containing certifications provided by the Applicant and Engineer, including the following:

1. Certification that facilities were constructed in accordance with the submitted and approved design and will function as designed.

2. As-built certification to be on as-built drawing submitted by Engineer after construction and prior to Certificate of Project Completion and confirming line, size, elevation and grade of constructed stormwater BMPs and drainage/conveyance systems.

A procedure may be used to release parts of the bond held by the *<local jurisdiction>* after various stages of construction have been completed and accepted by the *<local jurisdiction>*. Partial Bond release will be determined for the portion of work being accepted and construction work has been approved by *<<local jurisdiction* >. All requirements pertaining to this portion of work have been satisfied to include, but not be limited to, as-builts plans, all certifications and approvals for that portion of work related to the partial bond release have been provided by applicant's Engineer and approved by *<local jurisdiction* >.The procedures used for partially releasing performance bonds must be specified by the *<local jurisdiction>* in writing prior to the approval of a stormwater management design plan.

2.3 Construction Inspection Requirements

2.3.1 Inspection Schedule & Reports

Prior to the approval of a SWMP, the applicant will submit a proposed construction inspection schedule. The *<local jurisdiction>* will review the schedule to determine if changes are required. The construction schedule should reflect the construction sequences defined in each BMP section Stormwater Best Management Practices (BMPs) of this Manual. The construction and inspection schedule must be included in the SWMP. The *<local jurisdiction>* will conduct inspections and file reports of inspections during construction of BMPs and site stormwater conveyance systems to ensure compliance with the approved plans.

Note: No stormwater management work may proceed past the stage of construction that the *<local jurisdiction>* has identified as requiring an inspection unless

- the *<local jurisdiction>* has issued an "approved" or "passed" report;
- the *<local jurisdiction>* has approved a plan modification that eliminates the inspection requirement; or
- the *<local jurisdiction>* has eliminated or modified the inspection requirement in writing.

The *<local jurisdiction>* may require that the professional engineer responsible for sealing the approved SWMP, the professional engineer responsible for certifying the as-built SWMP, or, for a project entirely in the PROW, the officer of the contracting company responsible for certifying the Record Drawing be present during inspections.

If the *<local jurisdiction>* conducts an inspection and finds work that is not in compliance with the SWMP, the *<local jurisdiction>* will issue a written notice, and the applicant must take prompt corrective action. The written notice provides details on the nature of corrections required and the time frame within which corrections must be made.

2.3.2 Inspection Requirements Before & During Construction

The *<local jurisdiction>* construction stormwater inspection form is provided in Appendix E Construction Inspection Form.

Preconstruction Meetings. These meetings are required prior to the commencement of any land-disturbing activities and prior to the construction of any BMPs. The applicant is required to contact the *<local jurisdiction>* to schedule preconstruction meetings three (3) days prior to beginning any construction activity subject to the requirements the *<local jurisdiction>*.

Inspections During Construction. The applicant is required to contact the *<local jurisdiction>* to schedule inspection three (3) days prior to any stage of BMP construction, or other construction activity, requiring an inspection. For large, complicated projects, the applicant and the *<local jurisdiction>* may agree during the preconstruction meeting to an alternative approach such as a weekly notification schedule. Any such agreement must be made in writing and signed by all parties. The *<local jurisdiction>* will revert to the 3-day notification procedure if the agreement is not followed.

During construction, the *<local jurisdiction>* **may require the presence of the professional engineer responsible for sealing the approved SWMP; the professional engineer responsible for certifying the as-built SWMP; or for a project entirely in the PROW, the officer of the contracting company responsible for certifying the Record Drawing.**

Final Inspection. The applicant is required to contact the *<local jurisdiction>* to schedule a final inspection one week prior to the completion of a BMP construction to schedule a final inspection of the BMP. Upon completion of the BMP, *<local jurisdiction>* will conduct a final inspection to determine if the completed work was constructed in accordance with approved plans.

Inspection Requirements by BMP Type. Chapter 4 Stormwater Best Management Practices (BMPs) of this Manual provides details about the construction sequences for each BMP. After holding a preconstruction meeting, regular inspections will be made at the following specified stages of construction:

- **Infiltration Systems and Bioretention Areas** shall be inspected at the following stages to ensure proper placement and allow for infiltration into the subgrade:
    - During on-site or off-site percolation or infiltration tests;
    - Upon completion of stripping, stockpiling, or construction of temporary sediment control and drainage facilities;
    - Upon completion of excavation to the subgrade;
    - Throughout the placement of perforated PVC/HDPE pipes (for underdrains and observation wells) including bypass pipes (where applicable), geotextile materials, gravel, or crushed stone course and backfill; and
    - Upon completion of final grading and establishment of permanent stabilization;
- **Flow Attenuation Devices**, such as open vegetated swales upon completion of construction;
- **Retention and Detention Structures**, at the following stages:
    - Upon completion of excavation to the sub-foundation and, where required, installation of structural supports or reinforcement for structures, including but not limited to the following:
    - During testing of the structure for watertightness;
    - During placement of structural fill and concrete and installation of piping and catch basins;
    - During backfill of foundations and trenches;
    - During embankment construction; and
    - Upon completion of final grading and establishment of permanent stabilization.
- Stormwater Filtering Systems, at the following stages:

- Upon completion of excavation to the sub-foundation and installation of structural supports or reinforcement for the structure;
- During testing of the structure for watertightness;
- During placement of concrete and installation of piping and catch basins;
- During backfill around the structure;
- During prefabrication of the structure at the manufacturing plant;
- During pouring of floors, walls, and top slab;
- During installation of manholes/trap doors, steps, orifices/weirs, bypass pipes, and sump pit (when applicable);
- During placement of the filter bed; and
- Upon completion of final grading and establishment of permanent stabilization.

- Green Roof Systems, at the following stages:

  - During placement of the waterproofing layer, to ensure that it is properly installed and watertight;
  - During placement of the drainage layer and drainage system;
  - During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth (certification for vendor or source must be provided);
  - Upon installation of plants, to ensure they conform to the planting plan (certification from vendor or source must be provided); and
  - At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

2.3.3 Final Construction Inspection Reports

The *<local jurisdiction>* will conduct a final inspection to determine if the completed work is constructed in accordance with approved plans and the intent of this Manual and the Stormwater Ordinance. Within 21 days of the final inspection, the applicant must submit an as-built package, including one PDF copy of the as-built SWMP certified by a registered professional engineer licensed in the State of South Carolina. For a project consisting entirely of work in the PROW, the submission of a Record Drawing certified by an officer of the project contracting company is acceptable if it details the as-built construction of the BMPs, related stormwater infrastructure, and land covers.

A registered professional engineer licensed in South Carolina is required to certify as-built SWMPs and state that all activities including clearing, grading, site stabilization, the preservation or creation of pervious land cover, the construction of drainage conveyance systems, the construction of BMPs, and all other stormwater-related components of the project were accomplished in strict accordance with the approved SWMP and specifications. As stated in Section 2.2.2 Resubmission of Stormwater Management Plans, all plan changes are subject to the *<local jurisdiction>* approval. The as-built certification must be on the original SWMP.

Upon completion, these plans will be submitted to the *<local jurisdiction>* for processing. The estimated time for processing will be two weeks (10 working days), after which the plans will be returned to the engineer. The *<local jurisdiction>* will provide the applicant with written notification of the final inspection results.

2.3.4 Inspection for Preventative Maintenance

The Stormwater Ordinance requires maintenance inspections for BMPs and landcovers to ensure their ongoing performance is in compliance with their original design. The inspection will occur at least once

every three (3) years. Maintenance inspection forms are provided in Appendix F Maintenance Inspection Checklists. The *<local jurisdiction>* will conduct these maintenance inspections, though it may, in certain circumstances, allow a property to self-inspect and provide documentation.

The *<local jurisdiction>* will maintain maintenance inspection reports for all BMPs. The reports will evaluate BMP functionality based on the detailed BMP requirements of Stormwater Best Management Practices (BMPs) and inspection forms found in Appendix F Maintenance Inspection Checklists.

If, after an inspection by the *<local jurisdiction>*, the condition of a BMP presents an immediate danger to the public safety or health because of an unsafe condition or improper maintenance, the *<local jurisdiction>* will take such action as may be necessary to protect the public and make the BMP safe. Any costs incurred by the *<local jurisdiction>* will be assessed against the owner(s).

2.4 Inspections & Maintenance

2.4.1 Inspections & Maintenance Responsibilities

A site with an approved SWMP must also have a responsible party inspect and maintain the BMPs and land covers according to the inspections and maintenance schedule in the SWMP and this Manual. Land covers must be maintained in type and extent as approved. Approved BMPs must be kept in good condition, including all the engineered and natural elements of each practice, as well as conveyance features (e.g., grade surfaces, walls, drains, structures, vegetation, soil erosion and sediment control measures, and other protective devices). All repairs or restorations must be in accordance with the approved SWMP.

A declaration of covenants including an exhibit stating the owner's specific maintenance responsibilities must be recorded with the property deed at the Record of Deeds. An inspection and maintenance schedule for any BMP will be developed for the life of the project and shall state the inspection and maintenance to be completed, the time for completion, and who will perform the inspections and maintenance. The schedule will be printed on the SWMP and will appear as an exhibit in the declaration of covenants.

2.4.2 Inspection & Maintenance Agreements

Inspection and maintenance obligations are binding on current and future owners of a property subject to recorded covenants. The *<local jurisdiction>* will not issue final approval of a complete set of the SWMP for private parcels until the applicant has executed a declaration of covenants providing notice of this obligation to current and subsequent owners of the land served by the BMP(s) and land covers. Inspection and maintenance agreements by regulated projects include providing access to the site and the BMP(s) at reasonable times for regular inspection by the *<local jurisdiction>* and for regular or special assessments of property owners, as needed, to ensure that the BMP(s) is maintained in proper working condition and the land covers are retained as approved in the SWMP. An example of the declaration of covenants/maintenance agreement for a site with BMPs and designated land covers is provided at the end of this chapter.

The applicant must record the agreement as a declaration of covenants with the *<local jurisdiction>* Recorder of Deeds. The agreement must also provide that, if after written notice by the *<local jurisdiction>* to correct a violation requiring maintenance work, satisfactory corrections are not made by the owner(s) of the land served by the BMP within a reasonable period of time, not to exceed 45 to 60 days unless an extension is approved in writing by the *<local jurisdiction>.* The *<local jurisdiction>* may perform all necessary work to place the BMP in proper working condition. The owner(s) of property served by the BMP will be assessed the cost of the work and any penalties, and there will be a lien on

any property served by the BMP, which may be placed on the tax bill and collected as ordinary taxes by the State.

2.5 As-Built Submittals

One set of As-Built drawings sealed by a registered professional engineer licensed in the State of South Carolina must be submitted within 21 days after completion of construction of the site, all BMPs, land covers, and stormwater conveyances as required by the procedure for handling close out documents for private development projects by the *<local jurisdiction>.*

The following items must be completed and provided:

General Information:

- Words As-Built in or near the project title
- As-Built Signature/Approval block on each sheet
- As-builts shall have a coordinate system based on the South Carolina Coordinate System North American Datum of 1983 (NAD83).
- Elevations shown shall be based on the North American Vertical Datum of 1988 (NAVD88).
- Vicinity map
- Sheets numbered correctly
- Project ID number, Project Name, Permit number and name, address and contact information of project engineer
- All measurements and coordinates shall be shown on all drainage structures, detention and BMP structure outlets, outlet control structures and manholes.
- Any change to BMP capacities, dimensions, specifications or location shall be shown as mark-through of the original design on the drawings
- Elevations to the nearest 0.1 ft.

Basins:

- At least two benchmarks on the plans
- Profile of the top of berm
- Cross-section of emergency spillway at the control section
- Profile along the centerline of the emergency spillway
- Cross-section of berm at the principle spillway
- Elevation of the principle spillway crest or top of structure elevations
- Elevation of the principle spillway inlet and outlet invert
- Riser diameter/dimensions and riser base size
- Diameter, invert elevation and sizes of any stage orifices, weirs or storm drain pipes
- Barrel diameter, length, and slope
- Types of material used
- Outfall protection length, width, depth, size of rip rap and filter cloth
- Size, location, and type of anti-vortex and trash rack device (height and diameter, elevations and spacing)
- Pipe cradle information
- On plan view show length, width and depth of pond and contours of the basin area so that design volume is specified
- As-built spot elevations with the disturbed area required for basin construction in sufficient detail to provide accurate as-built contours

- Core trench limits and elevation s of bottom of cut off trench
- Show length width and depth of outfall rip rap
- Certification by a Geotechnical Engineer for compact and unified soil classes
- Vegetation cover certification
- Show location of planted landscaping
- Utility locations and elevations encountered, test pitted and/or relocation during contract work

Storm Drain Piping:

- At least two benchmarks on the plans
- Diameter and class of pipe
- Invert of pipe at outfall, structures and/or field connections
- Slope of pipe
- Pipe lengths (show stationing)
- Types of materials
- Location of all pipes and structures horizontally on the plan
- Length, width and depth of all rip rap and other outfall protection as specified
- Elevation of rip rap at outfall and at changes in grade
- Utility locations and elevations encountered, test pitted and/or relocation during contract work

Post construction BMP Specific details:

- Provide as-built details as described for each best management practice in Chapter 4.

2.6 References

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Chapter 3. Minimum Control Requirements

3.1 Introduction

This chapter establishes the minimum stormwater control standards necessary to implement the Southern Lowcountry Stormwater Ordinance within the <*local jurisdiction*>. The term "runoff reduction" is used throughout this chapter to describe the retention of the stormwater on site. The SWRv is used to describe the volume of stormwater to be retained on site.

Two levels of stormwater retention are prescribed, the 85th and the 95th percentile storm, and are assigned based on a site's subwatershed as identified by the U.S. Geological Survey Hydrologic Unit Code 12 (HUC-12) presented in Section 3.5.1 below. In addition, peak discharge control of the post-development 2-, 10- and 25-year, 24-hour storms to their predevelopment flow shall be provided by a combination of structural controls, GI/LID practices and other non-structural BMPs. As well, requirements to manage the 100-yr, 24-hour storm event are provided in the extreme flood event section below. Further, this Manual and Appendices provide the framework and necessary tools to document the methods proposed by development plans to comply with these requirements. It should be noted that stormwater ponds are considered the least favorable structural best management practice to meet the SWRv and water quality requirements of this Manual.

3.2 Regulated Site Definition

According to the Stormwater Ordinance, the design criteria of this Manual shall be applicable to any new development, redevelopment or major substantial improvement activity, including, but not limited to, site plan applications, public improvement projects, and subdivision applications that meet the applicability standards found in Chapter 1.4.

The Southern Lowcountry stormwater design requirements are applied according to the flow chart in Figure 3.1 and should be determined as follows:

1) In sequence, first determine which HUC-12 watershed that the project is in according to Table 3.1. Stormwater design criteria for the development follows the watershed area in which it is located. Next, determine the square feet of impervious area to be created, added or replaced as a part of the development or redevelopment. Does it equal or exceed 5,000 square feet? Or will the project disturb greater than 1 acre? If the answer is "yes" to either of these questions, the project plan must meet the requirements for stormwater management in this Manual for their respective watershed area.

2) If a project is a major substantial improvement, it must meet the water quality criteria for its respective watershed protection area to the maximum extent practicable (MEP) or obtain off-site stormwater credit. The terms MEP and off-site stormwater credit are further explained in Section 3.9 and 3.10 below. <u>Peak control requirements do not apply to major substantial improvement projects.</u>

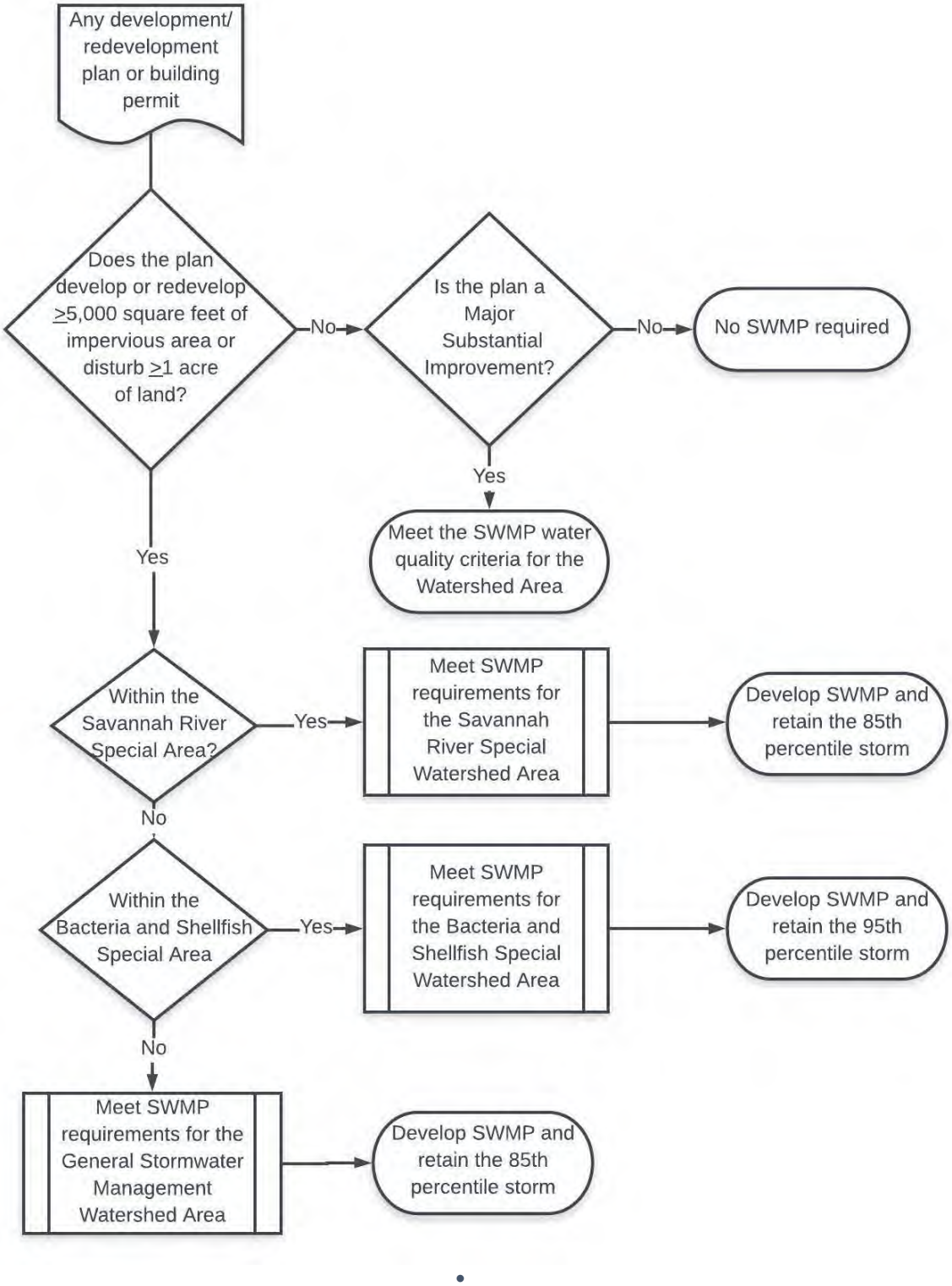

Figure 3.1. Southern Lowcountry Stormwater Design Manual applicability diagram.

3.3 Infill & Redevelopment

An infill project is one on a previously platted property that may or may not have stormwater management capacity in its original development plan. Regardless of size, infill that is part of a larger common plan of development, even through multiple, separate, and distinct land disturbing activities that may take place at different times and on different schedules must comply with this Manual. Such projects may include Planned Unit Developments (PUDs) that have stormwater systems built that do not meet the requirements of this Manual. If the proposed project meets the applicability criteria of Section 1.4.1, the stormwater plan review in this Manual is necessary. If the development's original stormwater management plan is sufficient to meet the current requirements of this Manual and is documented through approved plans and as-built drawings, or current field measurements and engineering calculations, no further stormwater requirements must be met. When the infill project is part of an original plan that does not meet the current stormwater requirements, the level of stormwater management that is provided in the current development may be credited toward the current volume and hydrologic analysis. Infill locations that, due to the municipal jurisdiction's zoning or land use requirements or site conditions, cannot meet the requirements of this Manual must complete the maximum extent practicable (MEP) evaluation in Section 3.9 for project approval.

Similarly, redevelopment may be credited for the level of stormwater in place. If the redevelopment's original stormwater management plan is sufficient to meet the current requirements of this Manual and is documented through approved plans and as-built drawings, or current field measurements and engineering calculations, no further stormwater requirements must be met. When the redevelopment is part of an original plan that does not meet the current stormwater requirements, the level of stormwater management that is provided in the current development may be credited toward the current volume and hydrologic analysis. Redevelopment projects that, due to the municipal jurisdiction's zoning or land use requirements or site conditions, cannot meet the requirements of this Manual must complete the maximum extent practicable (MEP) evaluation in Section 3.9 for project approval.

3.4 Stormwater Runoff Quality & Peak Discharge Control

Since its inception, the Clean Water Act was designed to address the water quality impacts of stormwater runoff. As it has been applied through successive stormwater permit cycles, the Act's requirements have been interpreted to mean application of stormwater best management practices to the maximum extent practicable. The U.S. Environmental Protection Agency (EPA) has stated that such conditions include specific tasks or best management practices (BMPs), BMP design requirements, and performance requirements (EPA, 81 Fed. Reg. 3).

Consistent with the EPA's Phase II MS4 permit, this Manual requires that stormwater runoff shall be adequately treated before it is discharged from a development site. A stormwater management system is assumed to meet the stormwater runoff quality criteria by satisfying the stormwater runoff volume criteria for its respective Watershed Area presented in this Manual. If any of the required stormwater runoff volume cannot be reduced on the site, due to impractical site characteristics or constraints, the following questions shall be addressed in the permitting process:

1. Can the required stormwater volume be obtained from an adjacent site owned or available for stormwater retention purposes;
2. Is there available stormwater retention volume within the adjacent right-of-way and available through fee-in-lieu arrangements within this jurisdiction; and

3. Is a waiver granted based on a maximum extent practicable evaluation?

Further, a stormwater management system is presumed to comply with these criteria if:

- It intercepts and treats stormwater runoff in stormwater management practices that have been selected, designed, constructed and maintained in accordance with this Manual;
- It is provided with documentation to show that total suspended solids, nitrogen and bacteria removal were considered during the selection of the stormwater management practices that will be used to intercept and treat stormwater runoff on the development site;
- It is designed to provide the amount of stormwater load reduction specified in the latest edition of this Manual; and
- It manages the peak flow and extreme flood event storms in accordance with this Manual.

3.5 Southern Lowcountry Stormwater Management Performance Requirements

Stormwater management requirements of this Manual are intended to enhance the quality of development, protect and enhance stormwater quality and management, protect aquatic resources from the negative impacts of the land development process, address water quality impairments or a total maximum daily load, as identified by the South Carolina Department of Health and Environmental Control (DHEC), or address localized flooding issues.

3.5.1 Watershed Protection Area Designations

Not all watersheds of the Southern Lowcountry region require the same level of post-construction stormwater management. Currently, three watershed protection areas are designated with specific unique stormwater management requirements based on the current and anticipated water quality control measures for their contributing watersheds. The Southern Lowcountry Stormwater Ordinance provides the *<local jurisdiction>* the flexibility and authority to designate subwatersheds or drainage areas as Special Watershed Protection Areas that lead to more restrictive requirements or special criteria. Such special designations and criteria will be provided as Appendix P to this Manual.

In the Southern Lowcountry, impairments include recreational water use impairment from bacteria (*Enterococcus* for saltwater and *E. coli* for freshwater), aquatic life use impairment from turbidity or dissolved oxygen, and shellfish harvesting use impairment from fecal coliform bacteria. Stormwater best management practices for these types of impairments include erosion and sediment control for turbidity impairments, illicit discharge detection, vegetated conveyances, vegetated buffers, pet waste programs, and post-construction runoff control. Currently, Southern Lowcountry water quality impairments do not include nutrient impairments, but nutrients can also be addressed through erosion and sediment control and the stormwater best management practices outlined in this Manual.

Most of Beaufort County and the lower reaches of the Jasper County watersheds have shellfish receiving waters or are recreational waters and are therefore sensitive to bacteria impairments. Land development and redevelopment projects in these watersheds require greater scrutiny to ensure that low impact development methods are designed, implemented and maintained to be protective of these water uses.

Watersheds tributary to the Savannah River in the Southern Lowcountry include most of the freshwater wetlands of the region. River water quality is excellent and is a supply for drinking water for the City of Savannah and the Beaufort Jasper Water and Sewer Authority. Savannah River impairments downstream of the I-95 bridge are primarily aquatic life use due to low dissolved oxygen. Since the

Savannah River is the boundary of Georgia and South Carolina, it is reasonable to align stormwater requirements within Jasper County with those in Chatham and Effingham Counties, GA. Stormwater permits for the Georgia jurisdictions require use of the Georgia Coastal Stormwater Supplement to the Georgia Stormwater Management Manual, which is primarily a green infrastructure/low impact development (GI/LID) design Manual with requirements specific to the Georgia coastal counties.

The remaining watersheds of the Southern Lowcountry are more upland areas and in agricultural or silvicultural use or are conservation lands. For these areas new development is subject to stormwater management requirements similar to previous county requirements. This Manual unifies stormwater management standards across the designated watersheds rather than differing across county or jurisdictional lines.

The map in Figure 3.2 outlines the boundaries of the three watershed protection areas of the Southern Lowcountry. Requirements specific to each area are further developed in this chapter. Table 3.1 lists the US Geological Survey 12-Digit Hydrologic Unit Code (HUC-12) for the watersheds in each area. To identify a site's HUC-12, refer to the South Carolina DHEC Watershed Atlas, available online at https://gis.dhec.sc.gov/watersheds/. After identifying the site's HUC 12, use Table 3.2 to identify the watershed protection area.

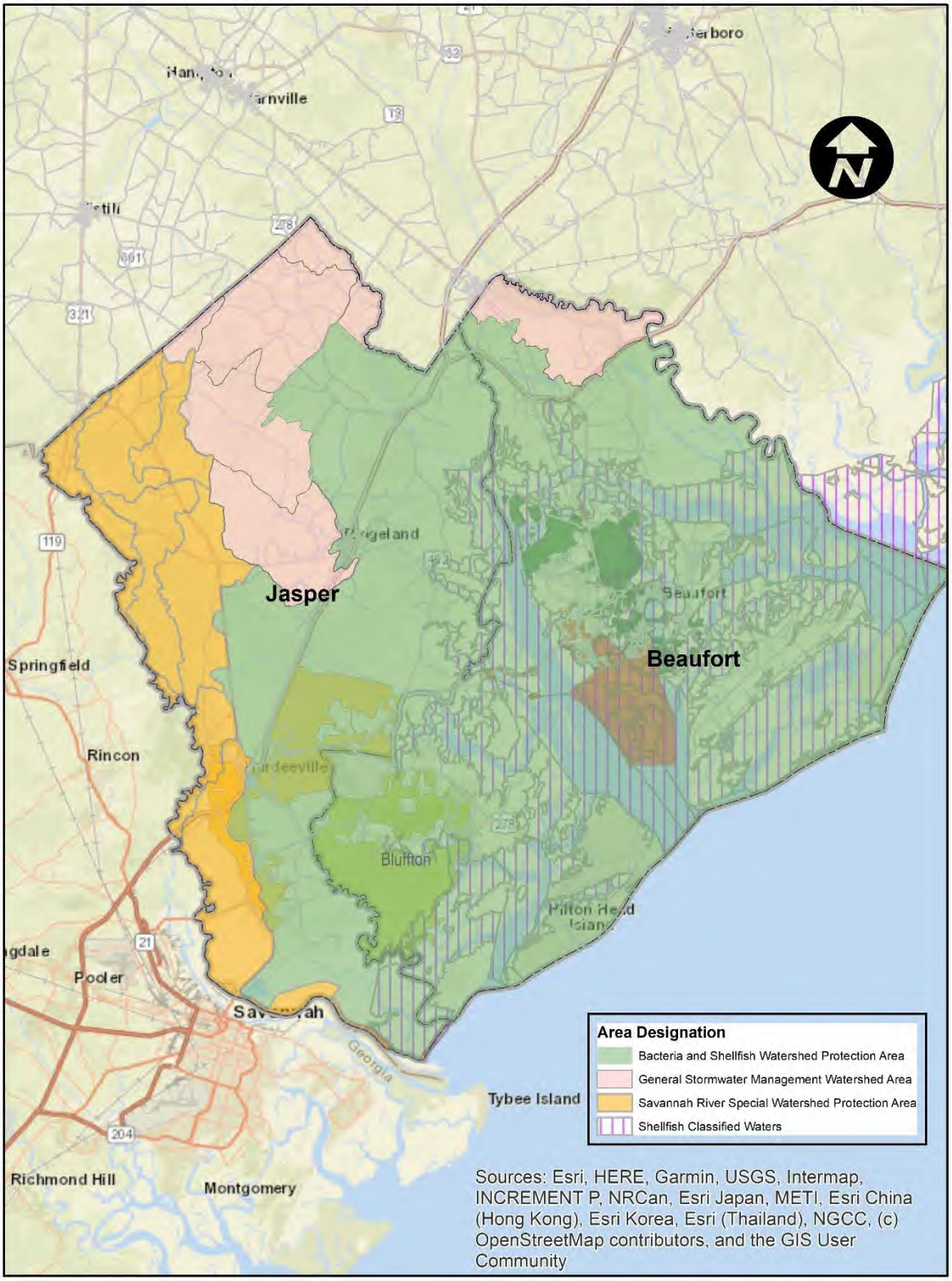

Figure 3.2. Watershed Protection Areas of the Southern Lowcountry.

Table 3.1. Watershed Protection Area HUC-12 Codes.

General Stormwater Management Watershed Areas		Savannah River Watershed Protection Area	
HUC-12 No.	**Watershed Name**	**HUC-12 No.**	**Watershed Name**
030502070704	Middle Combahee River	030601090107	Hog Branch-Savannah River
030502080301	Johns Pen Creek	030601090301	Cypress Branch
030502080302	Cypress Creek	030601090302	Black Swamp
030502080404	Mcpherson Creek-Coosawhatchie River	030601090303	Coleman Run
030502080405	Early Branch-Coosawhatchie River	030601090304	Sand Branch
030601100101	Gillison Branch	030601090305	Dasher Creek-Savannah River
030601100102	Upper Great Swamp	030601090307	Outlet Savannah River
Bacteria and Shellfish Watershed Protection Area			
HUC-12 No.	**Watershed Name**	**HUC-12 No.**	**Watershed Name**
030502070706	Lower Combahee River	030502080605	Boyd Creek-Broad River
030502071101	Wimbee Creek	030502080606	Colleton River
030502071102	Coosaw River	030502080607	Chechessee River
030502071103	Morgan River	030502080608	Broad River-Port Royal Sound
030502071104	Coosaw River-St. Helena Sound	030502100101	Harbor River-St. Helena Sound
030502080406	Bees Creek	030502100102	Harbor River-Trenchards Inlet
030502080407	Tulifiny River-Coosawhatchie River	030601090306	Wright River
030502080501	Battery Creek	030601100103	Lower Great Swamp
030502080502	Upper Beaufort River-Atlantic Intracoastal Waterway	030601100201	Upper New River-Atlantic Intracoastal Waterway
030502080503	Lower Beaufort River-Atlantic Intracoastal Waterway	030601100202	Lower New River-Atlantic Intracoastal Waterway
030502080601	Pocotaligo River-Broad River	030601100301	May River
030502080602	Huspa Creek	030601100302	Broad Creek
030502080603	Whale Branch	030601100303	Cooper River-Calibogue Sound
030502080604	Euhaw Creek	030601100304	Calibogue Sound

3.5.2 Overall Performance Requirements

Based on the watershed water quality criteria, its impairment status, or stormwater permit requirements, development and redevelopment stormwater management performance requirements will differ. These requirements are interpreted in terms of sizing and performance criteria. Table 3.2 presents a summary of the sizing criteria used to achieve the stormwater management performance requirements for each watershed protection area.

Table 3.2. Watershed Area Overall Performance Requirements.

General Stormwater Management Watershed Protection Areas	Savannah River Watershed Protection Area
Overall Performance Requirements	Overall Performance Requirements
• Water Quality: Implement Better Site Design, maintain pre-development hydrology of the site to the Maximum Extent Practicable (MEP) for the 85th percentile storm event. • Peak Control: Control post-development peak runoff discharge rate to pre-development rate for: 2-, 10- and 25-year, 24-hour design storm events. • Accommodate the 100-year, 24-hour storm event conveyance through the site and downstream without causing damage/inundation to structures. Provide 10% rule analysis. • As a pollutant removal minimum, intercept and treat stormwater runoff volume to at least an 80 percent reduction in total suspended solids load, 30 percent reduction of total nitrogen load and 60 percent reduction in bacteria load. • Complete a natural resources inventory for new site development applications.	• Water Quality: Implement Better Site Design, retain the 85th percentile storm event on-site to the MEP or obtain off-site credit. • Peak Control: Control post-development peak runoff discharge rate to pre-development rate for: 2-, 10- and 25-year, 24-hour design storm events. • Accommodate the 100-year, 24-hour storm event conveyance through the site and downstream without causing damage/inundation to structures. Provide 10% rule analysis. • As a pollutant removal minimum, intercept and treat stormwater runoff volume to at least an 80 percent reduction in total suspended solids load, 30 percent reduction of total nitrogen load and 60 percent reduction in bacteria load. • Complete a natural resources inventory for new site development applications.
Rationale	Rationale
The previous Jasper County stormwater design manual specified these overall performance requirements.	The Savannah River watershed adjoins Georgia counties that are subject to similar overall performance requirements as outlined in the Georgia Coastal Stormwater Supplement.
Bacteria and Shellfish Watershed Protection Area	
Overall Performance Requirements	
• Water Quality: Implement Better Site Design and retain the 95th percentile storm on-site with approved infiltration/filtering BMPs. Fulfill MEP requirements or, as a last resort, fulfill off-site credit and/or fee-in-lieu requirements. • As a pollutant removal minimum, intercept and treat stormwater runoff volume to at least an 80 percent reduction in total suspended solids load, 30 percent reduction of total nitrogen load and 60 percent reduction in bacteria load.	• Peak control: Control the post-development peak runoff discharge rate for the 2, 10 and 25-year, 24-hour design storm events to the pre-development discharge rates. • Accommodate the 100-year, 24-hour storm event conveyance through the site and downstream without causing damage/inundation to structures. Provide 10% rule analysis. • Complete a natural resources inventory for new site development applications.
Rationale	
The Bacteria and Shellfish Watershed Protection Areas are either impaired or have TMDLs, or the receiving waters are classified for shellfish harvesting. These watersheds require greater protection due to their Clean Water Act status or water quality classification. The site's natural resource inventory is a necessary component of permit application.	

3.5.3 Southern Lowcountry Stormwater Precipitation & Runoff

As in the natural environment, a site's stormwater runoff volume depends upon soil conditions and land cover. To evaluate each site's development plan, this Manual relies on the rainfall runoff estimating methods of the Natural Resources Conservation Service National Engineering Handbook (NEH). Sometimes referred to as the curve number method or soil cover complex method, NEH chapter 9 describes the runoff response to rainfall events based on hydrologic soil group (HSG A, B, C or D) and land cover type with an integer between 29 and 100 (NRCS, 2004). Accordingly, information documenting the site's soils, their permeability, predeveloped land use or natural cover, and post-developed land cover, as well as the shallow groundwater table, are required in development plans in order to review and permit the development activity.

Precipitation event size and distribution are set by this Manual for the three watershed protection areas that make up the Southern Lowcountry.

The precipitation event distribution terms used in this Manual are defined as follows:

> **85th Percentile Storm** is the 24-hour rainfall amount that according to the National Oceanic and Atmospheric Administration records for the past 30 years in which 85% of all rainfall events do not exceed at the nearest US Weather Service station to the County seat. For the General Stormwater Management Watershed Areas and the Savannah River Watershed Protection Areas, this number is 1.16 inches of rainfall.
>
> **95th Percentile Storm** is the 24-hour rainfall amount that according to the National Oceanic and Atmospheric Administration records for the past 30 years in which 95% of all rainfall events do not exceed at the nearest US Weather Service station to the County seat. For the Bacteria and Shellfish Watershed Protection Areas this is 1.95 inches of rainfall.

Plans submitted for new development or redevelopment must demonstrate through accepted hydrologic methods that the development at post-construction will attenuate and treat the prescribed storm events. This includes volume reduction, peak flow management and extreme flood protection both on site and downstream.

3.5.4 Savannah River Watershed Protection Area

Upon implementation of this Manual, any applicable new development, redevelopment or major substantial improvement in the designated HUC-12 watersheds that are part of the Savannah River watershed shall meet the following requirements:

- Complete a natural resources inventory for new site development applications.
- Document use of Better Site Design.
- Retain the 85th percentile storm event on-site to the MEP or obtain off-site credit.
- Control the post-development peak runoff discharge rate for the 2, 10 and 25-year, 24-hour design storm events to the pre-development discharge rates.
- Accommodate 100-year, 24-hour storm event through the development without causing damage to the on-site and offsite structures. Provide 10% rule analysis.
- At a minimum, intercept and treat stormwater runoff volume to at least an 80 percent reduction in total suspended solids load, 30 percent reduction of total nitrogen load and 60 percent reduction in bacteria load.

3.5.5 Bacteria & Shellfish Watershed Protection Area

Upon implementation of this Manual, any applicable new development, redevelopment or major substantial improvement in the designated HUC-12 watersheds that are part of the Bacteria and Shellfish Watershed Protection Area shall meet the following requirements:

- Complete a natural resources inventory for new site development applications.
- Document use of Better Site Design.
- Retain the 95th percentile storm on-site with approved infiltration/filtering BMPs.
- Fulfill MEP requirements or, as a last resort, fulfill off-site credit and/or fee-in-lieu requirements.
- At a minimum, intercept and treat stormwater runoff volume to at least an 80 percent reduction in total suspended solids load, 30 percent reduction of total nitrogen load and 60 percent reduction in bacteria load.
- Control the post-development peak runoff discharge rate for the 2, 10 and 25-year, 24-hour design storm events to the pre-development discharge rates.
- Accommodate the 100-year, 24-hour storm event conveyance through the site and downstream without causing damage/inundation to structures. Provide 10% rule analysis.

3.5.6 General Stormwater Management Watershed Area

Upon implementation of this Manual, any applicable new development, redevelopment or major substantial improvement in the designated HUC-12 watersheds for the General Stormwater Management Watershed Area shall meet the following requirements:

- Complete a natural resources inventory for new site development applications.
- Document use of Better Site Design.
- Maintain pre-development hydrology of the site to the Maximum Extent Practicable (MEP) for the 85th percentile storm event.
- Control post-development peak runoff discharge rate for the 2, 10 and 25-year, 24-hour design storm events to pre-development discharge rates.
- Accommodate 100-year, 24-hour storm event through the development without causing damage to the on-site and offsite structures. Provide 10% rule analysis.
- As a pollutant removal minimum, intercept and treat stormwater runoff volume to at least an 80 percent reduction in total suspended solids load, 30 percent reduction of total nitrogen load and 60 percent reduction in bacteria load.

3.5.7 Runoff Reduction & Pollutant Removal

It is the minimum criteria of this Manual that a site's stormwater best management practices shall retain the precipitation event size for its watershed protection area as summarized in Section 3.5.2. Through successive application of the practices below and that are described in detail in Chapter 4, provide at least an 80% reduction in total suspended solids loads, 30% reduction of total nitrogen load, and 60% reduction in bacteria load (Jasper County, 2011).

Stormwater best management practices, when built according to the standards in Chapter 4 and maintained according to the site's maintenance agreement, can be expected to achieve runoff reduction and pollutant removal efficiencies according to Table 3.3. These values are to be used in the pollutant removal documentation and are used within the stormwater runoff reduction calculator in Appendix H. Other water quality credits may be assigned for BMPs based on the determination by the *<local jurisdiction>* and valid study results presented with the Stormwater Management Plan submittal.

Table 3.3. Pollutant Removal Efficiencies of Structural BMPs.

BMP	Water Quality Credits			
	Runoff Reduction	TSS % Removal	Total N % Removal	Bacteria % Removal
Bioretention - No Underdrain	100%[1]	100%[1]	100%[6]	100%[6]
Bioretention – Internal Water Storage	75%[1]	85%[1]	85%[4]	80%[5]
Bioretention - Standard	60%[2]	85%[1]	75%[4]	80%[5]
Permeable Pavement - Enhanced	100%[1]	100%[1]	100%[6]	100%[6]
Permeable Pavement - Standard	30%[2]	80%[1]	45%[4]	30%[6]
Infiltration	100%[1]	100%[1]	100%[6]	100%[6]
Green Roof	100%[3]	100%[6]	100%[6]	100%[6]
Green Roof - Irrigated	50%[3]	50%[6]	50%[6]	50%[6]
Rainwater Harvesting	100%[3]	100%[6]	100%[6]	100%[6]
Impervious Surface Disconnection	40%[2]	80%[1]	40%[4]	40%[6]
Grass Channel	10%[2]	50%[1]	25%[4]	30%[5]
Grass Channel - Amended Soils	20%[2]	50%[1]	35%[4]	30%[5]
Dry Swale	60%[2]	85%	70%[4]	80%[5]
Wet Swale	0%[1]	80%[1]	25%[4]	60%[5]
Regenerative Stormwater Conveyance	0%[1]	80%[1]	40%[6]	80%[6]
Filtering Systems	0%[3]	80%[1]	30%[4]	80%[6]
Storage Practices	0%[3]	60%[1]	10%[4]	60%[5]
Stormwater Ponds	0%[1]	80%[1]	30%[4]	60%[5]
Stormwater Wetlands	0%[1]	80%[1]	25%[4]	60%[5]
Tree Planting and Preservation	see section 4.12			
Proprietary Practices	see section 4.13			
Conservation Areas	see section 4.14			

Notes:

The following resources were used to develop the runoff reduction and pollutant removal values in the above table.

1. (ARC, 2016).
2. (Hirschman, 2018).
3. (DOEE. 2013)
4. (Hirschman, 2018). Nitrogen removal values from this source were applied to the remaining volume after runoff reduction was applied. The values provided in the table above represent the results of this application.
5. (Chesapeake Stormwater Network, 2018)
6. Best professional judgement was used where a BMP's pollutant removal values were not available in the above sources, or conflicts were present. In all cases, a BMP's pollutant removal value must be at least as high as its runoff reduction values (for example, if a BMP is assigned a runoff reduction value of 100%, it will also have TSS, nitrogen, and bacteria removal rates of 100%). In addition, it was assumed that a Regenerative Stormwater Conveyance (RSC) will have similar nitrogen removal to bioretention systems, so the nitrogen removal value from the Runoff Reduction Method was applied as described in reference 4, above. It was also assumed that both RSCs and filtering systems will have the same bacterial removal rate as bioretention (with no runoff reduction).

3.6 Erosion & Sediment Control (ESC) Requirements

The design and management of construction site runoff control measures for all qualifying developments as defined in the Ordinance shall be in accordance with SCDHEC NPDES General Permit for Stormwater Discharges from Construction Activities, the SCDHEC Erosion and Sediment Reduction and Stormwater Management regulations and its most current version of standards, where applicable. The <*local jurisdiction*> reserves the right to require additional erosion and sediment control or a higher standard of measure and make their requirement a condition of a development permit approval.

3.7 Retention Standard & Volume

This section provides the formulas and rationale for use of the runoff reduction method to compare predeveloped and post-development hydrology for projects submitted for approval to the Southern Lowcountry jurisdictions.

Runoff reduction is defined as "the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended infiltration" (Hirschman, 2008). The formula to calculate the volume reduced through successive application of stormwater best management practices originates with the Natural Resources Conservation Service (NRCS) method of estimating direct runoff from storm rainfall and the curve number method of NEH Chapter 9 (NEH, 2004). As shown in Equation 3.1, rainfall event runoff (Q) is a function of depth of event rainfall (P) over the watershed, the initial abstraction (I_a) and the maximum potential retention (S).

Equation 3.1. Curve number runoff equation.

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

$$\boldsymbol{I_a = 0.2S}$$

$$\boldsymbol{Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}}$$

$$\boldsymbol{Q - R = \frac{(P - 0.2S)^2}{(P = 0.8S)}}$$

$$\boldsymbol{S = \frac{100}{CN} - 1}$$

Where:

Q =	Runoff depth (in)
P =	Depth of rainfall event for the designated watershed protection area (85th or 95th percentile rain event)
I_a =	Initial abstraction (in)
S =	Potential maximum retention after runoff begins (in)
CN =	Runoff curve number
R =	Retention storage provided by runoff reduction practices (in)

Not all stormwater BMPs provide runoff reduction equally. Through the crediting procedures of the Compliance Calculator found in Appendix H and the retention volumes required in this section, designers will be able to evaluate their proposed designs and submit for approval in a unified process across the Southern Lowcountry jurisdictions.[1]

Supplemental information on the terms below can be found in the *Low Impact Development in Coastal South Carolina: Planning and Design Guide*, and the Georgia Stormwater Management Manual (Ellis, K. et al., 2014; ARC, 2016).

The Stormwater Retention Volume (SWRv) is the volume of stormwater runoff that is required to be retained, post-development. It is calculated as shown in Equation 3.2 for the entire site and for each site drainage area (SDA). The SDA is defined as the area that drains to a single discharge point from the site or sheet flows from a single area of the site. A development site may have multiple SDAs and runoff coefficients.

Equation 3.2. Stormwater retention volume (SWRv) equation

$$\boldsymbol{SWRv} = \frac{\boldsymbol{P} \times [(\boldsymbol{Rv_I} \times \boldsymbol{I}) + (\boldsymbol{Rv_C} \times \boldsymbol{C}) + (\boldsymbol{Rv_N} \times \boldsymbol{N})]}{\mathbf{12}}$$

Where:

SWRv =	Volume required to be retained (cubic feet)
P =	Depth of rainfall event for the designated watershed protection area (85th or 95th percentile rain event)
Rv_I =	Runoff coefficient for impervious cover and BMP cover based on SCS hydrologic soil group (HSG) or soil type
I =	Impervious cover surface area (square feet)
Rv_C =	Runoff coefficient for compacted cover based on soil type
C =	Compacted cover surface area (square feet)
Rv_N =	Runoff coefficient for forest/open space based on soil type
N =	Natural cover surface area (square feet)
12 =	Conversion factor (inches to feet)

	Rv Coefficients			
	A soils	**B Soils**	**C Soils**	**D Soils**
Forest/Open Space (R_{VN})	0.02	0.03	0.04	0.05
Managed Turf (Rv_C)	0.15	0.20	0.22	0.25
Impervious Cover (R_{vI})	0.95	0.95	0.95	0.95
BMP	0.95	0.95	0.95	0.95

The surface area of a non-infiltrating BMP or its permanent pool shall be calculated as part of the impervious cover.

The Compliance Calculator in Appendix H uses best available pollutant removal efficiencies for total suspended solids, total nitrogen and fecal indicator bacteria. Use of the compliance calculator allows the designer to evaluate alternative designs to arrive at compliance with the runoff reduction and pollutant

[1] Compliance Calculator instructions are found in Appendix G

removal requirements and clearly summarize them for the local plan reviewer. The compliance calculator output is a necessary submittal for a plan reviewer to evaluate selected BMPs to demonstrate compliance with the watershed protection area standards of this Manual.

3.7.1 Total Suspended Solids, Nutrients, & Bacteria

The minimum pollutant removal performance requirements for all watersheds of the Southern Lowcountry include the interception and treatment of stormwater runoff volume to at least an 80% reduction in total suspended solids load, 30% reduction of total nitrogen load, and 60% reduction in bacteria load. These requirements are established for the following reasons.

Stormwater in the Lowcountry conveys the plant nutrients nitrogen and phosphorus. Nitrogen tends to dissolve in water, but phosphorus is adsorbed to suspended solids predominantly. Control of total suspended solids through the BMPs in this Manual will also remove a proportional amount of phosphorus. Relying on the judgement of stormwater researchers and other state design manuals, the approach for the Southern Lowcountry is similar. If a BMP is effective at runoff reduction or retention of stormwater, it is similarly effective at removal of the initial volume of suspended solids (NCDEQ, 2014).

Many of the Southern Lowcountry watersheds at the HUC-12 size are directly tributary to bacteria and shellfish impaired waters. As these watersheds develop with rooftops, roads and other impervious surfaces, there is an increasing potential for bacteria in the stormwater from wildlife populations (deer, racoons, waterfowl), pet waste, septic system discharges and sanitary sewer system malfunctions. Similarly, nutrients can be expected to increase due to fertilizer use in erosion control practices, managed turf and landscaping, septic system leachate, and atmospheric deposition on impervious surfaces. Best management practices, along with better site design practices, can be used to reduce bacteria and nutrients in stormwater to the benefit and restoration of Southern Lowcountry water quality.

3.7.2 Hydrologic & Hydraulic Analysis

In order to prevent an increase in the duration, frequency and magnitude of downstream overbank flooding and scouring, this Manual requires that enough stormwater detention be provided on a development site to control the post-development peak runoff discharge to the predevelopment runoff rates for the 2, 10, and the 25 -year, 24-hour storm events. The capacity of the existing downstream receiving conveyance system for all off-site discharge points must be determined to be adequate. An analysis of the downstream conveyance capacity to accommodate the site's post development 25- and 100-year, 24-hour peak flow shall be provided in the engineering report. Discharge to the public right-of-way of the SC State highway system shall comply with the SCDOT Requirements for Hydraulic Design Studies. Necessary upgrades within the public right-of-way due to inadequate capacity for the post-development 25-yr flow must be identified during the permit application process. Upgrades to the downstream system to accommodate the 100-yr 24-hour flow must be considered through the MEP process outlined in Section 3.9. Documentation supporting safe passage of the 100-yr post development flow to the downstream point where the detention or storage area comprises 10% of the total drainage area, and an analysis of the surrounding neighborhood area to identify any existing capacity shortfalls or drainage blockages is required for plan approval. This analysis is called the 10% analysis rule in Section 3.8 of this Manual.

The recommended 2, 10, 25, and 100-year, 24-hour storm event values from Appendix F of the South Carolina DHEC Storm Water Management BMP Handbook, July 31, 2005 for Beaufort and Jasper Counties are in Table 3.4[2].

Table 3.4. Rainfall depth (inches) for the Southern Lowcountry.

Return Period (years)				
County	**2**	**10**	**25**	**100**
Beaufort	4.5	6.9	8.4	11.0
Jasper	4.2	6.4	7.8	10.2

In this Manual, Appendix I General Design Criteria and Guidelines provides the acceptable methodologies and computer models for estimating runoff hydrographs before and after development, as well as design criteria for stormwater collection systems and land cover designations. The following are the acceptable methodologies and computer models for estimating runoff hydrographs before and after development. These methods are used to predict the runoff response from given rainfall information and site surface characteristic conditions. The design storm frequencies used in all of the hydrologic engineering calculations will be based on design storms required in this Manual unless circumstances make consideration of another storm intensity criterion appropriate:

- Rational Method (limited to sites under 10 acres)
- Urban Hydrology for Small Watersheds TR-55
- Storage-Indication Routing
- HEC-1, WinTR-55, TR-20, ICPR v3 or 4 and SWMM computer models

These methods are given as valid in principle and are applicable to most stormwater management design situations in the Southern Lowcountry.

The following conditions should be assumed when developing predevelopment, pre-project, and post-development hydrology, as applicable:

- The design storm duration shall be the 24-hour rainfall event, using the NRCS (SCS) Type III rainfall distribution with a maximum six-minute time increment.
- The predeveloped peaking factor shall be 200 for new development (Blair et al., 2012).
- The post development peaking factor shall be 323.
- For new development sites the predeveloped condition shall be calculated as a composite CN based on the HSG and meadow conditions (NEH, 2004).
- For infill and redevelopment sites, the predeveloped condition shall be calculated as a composite CN based on the HSG and the land cover type and hydrologic condition at the time of the project's initial submittal.
- Antecedent Runoff Condition (ARC) II is the average adjustment factor for calculations using TR-55. ARC III is to be used for wetter conditions such as areas that receive irrigation water harvested from stormwater ponds and for poorly drained soils.

[2] Until SCDHEC updates its Stormwater Management BMP Handbook rainfall table to the NOAA Atlas 14 values, the Southern Lowcountry region shall use the Handbook Appendix F rainfall table for 24 hour storm events.

Project designs must include supporting data and source information. All storm sewer systems shall be analyzed for both inlet and outlet control (including tailwater effects) by using the following:

a. Equations and nomographs as shown in the Federal Highway Administration (FHWA) Hydraulic Design Services (HDS) publication No. 5.

b. Computer programs that calculate the actual hydraulic grade line for the storm sewer system can be used, provided all losses (friction, bend, junction, etc.) are taken into account using the appropriate loss coefficient (K) values.

c. Design tailwater condition elevation shall be supported by a reasonable resource and/or analysis.

d. Allowable headwater. The allowable headwater of all culverts, pipe systems, open channels, bridges and roadway culverts shall be established following the SCDOT Requirements for Hydraulic Design Studies.

All culverts, pipe systems, and open channel flow systems shall be sized in accordance with the design criteria found in Appendix I Hydrology and Hydraulics Design Requirements.

3.7.3 Maintenance Easements

Maintenance easements are provided for the protection and legal maintenance of stormwater management facilities not within a right-of-way. Drainage easements shall be required in subdivisions over any portion of a stormwater management facilities not within a right-of-way and necessary for the functioning of the system. Drainage easements for all facilities must be shown on construction drawings and approved by the stormwater manager. The easements shall be designated on the plan prior to issuance of a development permit and recorded in public records with copy of recorded easement submitted prior to <*local jurisdiction*> permit termination. The minimum allowable width of drainage easements shall be as shown in Table 3.5.

Table 3.5. Drainage maintenance access easements.

Stormwater Management Facility	Minimum Easement Width
Closed systems (storm sewers/pipes/culverts)	diameter + 4 ft + 2D(20-ft minimum)*
Open drainage systems	
Bottom width 20 ft or less	15 ft + BW + 2SD (30 ft minimum)**
Bottom width 20 ft to 40 ft	30 ft + BW + 2SD**
Bottom width greater than 40 ft	40 ft + BW + 2SD**
Retention/detention BMPs	20 ft around facility***
Pond Maintenance Access	A 20' maintenance access easement between lot lines and top of bank shall be provided for stormwater ponds with a permanent pool. The easement shall be provided for boat trailer access, and for all structure maintenance and repair. No permanent structures (mechanical, electrical, phone, fences) or landscaping are allowed within the 20' pond maintenance access easement.
*Where: D = Depth from grade to pipe invert **Where: BW = Bottom width S = Side slope D = Depth of opening	
Note: The minimum required width and configuration of drainage easements may be modified if deemed necessary by the stormwater manager for justifiable reasons.	

3.8 Extreme Flood Requirement: 10% Rule

The peak discharge generated by the 100-year, 24-hour storm event under post-development conditions is considered the extreme peak discharge. The intent of the extreme flood protection is to prevent flood damage from infrequent but large storm events, maintain the boundaries of the mapped 100-year floodplain, and protect the physical integrity of the best management practices as well as downstream stormwater and flood control facilities. The 100-yr flow is to be used in the routing of runoff through the drainage system and stormwater management facilities to determine the effects on the facilities, adjacent property, and downstream. Emergency spillways of best management practices should be designed appropriately to pass the resulting flows safely.

Documentation supporting safe passage of the 100-year post-development flow shall be provided by the applicant/engineer. In order to prevent an increase in the duration, frequency and magnitude of downstream extreme flooding over existing conditions, an evaluation must be provided to include downstream analysis to the point where the project comprises 10% of the total contributing drainage area. The 10% rule evaluation must address existing conveyance system capacity and "pinch points" where a pipe/culvert would be overtopped and where the pipe/culvert will need to be upgraded or the peak discharge rate will need to be limited to the capacity of the downstream system.

The 10% rule recognizes the fact that a structural BMP control providing detention has a "zone of influence" downstream where its effectiveness can be felt. Beyond this zone of influence, the structural control becomes relatively small and insignificant compared to the runoff from the total drainage area at that point. Based on studies and master planning results from a large number of sites, that zone of influence is considered to be the point where the drainage area controlled by the detention or storage

facility comprises 10% of the total drainage area. For example, if the drainage control drains 10 acres, the zone of influence ends at a point where the total drainage area is 100 acres or greater (ARC, 2016).

Demonstration of safe passage of the 100-year, 24-hour storm shall include a stage storage analysis of the system, an inflow/outflow comparison of the system, and construction of a table showing peak stage elevations in comparison to safe freeboards to structures of the system and adjacent buildings/structures/infrastructure. Safe passage to the receiving water also requires that there be no additional downstream flooding or other environmental impacts (e.g., stream channel enlargement, degradation of habitat).

Typical steps in the application of the 10% rule are:

1. Determine the target peak flow for the site for predevelopment conditions.
2. Using a topographic map, determine the lower limit of the zone of influence (10% point)
3. Using a hydrologic model, determine the predevelopment peak flows and timing of those peaks at each tributary junction beginning at the pond outlet and ending at the next tributary junction beyond the 10% point.
4. Change land use on the site to post-development and rerun the model.
5. Design the structural control facility such that the overbank flood protection (25-year) post-development flow is adequately conveyed to the lower limit of the zone of influence and the Extreme Flood (100-year) post-development flow does not impact any existing structures within the area of zone of influence.
6. If the overbank flood protection (25-year) post-development flow is not adequately conveyed to the lower limit of the zone of influence and/or Extreme Flood (100-year) post-development flow is shown to impact any structure, the structural control facility must be redesigned or one of the following options considered:
    a. Work with the *<local jurisdiction>* to reduce the flow elevation through channel or flow conveyance structure improvements downstream.
    b. Obtain a flow easement from downstream property owners to the 10% point.
    c. Request a detention waiver from *<local jurisdiction>.* This waiver would be for water quantity control only and best management practices to achieve water quality goals will still be required.

3.9 Maximum Extent Practicable

Maximum extent practicable (MEP) is the language of the Clean Water Act that sets the standards to evaluate efforts pursued to achieve pollution reduction to the Waters of the United States. The MEP refers to management practices; control techniques; and system, design, and engineering methods for the control of pollutants. It allows for considerations of public health risks, societal concerns, and social benefits, along with the gravity of the problem and the technical feasibility of solutions. The MEP for stormwater management is achieved, in part, through a process of selecting and implementing different design options with various structural and non-structural stormwater best management practices (BMPs), where ineffective BMP options may be rejected, and replaced when more effective BMP options are found (DOEE, 2019).

There must be a serious and demonstrated attempt to comply with this Manual, and practical solutions may not be lightly rejected. If project applicants implement and demonstrate only a few of the least expensive BMPs, and the regulated volume has not been retained, it is likely that the MEP standard has

not been met. If, on the other hand, a project applicant implements all applicable and effective BMPs except those shown to be technically infeasible, then the project applicant would have achieved retention to the MEP.

Major land-disturbing activities, infill and redevelopment projects, and projects in the existing public right-of-way, must achieve the SWRv, and meet peak flow requirements for channel and extreme flood protection to the MEP. Through application of stormwater best management practices on site or at an off-site property within the same stormwater drainage catchment, land development projects should be able to comply with the Southern Lowcountry Stormwater Ordinance. It is the applicant's responsibility to demonstrate to the greatest extent that the requirements of this Manual can be met for the proposed development. The applicant must fully demonstrate that the requirements of the Manual are not possible or feasible before entering into a MEP analysis, and only after the concurrence of the *<local jurisdiction>* based on the project submittals, documentation and discussions. The applicant must realize that if the requirements of the Manual cannot be met, the site may not be conducive for development, as proposed, in the interest of public safety and welfare.

When a new land development project, infill or redevelopment cannot meet the volume and peak flow requirements of this Manual, the following design and review process is required to comply with the MEP requirement. This evaluation is intended to be completed during the concept review stage of plan development.

1) Demonstrate how BSD has been implemented to the maximum extent practicable or document site restrictions that prevent BSD application.
2) List the site restrictions that prevent the on-site use of the stormwater BMPs of this Manual.
3) Cite justification for not being able to retain the SWRv and attain the required peak discharge limits.
4) Is there off-site capacity in the same drainage catchment as defined by the *<local jurisdiction>* to meet the volume and/or peak flow requirements for the site's contributing drainage area(s)?
5) Does the publicly maintained stormwater drainage system have sufficient capacity for the development site's extreme flood peak flow?
6) Develop a cost versus aggregated stormwater retention volume achieved curve for the site's contributing drainage area. A minimum of five cost points with three of the BMP alternatives in series as a treatment train are necessary for the curve. Include the evaluation off-site capacity cost. Identify the inflection point of the cost curve to identify the optimal solution where increased cost does not result in increased effectiveness.
7) The optimum aggregated retention value and BMP selection and size analysis must be submitted as a part of the stormwater management plan for the project.
8) Offsite stormwater volume retention credit or fee-in-lieu documents will be required for project completion.

The MEP submittal must provide documentable evidence of the process the applicant has performed that demonstrates the restrictions to the use and implementation of BMPs to meet the requirements of this Manual in whole or in part.

3.10 Off-Site Stormwater Management

All stormwater management design plans shall include on-site stormwater management practices, unless post-construction stormwater runoff in an off-site or regional stormwater management practice is approved according to this Section.

The off-site or regional stormwater management practice must be located on property legally dedicated to that purpose, be designed and sized to meet the post-construction stormwater management criteria presented in this Manual, provide a level of stormwater quality and quantity control that is equal to or greater than that which would be provided by on-site green infrastructure and stormwater management practices, be in the same drainage catchment, as defined by the <*local jurisdiction*>, as the project area, and have an associated inspection and maintenance agreement and plan. In addition, appropriate stormwater management practices shall be installed, where necessary, to protect properties and drainage channels that are located between the development site and the location of the off-site or regional stormwater management practice.

To be eligible for compliance through the use of off-site stormwater management practices, the applicant must submit a stormwater management design plan to the <*local jurisdiction*> that demonstrates the adequacy of the off-site or regional stormwater management practice, and demonstrates, to the satisfaction of the <*local jurisdiction*> that the off-site or regional stormwater management practice will not result in any of the following impacts:

(1) Increased threat of flood damage or endangerment to public health or safety;

(2) Deterioration of existing culverts, bridges, dams, and other structures;

(3) Accelerated streambank or streambed erosion or siltation;

(4) Degradation of in-stream biological functions or habitat; or,

(5) Water quality impairment in violation of state water quality standards and/or violation of any other state or federal regulations.

3.11 Fee-in-Lieu

Fee-in-lieu is, as the name suggests, a program where an entity with the responsibility of managing stormwater runoff pays a fee in lieu of physically managing and maintaining stormwater on site or off site. Based on the cost of treatment, long term maintenance/repair/replacement and inspection costs, a representative cost of treating stormwater can be established, and that money can go to larger scale and more efficient practices being implemented (ARC, 2016). The developer provides a fee to the <*local jurisdiction*> (or its assigned entity) that will help cover cost of installation and long-term operation and maintenance of the stormwater practice. A fee-in-lieu program can be administered through the <*local jurisdiction*>, a public/private initiative, or a private bank. Any fee-in-lieu program must have an Enterprise Fund and ability to oversee construction activities (e.g. programs managed by the <l*ocal jurisdiction*>) or be able to collect fees and dedicate those funds to stormwater related projects. In-lieu fees typically need to cover higher municipal prevailing wage and public bidding costs. The off-site mitigation practices must be implemented in the same HUC-12 watershed as the original project (or more restrictive limits, at the discretion of the local authority). Therefore, careful accounting must take place to ensure that each site using off-site mitigation to meet pollutant removal requirements has corresponding off-site controls in the same watershed (CWP, 2012).

3.12 Waivers

Individuals seeking a waiver from the requirements of this Ordinance may submit to the *(administrator)* a request for a waiver in accordance with the Southern Lowcountry Stormwater Design Manual.

(1) Request of a Waiver at Staff Level
A written request for a waiver is required and shall state the specific waiver sought and the reasons, with supporting data, a waiver should be granted. The request shall include all information necessary to evaluate the proposed waiver. Requests must outline the need for such a waiver, such as site constraints, soil characteristics, or similar engineering limitations. Cost shall not be considered cause for a waiver. The applicant will address the criteria below for consideration of a waiver approval:

a. What exceptional circumstances to the site are evident that on-site or off-site stormwater management requirements cannot be met?
b. What unnecessary hardship is being caused?
c. How will denial of the waiver be inconsistent with the intent of the Ordinance?
d. How will granting the waiver comply with the intent of the Ordinance?
e. How are state and federal regulations still being met?

(2) Review of Waivers
The <*administrator*> will conduct a review of the request and will issue a decision within thirty (30) working days of receiving the request.

(3) Fee-in-Lieu Requirement
a. If a Waiver is granted, the applicant must submit a fee in lieu of meeting stormwater requirements as determined by <*local jurisdiction*> for regional stormwater management projects.

(4) Appeal of Decision
Any person aggrieved by the decision of the (*administrator*) concerning a waiver request may appeal such decision in accordance with the <*local jurisdiction*> established process.

3.13 References

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Chapter 4. Stormwater Best Management Practices (BMPs)

4.1 Standard Stormwater BMP Design Sections

This chapter summarizes and outlines performance criteria for 13 stormwater best management practice (BMP) categories that include:

- Bioretention
- Permeable Pavements
- Infiltration
- Green Roofs
- Rainwater Harvesting
- Impervious Surface Disconnection
- Open Channel Systems
- Filtering Systems
- Storage Practices
- Ponds
- Stormwater Wetlands
- Tree Planting and Preservation
- Proprietary Practices

Following these criteria is the criteria to credit for stormwater benefit the use of conservation areas and open space preservation.

4.1.1 Format of Standard Stormwater BMP Design Sections

BMP performance criteria are based on several critical design factors to ensure effective and long-lived BMPs. For each BMP, the following factors are discussed:

- General Feasibility
- Conveyance
- Pretreatment
- Design and Sizing
- Landscaping
- Construction Sequencing
- Maintenance
- Stormwater Compliance Calculations

Design components that differ from these specifications, but meet their intent, may be included at *<local jurisdiction>*'s discretion.

4.1.2 Standard Nomenclature

In this chapter, and throughout the guidebook, the terms, *must* or *shall*, denote required aspects of BMPs or their design and implementation. The term, *should*, denotes a recommendation, however, justification may be necessary for design or implementation that does not correspond to certain recommendations.

4.2 Summary of BMP Stormwater Management Capabilities, Site Applicability, & Physical Feasibility

Stormwater management requirements for a given site vary based on the site's location, and minimum control requirements discussed in detail in Section 3.5.

4.2.1 Stormwater Retention & Water Quality Treatment

It is important to note that this Manual, and the associated compliance calculators, make a distinction between stormwater retention volume and stormwater water quality treatment. Not all BMPs achieve stormwater retention and/or water quality treatment equally, as was summarized in Table 3.3. The level to which a BMP provides stormwater retention and water quality treatment is provided in the BMP summary table of each BMP. The stormwater runoff reduction (SWRv) rates are expressed as a percentage of the storage volume provided by the BMP. Calculations for determining storage volume are included in each BMP's specifications. Each BMP's performance on the water quality parameters of total suspended solids, nitrogen and bacteria are also included in the BMP summary table. Note that many BMPs whose main purpose is water quality treatment typically do not have enough volume control to manage larger storm events.

4.2.2 Site Applicability

Certain BMPs are more appropriate than others in certain land uses. Table 4.1 describes the site applicability for each BMP for the following factors:

- Rural Use: This column indicates whether or not the stormwater management practice is typically suited for use in rural areas and on low-density development sites.
- Suburban Use: This column indicates whether or not the stormwater management practice is typically suited for use in suburban areas and on medium-density development sites.
- Urban Use: This column identifies the stormwater management practices that are typically suited for use in urban and ultra-urban areas where space is at a premium.
- Construction Cost: This column assesses the relative construction cost of each of the stormwater management practices.
- Maintenance: This column assesses the relative maintenance burden associated with each stormwater management practice. Note that all stormwater management practices require routine inspection and maintenance.

Table 4.1. Site applicability for BMPs.

BMP	Rural Use	Suburban Use	Urban Use	Construction Cost	Maintenance
Bioretention	Yes	Yes	Yes	Medium	Medium
Permeable Pavement	Maybe	Yes	Yes	High	High
Infiltration	Yes	Yes	Yes	Medium	Medium
Green Roof	Maybe	Yes	Yes	High	Low
Rainwater Harvesting	Yes	Yes	Yes	Medium	Medium
Disconnection	Yes	Yes	Maybe	Low	Low
Open Channels	Yes	Yes	No	Low-Medium	Medium
Filtration	Maybe	Yes	Yes	High	High
Dry Ponds	Yes	Yes	No	Low	Low
Wet Ponds	Yes	Yes	No	Low	Low
Stormwater Wetlands	Yes	Yes	No	Low	Medium

4.2.3 Site Conditions & Physical Feasibility

While some BMPs can be applied almost anywhere, others require specific conditions to be most effective. Physical feasibility refers to the physical site conditions necessary to effectively design and install a BMP. Table 4.2 includes the feasibility factors listed below.

- Contributing Drainage Area (CDA): Volume of water received by a practice can affect BMP performance. This column indicates the contributing drainage areas that typically apply for each BMP.
- Slope: This column describes the influence that site slope can have on the performance of the BMP. It indicates the maximum slope on which the BMP should be installed.
- Minimum Head: This column provides an estimate of the minimum amount of elevation difference needed within the BMP, from the inflow to the outflow, to allow for gravity operation.
- Minimum Depth to Seasonal High Water Table: This column indicates the minimum distance that should be provided between the bottom of the stormwater management practice and the top of the water table.
- Soils: This column describes the influence that the underlying soils (i.e., hydrologic soil groups) can have on the performance of the stormwater management practice.

Table 4.2. Feasibility limitations for BMPs.

BMP	Contributing Drainage Area	Slope	Minimum Head	Minimum Depth to Water Table	Soils
Bioretention	Up to 2.5 acres	Up to 5%[2]	4 - 5 feet	0.5 feet	All soils[3]
Permeable Pavement	Up to 5 times practice surface area	Up to 5%	1 – 4 feet	0.5 feet	All soils[3]
Infiltration	Up to 2 acres	Up to 6%[2]	2 feet	0.5 feet	Must drain within 72 hours
Green Roof	Green roof area + 100%	Up to 30%[4]	N/A	N/A	N/A
Rainwater Harvesting	No limit	No limit	N/A	N/A	N/A
Disconnection	Up to 1,000 ft^2 per downspout	Up to 5%	N/A	N/A	All soils
Open Channels	Up to 2.5 acres	Up to 4%[2]	Varies	Varies	All soils
Filtration	Up to 5 acres	Up to 6%	2 – 10 feet	0.5 feet	All soils
Storage Practices	Varies	No limit	5 feet	0.5 feet	All soils
Ponds	Greater than 10 acres[1]	Up to 15%	6 – 8 feet	No limit	Slow-draining soils preferred
Stormwater Wetlands	Varies	Up to 8%[2]	2 – 4 feet	No limit	Slow-draining soils preferred

[1] *CDA can be smaller if practice intersects the water table.*
[2] *Check dams may be necessary to create sufficient ponding volume.*
[3] *Slow-draining soils may require an underdrain.*
[4] *Roof slope.*

Irrigation from ponds is not included as a specific best management practice in this M*anual* but is included as Rainwater Harvesting (§4.5). Requirements and guidance for irrigation use of retained stormwater have been included in Hydrologic and Hydraulic Analysis (ARC requirements in §3.7.2); Ponds (§4.10); and Rainwater Harvesting Treatment and Management Requirements (Appendix J). The Rainwater Harvesting Calculator in Appendix K will be used to determine the SWRv credit for ponds used for irrigation, and then these ponds are entered in the Compliance Calculator in Appendix H as rainwater harvesting. Instructions for these entries are included in Appendix G Compliance Calculator Instructions.

4.3 Bioretention

Bioretention				
Definition: Practices that capture and store stormwater runoff and pass it through a filter bed of engineered filter media composed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system or allowed to infiltrate into the soil.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Small to Large	**TSS[1]**	**Total N[1,]**	**Bacteria[1,2]**
		85%–100%	75%–100%	80%–100%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
Moderate	Moderate	High		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	No Underdrain	IWS	Standard
Quarterly	Every 2–3 years	100% of Sv	75% of Sv	60%
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Easily incorporated into new development ▪ High community acceptance ▪ Good for small, highly paved drainage areas (i.e. parking lots)		▪ Maximum CDA is 1 to 2.5 acres ▪ Requires pretreatment to prevent clogging ▪ Requires detailed landscape planning ▪ Not appropriate for steep slopes		
Components		**Design considerations**		
▪ Pretreatment ▪ Conveyance system ▪ Ponding area ▪ Soils/Filter Media/Mulch ▪ Observation Well/Monitoring Port ▪ Plants		▪ Maximum ponding depth 18 inches ▪ Minimum filter media bed depth 18 inches ▪ Depth to seasonal high water table must be at least 6 inches below bottom of practice ▪ Underdrain system may be needed		
Maintenance Activities				
▪ Mow turf cover periodically ▪ Replace mulch as needed to maintain depth of mulch		▪ Replace plant material, as needed ▪ Replace soil if it becomes clogged ▪ Clean conveyance system(s)		

[1]*Credited pollutant load removal*
[2]*In order to receive the full credit for bacteria removal a minimum media depth of 24" is required.*

Bioretention areas, shallow depressional areas that are filled with an engineered soil media and are planted with trees, shrubs, and other herbaceous vegetation, are one of the most effective stormwater management practices that can be used to reduce post-construction stormwater runoff rates, volumes, and pollutant loads. They also provide a number of other benefits, including improved aesthetics, wildlife habitat, urban heat island mitigation, and improved air quality. See Figure 4.1 for an example image.

They are designed to capture and temporarily store stormwater runoff in the engineered soil media, where it is subjected to the hydrologic processes of evaporation and transpiration, before being conveyed back into the storm drain system through an underdrain or allowed to infiltrate into the surrounding soils. The engineered soil media is comprised of sand, soil, and organic matter.

Typically, bioretention systems are not designed to provide stormwater detention of larger storms (e.g., 2-, 10-, 25-year), but in some circumstances that may be possible. Bioretention practices should generally be combined with a separate facility to provide those controls.

Figure 4.1. Bioretention in parking lot (photo credit: Center for Watershed Protection, Inc.).

Definition. Practices that capture and store stormwater runoff and pass it through a filter bed of engineered filter media composed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system or allowed to infiltrate into the soil. Design variants include the following:

B-1 Bioretention

B-2 Streetscape bioretention

B-3 Engineered tree pits

B-4 Stormwater planters

B-5 Residential rain gardens (for single family homes)

There are three different bioretention design configurations:

1) **No Underdrain**. Practices that can infiltrate the design storm volume within 72 hours, and therefore need no underdrain (see Figure 4.2).
2) **Internal Water Storage (IWS)**. Practices that include an infiltration sump/storage layer (see Figure 4.3) below the underdrain.
3) **Standard**. Practices with underdrains (see Figure 4.4).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed in this chapter.

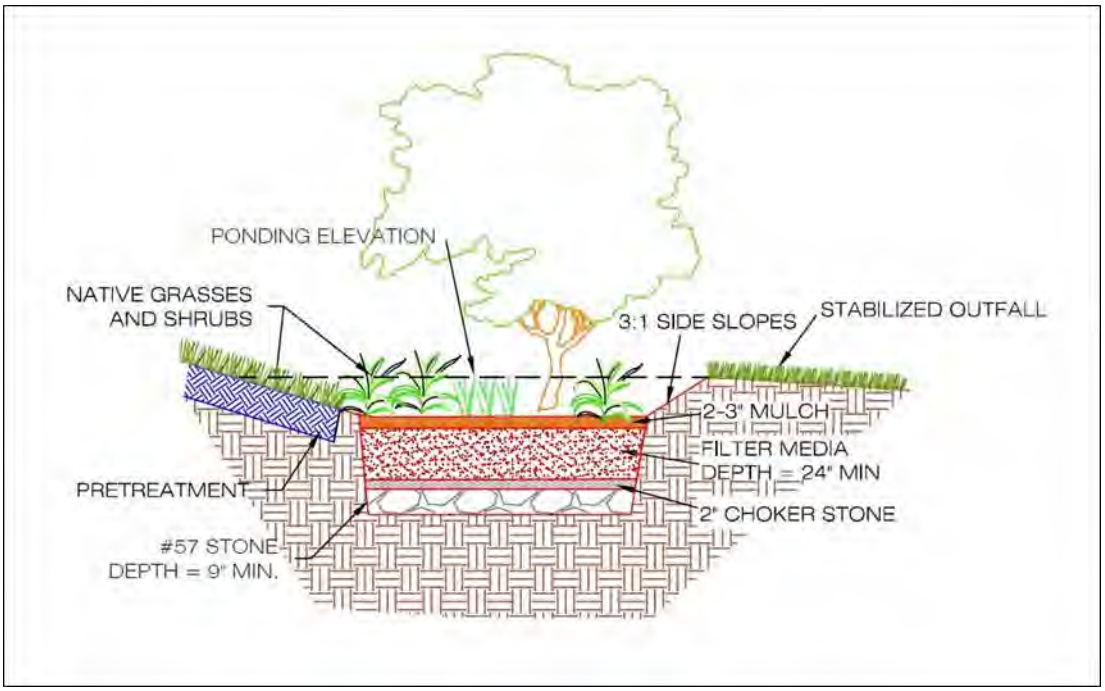

Figure 4.2. Example bioretention design without an underdrain.

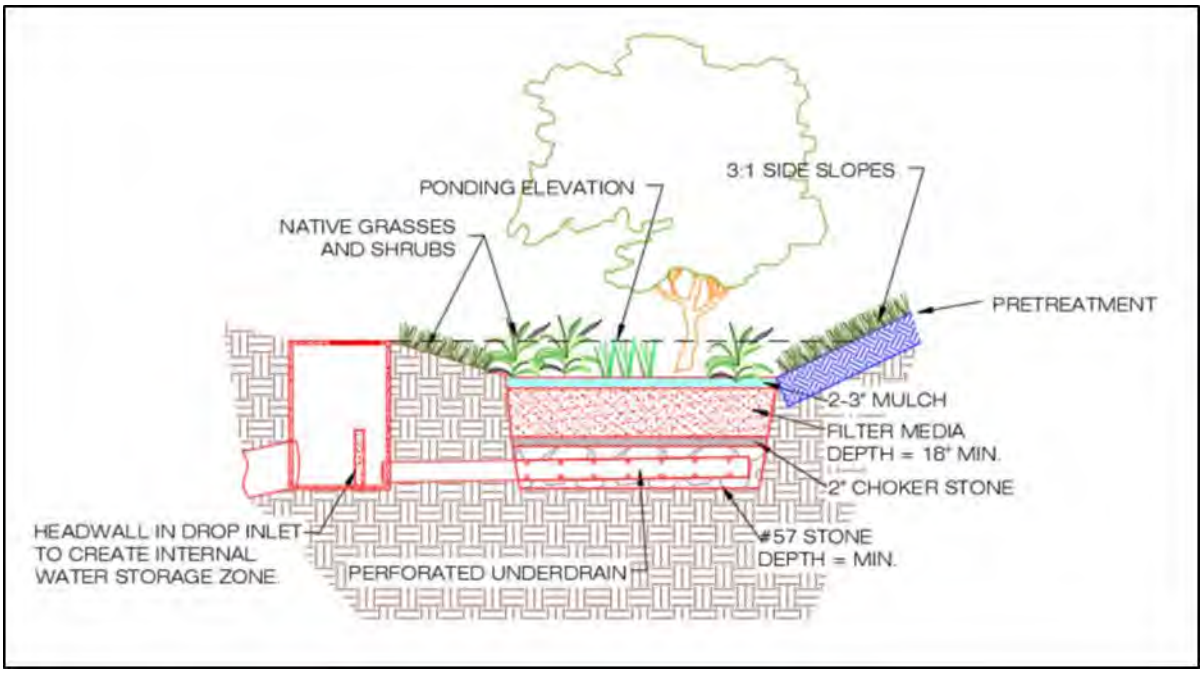

Figure 4.3. Example bioretention design with internal water storage (IWS).

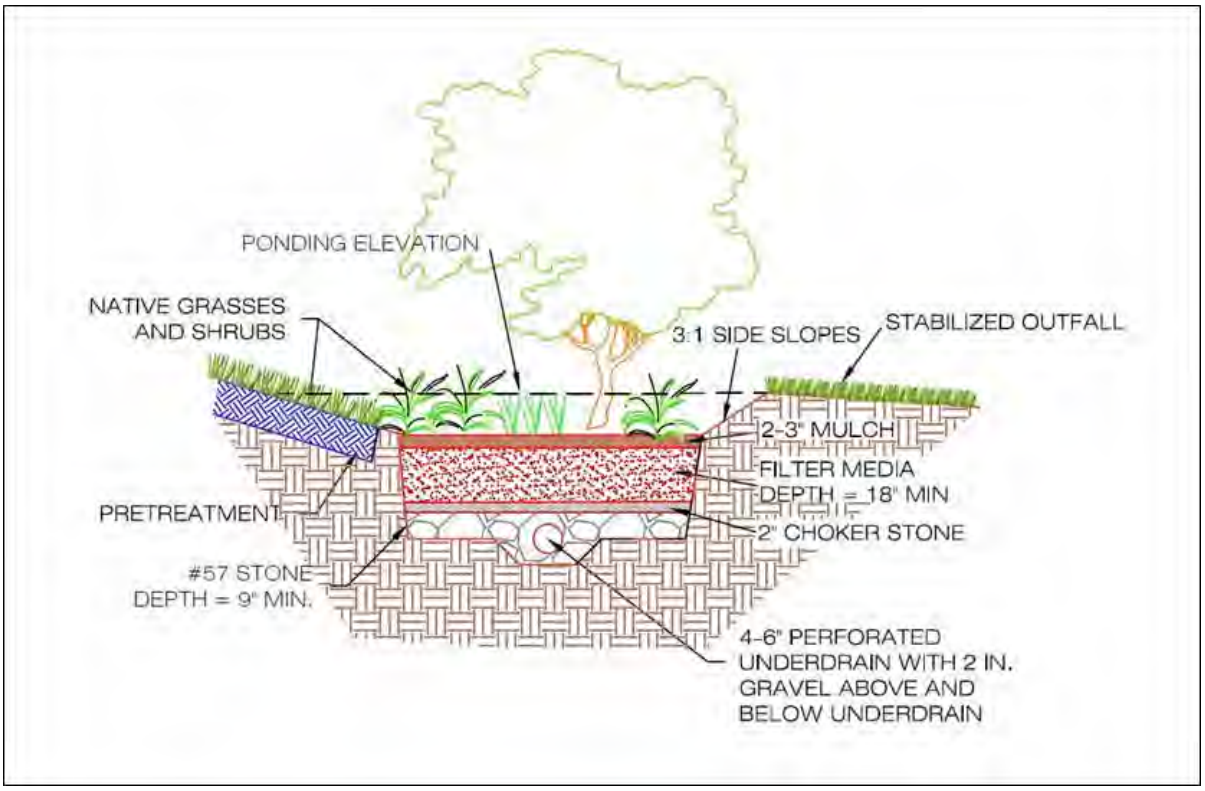

Figure 4.4. Example standard bioretention design.

Figure 4.5. Example streetscape bioretention.

4.3.1 Bioretention Feasibility Criteria

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and is infiltrated or returned to the stormwater system via an underdrain. Key constraints with bioretention include the following:

Required Space

Planners and designers can assess the feasibility of using bioretention facilities based on a simple relationship between the CDA and the corresponding bioretention surface area. The surface area is recommended to be approximately 3 to 6% of CDA, depending on the imperviousness of the CDA and the desired bioretention ponding depth.

Site Topography

Bioretention can be used for sites with a variety of topographic conditions, but it is best applied when the grade of the area immediately adjacent to the bioretention practice (within approximately 15 to 20 feet) is greater than 1% and less than 5%.

Available Hydraulic Head

Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention area into the storm drain system). In general, 4 to 5 feet of elevation above this invert is

needed to accommodate the required ponding and filter media depths. If the practice does not include an underdrain or if an inverted or elevated underdrain design is used, less hydraulic head may be adequate.

Water Table

Bioretention must be separated from the water table to ensure that groundwater does not intersect the filter bed. Mixing can lead to possible groundwater contamination or failure of the bioretention facility. A separation distance of no less than 0.5 feet is required between the bottom of the excavated bioretention area and the seasonally high groundwater table.

Tidal Impacts

For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations. Also, salt-tolerant vegetation may be necessary in these areas.

Soils and Underdrains

Soil conditions do not typically constrain the use of bioretention, although they do determine whether an underdrain is needed. Underdrains may be required if the measured permeability of the underlying soils is less than 0.3 inches per hour. When designing a bioretention practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B for Geotechnical Information Requirements for Underground BMPs. Impermeable soils will require an underdrain.

For fill soil locations, geotechnical investigations are required to determine if it is necessary to use an impermeable liner and underdrain.

Contributing Drainage Area

Bioretention cells work best with smaller CDAs, where it is easier to achieve flow distribution over the filter bed. The maximum CDA to a standard bioretention area (B-1) is 2.5 acres and can consist of up to 100% impervious cover. The CDA for smaller bioretention practices (B-2, B-3, B-4, and B-5) is a maximum of 1 acre. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger CDAs, such as off-line or low-flow diversions, or forebays, there may be case-by-case instances where the maximum CDAs can be adjusted. summarizes typical recommendations for bioretention CDAs.

Table 4.3. Maximum contributing drainage area (CDA) to bioretention.

Bioretention Type	Design Variants	Maximum CDA (acres of impervious cover)
Standard	B-1	2.5
Small-scale bioretention	B-2, B-3, B-4, and B-5	1.0

Pollutant Hotspot Land Uses

Bioretention may not be an appropriate stormwater management practice for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from

industrial processes), appropriate pretreatment, such as an oil- water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the bioretention area and subsequent water bodies.

On sites with existing contaminated soils, infiltration is not allowed. An impermeable bottom liner and an underdrain system must be employed when a bioretention area will receive untreated hotspot runoff, and the No Underdrain design configuration cannot be used.

Bioretention can still be used to treat parts of the site that are outside of the hotspot area. For instance, roof runoff can go to bioretention while vehicular maintenance areas would be treated by a more appropriate hotspot practice.

No Irrigation or Baseflow

The planned bioretention area should not receive baseflow, irrigation water, chlorinated wash-water or any other flows not related to stormwater. During the establishment period of the bioretention area, irrigation is allowed, however, to ensure plant survival. In addition, rain gardens or bioretention practices may be incorporated into the design of a Rainwater Harvesting System (See Section 4.7).

Setbacks

To avoid the risk of seepage, stormwater cannot flow from the bioretention area reservoir layer to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties.

Bioretention areas should be located at least:

10 feet from building foundations*
10 feet from property lines
150 feet from private water supply wells
50 feet from septic systems

*For building foundations, where the 10-foot setback is not possible, an impermeable liner may be used along the sides and bottom of the bioretention area (extending from the surface to the bottom of the practice and outward to meet the 10-foot setback) to prevent seepage or foundation damage.

Proximity to Utilities

Designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the PROW. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the bioretention system. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the bioretention to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the bioretention and the utility to coexist. The bioretention design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings.
- Work with the utility to evaluate the relocation of the existing utility and install the optimum placement and sizing of the bioretention.

- If utility functionality, longevity, and vehicular access to manholes can be assured, accept the bioretention design and location with the existing utility. Incorporate into the bioretention design sufficient soil coverage over the utility or general clearances or other features such as an impermeable liner to assure all entities the conflict is limited to maintenance.

When accepting utility conflict into the bioretention location and design, it is understood the bioretention will be temporarily impacted during utility work but the utility owner will replace the bioretention or, alternatively, install a functionally comparable bioretention according to the specifications in the current version of this Manual. If the bioretention is located in the PROW, the bioretention restoration will also conform with the State of South Carolina Department of Transportation design specifications.

Minimizing External Impacts

Urban bioretention practices may be subject to higher public visibility, greater trash loads, pedestrian traffic, vandalism, and even vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal design. When urban bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates, or other measures to prevent damage from pedestrian short-cutting across the practices.

When bioretention will be included in public rights-of-way or spaces, design manuals and guidance developed by agencies or organizations other than <*local jurisdiction*> may also apply (e.g., State Department of Transportation).

Economic Considerations

Bioretention areas can be particularly cost effective when they are included in areas of the site already planned for landscaping.

4.3.2 Bioretention Conveyance Criteria

There are two basic design approaches for conveying runoff into, through, and around bioretention practices:

1. Off-line: Flow is split or diverted so that only the design storm or design flow enters the bioretention area. Larger flows bypass the bioretention treatment.
2. On-line: All runoff from the CDA flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

If runoff is delivered by a storm drain pipe or is along the main conveyance system, the bioretention area should be designed off-line so that flows do not overwhelm or damage the practice.

Off-line Bioretention

Overflows are diverted from entering the bioretention cell. Optional diversion methods include the following:

1) Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case,

the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filters through the filter media. With this design configuration, an overflow structure in the bioretention area is not required.

2) Utilize a low-flow diversion or flow splitter at the inlet to allow only the design storm volume (i.e., the SWRv) to enter the facility (calculations must be made to determine the peak flow from the 85th or 95th percentile storm). This may be achieved with a weir, curb opening, or orifice for the target flow, in combination with a bypass channel or pipe. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. With this design configuration, an overflow structure in the bioretention area is required (see on-line bioretention below).

On-line Bioretention

An overflow structure must be incorporated into on-line designs to safely convey larger storms through the bioretention area (see Figure 4.6). The following criteria apply to overflow structures:

1) An overflow shall be provided within the practice to pass storms greater than the design storm storage to a stabilized water course. A portion of larger events may be managed by the bioretention area so long as the maximum depth of ponding in the bioretention cell does not exceed 18 inches.
2) The overflow device must convey runoff to a storm sewer, stream, or the existing stormwater conveyance infrastructure, such as curb and gutter or an existing channel.
3) Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum ponding depth of the bioretention area, which is typically 6 to 18 inches above the surface of the filter bed.
4) The overflow device should be scaled to the application. This may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.
5) Sufficient depth must be provided between the top of the overflow device and the top of the bioretention area to ensure that the 25-year storm can be safely conveyed through the overflow device.
6) The overflow associated with the 2- to 25-year design storms must be controlled so that velocities are non-erosive (generally less than 6 feet per second) at the outlet point, to prevent downstream erosion.

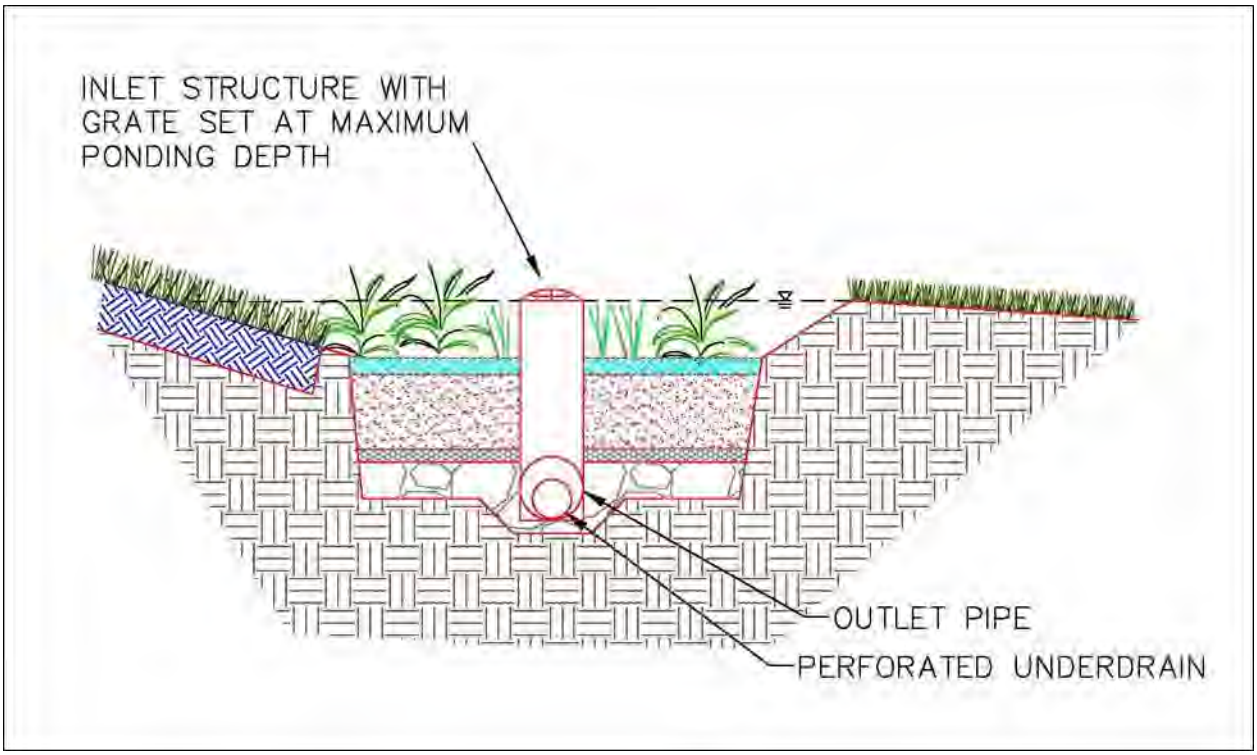

Figure 4.6. Example design of an on-line bioretention with an overflow structure.

4.3.3 Bioretention Pretreatment Criteria

Pretreatment of runoff entering bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pretreatment measures must be designed to evenly spread runoff across the entire width of the bioretention area. Several pretreatment measures are feasible, depending on the type of the bioretention practice and whether it receives sheet flow, shallow concentrated flow, or deeper concentrated flows. The following are appropriate pretreatment options:

Standard Bioretention (B-1)

1) **Pretreatment Cells** (for channel flow). Similar to a forebay, this cell is located at piped inlets or curb cuts leading to the bioretention area and consists of an energy dissipator sized for the expected rates of discharge. It has a storage volume equivalent to at least 15% of the total storage volume (inclusive) with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock berm. Pretreatment cells do not need underlying engineered filter media, in contrast to the main bioretention cell. However, if the volume of the pretreatment cell will be included as part of the bioretention storage volume, the pretreatment cell must de-water between storm events. It cannot have a permanent ponded volume.

2) **Grass Filter Strips** (for sheet flow). Grass filter strips that are perpendicular to incoming sheet flow extend from the edge of pavement, with a slight drop at the pavement edge, to the bottom of the bioretention basin at a 5H:1V slope or flatter. Alternatively, if the bioretention basin has side slopes that are 3H:1V or flatter, a 5-foot grass filter strip can be used at a maximum 5% (20H:1V) slope.

3) **Stone Diaphragms** (for sheet flow). A stone diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pretreat lateral runoff, with a 2- to 4-inch drop from the pavement edge to the top of the stone. The stone must be sized according to the expected rate of discharge.

4) **Gravel or Stone Flow Spreaders** (for concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel must extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin.

5) **Filter System** (see Section 4.10 Filtering Systems). If using a filter system as a pretreatment facility, the filter will not require a separate pretreatment facility.

6) **Innovative or Proprietary Structure**. An approved proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pretreatment. Refer to Section 0 Proprietary Practices for information on approved proprietary structures.

Other pretreatment options may be appropriate, but they must trap coarse sediment particles and evenly spread runoff across the entire width of the bioretention area.

Small-Scale Bioretention (B-2, B-3, B-4, and B-5)

- **Leaf Screens**. A leaf screen serves as part of the gutter system to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- **Pretreatment Cells** (for channel flow). Pretreatment cells are located above ground or covered by a manhole or grate. Pretreatment cells are atypical in small-scale bioretention and are not recommended for residential rain gardens (B-5).
- **Grass Filter Strips** (for sheet flow). Grass filter strips are applied on residential lots, where the lawn area can serve as a grass filter strip adjacent to a rain garden.
- **Stone Diaphragm** (for either sheet flow or concentrated flow). The stone diaphragm at the end of a downspout or other concentrated inflow point should run perpendicular to the flow path to promote settling.

  Note: stone diaphragms are not recommended for school settings.
- **Trash Racks** (for either sheet flow or concentrated flow). Trash racks are located between the pretreatment cell and the main filter bed or across curb cuts to allow trash to collect in specific locations and make maintenance easier.

4.3.4 Bioretention Design Criteria

Design Geometry

Bioretention basins must be designed with an internal flow path geometry such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited. So that the bioretention area to have an acceptable internal geometry, the travel time from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible. In addition, incoming flow must be distributed as evenly as possible across the entire filter surface area.

Inlets and Energy Dissipation

Where appropriate, the inlet(s) to streetscape bioretention (B-2), engineered tree boxes (B-3), and stormwater planters (B-4) should be stabilized using No. 3 stone, splash block, river stone, or other acceptable energy dissipation measures. The following types of inlets are recommended:

- Downspouts to stone energy dissipators.
- Sheet flow over a depressed curb with a 3-inch drop.
- Curb cuts allowing runoff into the bioretention area.
- Covered drains that convey flows across sidewalks from the curb or downspouts.
- Grates or trench drains that capture runoff from a sidewalk or plaza area.
- Drop structures that appropriately dissipate water energy.

Inlets must be designed with sufficient width and slope to avoid unintended bypass. This is of particular concern for curb cuts on streetscape bioretention designs.

Ponding Depth

The recommended surface ponding depth is 6 to 12 inches. Minimum surface ponding depth is 3 inches (averaged over the surface area of the BMP). Ponding depths can be increased to a maximum of 18 inches. However, when higher ponding depths are utilized, the design must consider carefully issues such as safety, fencing requirements, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. This is especially true where bioretention areas are built next to sidewalks or other areas were pedestrians or bicyclists travel. Shallower ponding depths (typically 6 to 12 inches) are recommended for streetscape bioretention (B-2), engineered tree boxes (B-3), and stormwater planters (B-4).

Side Slopes

Traditional bioretention areas (B-1) and residential rain gardens (B-5) should be constructed with side slopes of 3H:1V or flatter. In space-constrained areas, a drop curb design or a precast structure can be used to create a stable, vertical side wall. These drop curb designs should not exceed a vertical drop of more than 12 inches, unless safety precautions, such as railings, walls, grates, etc. are included.

Filter Media

The filter media of a bioretention practice consists of an engineered soil mixture that has been carefully blended to create a filter media that maintains long-term permeability while also providing enough nutrients to support plant growth. The final filter media shall consist of a well-blended mixture of medium to coarse **sand**, **loam soil**, and an **organic amendment** (compost). The sand maintains the desired permeability of the media while the limited amount of loam soil and organic amendments are considered adequate to help support initial plant growth. It is anticipated that the gradual increase of organic material through natural processes will continue to support plant growth without the need to add fertilizer, and the root structure of maturing plants and the biological activity of the media will maintain sufficient long-term permeability.

The following is the recommended composition of the three media ingredients:

- **Sand (Fine Aggregate).** Sand should consist of silica-based medium to coarse sand and be angular or round in shape. The materials shall not be derived from serpentine, shall be free of surface coatings or any other deleterious materials, and shall contain less than 0.5% mica by weight when tested with ASTM C295, Standard Guide for Petrographic Examination of Aggregates for Concrete.

  ASTM C-33 concrete sand will typically meet the requirements for the sand to be used in filter media. However, some samples of ASTM C-33 sand may have too high a fraction of fine sand and silt- and clay-sized particles to meet the final filter media particle size distribution requirements. In general, coarser gradations of ASTM C-33 will better meet the filter media particle size distribution and hydraulic conductivity requirements.

  Any other materials, such as manufactured sand, limestone-based sands, or crushed glass, shall meet the required particle size distribution (of final filter media mixture) and be demonstrated as adequately durable when tested by AASHTO T-103 or T-104.

- **Loam Soil.** Loam soil is generally defined as the combination of sand-sized material, fines (silt and clay), and any associated soil organic matter. Since the objective of the specification is to carefully establish the proper blend of these ingredients in the final filter media, the designer (or contractor or materials supplier) must carefully select the topsoil source material so as not exceed the amount of any one ingredient.

  Generally, a natural loamy sand, sandy loam, or loam (per the USDA Textural Triangle) A-horizon topsoil free of subsoil, large stones, earth clods, sticks, stumps, clay lumps, roots, viable noxious weed seed, plant propagules, brush, or other objectionable, extraneous matter or debris is suitable for the loam soil source material.

- **Organic Amendments.** Organic amendments shall consist of stable, well-composted, natural, carbon-containing organic materials such as leaf mulch, peat moss, humus, or yard waste (consistent with the material specifications found in Appendix C Soil Compost Amendment Requirements). The material shall be free of debris such as plastics, metal, concrete, stones larger than ½ inch, larger branches and roots, and wood chips over 1 inch in length or diameter.

Complete Filter Media

The complete filter media shall consist of a pug milled or mechanically blended mix of the three source materials. Mixing the filter media on site with excavation or loading equipment is not sufficient to achieve the required blending. The resulting filter media must meet the following particle size composition:

- 80%–90% sand
- 10%–20% silt and clay
- Maximum 10% clay

The particle size analysis must be conducted on the mineral fraction only or following appropriate treatments to remove organic matter before particle size analysis. Note: The above percentages are based on weight rather than volume.

Additionally, the final filter media mix must either meet the grain size distribution indicated in Table 4.4, or have a saturated hydraulic conductivity of 2 to 6 inches per hour according to test procedure ASTM

D2434 when compacted (at 60% to 80% optimum moisture content) to a minimum of 86% of the maximum density as determined by AASHTO T 99 (ASTM, 2006).

Table 4.4. Filter media grain size distribution.

Sieve Type	Particle Size (mm)	Percent Passing (%)
-	8.0	100
No. 5	4.0	92–100
No. 10	2.0	72–100
No. 18	1.0	43–95
No. 35	0.5	20–65
No. 60	0.25	11–37
No. 140	0.105	10–25
No. 270	0.053	10–20
-	0.002	0–10

The filter media shall also meet the following criteria (see summary in Table 4.5):

- Organic content shall be between 3.0% and 5.0% by weight;
- pH shall be between 6.0 and 7.5;
- Cation exchange capacity (CEC) shall be a minimum of 5 meq/100g or cmol+/kg;
- Phosphorus content shall meet one of the following:
    - P-Index between 10 and 30;
    - 15 mg/kg Mehlich I Extraction;
    - 18 to 40 mg/kg Mehlich III Extraction; and
- Soluble salts shall be less than 500 ppm or less than 0.5 mmhos/cm.

Notes:

P-Index is an agronomic test used in North Carolina to indicate the potential for P leaching from soil. The test method has been revised to add P concentration to facilitate local lab testing. The value of the P-Index is the correlation between the CEC and P concentrations: higher CEC indicates greater adsorption sites within the media, thus increasing the ability to fix P within the soil, thereby allowing higher P concentrations without leaching. While P-Index may be a better overall representation of P, the test method may not be readily available.

Tests for organic content, CEC, soluble salts, and pH are referenced to be in accordance with Recommended Soil Testing Procedures from the Southeastern United States, Current Edition, Southern Cooperative Series Bulletin No. 419. Use the following tests from Southern Cooperative Series Bulletin No. 419:

(a) Test for soil content by loss of weight on ignition

(b) Test for soil CEC by exchangeable acidity method

(c) Test for soluble salts shall be by the 1:2 (v:v) soil:water Extract Method

(d) Test for pH by the SMP method

Table 4.5. Summary of filter media criteria for bioretention.

Filter Media Criterion	Description	Standard(s)
General Composition	Filter media must have the proper proportions of sand, loam soil, and organic amendments to promote plant growth, drain at the proper rate, and filter pollutants.	80%–90% sand; 10%–20% soil fines; maximum of 10% clay; and 3%–5% organic content Must meet final filter media grain size distribution OR have a saturated hydraulic conductivity of 2–6 inches per hour
Sand	Medium to coarse aggregate	Based on final filter media grain size distribution
Loam Soil	Loamy sand, sandy loam, or loam	USDA Textural Triangle
Organic Amendments	Stable, well-composted, natural, carbon-containing organic materials such as leaf mulch, peat moss, humus, or yard waste.	Appendix C
P-Index or Phosphorus (P) Content	Filter media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters.	P-Index of 10–30 or P content = 5–15 mg/kg (Mehlich I) or 18–40 mg/kg (Mehlich III)
Cation Exchange Capacity (CEC)	The CEC is determined by the amount of soil fines and organic matter. Higher CEC will promote pollutant removal.	CEC > 5 milliequivalents per 100 grams
pH	Soil pH influences nutrient availability and microbial populations.	Between 6.0 and 7.5
Soluble Salts	Filter media with high levels of soluble salts can injure or kill plants.	Less than 500 ppm or less than 0.5 mmhos/cm.

In cases where greater removal of specific pollutants is desired, additives with documented pollutant removal benefits, such as water treatment residuals, alum, iron, or other materials, may be included in the filter media if accepted by *<local jurisdiction>*.

Filter Media Depth

The filter media bed depth must be a minimum of 18 inches for the No Underdrain or Standard designs. The media depth must be 24 inches or greater for the IWS design. **In order to receive the full credit for bacteria removal a minimum media depth of 24" is required.** The media depth must not exceed 6.0

feet. Turf, perennials, or shrubs should be used instead of trees to landscape shallower filter beds. See Table 4.7 and Table 4.8 for a list of recommended native plants.

Surface Cover

Mulch is the recommended surface cover material, but other materials may be substituted, as described below:

- **Mulch**. A 2- to 3-inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, pretreats runoff before it reaches the filter media, and prevents rapid evaporation of rainwater. Shredded hardwood bark mulch, aged for at least 6 months, is recommended/required for surface cover, as it retains a significant amount of pollutants and typically will not float away. The maximum depth of the mulch layer is 3 inches.
- **Alternative to Mulch Cover**. In some situations, designers may consider alternative surface covers, such as turf, native groundcover, erosion control matting (e.g., coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, expected pedestrian traffic, cost, and maintenance. When alternative surface covers are used, methods to discourage pedestrian traffic should be considered. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water-holding capacity.
- **Media for Turf Cover**. One adaptation suggested for use with turf cover is to design the filter media primarily as a sand filter with organic content only at the top. Compost, as specified in Appendix C Soil Compost Amendment Requirements, tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of organic matter in the filter media composition may be reduced.

Choking Layer

A 2- to 4-inch layer of choker stone (e.g., typically ASTM D448 No. 8 or No. 89 washed gravel) should be placed beneath the filter media and over the underdrain stone.

Geotextile

If the available head is limited, or the depth of the practice is a concern, geotextile fabric may be used in place of the choking layer. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude (10 times) higher than the soil subgrade permeability must be used. Geotextile fabric may be used on the sides of bioretention areas as well.

Underdrains

Many bioretention designs will require an underdrain (see Section 4.3.1 Bioretention Feasibility Criteria). The underdrain should be a 4- or 6-inch perforated schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with three or four rows of 3/8-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, double washed ASTM D448 No.57 or smaller (No. 68, 8, or 89) stone. The maximum depth of the underdrain stone layer combined with the choking layer is 12 inches, and it cannot extend beyond the surface dimensions of the bioretention filter media. The underdrain must be sized so that the bioretention BMP fully drains within 72 hours or less.

Multiple underdrains may be necessary for bioretention areas wider than 40 feet, and each underdrain is recommended to be located no more than 20 feet from the next pipe or the edge of the bioretention.

For long and narrow applications, a single underdrain running the length of the bioretention is sufficient. Each underdrain must include a cleanout pipe (minimum 4 inches in diameter).

All bioretention practices should include at least one observation well and/or cleanout pipe (minimum 4 inches in diameter). The observation wells should be tied into any of the Ts or Ys in the underdrain system and must extend upward above the surface of the bioretention area.

Internal Water Storage (IWS)

In cases where limited head is a site constraint and the bioretention must be designed to be relatively shallow (e.g., depth to groundwater, relatively flat sites, or other factors), or where increased nitrogen removal is desired, an internal water storage design that creates an infiltration sump below the underdrain can be used. The internal water storage zone may be created by an upturned elbow in the underdrain, a weir in the outlet structure, or other means that create a permanently saturated depth above the underdrain. The internal water storage zone must be kept at least 12 inches below the surface of the bioretention area. For more information on this design consult North Carolina Stormwater Design Manual Chapter C-2. (NCDEQ, 2017)

Observation Wells

All bioretention practices must include at least one observation well consisting of a well-anchored, 4- to 6-inch diameter PVC pipe (see Figure 4.7). For standard and IWS bioretention designs, the non-perforated observation wells should be tied into any of the Ts or Ys in the underdrain system and must extend upward above the ponding level. These observation wells can also double as cleanouts. Observation wells for bioretention designs without underdrains should be perforated in the gravel layer only and also must extend upward to the top of ponding.

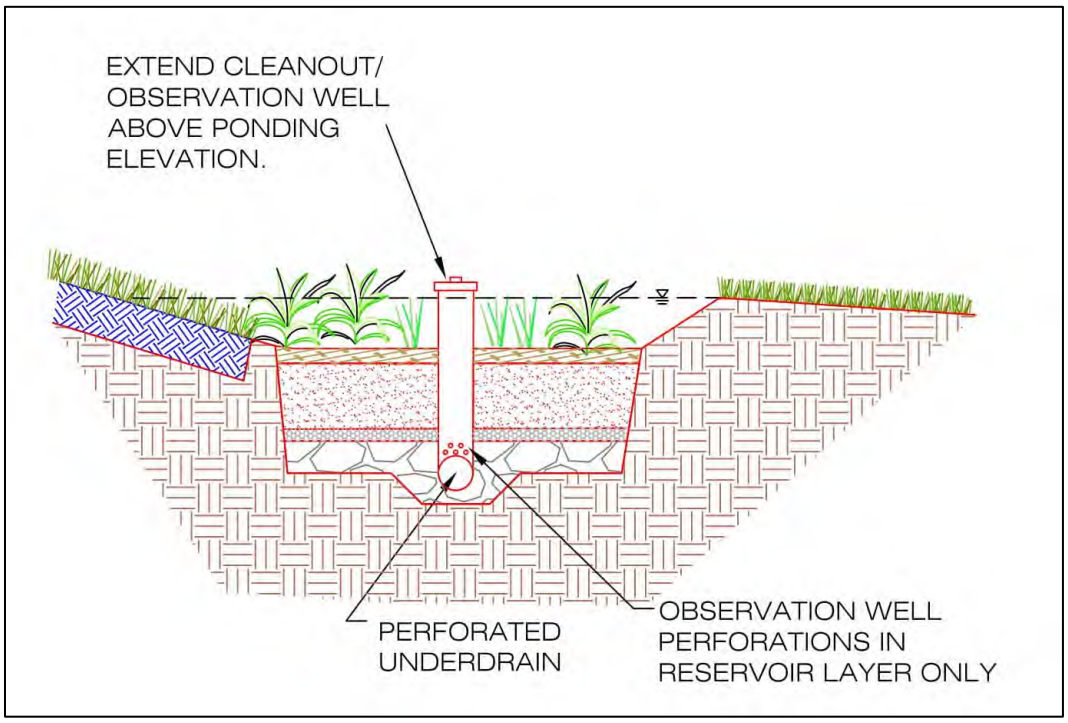

Figure 4.7. Example design of a bioretention with an observation well/cleanout device.

Underground Storage Layer (optional)

For IWS bioretention designs, an underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer and underdrain to increase the storage for larger storm events. Unlike the underdrain stone layer, this storage layer can be extended beyond the surface dimensions of the bioretention filter media if additional storage volume is needed. The underground storage layer may be designed to provide detention for the 2- to 25-year, or 100-year storms, as needed. The depth and volume of the storage layer will depend on the target storage volumes needed to meet the applicable detention criteria. Suitable conveyance must also be provided to ensure that the storage is fully utilized without overflow of the bioretention area.

Impermeable Liner (optional)

An impermeable liner is not typically required, although it may be utilized for Standard designs in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a PVC geomembrane liner or equivalent of an appropriate thickness (follow manufacturer's instructions for installation). Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Material Specifications

Recommended material specifications for bioretention areas are shown in Table 4. 6.

Table 4.6. Bioretention material specifications.

Material	Specification	Notes
Filter Media	▪ See Table 4.5 and Table 4.6	Minimum depth of 24 inches (18 inches for standard design). To account for settling/compaction, it is recommended that 110% of the plan volume be utilized.
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2- to 3-inch layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2- to 3-inch layer of to suppress weed growth.
Topsoil for Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%.	3-inch tilled into surface layer.
Geotextile or Choking Layer	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude (10 times) higher than the soil subgrade permeability must be used	Can use in place of the choking layer where the depth of the practice is limited. Geotextile fabric may be used on the sides of bioretention areas as well.
	Lay a 2- to 4-inch layer of choker stone (e.g., typically No.8 or No.89 washed gravel) over the underdrain stone.	
Underdrain Stone	1-inch diameter stone must be double-washed and clean and free of all fines (e.g., ASTM D448 No. 57 or smaller stone).	At least 2 inches above and below the underdrain.
Storage Layer (optional)	To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer.	
Impermeable Liner (optional)	Where appropriate, use a PVC Geomembrane liner or equivalent material of an appropriate thickness.	
Underdrains, Cleanouts, and Observation Wells	Use 4- or 6-inch rigid schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with three or four rows of 3/8-inch perforations at 6 inches on center. Multiple underdrains may be necessary for bioretention areas wider than 40 feet, and each underdrain is recommended to be located no more than 20 feet from the next pipe or the edge of the bioretention.	Lay the perforated pipe under the length of the bioretention cell and install non-perforated pipe as needed to connect with the storm drain system or to daylight in a stabilized conveyance. Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface of ponding.
Plant Materials	See Section 4.3.5 Bioretention Landscaping Criteria	Establish plant materials as specified in the landscaping plan and the recommended plant list.

Signage

Bioretention units in highly urbanized areas should be stenciled or otherwise permanently marked to designate it as a structural BMP. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

Specific Design Issues for Streetscape Bioretention (B-2)

Streetscape bioretention is installed in the road right-of-way either in the sidewalk area or in the road itself. In many cases, streetscape bioretention areas can also serve as traffic-calming or street-parking control devices. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the right-of-way. Roadway stability can be a design issue where streetscape bioretention practices are installed. Designers should consult design standards pertaining to roadway drainage. It may be necessary to provide an impermeable liner on the road-side of the bioretention area to keep water from saturating the road's sub-base. Streetscape bioretention in the PROW should comply with State Department of Transportation requirements, where applicable.

Specific Design Issues for Engineered Tree Boxes (B-3)

Engineered tree boxes are installed in the sidewalk zone near the street where urban street trees are normally installed (see Figure 4.8). The soil volume for the tree pit is increased and used to capture and treat stormwater. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment. Engineered tree boxes in the PROW should comply with State Department of Transportation requirements, where applicable.

When designing engineered tree boxes, the following criteria may apply.

- Engineered tree box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks (see Figure 4.9). In these situations, the following design considerations must be incorporated:
    - The filter media must be connected beneath the surface so that stormwater and tree roots can share this space.
    - As with all bioretention areas, a minimum surface ponding depth of 3 inches, averaged over the surface area of the bioretention area, is required. For example, if the additional surface area under the pavement doubles the overall surface area, then the ponding depth will need to be at least 6 inches.
    - Sand based structural soil (SBSS) may be considered as bioretention filter media if it meets the same phosphorus content limits. However, if the SBSS is to be compacted beyond the State Standards' maximum compaction for bioretention, it shall be assigned a porosity of 0.10. The State Standards call for bioretention soil to be compacted to 84% maximum dry density while SBSS is to be compacted to 93%.
- Installing an engineered tree pit grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.

- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a drop-off from the pavement to the micro-bioretention cell.
- A removable grate may be used to allow the tree to grow through it.
- Each tree needs a minimum rootable soil volume as described in Section 4.12 Tree Planting and Preservation.
- See Section 4.14.2 Planting Trees for further guidance and requirements on tree planting.

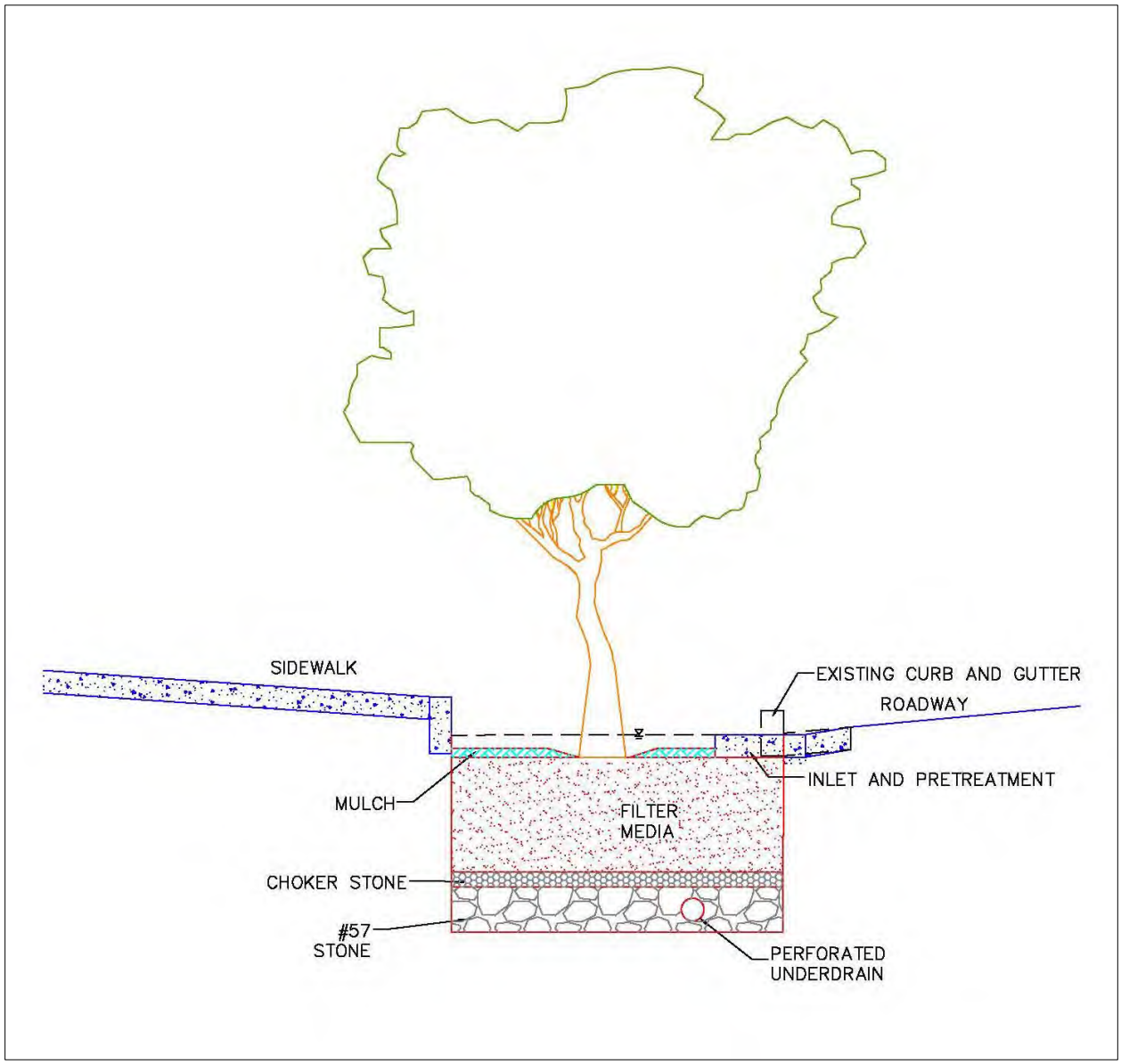

Figure 4.8. Example design of a tree box.

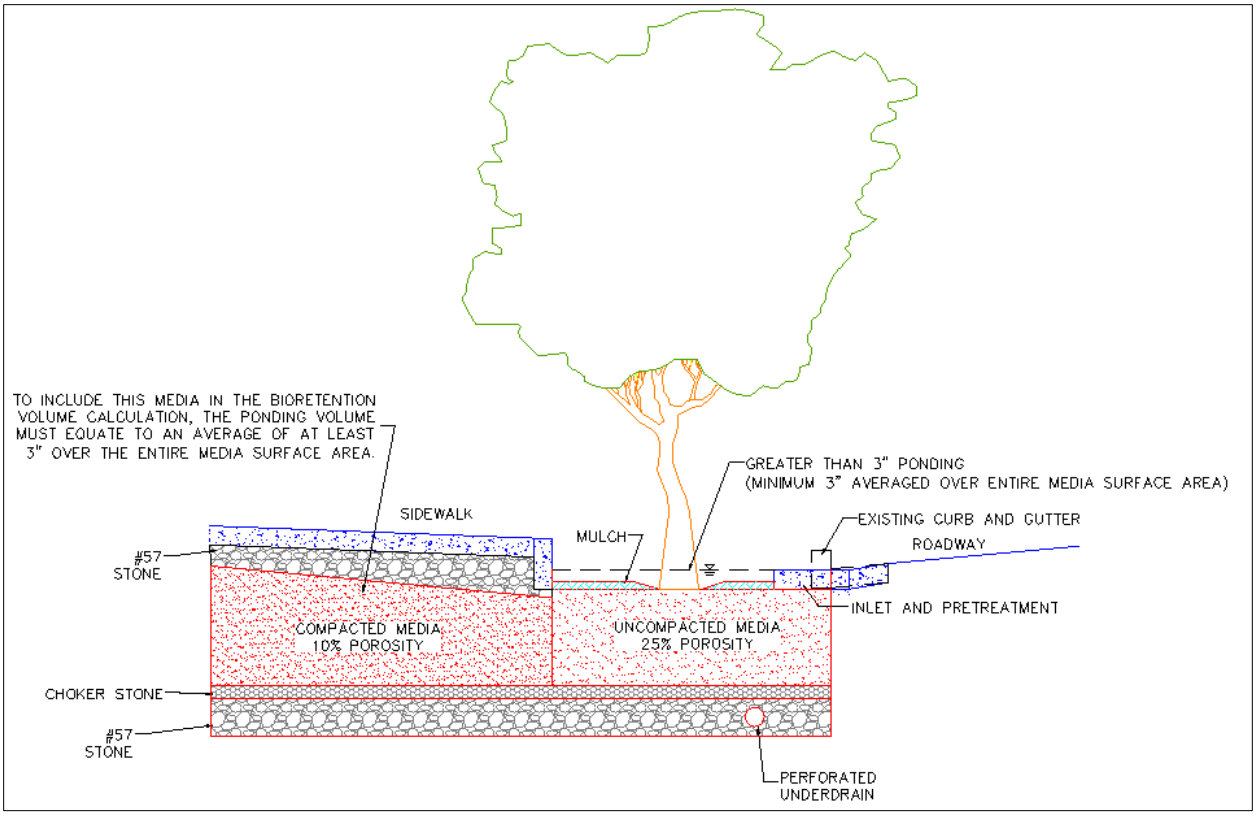

Figure 4.9. Example design of a tree box with compacted media extending below sidewalk.

<u>Specific Design Issues for Stormwater Planters (B-4)</u>

Stormwater planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that tolerate periods of both drought and inundation. The two basic design variations for stormwater planters are the infiltration planter and the filter planter. A filter planter is illustrated in Figure 4.10.

An infiltration planter filters rooftop runoff through soil in the planter followed by infiltration into soils below the planter. Infiltration planters should be placed at least 10 feet away from a building to prevent possible flooding or basement seepage damage.

A filter planter does not allow for infiltration and is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage. Since a filter planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded, to avoid water spilling over the side of the planter. In addition, an underdrain is used to carry runoff to the storm sewer system.

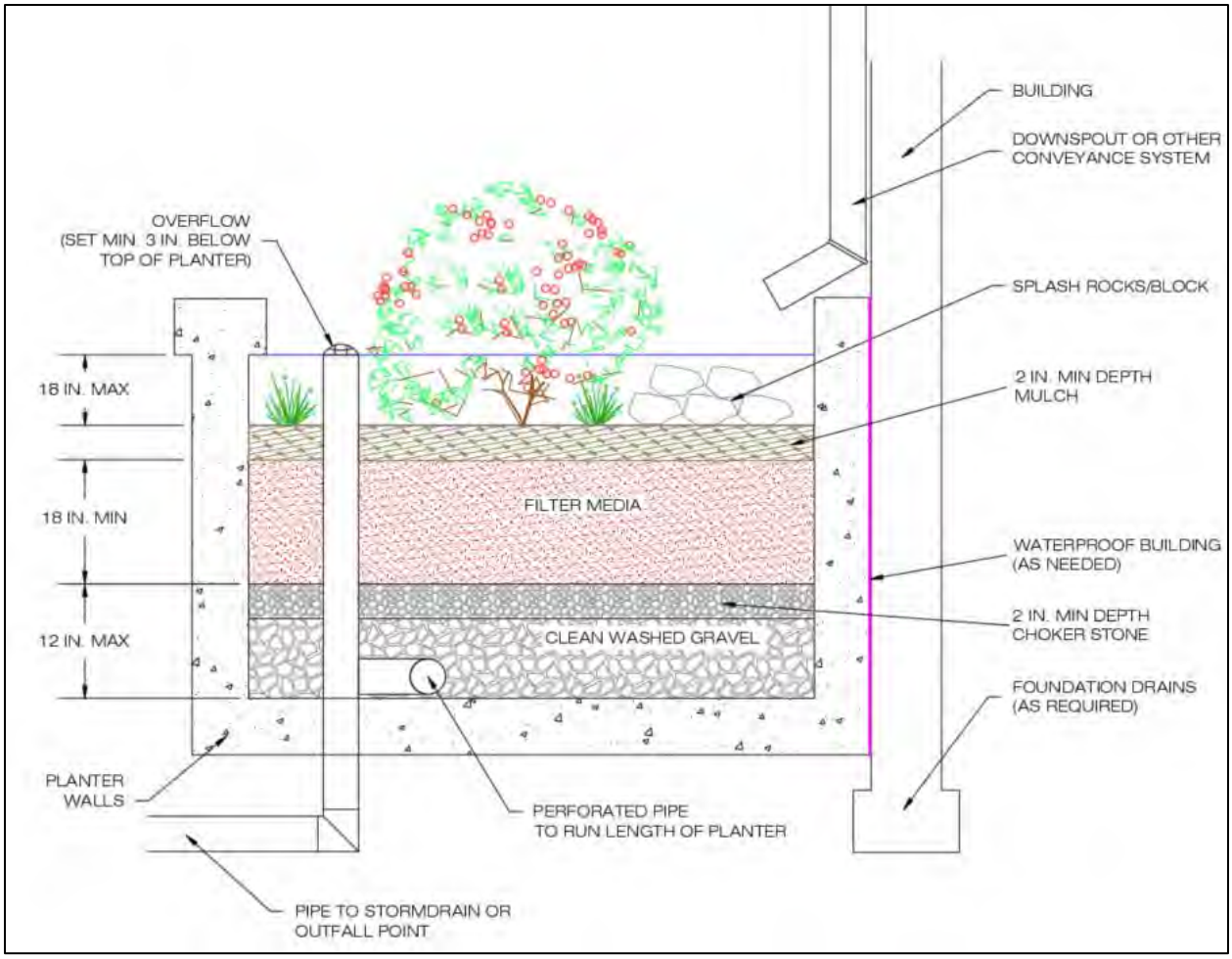

Figure 4.10. Example design of a stormwater planter (B-4).

Plant materials must be capable of withstanding moist and seasonally dry conditions. The planter can be constructed of stone, concrete, brick, wood, or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter.

Specific Design Issues for Residential Rain Gardens (B-5)

For some residential applications, front, side, and/or rear yard bioretention may be an attractive option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium- density residential lots in a depressed area (i.e., 6 to 12 inches) between the home and the primary stormwater conveyance system (i.e., roadside ditch or pipe system).

BMP Sizing

Bioretention is typically sized to capture the SWRv or larger design storm volumes in the surface ponding area, filter media, and gravel reservoir layers of the BMP.

Total storage volume of the BMP is calculated using Equation 4.1.

Equation 4.1. Bioretention storage volume.

$$S_v = SA_{bottom} \times \left[(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})\right] + (SA_{average} \times d_{ponding})$$

Where:

Sv = Total storage volume of bioretention (cubic feet)
SA_{bottom} = Bottom surface area of bioretention (square feet)
d_{media} = Depth of filter media, including mulch later (ft)
η_{media} = Effective porosity of the filter media (typically 0.25)
d_{gravel} = Depth of the underdrain and underground storage gravel layer, including choker stone (ft)
η_{gravel} = Effective porosity of the gravel layer (typically 0.4)
$SA_{average}$ = Average surface area of the bioretention (square feet), where SA_{top} is the surface area of the top of the bioretention

$$SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$$

$d_{ponding}$ = Maximum ponding depth of bioretention (ft)

Equation 4.1 can be modified if the storage depths of the filter media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the bioretention must not exceed 18 inches. If storage practices will be provided off-line or in series with the bioretention area, the storage practices should be sized using the guidance in Section 4.9 Storage Practices.

Note: In order to increase the storage volume of a bioretention area, the ponding surface area may be increased beyond the filter media surface area. However, the top surface area of the practice (i.e., at the top of the ponding elevation) may not be more than twice the size of the surface area of the filter media (SA_{bottom}).

For bioretention designs without an underdrain, the storage volume must infiltrate within 72 hours, as in Equation 4.2.

Equation 4.2. Bioretention infiltration rate check equation.

$$Sv_{infiltrate} = \frac{SA_{bottom}(K_{sat} \times t_d)}{12}$$

$Sv_{infiltrate}$ =	Storage volume that will infiltration within 72 hours (cubic feet)
SA_{bottom} =	Bottom surface area of bioretention (square feet)
K_{sat} =	Field-verified saturated hydraulic conductivity for the native soils (ft/day)
t_d =	Drawdown time (3 days)

If $Sv_{infiltrate}$ is greater than or equal to Sv, then the entire Sv will infiltrate within 72 hours. If it is not, the storage volume of the bioretention area should be reduced accordingly.

Bioretention can be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The Sv can be counted as part of the 2- to 25-year runoff volumes to satisfy stormwater quantity control requirements.

4.3.5 Bioretention Landscaping Criteria

Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan shall be provided for bioretention areas.

Minimum plan elements include the proposed bioretention template to be used, delineation of planting areas, and the planting plan including the following:

- Common and botanical names of the plants used
- Size of planted materials
- Mature size of the plants
- Light requirements
- Maintenance requirements
- Source of planting stock
- Any other specifications
- Planting sequence

It is recommended that the planting plan be prepared by a qualified landscape architect professional (e.g., licensed professional landscape architect, certified horticulturalist) to tailor the planting plan to the site-specific conditions.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. Some popular native species that work well in bioretention areas and are commercially available can be found in Table 4.7 and Table 4.8.

The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site that will receive minimum annual maintenance. In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model where the turf is mowed along with other turf areas on the site. Spaces for herbaceous flowering plants can be included.

Table 4.7. Bioretention-appropriate plants: perennial and grass

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Aletris farinosa	White Colicroot	FAC	Moist soil	None	
Andropogon gerardii	Big Bluestem	FAC	No	Moderate	
Aquilegia canadensis	Wild Columbine	FACU	No	None	
Asclepias incarnata	Swamp Milkweed	OBL	Saturated	None	
Asclepias lanceolata	Red Milkweed	OBL	Wet soils	Moderate / brackish	
Aster novae-angliae	New England Aster	FACW	Moist soils, yes	Yes	
Athyrium filix-femina	Lady Fern	FAC	Moist to wet soils	None	
Canna glauca	Water Canna	OBL	Moist to wet soils	None	
Canna flaccida	Golden Canna	OBL	Moist to wet soils	None	
Carex stricta	Tussock Sedge	OBL	Saturated, 0-6”	None	
Chasmanthium latifolium	River Oats	FAC	Moist soils	None	
Chelone glabra	White Turtlehead	OBL	Moist to wet soils		
Conoclinium coelestinum	Blue Mistflower	FAC	Moist to Wet soils		
Crinum americanum	Southern Swamp Lily	OBL	Saturated		
Dulichium arundinaceum	Threeway Sedge	OBL	Saturated, shallow	None	
Echinodorus cordifolius	Creeping Burhead	OBL	Saturated, shallow		
Equisetum hyemale	Scouring Rush	FACW	Saturated, shallow		
Eupatorium fistulosum	Joe Pye Weed	FACW	Moist to Wet Soils		
Geranium maculatum	Spotted Geranium	FACU	Moist Soils		
Helianthus angustifolius	Swamp Sunflower, Narrowleaf Sunflower	FACW	Wet Soils		

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Hibiscus coccineus	Scarlet Swamp Hibiscus	OBL	Saturated, shallow		
Hibiscus moscheutos	Rose Mallow, Hibiscus	OBL	Saturated, shallow	Low	
Hymenocallis caroliniana	Spider Lily	OBL	Saturated, shallow	None	
Iris versicolor	Virginia Iris	OBL	Shallow	None	
Juncus effuses	Common Rush	OBL	Shallow <6”	Low	
Liatris spicata	Gayfeather, Blazing Star	FAC	Moist Soils	Low	
Lobelia cardinalis	Cardinal Flower	FACW	Moist to Wet Soils	None	
Lobelia siphilitica	Blue Lobelia	OBL	Moist to wet soils		
Lysimachia ciliata	Fringed Loosestrife	FACW	Moist to wet soils, seasonal flooding		
Mimulus ringens	Allegheny Monkeyflower	OBL	Saturated, shallow		
Onoclea sensibilis	Sensitive Fern	FACW	Moist to wet soils		
Osmunda cinnamomea	Cinnamon Fern	FACW	Moist to wet soils	Low	
Osmunda spectabilis	Royal Fern	OBL	Moist to wet soils	None	
Orontium aquaticum	Golden Club	OBL	Up to 10”		
Panicum virgatum	Switch Grass	FAC	Moist soil	Moderate	
Peltandra virginica	Green Arrow Arum	OBL	Shallow < 1’	Low (< 2 ppt)	
Pontederia cordata	Pickerelweed	OBL	Shallow < 1’	Low (< 3 ppt)	
Physostegia virginiana	Obedient Plant	FACW	Moist soil		
Polygonatum biflorum	Great Solomon’s Seal	FACU	Moist soil		
Rhynchospora colorata	Starrush Whitetop	FACW	Saturated		
Rudbeckia laciniata	Cutleaf Coneflower	FACW	Moist soil	None	

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Sagittaria latifolia	Common Arrowhead, Duck Potato	OBL	Up to 2.0’	None	
Saururus cernuus	Lizard’s Tail	OBL	Shallow < 4”	None	
Schizachyrium scoparium	Little Bluestem	FACU	Moist soil	None	
Schoenoplectus tabernaemontani	Softstem Bulrush	OBL	Wet soil to standing water	Fresh or Brackish	
Solidago sempervirens	Seaside Goldenrod	FACW	Yes	High	
Sorghastrum nutans	Indiangrass	FACU	Moist soil	Moderate	
Spartina alterniflora	Saltmarsh Cordgrass	OBL	Yes	High	
Spartina bakeri	Sand cordgrass	FACW	Moist to wet soils	Fresh - Saline	
Spartina patens	Saltmeadow Cordgrass	FACW	Wet soils	High	
Thalia dealbata	Powdery Alligator-flag	OBL	up to 1.5’	Yes	
Tradescantia virginiana	Virginia Spiderwort	FAC	Moist soils	None	
Vernonia noveboracensis	Ironweed	FACW	Moist soils	None	

1. Wetland Indicator Notes:
FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%–66%).
FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%–99%), but occasionally found on wetlands (estimated probability 1%–33%).
FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%–99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands

Table 4.8. Bioretention-appropriate plants: shrubs and bushes

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Baccharis halimifolia	Groundsel Tree, Salt Myrtle	FAC	Wet soils	High	
Callicarpa americana	Beautyberry	FACU	Moist soils	None	
Cephalanthus occidentalis	Button Bush	OBL	Up to 3 ft	Low	
Clethra alnifolia	Summersweet Sweet Pepperbush	FACW	Moist to wet soils	None	
Cyrilla racemiflora	Swamp Titi	FACW	Moist to wet soils	Low	
Hamamelis virginiana	Witch Hazel	FACU	Moist to wet soils	None	
Hypericum prolificum	Shrubby St. John's Wort	FAC	Moist soils, flood tolerant	None	
Ilex glabra	Inkberry	FACW	Wet soils, flood tolerant	Moderate	
Ilex verticillata	Winterberry Holly	FACW	Moist to wet soils	None	
Ilex vomitoria	Yaupon Holly	FAC	Moist soils	Moderate	
Itea virginica	Virginia Sweetspire	FACW	Moist to wet soils	None	
Kosteletzkya virginica	Seashore Mallow	OBL	Moist to wet soils	Moderate	
Lindera benzoin	Spicebush	FACW	Seasonal inundation	None	
Myrica cerifera	Wax Myrtle	FAC	Moist to wet soils	Moderate	
Photinia pyrifolia	Red Chokeberry	FACW	Moist soils	Low	
Rhododendron canescens	Dwarf Azalea	FACW	Moist soils	None	
Rhododendron viscosum	Swamp Azalea	OBL	Wet soil	None	
Rosa carolina	Carolina Rose	FACU	Moist to wet soils	Moderate	
Sabal minor	Dwarf Palmetto	FACW	Moist to wet soils	None	
Sambucus canadensis	Elderberry	FACW	Moist to wet soils	None	

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Serenoa repens	Saw Palmetto	FACU	Occasionally wet	None	
Vaccinium corymbosum	Highbush Blueberry	FACW	Wet soil	High	
Viburnum dentatum	Arrowwood	FAC	Moist to wet	None	

1. Wetland Indicator Notes:
FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%–66%).
FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%–99%), but occasionally found on wetlands (estimated probability 1%–33%).
FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%–99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

Planting recommendations for bioretention facilities are as follows:

- The primary objective of the planting plan is to cover as much of the surface areas of the filter bed as quickly as possible. Herbaceous or ground cover layers are as or more important than more widely spaced trees and shrubs.
- Native plant species should be specified over non-native species.
- Plants should be selected based on a specified zone of hydric tolerance and must be capable of surviving both wet and dry conditions ("Wet footed" species should be planted near the center, whereas upland species do better planted near the edge).
- Woody vegetation should not be located at points of inflow; trees should not be planted directly above underdrains but should be located closer to the perimeter.
- Shrubs and herbaceous vegetation should generally be planted in clusters and at higher densities (i.e., 5 feet on-center and 1 to 1.5 feet on-center, respectively).
- If trees are part of the planting plan, a tree density of approximately one tree per 250 square feet (i.e., 15 feet on-center) is recommended.
- Designers should also remember that planting holes for trees must be at least 3 feet deep to provide enough soil volume for the root structure of mature trees. This applies even if the remaining filter media layer is shallower than 3 feet.
- Tree species should be those that are known to survive well in the compacted soils and the polluted air and water of an urban landscape.
- If trees are used, plant shade-tolerant ground covers within the drip line.

4.3.6 Bioretention Construction Sequence

Soil Erosion and Sediment Controls

The following soil erosion and sediment control guidelines must be followed during construction:

All bioretention areas must be fully protected by silt fence or construction fencing.

Bioretention areas intended to infiltrate runoff must remain outside the limits of disturbance during construction to prevent soil compaction by heavy equipment and loss of design infiltration rate.

- Where it is infeasible keep the proposed bioretention areas outside of the limits of disturbance, there are several possible remedies for the impacted area. If excavation in the proposed bioretention area can be restricted, then the remediation can be achieved with deep tilling practices. This is only possible if in situ soils are not disturbed any deeper than 2 feet above the final design elevation of the bottom of the bioretention. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled to a depth of 12 inches below the bottom of the bioretention.
- Alternatively, if it is infeasible to keep the proposed bioretention areas outside of the limits of disturbance, and excavation of the area cannot be restricted, then infiltration tests will be required prior to installation of the bioretention to ensure that the design infiltration rate is still present. If tests reveal the loss of design infiltration rates, then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the bioretention area can be installed.
- Finally, if it is infeasible to keep the proposed bioretention areas outside of the limits of disturbance, excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.

Bioretention areas must be clearly marked on all construction documents and grading plans.

Large bioretention applications may be used as small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the soil erosion and sediment control plan specifying that:

(1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the post-construction (final) invert (bottom of the facility), and
(2) the facility must contain an underdrain.

The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention BMP, including dewatering, cleanout, and stabilization.

Bioretention Installation

The following is a typical construction sequence to properly install a bioretention basin. These steps may be modified to reflect different bioretention applications or expected site conditions:

1. Stabilize Contributing Drainage Area

Construction of the bioretention area may only begin after the entire CDA has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

2. Preconstruction Meeting

The designer, the installer, and <*local jurisdiction*> inspector must have a preconstruction meeting, checking the boundaries of the CDA and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the inspector. Material certifications for aggregate, filter media, and any geotextiles must be submitted for approval to the inspector at the preconstruction meeting.

3. Install Soil Erosion and Sediment Control Measures to Protect the Bioretention

Temporary soil erosion and sediment controls (e.g., diversion dikes, reinforced silt fences) are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the construction process.

4. Install Pretreatment Cells

Any pretreatment cells should be excavated first and then sealed to trap sediment.

5. Avoid Impact of Heavy Installation Equipment

Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500- to 1,000-square foot temporary cells with a 10- to 15-foot earth bridge in between, so that cells can be excavated from the side.

6. Promote Infiltration Rate

It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

7. Order of Materials

If using a geotextile fabric, place the fabric on the sides of the bioretention area with a 6-inch overlap on the sides. If a stone storage layer will be used, place the appropriate depth of No. 57 stone (clean, double washed) on the bottom, install the perforated underdrain pipe, pack No. 57 stone at least 2 inches above the underdrain pipe, and add the choking layer or appropriate geotextile layer as a filter between the underdrain and the filter media layer. If no stone storage layer is used, start with at least 2 inches of No. 57 stone on the bottom and proceed with the layering as described above.

8. Layered Installation of Media

Apply the media in 12-inch lifts until the desired top elevation of the bioretention area is achieved. Wait a few days to check for settlement and add additional media, as needed, to achieve the design elevation.

Note: The batch receipt confirming the source of the filter media must be submitted to the <*local jurisdiction*> inspector.

9. Prepare Filter Media for Plants
Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

10. Planting
Install the plant materials as shown in the landscaping plan, and water them as needed.

11. Secure Surface Area
Place the surface cover (i.e., mulch, river stone, or turf) in both cells, depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 10), and holes or slits will have to be cut in the matting to install the plants.

12. Inflows
If curb cuts or inlets are blocked during bioretention installation, unblock these after the CDA and side slopes have good vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the CDA includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

13. Final Inspection
Conduct the final construction inspection using a qualified professional, providing *<local jurisdiction>* with an as-built, then log the GPS coordinates for each bioretention facility, and submit them for entry into the maintenance tracking database.

14. Construction Supervision
Supervision during construction is recommended to ensure that the bioretention area is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists that include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

Construction phase inspection checklist can be found in Appendix E Construction Inspection Checklists.

4.3.7 Bioretention Maintenance Criteria

When bioretention practices are installed, it is the owner's responsibility to ensure they, or those managing the practice:

(1) be educated about their routine maintenance needs,
(2) understand the long-term maintenance plan, and
(3) be subject to a maintenance covenant or agreement, as described below.

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides.

Maintenance tasks and frequency will vary depending on the size and location of the bioretention, the landscaping template chosen, and the type of surface cover in the practice. A generalized summary of common maintenance tasks and their frequency is provided in Table 4.9.

Table 4.9. Typical maintenance tasks for bioretention practices.

Frequency	Maintenance Tasks
Upon establishment	▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 0.5 inch of rainfall. Conduct any needed repairs or stabilization. ▪ Inspectors should look for bare or eroding areas in the CDA or around the bioretention area and make sure they are immediately stabilized with grass cover. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Watering is needed once a week during the first 2 months, and then as needed during first growing season (April through October), depending on rainfall. ▪ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.
At least 4 times per year	▪ Mow grass filter strips and bioretention with turf cover ▪ Check curb cuts and inlets for accumulated grit, leaves, and debris that may block inflow
Twice during growing season	▪ Spot weed, remove trash, and rake the mulch
Annually	▪ Conduct a maintenance inspection ▪ Supplement mulch in devoid areas to maintain a 3-inch layer ▪ Prune trees and shrubs ▪ Remove sediment in pretreatment cells and inflow points
Once every 2–3 years	▪ Remove sediment in pretreatment cells and inflow points ▪ Remove and replace the mulch layer
As needed	▪ Add reinforcement planting to maintain desired vegetation density ▪ Remove invasive plants using recommended control methods ▪ Remove any dead or diseased plants ▪ Stabilize the CDA to prevent erosion

Standing water is the most common problem outside of routine maintenance. If water remains on the surface for more than 72 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter. These are listed below, starting with the simplest approach and ranging to more involved procedures (i.e., if the simpler actions do not solve the problem):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be cleaned out.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 6 to 12 inches of soil.

- Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or auguring (i.e., using a tree auger or similar tool) down to the top of the underdrain layer to create vertical columns that are then filled with a clean open-graded coarse sand material (e.g., ASTM C-33 concrete sand or similar approved sand mix for bioretention media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- Remove and replace some or all of the filter media.

Maintenance Inspections

It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each bioretention area. Maintenance inspections should include information about the inlets, the actual bioretention facility (sediment buildup, outlet conditions, etc.), and the state of vegetation (water stressed, dead, etc.) and are intended to highlight any issues that need or may need attention to maintain stormwater management functionality.

Maintenance inspection checklists for bioretention areas and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material

Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.3.8 Bioretention Stormwater Compliance Calculations

Bioretention performance varies depending on the design configuration of the system.

No Underdrain

Bioretention designs with no underdrain are credited with100% retention for the storage volume (Sv) provided by the practice as well as 100% TSS, TN, and bacteria removal (Table 4.10).

Table 4.10. Retention and pollutant removal for bioretention practices without underdrains.

Retention	= 100%
TSS Removal	= 100%
TN Removal	= 100%
Bacteria Removal	= 100%

Internal Water Storage (IWS)

Bioretention designs with IWS are credited with75% retention for the storage volume (Sv) provided by the practice as well as 85% TSS, 85% TN, and 80% bacteria removal (Table 4.11).

Table 4.11. Retention and pollutant removal for bioretention practices with IWS design.

Retention	= 75%
TSS Removal	= 85%
TN Removal	= 85%
Bacteria Removal	= 80%

Standard

Standard bioretention designs are credited with 60% retention for the storage volume (Sv) provided as well as 85% TSS, 75% TN, and 80% bacteria removal. (Table 4.12).

Table 4.12. Retention and pollutant removal for standard bioretention practices.

Retention	= 60%
TSS Removal	= 85%
TN Removal	= 75%
Bacteria Removal	= 80%

The practice must be sized using the guidance detailed in Section 4.1.4 Bioretention Design Criteria. Note: Additional retention can be achieved if trees are utilized as part of a bioretention area (see Section 4.14 Tree Planting and Preservation).

Bioretention also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) from the total runoff volume for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

4.3.9 References

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4.4 Permeable Pavement Systems

Permeable Pavement Systems				
Definition: Paving systems that capture and temporarily store the SWRv by filtering runoff through voids in an alternative pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system or allowed to partially (or fully) infiltrate into the soil.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		80-100%	45-100%	30-100%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
High	High	Moderate		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	**Standard Design**	**Enhanced Design**	
2-4 times per year	Every 2-3 years	30%	100%	
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Reduces runoff volume, attenuates peak runoff rate and outflow ▪ Reduces slick surfaces during rain ▪ Water quality enhancement from filtration of stormwater		▪ Sediment-laden runoff can clog pervious pavement, causing it to fail ▪ Incorrect installation practices can clog pores		
Components		**Design considerations**		
▪ Open graded pavement mix or pavers with open surfaces ▪ Bedding course ▪ Open-graded base material ▪ Underdrain (where required) ▪ Subgrade with minimal compaction		▪ Same basic considerations as any paved area ▪ Infiltration rate of native soil determines applicability and need for underdrain ▪ Depth to seasonal high water table must be at least 6 inches below bottom of practice ▪ Not appropriate for heavy or high traffic areas ▪ Accessibility, aesthetics, maintainability		
Installation Considerations		**Maintenance Activities**		
▪ Proper construction sequencing and installation is crucial to ensure proper functioning ▪ Subgrade cannot be overly compacted		▪ Vacuum or jet wash to increase pavement life and avoid clogging ▪ Ensure that contributing area is clear of debris and sediment.		

[1]*Credited pollutant load removal*

Permeable pavement systems represent alternative paving surfaces that capture and temporarily store the design volume by filtering runoff through voids in the pavement surface into an underlying stone reservoir (see Figure 4.11). Filtered runoff may be collected and returned to the conveyance system, or it may be allowed to infiltrate into the soil**.** Permeable pavement systems may also provide stormwater detention of larger storms (e.g., 2- to 25-year).

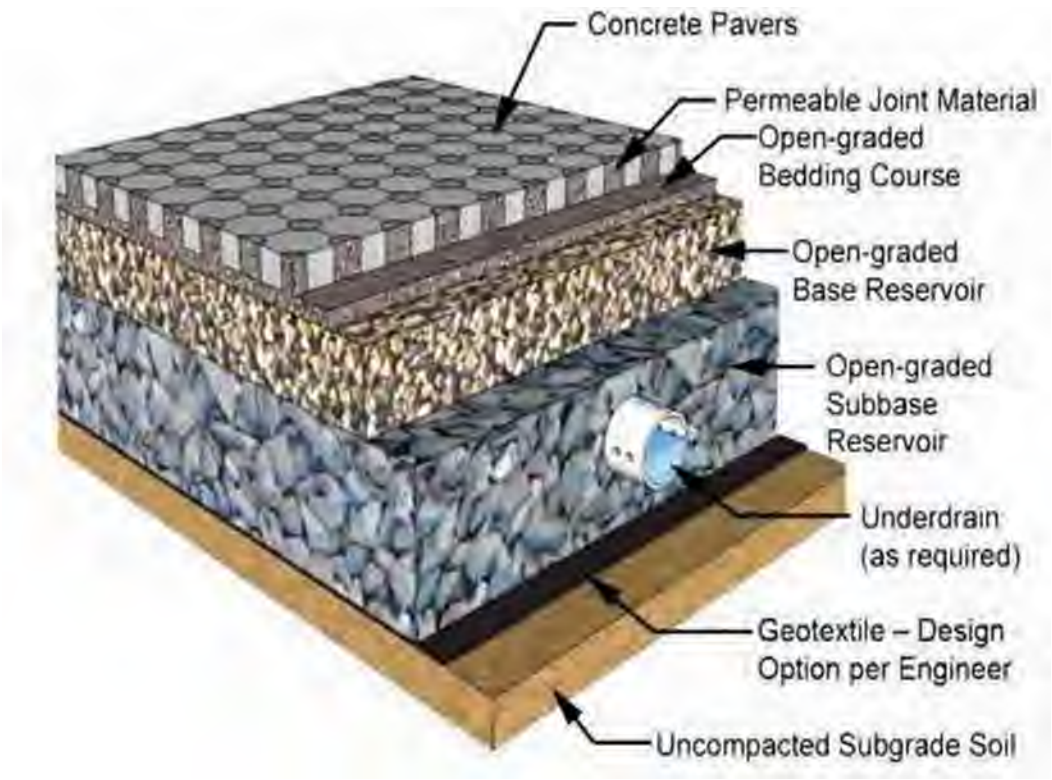

Figure 4.11. Cross-section of permeable pavement (source: ICPI).

Definition

This is a paving system that captures and temporarily stores the SWRv by filtering runoff through voids in an alternative pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system or allowed to infiltrate into the soil.

Design variants include the following:

P-1 Porous asphalt (PA)
P-2 Pervious concrete (PC)
P-3 Permeable pavers (PP)

Other surface material variations of permeable pavement that can be part of a permeable pavement system, such as porous rubber, plastic grid pavers, and synthetic turf systems are also encompassed in this section.

Porous Asphalt

Porous asphalt (also known as pervious asphalt) consists of a special open-graded surface course bound together by asphalt cement. The open-graded surface course in a typical porous asphalt installation is 3 to 7 inches thick and has a void ratio of between 15% and 20%. Porous asphalt is thought to have a limited ability to maintain its structure and permeability during hot summer months and, consequently, is currently not recommended for use in coastal South Carolina. If it is used on a development site in the coastal region, it should be carefully monitored and maintained over time.

Pervious Concrete

Pervious concrete (also known as porous concrete) is similar to conventional concrete in structure and form but consists of a special open-graded surface course, typically 4 to 8 inches thick, that is bound together with Portland cement. This open-graded surface course has a void ratio of 15% to 25% (conventional concrete pavement has a void ratio of between 3% and 5%), which gives it a high permeability that is often many times more than that of the underlying native soils, and allows rainwater and stormwater runoff to rapidly pass through it and into the underlying stone reservoir. Although this particular type of permeable pavement surface may not require an underlying base layer to support traffic loads, site planning and design teams may wish to provide it to increase the stormwater storage capacity provided by a pervious concrete system.

Permeable Pavers

Permeable pavers (PP) are solid structural units (e.g., blocks, bricks) that are installed in a way that provides regularly spaced openings through which stormwater runoff can rapidly pass through the pavement surface and into the underlying stone reservoir. The regularly spaced openings, which generally make up between 8% and 20% of the total pavement surface, are typically filled with pea gravel (i.e., ASTM D 448 Size No. 8, 3/8 inch to 1/8 inch). Typical PP systems consist of the pavers, a 1.5- to 3-inch thick fine gravel bedding layer and an underlying stone reservoir.

Design Configurations

There are two types of permeable pavement design configurations:

- **Standard Design**
  Practice with a standard underdrain design and no infiltration sump or water quality filter (see Figure 4.12).
- **Enhanced Design**
  Practice with underdrains that contain a water quality filter layer and an infiltration sump beneath the underdrain sized to drain the design storm in 48 hours (see Figure 4.13) or practices with no underdrains that can infiltrate the entire design storm volume in 48 hours (see Figure 4.14).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed below.

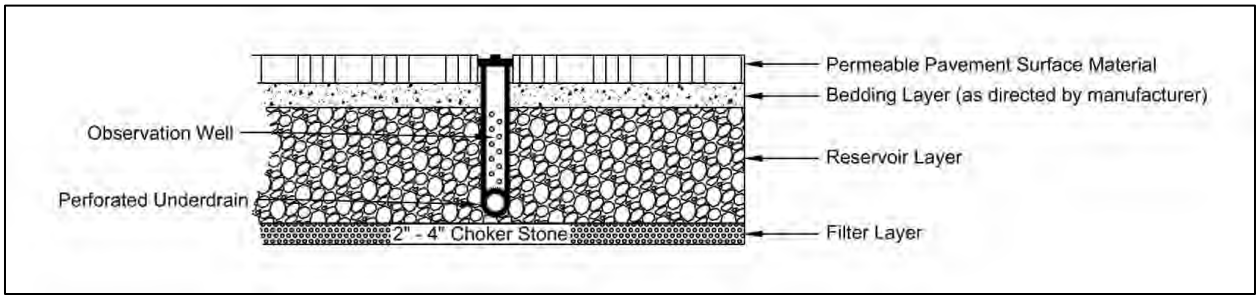

Figure 4.12. Cross-section of a standard permeable pavement design.

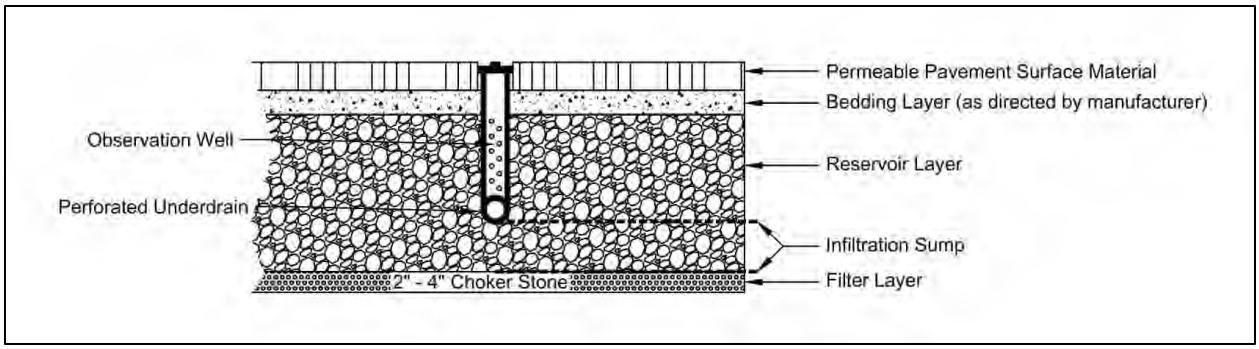

Figure 4.13. Cross-section of an enhanced permeable pavement design with an underdrain.

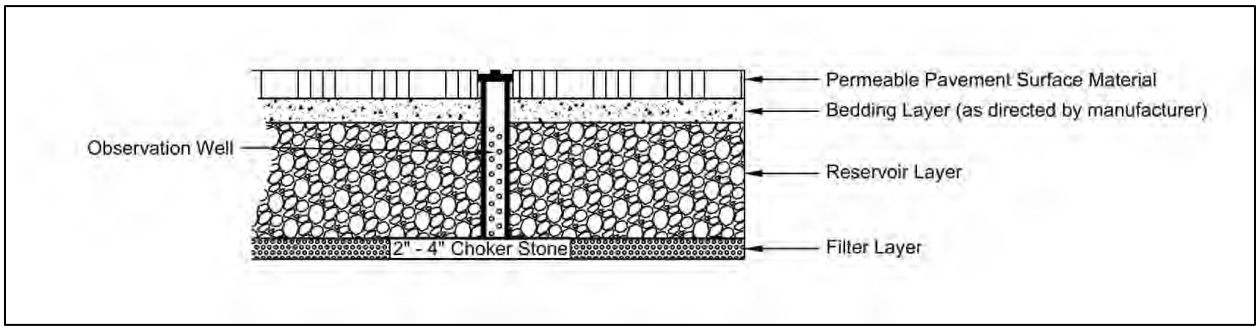

Figure 4.14. Cross-section of an enhanced permeable pavement design without an underdrain.

4.4.1 Permeable Pavement Feasibility Criteria

Since permeable pavement has a very high retention capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

Required Space

A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Soils

Soil conditions do not typically constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Underdrains may be required if the measured permeability of the underlying soils is less than 0.5 inches per hour (although utilization of an infiltration sump may still be feasible). When designing an infiltrating permeable pavement practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B Geotechnical Information Requirements for Underground BMPs. Impermeable soils will require an underdrain.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary or if the use of an infiltration sump is permissible (see Section 4.4.4 Permeable Pavement Design Criteria).

Contributing Drainage Area

The portion of the CDA that does not include the permeable pavement may not exceed 5 times the surface area of the permeable pavement (2 times is recommended) and it should be as close to 100% impervious as possible to reduce sediment loading.

Pavement Surface Slope

Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. The permeable pavement slope must be less than 5%. Designers may consider using a terraced design for permeable pavement in areas with steeper slopes (3%–5%). In all cases, designs must ensure that the slope of the pavement does not lead to flow occurring out of the stone reservoir layer onto lower portions of the pavement surface.

Minimum Hydraulic Head

The elevation difference needed for permeable pavement to function properly is generally nominal, although 1 to 4 feet of head from the pavement surface to the underdrain outlet is typically necessary. This value may vary based on several design factors, such as required storage depth and underdrain location.

Minimum Depth to Water Table

A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 0.5 feet (preferably 2 feet) must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Tidal Impacts

For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

Setbacks

To avoid the risk of seepage, stormwater cannot flow from the permeable pavement reservoir layer to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides and bottom of the permeable pavement practice (extending from the surface to the bottom of the practice and outward to meet the 10-foot setback).

Proximity to Utilities

Interference with underground utilities should be avoided if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way (PROW). Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the permeable pavement. Permeable pavement in the public right-of-way (PROW) must conform with the State of South Carolina Department of Transportation design specifications. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the permeable pavement to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the permeable pavement and the utility to coexist. The permeable pavement design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings.
- Work with the utility company to evaluate the relocation of the existing utility and install the optimum placement and sizing of the permeable pavement.
- If utility functionality, longevity, and vehicular access to manholes can be assured, accept the permeable pavement design and location with the existing utility. Design sufficient soil coverage over the utility or general clearances or other features, such as an impermeable liner, to assure all entities that the conflict is limited to maintenance.

When accepting utility conflict into the permeable pavement location and design, it is understood the permeable pavement will be temporarily impacted during utility work, but the utility owner will replace the permeable pavement or, alternatively, install functionally comparable permeable pavement according to the specifications in the current version of this guidebook. Restoration of permeable pavement that is located in the PROW will also conform with the State of South Carolina Department of Transportation design specifications.

Pollutant Hotspot Land Uses

Permeable pavement is not appropriate for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided, or the areas should be diverted from the permeable pavement.

On sites with existing contaminated soils, infiltration is not allowed. Permeable pavement areas must include an impermeable liner, and the Enhanced Design configuration cannot be used.

High Loading Situations

Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail. Sites with considerable pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted if possible, from the permeable pavement area. If unavoidable, pretreatment measures, such as a gravel or a sod filter strip should be employed (see Section 4.4.3 Permeable Pavement Pretreatment Criteria).

High Speed Roads

Permeable pavement should not be used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes, and roadway shoulders.

Economic Considerations

Permeable pavement tends to be expensive relative to other practices, but when the cost of land and traditional paving are included in the calculations, permeable pavement becomes much more competitive. Permeable pavement is very space-efficient, since it combines a useful pavement surface with stormwater management for runoff and, in standard design configurations, water quality treatment.

4.4.2 Permeable Pavement Conveyance Criteria

Permeable pavement designs must include methods to convey larger storms (e.g., 2- to 25-year) to the storm drain system. Conveyance methods include the following:

- Place an overdrain—a horizontal perforated pipe near the top of the reservoir layer—to pass excess flows after water has filled the base.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route overflows to another detention or conveyance system.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

4.4.3 Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary. Additional pretreatment is recommended if the pavement receives runoff from adjacent pervious areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface in order to reduce clogging.

4.4.4 Permeable Pavement Design Criteria

Type of Surface Pavement

The type of pavement should be selected based on a review of the pavement specifications and properties and designed according to the product manufacturer's recommendations.

Pavement Bottom Slope

For unlined designs, the bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or barriers, as shown in Figure 4.15 can be incorporated into the subsurface to encourage infiltration. Barriers may be constructed of concrete, earthen berms, impermeable membranes, or low permeability geotextile. In this type of design, the depth of the infiltration sump would be the depth behind the check dams. The depth and spacing of the barriers are dependent upon the underlying slope and the saturated hydraulic conductivity, as any water retained by the flow barriers must infiltrate within 48 hours. If an underdrain will be used in conjunction with the flow barriers, it can be installed over the top of the barriers, or parallel to the barriers with an underdrain in each cell.

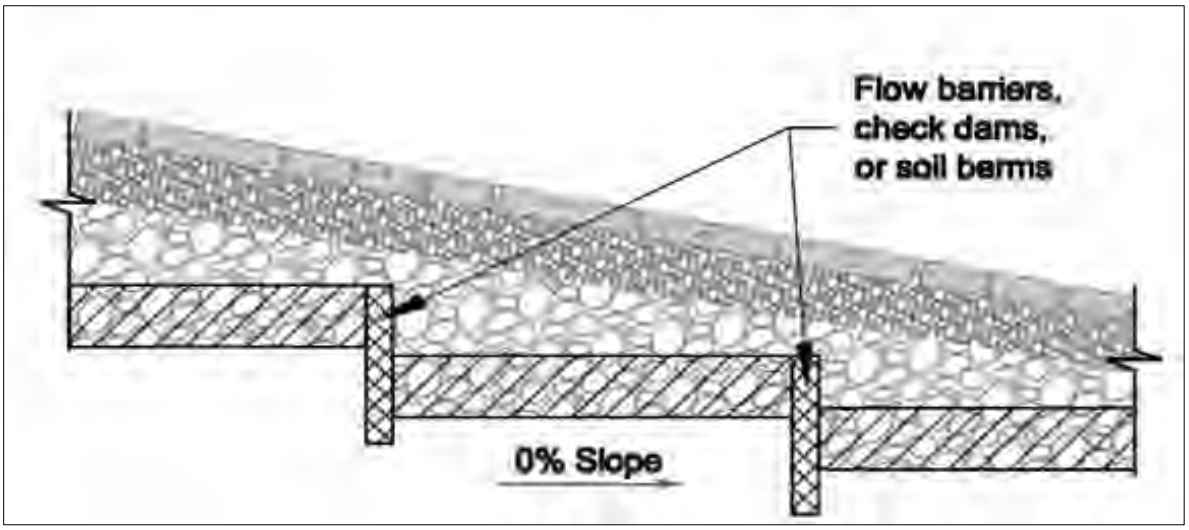

Figure 4.15. Use of flow barriers to encourage infiltration on sloped sites.

Internal Geometry and Drawdowns

- **Rapid Drawdown**
  Permeable pavement must be designed so that the target storage volume is detained in the reservoir for as long as possible, 36 to 48 hours, before completely discharging through an underdrain. A minimum orifice size of 1 inch is recommended regardless of the calculated drawdown time.

  Note: A 48-hour maximum drawdown time is utilized for permeable pavement rather than the 72-hour value used for other BMPs. This shorter drawdown time, in accordance with industry standards, is intended to ensure that the subgrade does not stay saturated for too long and cause problems with the pavement.

- **Infiltration Sump**
  To promote greater retention for permeable pavement located on marginal soils, an infiltration sump can be installed to create a storage layer below the underdrain invert. This design configuration is discussed further below.

Reservoir Layer

The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils, including the optional infiltration sump. The total thickness of the reservoir layer is determined by runoff storage needs, the saturated hydraulic conductivity of in-situ soils, structural requirements of the pavement sub-base, depth to water table, and frost depth conditions (see Section 4.4.1 Permeable Pavement Feasibility Criteria). A geotechnical engineer should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, double-washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading. Additional chamber structures may also be used to create larger storage volumes.
- The storage layer may consist of clean, double-washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability. Other appropriate materials may be used if accepted by the *<local jurisdiction>*.

- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

Underdrains

Most permeable pavement designs will require an underdrain (see Section 4.4.1 Permeable Pavement Feasibility Criteria). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme rain events. Multiple underdrains are typically necessary for permeable pavement wider than 40 feet, and each underdrain is recommended to be located 20 feet or less from the next pipe or the edge of the permeable pavement. For long and narrow applications, a single underdrain running the length of the permeable pavement is sufficient. The underdrain should be perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with three or four rows of 3/8-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, double-washed No. 57 stone, with a minimum 2-inch cover over the top of the underdrain. The underdrain system must include a flow control to ensure that the reservoir layer drains slowly (within 36 to 48 hours).

- The underdrain outlet can be fitted with a flow-reduction orifice within a weir or other easily inspected and maintained configuration in the downstream manhole as a means of regulating the stormwater detention time. The minimum diameter of any orifice is 1 inch. The designer should verify that the volume will draw down completely within 36 to 48 hours.
- On infiltration designs, an underdrain(s) can be installed and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

Observation Wells

All permeable pavement practices must include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation well should consist of a well-anchored, perforated 4- to 6-inch diameter PVC pipe. There should be no perforation within 1 foot of the surface. If the permeable pavement has an underdrain, tie the observation well into any Ts or Ys in the underdrain system. The observation well should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap.

Infiltration Sump (optional, required for enhanced designs with an underdrain)

For unlined permeable pavement systems, an optional upturned elbow or elevated underdrain configuration can be used to promote greater retention for permeable pavement located on marginal soils. The infiltration sump must be installed to create a storage layer below the underdrain or upturned elbow invert. The depth of this layer must be sized so that the design storm can infiltrate into the subsoils in a 48-hour period. The bottom of the infiltration sump must be at least 0.5 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

Filter Layer (optional)

To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used. The underlying native soils should be separated from the stone reservoir by a 2- to 4-inch layer of choker stone (e.g., No. 8).

Geotextile (optional)

Geotextile fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of fabric beneath permeable pavements since it may become a future plane of clogging within the system. Geotextile fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10 times) than the soil subgrade permeability must be used.

Impermeable Liner

An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a PVC geomembrane liner or equivalent of an appropriate thickness (follow manufacturer's instructions for installation). Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in Table 4.13, but designers should consult manufacturer's technical specifications for specific criteria and guidance. Table 4.14 provides general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table 4.13. Permeable pavement specifications for a variety of typical surface materials.

Material	Specification	Notes
Permeable Pavers (PP)	Void content, thickness, and compressive strength vary based on type and manufacturer Open void fill media: aggregate, topsoil and grass, coarse sand, etc.	Reservoir layer required to support the structural load.
Pervious Concrete (PC)	Void content: 15%–20% Thickness: Typically 4–8 inches Compressive strength: 2.8–28 MPa Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration. Requires certified supplier and installer.
Porous Asphalt (PA)	Void content: 15%–20% Thickness: Typically 3–7 inches (depending on traffic load) Open void fill media: None	Reservoir layer required to support the structural load. Requires certified supplier and installer.

Table 4.14. Material specifications for typical layers beneath the surface of permeable pavements.

Material	Specification	Notes
Bedding Layer	PC: 3–4 inches of No. 57 stone if No. 2 stone is used for Reservoir Layer PA: 3–4 inches of No. 57 stone PP: Follow manufacturer specifications	ASTM D448 size No. 57 stone (i.e., 1/2 to 1 1/2 inches in size). Must be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone or No. 2 stone PA: No. 2 stone PP: Follow manufacturer specifications	ASTM D448 size No. 57 stone (i.e., 1/2 to 1 1/2 inches in size); No. 2 Stone (i.e., 3/4 to 3 inches in size). Depth is based on the pavement structural and hydraulic requirements. Must be double-washed and clean and free of all fines. Other appropriate materials may be used if accepted by *<local jurisdiction>*.
Underdrain	Use 4- to 6-inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3 or 4 rows of 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface.	
Infiltration Sump (optional)	An aggregate storage layer below the underdrain invert. The material specifications are the same as Reservoir Layer.	
Filter Layer (optional)	The underlying native soils should be separated from the stone reservoir by a 2- to 4-inch layer of choker stone (e.g., No. 8).	
Geotextile (optional)	Use an appropriate geotextile fabric for both sides and/or bottom that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher than (10 times) the soil subgrade permeability. Low-permeability geotextile fabric may be used as a check dam material.	
Impermeable Liner (optional)	Where appropriate, use PVC geomembrane liner or equivalent.	
Observation Well	Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M-252) with a lockable cap, installed flush with the surface.	

Permeable Pavement Sizing

The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and to support the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below.

Structural Design

If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (i.e., the water quality,

channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic
- In situ soil strength
- Environmental elements
- Bedding and reservoir layer design

The resulting structural requirements may include the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which may limit their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- ASCE/T&DI/ICPI 68-18 Permeable Interlocking Concrete Pavement (2018)
- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

Hydraulic Design. Permeable pavement is typically sized to store the SWRv or larger design storm volumes in the reservoir layer. The storage volume in the pavements must account for the underlying saturated hydraulic conductivity and outflow through any underdrains. The design storm should be routed through the pavement to accurately determine the required reservoir depth. The depth of the reservoir layer or infiltration sump needed to store the design storm can be determined by using Equation 4.3.

Equation 4.3. Reservoir layer or infiltration sump depth.

$$d_p = \frac{\left(\frac{P \times Rv_I \times CDA}{A_p}\right) - (K_{sat} \times t_f)}{\eta_r}$$

Where:

d_p = Depth of the reservoir layer, or depth of the infiltration sump for enhanced designs with underdrains (ft)
P = Rainfall depth for the SWRv or other design storm (ft)
Rv_I = 0.95 (runoff coefficient for impervious cover)
CDA = Total contributing drainage area, including permeable pavement surface area (square feet)
A_p = Permeable pavement surface area (square feet)
K_{sat} = Field-verified saturated hydraulic conductivity for subgrade soils (ft/day). If an impermeable liner is used in the design, then this value is 0
t_f = Time to fill the reservoir layer (days; assume 2 hours or 0.083 day)

η_r = 0.4 (effective porosity for the reservoir layer)

This equation makes the following design assumptions:

- The CDA does not contain pervious areas.
- If the subgrade will be compacted to meet structural design requirements of the pavement section, the measured saturated hydraulic conductivity shall be based on measurement of the subgrade soil subjected to the compaction requirements.

The depth of the reservoir layer cannot be less than the depth required to meet the pavement structural requirement. The depth of the reservoir layer may need to be increased to meet structural or larger storage requirements.

For infiltration designs without underdrains or designs with infiltration sumps, the captured volume must drain from the practice within 48 hours. Equation 4.4 can be used to determine the drawdown time in the reservoir layer or infiltration sump.

Equation 4.4. Drawdown time.

$$t_d = \frac{d_p \times \eta_r}{K_{sat}}$$

Where:

t_d = Drawdown time (days)
d_p = Depth of the reservoir layer, or depth of the infiltration sump for enhanced designs with underdrains (ft)
η_r = 0.4 (effective porosity for the reservoir layer)
K_{sat} = Field-verified saturated hydraulic conductivity for subgrade soils (ft/day). If an impermeable liner is used in the design, then this value is 0

For designs with underdrains, the captured volume must drain in 36-48 hours. The drawdown time should be determined using the hydrologic routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate.

The total storage volume provided by the practice, Sv, should be determined using Equation 4.5.

Equation 4.5. Permeable pavement storage volume.

$$Sv = A_p[(d_p \times \eta_r) + K_{sat} \times t_f]$$

Where:

Sv = Storage volume (cubic feet)
d_p = Depth of the reservoir layer, or depth of the infiltration sump for enhanced designs with underdrains (ft)
η_r = 0.4 (effective porosity for the reservoir layer)
A_p = Permeable pavement surface area (square feet)

K_{sat} = Field-verified saturated hydraulic conductivity for subgrade soils (ft/day). If an impermeable liner is used in the design, then this value is 0

t_f = Time to fill the reservoir layer (days; assume 2 hours or 0.083 day)

Detention Storage Design

Permeable pavement can also be designed to address, in whole or in part, the detention storage for larger storm events. The designer can model various approaches by factoring in storage within the stone aggregate layer (including chamber structures that increase the available storage volume), expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet (see Section 4.4.2 Permeable Pavement Conveyance Criteria).

4.4.5 Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot, such as trees and islands, in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, and other plant matter will inadvertently clog the paving surface. Bioretention areas (see Section 4.3 Bioretention) may be a good design option to meet these landscaping goals.

4.4.6 Permeable Pavement Construction Sequence

Experience has shown that proper installation is critical to the effective operation of a permeable pavement system.

Soil Erosion and Sediment Controls

The following soil erosion and sediment control guidelines must be followed during construction:

- All permeable pavement areas must be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas intended to infiltrate runoff must remain outside the limits of disturbance during construction to prevent soil compaction by heavy equipment and loss of design infiltration rate (unless the area has been determined to have a low California Bearing Ratio and will require compaction during the permeable pavement construction phase). Where it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, there are several possible remedies for the impacted area.
- If excavation in the proposed permeable pavement areas can be restricted, then remediation can be achieved with deep tilling practices. This is only possible if in situ soils are not disturbed any deeper than 2 feet above the final design elevation of the bottom of the aggregate reservoir course. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled to a depth of 12 inches below the bottom of the reservoir layer.
- Alternatively, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted, then infiltration tests will

be required prior to installation of the permeable pavement to ensure that the design infiltration rate is still present. If tests reveal the loss of design infiltration rates, then deep tilling practices may be used in an effort to restore those rates. In this case, further testing must be done before the permeable pavement can be installed to establish that design rates have been achieved.

- Finally, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.
- Permeable pavement areas must be clearly marked on all construction documents and grading plans.
- During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid post-construction clogging and long-term maintenance issues.
- Any area of the site intended ultimately to be a permeable pavement area with an infiltration component should not be used as the site of a temporary sediment trap or basin. If locating a temporary sediment trap or basin on an area intended for permeable pavement is unavoidable, the remedies are similar to those discussed for heavy equipment compaction.
- If it is possible, restrict the invert of the sediment trap or basin to at least 1 foot above the final design elevation of the bottom of the aggregate reservoir course of the proposed permeable pavement. Then remediation can be achieved with proper removal of trapped sediments and deep tilling practices.
- An alternate approach to deep tilling is to use an impermeable linear to protect the in situ soils from sedimentation while the sediment trap or basin is in use.
- In each case, all sediment deposits in the excavated area must be carefully removed prior to installing the sub-base, base, and surface materials. The plan must also show the proper procedures for converting the temporary sediment control practice to a permeable pavement BMP, including dewatering, cleanout, and stabilization.

Permeable Pavement Installation

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified depending on the particular type of permeable pavement that is being installed.

1. Stabilize Contributing Drainage Area

Construction of the permeable pavement should only begin after the entire CDA has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain.

2. Install Soil Erosion and Sediment Control Measures for the Permeable Pavement

As noted above, temporary soil erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediment must be removed and replaced with clean material.

3. Minimize Impact of Heavy Installation Equipment

Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach,

whereby the proposed permeable pavement area is split into 500- to 1,000-square foot temporary cells with a 10- to 15-foot-wide earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

4. Promote Infiltration Rate
The native soils along the bottom of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or geotextile fabric. In large-scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity.

Note: This may reduce or eliminate the infiltration function of the installation, and it must be addressed during hydrologic design.

5. Order of Materials
Geotextile fabric should be installed on the sides of the reservoir layer (and the bottom if the design calls for it). Geotextile fabric strips should overlap down-slope by a minimum of 2 feet and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of geotextile fabric 1 foot below the surface to prevent sediment from entering into the reservoir layer. Excess geotextile fabric should not be trimmed until the site is fully stabilized.

6. Install Base Material Components
Provide a minimum of 2 inches of aggregate above and below the underdrains. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

7. Stone Media
Spread 6-inch lifts of the appropriate clean, double-washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

8. Reservoir Media
Install the desired depth of the bedding layer, depending on the type of pavement, as indicated in Table 4.14.

9. Paving Media
Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

10. Installation of Porous Asphalt
The following has been excerpted from various documents, most notably Jackson (2007):

- Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230°F and 260°F, with a minimum air temperature of 50°F, to ensure the surface does not stiffen before compaction.
- Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.

- The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM D1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.
- Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
- Test the full permeability of the pavement surface by application of clean water at a rate of at least 5 gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
- Inspect the facility 18 to 30 hours after a significant rainfall (0.5 inch or greater) or artificial flooding to determine if the facility is draining properly.

11. Pervious Concrete Installation

The basic installation sequence for pervious concrete is outlined by the National Ready Mixed Concrete Association (NRMCA; NRMCA, 2004). Concrete installers are required to be certified by a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:

- Drive the concrete truck as close to the project site as possible.
- Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.
- After the concrete is placed, approximately 3/8 to 1/2 inches is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
- Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.
- Cut joints for the concrete to a depth of 1/4 inch.
- The curing process is very important for pervious concrete. Concrete installers should follow manufacturer specifications to the extent allowed by on-site conditions when curing pervious concrete. This typically requires covering the pavement with plastic sheeting within 20 minutes of the strike-off and may require keeping it covered for at least 7 days. Do not allow traffic on the pavement during the curing period.
- Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (0.5 inch or greater) or artificial flooding, to determine if the facility is draining properly.

12. Permeable Interlocking Concrete Paver Installation

The basic installation process is described in greater detail by Smith (2006):

- Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement systems require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.

- Place the double-washed No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
- Place and screed the bedding course material (typically No. 8 stone).
- Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than 1/3 of the full unit size.
- Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with ASTM D448 No. 8 stone; although, No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
- Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-pound-foot, 75- to 95-Hz plate compactor.
- Do not compact within 6 feet of the unrestrained edges of the pavers.
- The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a significant rainfall (0.5 inch or greater) or artificial flooding to determine whether the facility is draining properly.

13. Construction Supervision

Supervision before, during, and after construction by a qualified professional is recommended to ensure permeable pavement is built in accordance with these specifications. ASTM test C1781 or C1701 must be performed to ensure initial pavement permeability of at least 6 inches per hour. Inspection checklists that require sign-offs by qualified individuals should be used at critical stages of construction to ensure the contractor's interpretation of the plan is consistent with the designer's intent.

Construction phase inspection checklist for permeable pavement practices can be found in Appendix E Construction Inspection Checklists.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The CDA should be stabilized prior to directing water to the permeable pavement area.
- Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.
- Check elevations (i.e., the invert of the underdrain, inverts for the inflow, and outflow points) and the surface slope.

- Make sure the permeable pavement surface is even, runoff spreads evenly across it, and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the BMP maintenance tracking database.

Runoff diversion structures are recommended to protect larger permeable pavement applications from early runoff-producing storms, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid.

4.4.7 Permeable Pavement Maintenance Criteria

Maintenance is a required and crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on all permeable pavements:

- Sanding
- Resealing
- Resurfacing
- Power washing
- Storage of mulch or soil materials
- Construction staging on unprotected pavement

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications (e.g., parking lots) involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the site. Many experts consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Typical maintenance tasks are outlined in Table 4.15.

Table 4.15. Typical maintenance tasks for permeable pavement practices.

Frequency	Maintenance Tasks
After installation	▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 0.5 inch of rainfall. Conduct any needed repairs or stabilization.
Once every 1–2 months during the growing season	▪ Mow grass in grid paver applications (clippings should be removed from the pavement area).
As needed	▪ Stabilize the CDA to prevent erosion. ▪ Remove any soil or sediment deposited on pavement. ▪ Replace or repair any pavement surfaces that are degenerating or spalling.
2–4 times per year (depending on use)	▪ Mechanically sweep pavement with a standard street sweeper to prevent clogging.
Annually	▪ Conduct a maintenance inspection ▪ Remove weeds as needed.
Once every 2–3 years	▪ Remove any accumulated sediment in pretreatment cells and inflow points.
If clogged	▪ Conduct maintenance using a regenerative street sweeper or a vacuum sweeper ▪ Replace any necessary joint material.

When permeable pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs and (2) understand the long-term maintenance plan.

It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each permeable pavement site, particularly at large-scale applications. Maintenance inspection checklists for permeable pavements and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material

Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.4.8 Permeable Pavement Stormwater Compliance Calculations

Permeable pavement retention credit varies depending on the design configuration of the system.

Enhanced Designs

These permeable pavement applications have an infiltration sump and water-quality filter, but no underdrain. Enhanced designs are credited with 100% retention for the storage volume (Sv) provided by the practice as well as 100% TSS, TN, and bacteria removal (Table 4.16).

Table 4.16. Retention and pollutant removal for enhanced permeable pavement practices.

Retention	= 100%
TSS Removal	= 100%
TN Removal	= 100%
Bacteria Removal	= 100%

Note: If using an infiltration sump design, only the volume stored in the sump can be counted as the Enhanced Design Storage Volume (Sv). Any volume stored in the practice above the sump is counted as a standard design. When using the SoLoCo Compliance Calculator, the Sv of the infiltration sump should be entered into the cell "Storage Volume Provided by BMP" in the Permeable Pavement – Enhanced row. Permeable Pavement – Standard should then be selected as the downstream practice. Next, in the Permeable Pavement - Standard row, the Sv provided above the infiltration sump should be entered into the cell "Storage Volume Provided by BMP."

Standard Designs

These permeable pavement applications have an underdrain, but no infiltration sump or water quality filter. Standard designs are credited with 30% retention for the storage volume (Sv) provided as well as 80% TSS, 45% TN, and 30% bacteria removal. (Table 4.17).

Table 4.17. Retention and pollutant removal for standard permeable pavement practices.

Retention	= 30%
TSS Removal	= 80%
TN Removal	= 45%
Bacteria Removal	= 30%

The practice must be sized using the guidance detailed in Section 4.2.4 Permeable Pavement Design Criteria.

Permeable pavement also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) achieved by the practice from the total runoff volumes for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

4.4.9 References

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4.5 Infiltration Practices

Infiltration				
Definition: Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a three-day period.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		100%	100%	100%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
Moderate	Moderate	High		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	**Basin**	**Trench**	
Quarterly	Every 5-10 years	100%	100%	
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Excellent in impervious CDAs ▪ Helps restore pre-development hydrologic conditions through groundwater recharge ▪ Reduces runoff rates, volumes, and pollutant loads ▪ Attractive landscaping features ▪ Good for small sites with porous soils		▪ CDA should be less than 2 acres. ▪ Potential for groundwater contamination ▪ High clogging potential; ▪ Not for sites with fine soils (clays/silts) in CDA ▪ Geotechnical testing required		
Components		**Design considerations**		
▪ Pretreatment ▪ Conveyance system ▪ Ponding area ▪ Soils/Filter Media/Mulch ▪ Observation Well/Monitoring Port ▪ Plants		▪ Depth to seasonal high water table must be at least 6 inches below bottom of practice ▪ Must infiltrate within 72 hours		
Maintenance Activities				
▪ Inspect for clogging		▪ Replace soil/stone if it becomes clogged ▪ Clean conveyance system(s)		

[1]*Credited pollutant load removal*

Infiltration practices are suitable for use in residential and other urban areas where field measured soil infiltration rates are sufficient. To prevent possible groundwater contamination, infiltration must not be utilized at sites designated as stormwater hotspots. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites (Figure 4.16)

Figure 4.16. Infiltration practice in median strip.

Definition

Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a three-day period. Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where field-verified saturated hydraulic conductivity is sufficient.

Design variants include the following:

I-1 Infiltration trench

I-2 Infiltration basin

Infiltration Trenches

Infiltration trenches are excavated trenches filled with stone. Stormwater runoff is captured and temporarily stored in the stone reservoir, where it is allowed to infiltrate into the surrounding and underlying native soils. Infiltration trenches can be used to "receive" stormwater runoff from contributing drainage areas of up to 2 acres in size and should only be used on development sites where sediment loads can be kept relatively low (see Figure 4.17 and Figure 4.18).

Infiltration Basins

Infiltration basins are shallow, landscaped excavations filled with an engineered soil mix. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being allowed to infiltrate into the surrounding soils. They are essentially non-underdrained bioretention areas and should also only be used on drainage areas up to 5 acres where sediment loads can be kept relatively low (Figure 4.19).

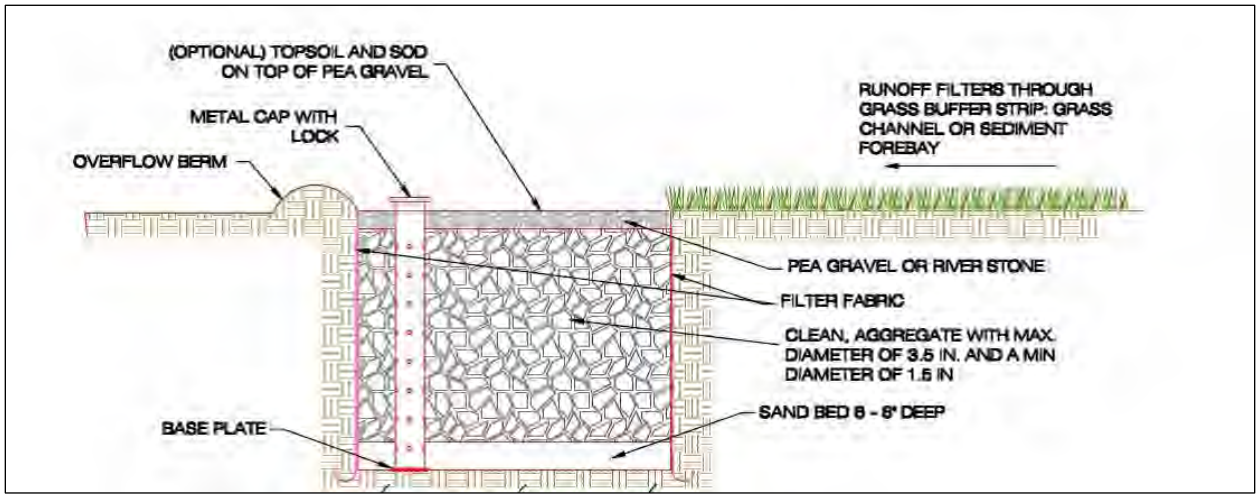

Figure 4.17. Example design of an infiltration trench.

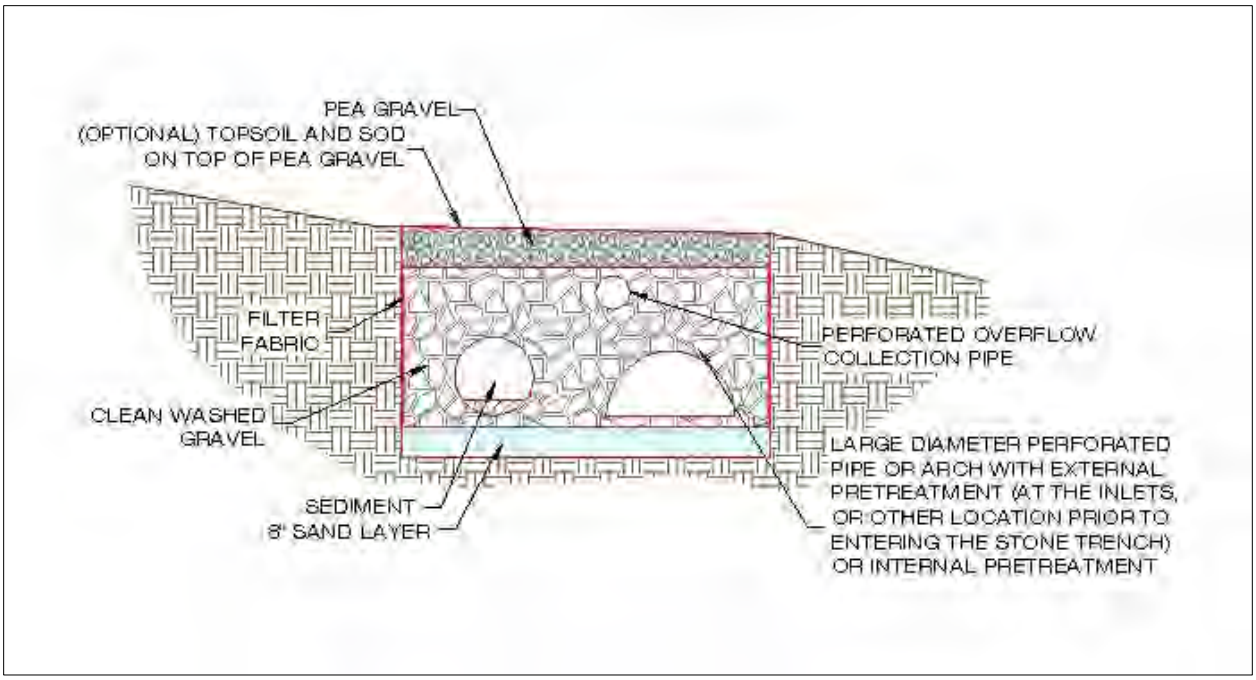

Figure 4.18. Example design of an infiltration practice with supplemental pipe storage.

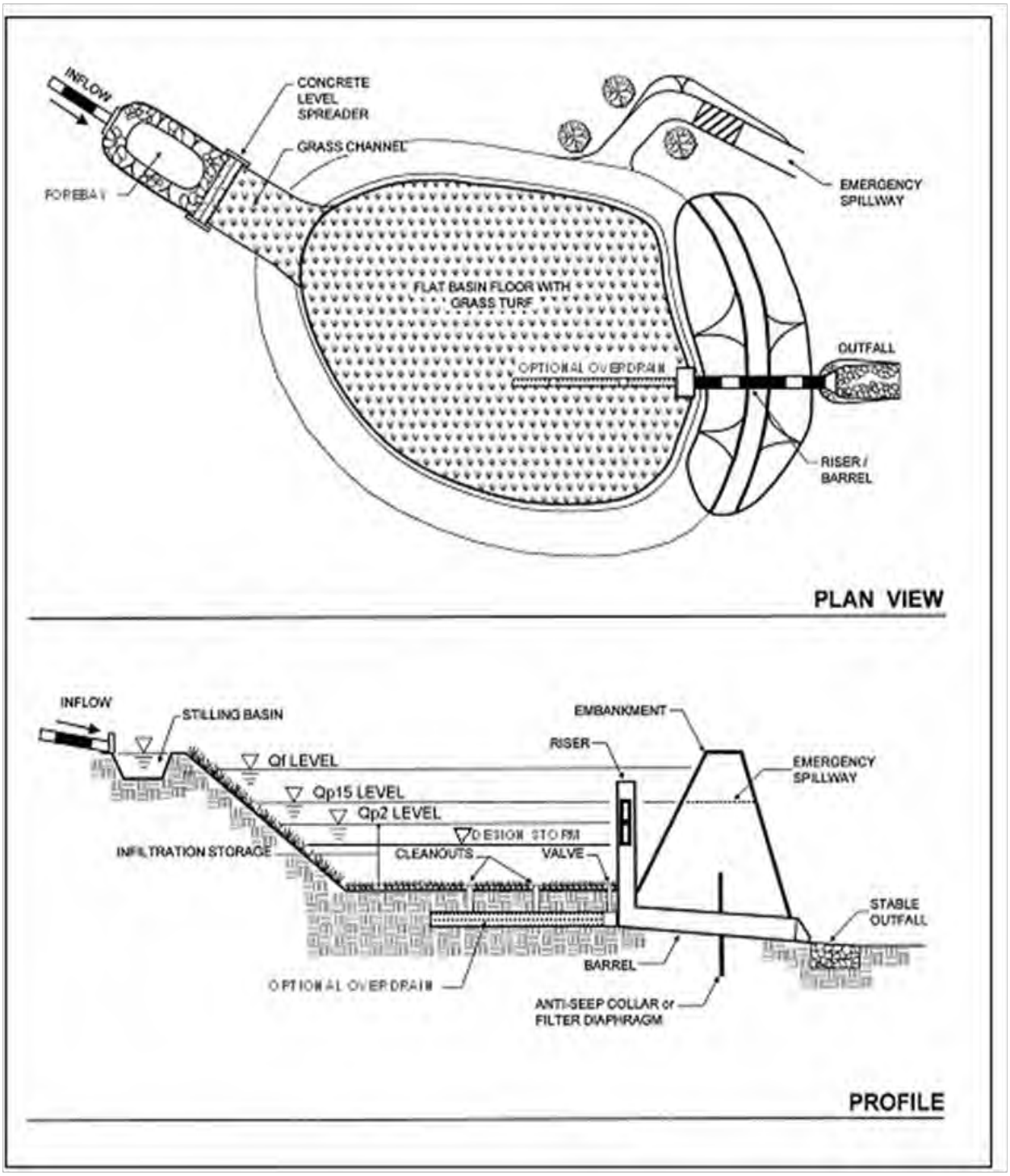

Figure 4.19. Example design of an infiltration basin.

4.5.1 Infiltration Feasibility Criteria

Infiltration practices have very high storage and retention capabilities when sited and designed appropriately. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of HSG A or B soils, shown on the U.S. Department of Agriculture's NRCS soil surveys, should be considered as primary locations for infiltration practices. Additional information about soil and infiltration are described in more detail later in this section. During initial design phases, designers should carefully identify and evaluate constraints on infiltration, as follows:

Underground Injection Control for Class V Wells

In order for an infiltration practice to avoid classification as a Class V well, which is subject to regulation under the Federal Underground Injection Control program, the practice must be wider than the practice is deep. If an infiltration practice is "deeper than its widest surface dimension" or if it includes an underground distribution system, then it will likely be considered a Class V injection well. Class V injection wells are subject to permit approval by the U.S. Environmental Protection Agency (EPA). For more information on Class V injection wells and stormwater management, designers should consult https://www.epa.gov/sites/production/files/2015-10/documents/epamemoinfiltrationclassvwells.pdf for EPA's clarification for stormwater infiltration.

Contributing Drainage Area

The maximum CDA to an individual infiltration practice should be less than 2 acres and as close to 100% impervious as possible. The design, pretreatment, and maintenance requirements will differ depending on the size of the infiltration practice.

Site Topography

The infiltration practice shall not be located on slopes greater than 6%, although check dams or other devices may be employed to reduce the effective slope of the practice. Further, unless slope stability calculations demonstrate otherwise, infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%.

Minimum Hydraulic Head

Two or more feet of head may be needed to promote flow through infiltration practices.

Minimum Depth to Water Table

A minimum vertical distance of 0.5 feet must be provided between the bottom of the infiltration practice.

Tidal Impacts

The bottom of an infiltration practice should be located above the tidal mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

Soils

Initially, soil infiltration rates can be estimated from NRCS soil data for feasibility purposes, but designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B Geotechnical Information Requirements for Underground BMPs for their design.

Use on Urban Fill Soils/Redevelopment Sites
Sites that have been previously graded or disturbed do not typically retain their original soil permeability due to compaction. Therefore, such sites are often not good candidates for infiltration practices unless the geotechnical investigation shows that a sufficient saturated hydraulic conductivity exists.

Dry Weather Flows
Infiltration practices should not be used on sites receiving regular dry-weather flows from sump pumps, irrigation water, chlorinated wash-water, or flows other than stormwater.

Setbacks
To avoid the risk of seepage, stormwater cannot flow from infiltration practices to traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides and bottom of the infiltration area (extending from the surface to the bottom of the practice and outward to meet the 10-foot setback). Areas where the liner blocks infiltration should be excluded from surface area calculations for the practice. In locations where the surface soil consists of highly permeable soils with little separation of the infiltration trench or basin bottom, the extent of ground water mounding should be considered. Mounding can occur in areas where infiltrating water intersects a groundwater table and the rate of water entering the subsurface is greater than the rate at which water is conveyed away from the infiltration system (MPCA, 2019). Ground water mounding may impact building foundations, soil stability, underground utilities and potentially on-site treatment systems (septic leach beds).

All setbacks must be verified by a professional geotechnical engineer registered in the State of South Carolina.

Proximity to Utilities
Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the PROW. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the infiltration BMP. Infiltration BMPs in the PROW will also conform with the State of South Carolina Department of Transportation design specifications. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the infiltration BMP to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the infiltration BMP and the utility to coexist. The infiltration BMP design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings. Other key design features may need to be moved, added, or deleted.
- Evaluate the relocation of the existing utility and install an optimally placed and sized infiltration BMP.
- If utility functionality, longevity and vehicular access to manholes can be assured, accept the infiltration BMP design and location with the existing utility. Incorporate into the infiltration BMP design sufficient soil coverage over the utility or general clearances or other features such as an impermeable linear to assure all entities the conflict is limited to maintenance.

Note: When accepting utility conflict into the infiltration BMP location and design, it is understood the infiltration BMP will be temporarily impacted during utility work. At the conclusion of this work, the utility owner will replace the infiltration BMP or, alternatively, install a functionally comparable infiltration BMP according to the specifications in the current version of this guidebook. If the infiltration BMP is located in the PROW the infiltration BMP restoration will also conform with the State of South Carolina Department of Transportation design specification.

Pollutant Hotspots and High Loading Situations

Infiltration practices are not intended to treat sites with high sediment or trash or debris loads, because such loads will cause the practice to clog and fail. Infiltration practices must be avoided at potential stormwater hotspots that pose a risk of groundwater contamination. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the infiltration area and groundwater.

On sites with existing contaminated soils, infiltration is not allowed.

Economic Considerations

Infiltration practices do require a designated space on the site, which in space-constrained areas, may reduce available building space. However, infiltration practices have a relatively low construction cost, and high space efficiency. In some cases, they can even be incorporated into the detention design or landscaped areas

4.5.2 Infiltration Conveyance Criteria

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line. Where possible, conventional infiltration practices should be designed off-line to avoid damage from the erosive velocities of larger design storms. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice shall be designed as an off-line practice. Pretreatment shall be provided for storm drain pipes and conveyance systems discharging directly to infiltration systems.

Off-line Infiltration

Overflows can either be diverted from entering the infiltration practice or dealt with via an overflow inlet. Optional overflow methods include the following:

- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design SWRv to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency (further guidance on determining the peak flow rate will be necessary in order to ensure proper design of the diversion structure).
- Use landscaping type inlets or standpipes with trash guards as overflow devices.

On-line Infiltration

An overflow structure must be incorporated into on-line designs to safely convey the 25-year storm through the infiltration area. Mechanisms such as elevated drop inlets and overflow weirs are examples of how to direct high flows to a non-erosive down-slope overflow channel, stabilized water course, or storm sewer system designed to convey the 25-year design storm.

4.5.3 Infiltration Pretreatment Criteria

Every infiltration system shall have pretreatment mechanisms to protect the long-term integrity of the infiltration rate. One of the following techniques must be installed to pretreat 100% of the inflow in every facility:

- Grass channel
- Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained)
- Forebay or sump pit (must accommodate a minimum 15% of the design storm volume)
- Gravel diaphragm (minimum 1 foot deep and 2 feet wide and only if sheet flow is established and maintained)
- Filter system (see Section 4.10 Filtering Systems) If using a filter system as a pretreatment facility, the sand filter will not require its own separate pretreatment facility.
- A proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pretreatment. Refer to Section 0 Proprietary Practices.

If the basin serves a CDA greater than 20,000 square feet, a forebay, sump pit, filter system, or proprietary practice must be used for pretreatment.

Exit velocities from the pretreatment chamber shall not be erosive (above 6 fps) during the 25-year design storm and flow from the pretreatment chamber should be evenly distributed across the width of the practice (e.g., using a level spreader).

4.5.4 Infiltration Design Criteria

Geometry

Where possible, an infiltration practice should be designed to be wider than it is deep, to avoid classification as a Class V injection well. For more information on Class V wells see https://www.epa.gov/sites/production/files/2015-10/documents/epamemoinfiltrationclassvwells.pdf

Practice Slope

The bottom of an infiltration practice should be flat (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater.

Infiltration Basin Geometry

The maximum vertical depth to which runoff may be ponded over an infiltration basin is 24 inches. The side-slopes should be no steeper than 4H:1V.

Surface Cover (optional)

Designers may choose to install a layer of topsoil and grass above the infiltration practice.

Surface Stone

A 3-inch layer of clean, washed river stone or No. 8 or 89 stone should be installed over the stone layer.

Stone Layer

Stone layers must consist of clean, washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches.

Observation Wells
All infiltration practices must include at least one observation well. The observation well is used to observe the rate of drawdown within the infiltration practice following a storm event and to facilitate periodic inspection and maintenance. The observation well should consist of a well-anchored, perforated 4- to 6-inch diameter PVC pipe. There should be no perforation within 1 foot of the surface. The observation well should extend vertically to the bottom of the stone layer and extend upward to the top of ponding.

Underground Storage (optional)
In the underground mode, runoff is stored in the voids of the stones and infiltrates into the underlying soil matrix. Perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond.

Overflow Collection Pipe (Overdrain)
An optional overflow collection pipe can be installed in the stone layer to convey collected runoff from larger storm events to a downstream conveyance system.

Trench Bottom
To protect the bottom of an infiltration trench from intrusion by underlying soils, a sand layer must be used. The underlying native soils must be separated from the stone layer by a 6- to 8-inch layer of coarse sand (e.g., ASTM C-33, 0.02–0.04 inches in diameter).

Geotextile Fabric
An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude (10 times) higher than the soil subgrade permeability must be used. This layer should be applied only to the sides of the practice.

Material Specifications
Recommended material specifications for infiltration areas are shown in Table 4.18.

Table 4.18. Infiltration practice material specifications.

Material	Specification	Notes
Surface Layer (optional)	Topsoil and grass layer	
Surface Stone	Install a 3-inch layer of river stone or pea gravel.	Provides an attractive surface cover that can suppress weed growth.
Stone Layer	Clean, double-washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches.	
Observation Well	Install a vertical 6-inch Schedule 40 PVC perforated pipe, with a lockable cap and anchor plate.	Install one per 50 feet of length of infiltration practice.
Overflow Collection Pipe (optional)	Use 4- or 6-inch rigid schedule 40 PVC pipe, with three or four rows of 3/8-inch perforations at 6 inches on center.	
Trench Bottom	Install a 6- to 8-inch sand layer (e.g., ASTM C-33, 0.02–0.04 inches in diameter)	
Geotextile Fabric (sides only)	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude (10 times) higher than the soil subgrade permeability must be used.	

Practice Sizing

The proper approach for designing infiltration practices is to avoid forcing a large amount of infiltration into a small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to achieve the full design storm volume (SWRv) for the CDA, as long as other stormwater treatment practices are applied at the site to meet the remainder of the design storm volume.

Several equations (see following page) are needed to size infiltration practices. The first equations establish the maximum depth of the infiltration practice, depending on whether it is a surface basin (Equation 4.6) or trench with an underground reservoir (Equation 4.7)

Equation 4.6. Maximum surface basin depth for infiltration basins.

$$d_{max} = K_{sat} \times t_d$$

Equation 4.7. Maximum underground reservoir depth for infiltration trenches.

$$d_{max} = \frac{(K_{sat} \times t_d)}{\eta_r}$$

Where:

d_{max} = Maximum depth of the infiltration practice (ft)
K_{sat} = Field-verified saturated hydraulic conductivity for the native soils (ft/day)
t_d = Maximum drawdown time (days, normally 3 days)
η_r = Available porosity of the stone reservoir (assume 0.4)

These equations make the following design assumptions:

- **Stone Layer Porosity**
  A porosity value of 0.4 shall be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir.
- **Rapid Drawdown**
  Infiltration practices must be sized so that the design volume infiltrates within 72 hours, to prevent nuisance ponding conditions.

Designers should compare these results to the maximum allowable depths in Table 4.19 and use whichever value is less for the subsequent design.

Table 4.19. Maximum facility depth for infiltration practices.

Mode of Entry	Scale of Infiltration		
	Micro Infiltration (250–2,500 ft²)	**Small Scale Infiltration (2,500–20,000 ft²)**	**Conventional Infiltration (20,000–100,000 ft²)**
Surface Basin	1.0	1.5	2.0
Underground Reservoir	3.0	5.0	varies

Once the maximum depth is known, calculate the surface area needed for an infiltration practice using Equation 4.8 or Equation 4.9.

Equation 4.8. Surface basin surface area for infiltration basins.

$$\mathrm{SA} = \frac{\mathrm{DesignStorm}}{\mathrm{d} + (\mathrm{K_{sat}} \times \mathrm{t_f})}$$

Equation 4.9. Underground reservoir surface area for infiltration trenches.

$$SA = \frac{DesignStorm}{(\eta_r \times d) + (0.5 \times K_{sat} \times t_f)}$$

Where:

SA = Surface area (square feet)
DesignStorm = SWRv or other design storm volume (e.g., portion of the SWRv; cubic feet)
η_r = Available porosity of the stone reservoir (assume 0.4)
d = Infiltration depth (feet; maximum depends on the scale of infiltration and the results of Equation 4.6 or Equation 4.7)
K_{sat} = Field-verified saturated hydraulic conductivity for the native soils (ft/day)
t_f = Time to fill the infiltration facility (days; typically 2 hours or 0.083 days)

The storage volume (Sv) captured by the infiltration practice is defined as the volume of water that is fully infiltrated through the practice (i.e., no overflow). Designers may choose to infiltrate less than the full design storm (SWRv). In this case, the design volume captured must be treated as the Sv of the

practice (see Section 4.5.4 Infiltration Design Criteria). Sv can be determined by rearranging Equation 4.8 and Equation 4.9 to yield Equation 4.10 and Equation 4.11.

Equation 4.10. Storage volume for surface basin area for infiltration basins.

$$Sv = SA \times [d + (K_{sat} \times t_f)]$$

Equation 4.11. Storage volume for underground reservoir surface area for infiltration trenches.

$$Sv = SA \times [(\eta_r \times d) + (K_{sat} \times t_f)]$$

Infiltration practices can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, any perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials installed within the reservoir, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

4.5.5 Infiltration Landscaping Criteria

Infiltration trenches can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover, subject to the following additional design considerations:

- Infiltration practices should not be installed until all up-gradient construction is completed and pervious areas are stabilized with dense and healthy vegetation, unless the practice can be kept off-line so it receives no runoff until construction and stabilization is complete.
- Vegetation associated with the infiltration practice buffers should be regularly maintained to limit organic matter in the infiltration device and maintain enough vegetation to prevent soil erosion from occurring.

4.5.6 Infiltration Construction Sequence

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. Second, loading from heavy construction equipment can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed.

During site construction, the following protective measures are absolutely critical:

- All areas proposed for infiltration practices should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Avoid excessive compaction by preventing construction equipment and vehicles from traveling over the proposed location of the infiltration practice. To accomplish this, areas intended to infiltrate runoff must remain outside the limits of disturbance during construction.
- When this is unavoidable, there are several possible remedies for the impacted area.
    - If excavation at the impacted area can be restricted then remediation can be achieved with deep tilling practices. This is only possible if in situ soils are not disturbed below 2 feet above the final design elevation of the bottom of the infiltration practice. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled a minimum of 12 inches below the bottom of the infiltration practice.

  - Alternatively, if it is infeasible to keep the proposed infiltration practice outside of the limits of disturbance, and excavation of the area cannot be restricted, then infiltration tests will be required prior to installation of the infiltration practice to ensure that the design infiltration rate is still present. If tests reveal the loss of design infiltration rates then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the infiltration practice can be installed.
  - Finally, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.
- Any area of the site intended ultimately to be an infiltration practice should not be used as the site of a temporary sediment trap or basin. If locating a sediment trap or basin on an area intended for infiltration is unavoidable, the remedies are similar to those discussed for heavy equipment compaction. If it is possible, restrict the invert of the sediment trap or basin to at least 2 feet above the final design elevation of the bottom of the proposed infiltration practice. Then remediation can be achieved with proper removal of trapped sediments and deep tilling practices. An alternate approach to deep tilling is to use an impermeable linear to protect the in situ soils from sedimentation while the sediment trap or basin is in use. In each case, all sediment deposits must be carefully removed prior to installing the infiltration practice.
- Keep the infiltration practice off-line until construction is complete. Prevent sediment from entering the infiltration site by using super silt fence, diversion berms, or other means. In the soil erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to a conventional infiltration basin. The soil erosion and sediment control plan must also indicate the specific methods to be used to temporarily keep runoff from the infiltration site.
- Upland CDAs need to be completely stabilized with a well-established layer of vegetation prior to commencing excavation for an infiltration practice.

Infiltration Installation

The actual installation of an infiltration practice is done using the following steps:

1. Avoid Impact of Heavy Installation Equipment

Excavate the infiltration practice to the design dimensions from the side using a backhoe or excavator. The floor of the pit should be completely level, but equipment should be kept off the floor area to prevent soil compaction.

2. Hang Geotextile Walls

Install geotextile fabric on the trench sides. Large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the geotextile fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The geotextile fabric itself should be tucked under the sand layer on the bottom of the infiltration trench. Stones or other anchoring objects should be placed on the fabric at the trench sides, to keep the trench open during windy periods. Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids, to ensure the fabric conforms smoothly to the sides of excavation.

3. Promote Infiltration Rate
Scarify the bottom of the infiltration practice and spread 6 inches of sand on the bottom as a filter layer.

4. Observation Wells
Anchor the observation well(s) and add stone to the practice in 1-foot lifts.

5. Stabilize Surrounding Area
Use sod, where applicable, to establish a dense turf cover for at least 10 feet around the sides of the infiltration practice, to reduce erosion and sloughing.

Construction Supervision
Supervision during construction is recommended to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists to include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

4.5.7 Infiltration Maintenance Criteria

Maintenance is a crucial and required element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the stone layer by organic matter and sediment. The following design features can minimize the risk of clogging:

Stabilized CDA
Infiltration systems may not receive runoff until the entire CDA has been completely stabilized.

Observation Well
Infiltration practices must include an observation well to facilitate periodic inspection and maintenance. Design criteria must include an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface.

No Geotextile Fabric on Bottom
Avoid installing geotextile fabric along the bottom of infiltration practices. Experience has shown that geotextile fabric is prone to clogging. However, permeable geotextile fabric should be installed on the trench sides to prevent soil piping.

Direct Maintenance Access
Access must be provided to allow personnel and heavy equipment to perform atypical maintenance tasks, such as practice reconstruction or rehabilitation. While a turf cover is permissible for small-scale infiltration practices, the surface must never be covered by an impermeable material, such as asphalt or concrete.

Maintenance Inspections
Effective long-term operation of infiltration practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in Table 4.20. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 4.20. Typical maintenance activities for infiltration practices.

Schedule	Maintenance Activity
Quarterly	▪ Ensure that the CDA, inlets, and facility surface are clear of debris. ▪ Ensure that the CDA is stabilized. Perform spot-reseeding if where needed. ▪ Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ▪ Repair undercut and eroded areas at inflow and outflow structures.
Semi-annual inspection	▪ Check observation wells 3 days after a storm event in excess of 0.5 inch in depth. Standing water observed in the well after 3 days is a clear indication of clogging. ▪ Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
Annually	▪ Clean out accumulated sediment from the pretreatment cell.
As needed	▪ Replace pea gravel/topsoil and top surface geotextile fabric (when clogged). ▪ Mow vegetated filter strips as necessary and remove the clippings.

It is highly recommended that a qualified professional conduct annual site inspections for infiltration practices to ensure the practice performance and longevity of infiltration practices.

<local jurisdiction>'s maintenance inspection checklist for infiltration systems and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

<u>Waste Material</u>
Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.5.8 Infiltration Stormwater Compliance Calculations

Infiltration practices are credited with 100% retention for the storage volume (Sv) provided by the practice as well as 100% TSS, TN, and bacteria removal (Table 4.21).

Table 4.21. Retention and pollutant removal for infiltration practices.

Retention	= 100%
TSS Removal	= 100%
TN Removal	= 100%
Bacteria Removal	= 100%

The practice must be sized using the guidance detailed in Section 4.3.4 Infiltration Design Criteria.

Infiltration practices also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) from the total runoff volume for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate

peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

4.5.9 References

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4.6 Green Roofs

Green Roofs				
Definition: Practices that capture and store rainfall in an engineered growing media installed over a waterproof membrane that is designed to support plant growth on the roof of a building or other structure.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		100%	100%	100%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
High	Low	High		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	100% of *Sv*		
Semi-annually	As needed			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Reduces runoff volume and pollutant loads ▪ Energy savings: keep buildings cool, prolongs roof life ▪ Possible amenity space for public or users ▪ Sound absorption ▪ Life cycle costs comparable to traditional roof		▪ For retrofits, strengthening structure may be required ▪ If roof leaks occur, may be harder to trace ▪ Design and installation require specialized knowledge ▪ Typically applied on flat roofs (1%–2% pitch) ▪ Installation costs higher than for traditional roof		
Components		**Design considerations**		
▪ Vegetation that thrives in rooftop climate. ▪ Engineered planting medium (not soil). ▪ Containment (Modular systems - plant containers; Non-modular systems - barriers at roof perimeter/drainage structures). ▪ Drainage layer, sometimes with built-in water reservoirs. ▪ Water proofing layer or roof membrane with root repellant.		▪ Good waterproofing material and installation are essential. ▪ Materials used must be lightweight. ▪ Building structure must be able to support saturated weight. ▪ Roofs with moderate to flat slopes are most appropriate. Maximum roof slope of 30%.		
Maintenance Activities				
▪ Watering and fertilization until well-established ▪ Occasional weeding		▪ Inspection for proper drainage and plant health ▪ Ordinary life cycle roof replacement		

[1]*Credited pollutant load removal*

Green roofs are practices that capture and store rainfall in an engineered growing media that is designed to support plant growth (see Figure 4.20). A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites. Green roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Extensive green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2 - 25-year) although some intensive green roof systems may be designed to meet these criteria. Green roof designs should generally be combined with a separate facility to provide large storm controls.

Figure 4.20. Green roof (photo: Center for Watershed Protection, Inc.)

Definition

Practices that capture and store rainfall in an engineered growing media installed over a waterproof membrane that is designed to support plant growth on the roof of a building or other structure. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites. Green roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Plant species are selected so that the roof does not need supplemental irrigation and requires minimal, infrequent fertilization after vegetation is initially established.

Design variants include extensive and intensive green roofs.

G-1 Extensive green roofs have a much shallower growing media layer that typically ranges from 3 to 8 inches thick and are designed to have minimal maintenance requirements.

G-2 Intensive green roofs have a growing media layer that typically ranges from 8 to 48 inches thick.

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2 - 25-year) although some intensive green roof systems may be designed to meet these criteria. Most green roof designs shall generally be combined with a separate facility to provide large storm controls.

This specification is intended for situations where the primary design objective of the green roof is stormwater management and, unless specified otherwise, addresses the design of extensive roof systems. While rooftop practices such as urban agriculture may provide some retention, their primary design objective is not stormwater management and is not addressed in this specification.

4.6.1 Green Roof Feasibility Criteria

Green roofs are ideal for use on commercial, institutional, municipal, and multi-family residential buildings. They are particularly well-suited for use on ultra-urban development and redevelopment sites. Key constraints with green roofs include the following:

Structural Capacity of the Roof

When designing a green roof, designers must not only consider the stormwater storage capacity of the green roof but also its structural capacity to support the weight of the additional water. A conventional rooftop should typically be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive green roof. As a result, a structural engineer, architect, or other qualified professional should be involved with all green roof designs to ensure that the building has enough structural capacity to support a green roof. See Section 4.6.4 Green Roof Design Criteria for more information on structural design considerations.

Hurricane-Prone Areas

As South Carolina is subject to hurricanes, some may be concerned about the durability of green roofs in high winds. Having good vegetative cover and root growth in the growing media is the most effective way to reduce wind erosion of the media during high winds. New green roofs where the plants have not yet deeply rooted are the most susceptible to plant damage and media blow-off in a hurricane. Therefore, it is best to install a green roof three or more months prior to hurricane season, to allow enough time for the plants to be established.

Roof Pitch

Green roof storage volume is maximized on relatively flat roofs (a pitch of 1% to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Green roofs can be installed on rooftops with slopes up to 30% if baffles, grids, or strips are used to prevent slippage of the media. These baffles must be designed to ensure the roof provides adequate storage for the design storm. Slopes greater than 30% would be considered a green wall, which is not specifically identified as a stormwater BMP. Green walls can be used to receive cistern discharge (calculations are necessary to determine demand).

Roof Access

Adequate, permanent access to the roof must be available to deliver construction materials and perform routine maintenance. A temporary ladder is not sufficient for access to the roof. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane) and how the roof structure can accommodate material stockpiles and equipment loads. If material and equipment storage is required, rooftop storage areas must be identified and clearly marked based on structural load capacity of the roof.

Roof Type

Green roofs can be applied to most roof surfaces. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for green rooftops due to pollutant leaching through the media (Clark et al., 2008).

Setbacks

Green roofs should not be located near rooftop electrical and HVAC systems. A 2-foot-wide vegetation-free zone is recommended along the perimeter of the roof with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed for small or low green roof applications where parapets have been properly designed.

Contributing Drainage Area

It is recommended that the contributing drainage area (CDA) to a green roof be limited to the green roof itself. In cases where there will be additional CDA, the designer must provide sufficient design detail showing distribution of this additional runoff throughout the green roof area to prevent erosion or overloading of the roof growing media with the use of level spreaders, splash pads, perforated piping, or other flow dissipation techniques. The absolute maximum CDA to a green roof shall be no more than 100% larger than the area of the green roof (e.g., a 1,000-square-foot green roof can have no more than 1,000 square feet of additional impervious cover draining to it).

Local Building Codes

The green roof design must comply with the local building codes with respect to roof drains and emergency overflow devices. Additionally, a structural engineer should certify that the design complies with structural building codes. For green roofs installed on historic buildings or in historic districts, consult local building codes and architectural review criteria to determine if any special requirements exist for green roof design or maintenance.

Additionally, a State of South Carolina registered structural engineer must certify that the design complies with State building structural codes. This is true for new construction as well as retrofit projects.

Economic Considerations

Green roofs tend to be one of the most expensive BMPs on a per cubic foot captured basis. However, a green roof allows stormwater management to be achieved in otherwise unused space, a major benefit in space-constrained locations. Further, green roofs provide many other non-stormwater services with economic benefits, including increased insulation and roof life expectancy

4.6.2 Green Roof Conveyance Criteria

The green roof drainage layer (refer to Section 4.4.4 Green Roof Design Criteria) must convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. The green roof drainage layer must be adequate to convey the volume of stormwater equal to the flow capacity of the overflow or downspout system without backing water up onto the rooftop or into the green roof media. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging. However, an adequate number of roof drains that are not immediately adjacent to the growing media must be provided so as to allow the roof to drain without 3 inches of ponding above the growing media.

4.6.3 Green Roof Pretreatment Criteria

Pretreatment is not necessary for green roofs.

4.6.4 Green Roof Design Criteria

Structural Capacity of the Roof

Green roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer shall consult with a licensed structural engineer to ensure that the building will be able to support the additional live and dead structural load and to determine the maximum depth of the green roof system and any needed structural reinforcement. Typically, the green roof manufacturer can provide specific background specifications and information on their product for planning and design.

In most cases, fully saturated extensive green roofs have loads of about 15 to 30 pounds per square foot, which is fairly similar to traditional new rooftops (12 to 15 pounds per square foot) that have a waterproofing layer anchored with stone ballast. For a discussion of green roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E2397 / E2397M-15, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems (ASTM, 2015).

Functional Elements of a Green Roof System

A green roof is composed of up to nine different systems or layers that combine to protect the roof and maintain a vigorous cover (see Figure 4.21).

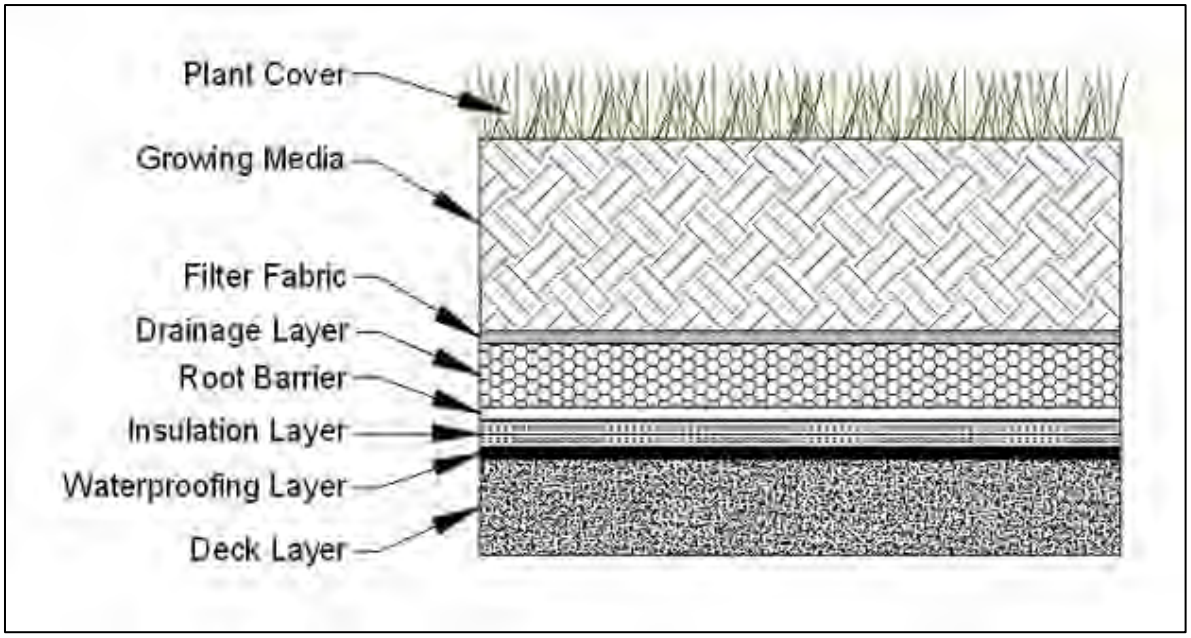

Figure 4.21. Green roof layers (note: the relative placement of various layers may vary depending on the type and design of the green roof system).

The design layers include the following:

Deck Layer. The roof deck layer is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity, and potential need for insulation in the green roof system.

Leak Detection System (optional). Leak detection systems are often installed above the deck layer to identify leaks, minimize leak damage through timely detection, and locate leak locations. Electric Field Vector Mapping (EFVM®) or other leak detection techniques are strongly recommended as part of the green roof installation process. In the case of EFVM, the deck material must be conductive. If it is not, an additional conductive medium may need to be added on top of the deck. Other leak detection systems may require additional materials between the deck layer and the waterproofing layer.

Waterproofing Layer. All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including hot applied rubberized asphalt, built up bitumen, modified bitumen, thermoplastic membranes, polyvinyl chloride (PVC), thermoplastic olefin membrane (TPO), and elastomeric membranes (EPDM) (see Weiler and Scholz-Barth, 2009, and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the green roof system. The waterproofing material may be loose laid or bonded (recommended). If loose laid, overlapping and additional construction techniques should be used to avoid water migration.

Insulation Layer. Many green rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems. The

designer should consider the use of open or closed cell insulation depending on whether the insulation layer is above or below the waterproofing layer (and thus exposed to wetness), with closed cell insulation recommended for use above the waterproofing layer.

Root Barrier. Another layer of a green roof system, which can be either above or below the insulation layer depending on the system, is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals, or other chemicals that could leach into stormwater runoff must be avoided in systems where the root barrier layer will come in contact with water or allow water to pass through the barrier.

Drainage Layer and Drainage System. A drainage layer is placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection and thickness of the drainage layer type is an important design decision that is governed by the desired stormwater storage capacity, the required conveyance capacity, and the structural capacity of the rooftop. The effective depth of the drainage layer is generally 0.25–1.5 inches thick for extensive green roof system and increases for intensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., 1–2-inch layer of clean, washed granular material (ASTM D448 size No. 8 stone or lightweight granular mix), high density polyethylene (HDPE)) that are capable of retaining water and providing efficient drainage (ASTM, 2017). A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders. ASTM E2396 and E2398 can be used to evaluate alternative material specifications (ASTM E2396, 2015 and ASTM E2398, 2015).

Root-Permeable Filter Fabric. A semi-permeable needled polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it. The filter fabric must not impede the downward migration of water into the drainage layer.

Growing Media. The next layer in an extensive green roof is the growing media, which is typically 3–8 inches deep. The recommended growing media for extensive green roofs is typically composed of approximately 70%–80% lightweight inorganic materials, such as expanded slates, shales or clays; pumice; scoria; or other similar materials. The media must contain no more than 30% organic matter, normally well-aged compost (see Appendix C Soil Compost Amendment Requirements). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. It is advisable to mix the media in a batch facility prior to delivery to the roof. Manufacturer's specifications should be followed for all proprietary roof systems. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

The composition of growing media for intensive green roofs may be different (although the organic material limit still applies), and it is often much greater in depth (e.g., 8–48 inches). If trees are included in the green roof planting plan, the growing media must be sufficient to provide enough soil volume for the root structure of mature trees.

Plant Cover. The top layer of an extensive green roof typically consists of plants that are slow-growing, shallow-rooted, perennial, and succulent. These plants are chosen for their ability to withstand harsh conditions at the roof surface. Guidance on selecting the appropriate green roof plants can often be provided by green roof manufacturers and can also be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually *Sedum* species) and accent plants can be used to

enhance the visual amenity value of a green roof. See Section 4.6.4 Green Roof Design Criteria for additional plant information. The design must provide for temporary, manual, and/or permanent irrigation or watering systems, depending on the green roof system and types of plants. For most applications, some type of watering system should be accessible for initial establishment or drought periods. The use of water efficient designs and/or use of non-potable sources are strongly encouraged.

Material Specifications

Standard specifications for North American green roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The ASTM has recently issued several overarching green roof standards, which are described and referenced in Table 4.22 below.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules.

Table 4.22. Extensive Green Roof Material Specifications

Material	Specification
Roof	Structural capacity must conform to ASTM E2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems*. In addition, use standard test methods ASTM E2398, *Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetated (Green) Roof Systems* and ASTM E2399, *Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems*.
Leak Detection System	Optional system to detect and locate leaks in the waterproof membrane.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	Depth of the drainage layer is generally 0.25–1.5 inches thick for extensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, HDPE, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders. Designers should consult the material specifications as outlined in ASTM E2396 and E2398. Roof drains and emergency overflow must be designed in accordance with the local construction codes.

Material	Specification
Filter Fabric	Generally, needle-punched, non-woven, polypropylene geotextile, with the following qualities: ▪ Strong enough and adequate puncture resistance to withstand stresses of installing other layers of the green roof. Density as per ASTM D3776 ≥ 8 oz/yd^2. Puncture resistance as per ASTM D4833 ≥ 130 lb. These values can be reduced with submission of a Product Data Sheet and other documentation that demonstrates applicability for the intended use. ▪ Adequate tensile strength and tear resistance for long-term performance. ▪ Allows a good flow of water to the drainage layer. Apparent Opening Size, as per ASTM D4751, of ≥ 0.06mm ≤ 0.2mm, with other values based on Product Data Sheet and other documentation as noted above. ▪ Allows at least fine roots to penetrate. ▪ Adequate resistance to soil borne chemicals or microbial growth both during construction and after completion since the fabric will be in contact with moisture and possibly fertilizer compounds.
Growth Media	70%–80% lightweight inorganic materials and a maximum of 30% organic matter (e.g., well-aged compost). Material makeup of the growing media must be provided. Media must provide sufficient nutrient and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396. An acceptable emerging industry practice combines the drainage layer with the growing media layer.
Plant Materials	*Sedum*, herbaceous plants, and perennial grasses that are shallow-rooted, low maintenance, and tolerant of full and direct sunlight, drought, wind, and frost. See ASTM E2400, *Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems*.

Solar Panels and Other Structures

Occasionally, structures such as solar panels or HVAC systems must be installed above a green roof. These structures can be incorporated into a green roof design with no adverse effects to the retention credit assigned to the green roof if specific design requirements for runoff disbursement, maintenance access, and sun/wind exposure are incorporated, including the following:

- Structures above the green roof must be no more than 6.5 feet wide.
- Structures must have a minimum 3-foot separation between them.
- The lower edge of the structure must be at least 1 foot above the top of the green roof, and the upper edge must be at least 2.5 feet above the top of the green roof. This allows for at least a 15-degree tilt. For flatter installations, the lower edge would need to be raised to ensure that the 2.5-foot minimum for the upper edge is met.

These design requirements are illustrated in Figure 4.22**.**

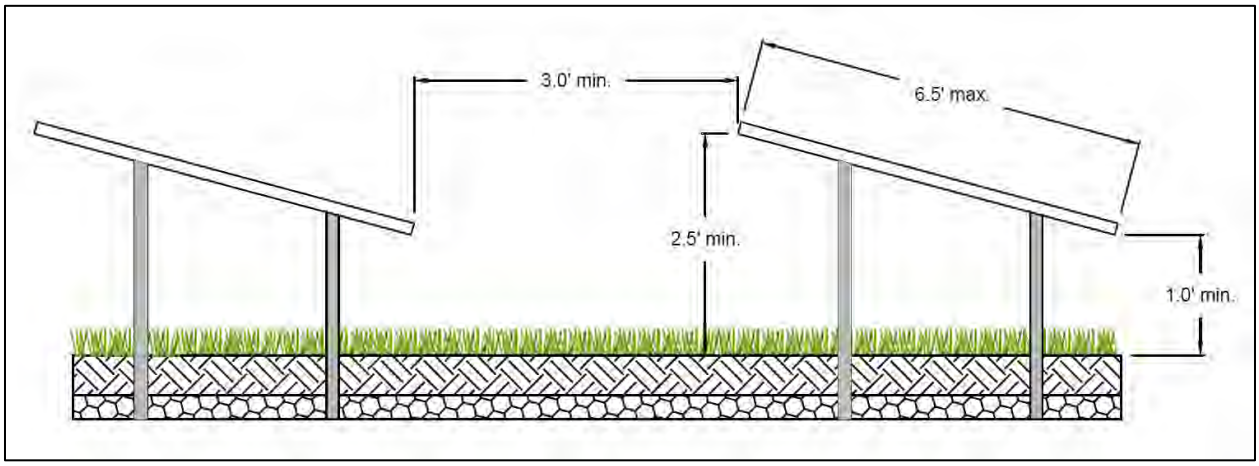

Figure 4.22. Design requirements for structures constructed above green roofs.

Green Roof Sizing

Green roof areas can be designed to capture the entire Stormwater Retention Volume (SWRv). In some cases, they could be designed to capture larger design storm volumes as well. The required size of a green roof will depend on several factors, including maximum water retention of the growing media and the underlying drainage and storage layer materials, if present (e.g., prefabricated water cups or plastic modules). As maximum water retention can vary significantly between green roof products, verification of this value must be included with the Stormwater Management Plan (SWMP). Verification shall be provided by an ASTM-certified lab using the methods described by ASTM tests E2396, E2397, E2398, or E2399, as appropriate. In the absence of laboratory test results, the baseline default values must be used. Equation 4.12 below shall be used to determine the storage volume retained by a green roof.

Equation 4.12. Storage Volume for Green Roofs

$$\mathrm{Sv} = \frac{\mathrm{SA} \times [(\mathrm{d} \times \mathrm{MWR}_1) + (\mathrm{DL} \times \mathrm{MWR}_2)]}{12} \times \mathrm{IF}$$

Where:

Sv	=	green roof storage volume (ft^3)
SA	=	green roof area (ft^2)
d	=	media depth (in.) (minimum 3 in.)
MWR_1	=	verified media maximum water retention (use 0.10 as a baseline default in the absence of verification data)
DL	=	drainage layer depth (in.) (if the drainage layer is combined with the media layer, then this value is 0)
MWR_2	=	verified drainage layer maximum water retention (use 0.0 as a baseline default in the absence of verification data)
IF	=	irrigation factor (0.5 for irrigated green roofs, 1.0 for unirrigated green roofs)

The appropriate Sv can then be compared to the required SWRv for the entire rooftop area (including all conventional roof areas) to determine the portion of the design storm captured.

Green roofs can have dramatic rate attenuation effects on larger storm events and may be used, in part, to manage a portion of the 2- to 25-year events. Designers can model various approaches by factoring in storage within the drainage layer. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

4.6.5 Green Roof Landscaping Criteria

Plant selection, landscaping, and maintenance are critical to the performance and function of green roofs. Therefore, a landscaping plan shall be provided for green roofs.

A planting plan must be prepared for a green roof by a landscape architect, botanist, or other professional experienced with green roofs and submitted with the SWMP.

Plant selection for green roofs is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most green roof installations is a hardy, low-growing succulent, such as *Sedum*, *Delosperma*, *Talinum*, *Semperivum*, or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

A list of some common green roof plant species that work well in the can South Lowcountry region be found in Table 4.23 below.

Table 4.23. Ground Covers Appropriate for Green Roofs in the State of South Carolina

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self-sows

Note: Designers should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for a definitive list of green roof plants, including accent plants.

- Plant choices can be much more diverse for deeper intensive green roof systems. Herbs, forbs, grasses, shrubs, and even trees can be used, but designers should understand they may have higher watering, weeding, and landscape maintenance requirements.
- The species and layout of the planting plan must reflect the location of the building, in terms of its height, exposure to wind, heat stress, orientation to the sun, and impacts from surrounding buildings. Wind scour and solar burning have been observed on green roof installations that failed to adequately account for neighboring building heights and surrounding window reflectivity. In addition, plants must be selected that are fire resistant and able to withstand heat, cold, and high winds.
- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on green roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most green roof plant species will not be native to the Chesapeake Bay watershed (which contrasts with native plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of green roof plant nurseries in the region, it may be necessary for designers to order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract grown.
- Plants can be established using cuttings, plugs, mats, and, more rarely, containers. Several vendors also sell mats, rolls, or proprietary green roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006). To achieve 50% coverage after 1 year and 80% coverage after 2 years, the recommended minimum spacing for succulent plantings is 2 plugs per square foot and 10 pounds per 100 square feet.
- When planting cuttings, plugs, and mats, the planting window extends from the spring to early fall; although, it is important to allow plants to root thoroughly before the first killing frost. Green roof manufacturers and plant suppliers may provide guidance on planting windows as well as winter care. Proper planting and care may also be required for plant warranty eligibility.
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except for temporary irrigation during drought or initial establishment. The use of water-efficient designs and/or use of non-potable sources is strongly encouraged. Permanent irrigation of extensive roof designs is prohibited. For intensive roofs, permanent irrigation may be included. However, permanent irrigation can adversely impact the rainfall retention capacity of the green roof. For this reason, soil moisture monitors are a required part of the irrigation system for all irrigated green roofs, and the calculated storage volume for green roofs with permanent irrigation must be reduced by 50%.
- The goal for green roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining (not requiring fertilizer inputs) and requires minimal mowing, trimming, and weeding.

The green roof design should include non-vegetated walkways (e.g., paver blocks) to allow for easy access to the roof for weeding and making spot repairs (see Section 4.6.4 Green Roof Design Criteria).

4.6.6 Green Roof Construction Sequence

Green Roof Installation

Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct electric field vector mapping (EVFM®) or flood testing to ensure the system is watertight. Where possible, EVFM® is strongly recommended over the flood test, but not all impermeable membranes and deck systems are compatible with this method. Problems have been noted with the use of EFVM on black ethylene propylene diene terpolymer (EPDM) and with aluminized protective coatings commonly used in conjunction with modified bituminous membranes. If EVFM® or other leak detection systems are not possible, a flood test should be performed instead. The flood test is done by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) per the manufacturer's specifications, taking care not to damage the waterproofing. Any damage occurring must be reported immediately. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media must be spread evenly over the filter fabric surface as required by the manufacturer. If a delay between the installation of the growing media and the plants is required, adequate efforts must be taken to secure the growing media from erosion and the seeding of weeds. The growing media must be covered and anchored in place until planting. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction beyond manufacturer's recommendations.
- The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan or in accordance with ASTM E2400 (2015). Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 2 to 3 growing seasons to fully establish the vegetated roof. The growing medium should contain enough organic matter to support plants for the first growing season, so initial fertilization is not required. Extensive green roofs may require supplemental irrigation during the first few months of establishment. Hand weeding is also critical in the first 2 years (see Table 10.1 of Weiler & Scholz-Barth (2009) for a photo guide of common rooftop weeds).
- Most construction contracts should contain a care and replacement warranty that specifies at least 50% coverage after 1 year and 80% coverage after 2 years for plugs and cuttings, and 90% coverage after 1 year for *Sedum* carpet/tile.

Construction Supervision

Supervision during construction is recommended to ensure that the vegetated roof is built in accordance with these specifications. Inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision/inspection is needed throughout the installation of a vegetated roof, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight.
- During placement of the drainage layer and drainage system.
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth (certification for vendor or source should be provided).
- Upon installation of plants, to ensure they conform to the planting plan (certification from vendor or source should be provided).
- Before issuing use and occupancy approvals.
- At the end of the first or second growing season to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

Construction phase inspection checklist for green roof practices can be found in Appendix E Construction Inspection Checklists.

4.6.7 Green Roof Maintenance Criteria

Maintenance Inspections

A green roof should be inspected by a qualified professional twice a year during the growing season to assess vegetative cover and to look for leaks, drainage problems, and any rooftop structural concerns (see Table 4.24). In addition, the green roof should be hand weeded to remove invasive or volunteer plants, and plants and/or media should be added to repair bare areas (refer to ASTM E2400; ASTM, 2015).

If a roof leak is suspected, it is advisable to perform an electric leak survey (e.g., EVFM®), if applicable, to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of some waterproofing membranes. Check with the membrane manufacturer for approval and warranty information. Also, power washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the green roof plant communities.

Fertilization is generally not recommended due to the potential for leaching of nutrients from the green roof. Supplemental fertilization may be required following the first growing season, but only if plants show signs of nutrient deficiencies and a media test indicates a specific deficiency. Addressing this issue with the holder of the vegetation warranty is recommended. If fertilizer is to be applied, it must be a slow-release type, rather than liquid or gaseous form.

Maintenance inspection checklist for green roofs and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Table 4.24. Typical Maintenance Activities Associated with Green Roofs

Schedule (following construction)	**Activity**
As needed or As required by manufacturer	▪ Water to promote plant growth and survival. ▪ Inspect the green roof and replace any dead or dying vegetation.
Semi-annually	▪ Inspect the waterproof membrane for leaks and cracks. ▪ Weed to remove invasive plants and tree seedlings (do not dig or use pointed tools where there is potential to harm the root barrier or waterproof membrane). ▪ Inspect roof drains, scuppers, and gutters to ensure they are not overgrown and have not accumulated organic matter deposits. Remove any accumulated organic matter or debris. ▪ Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.

Waste Material

Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.6.8 Green Roof Stormwater Compliance Calculations

Green roofs are credited with 100% retention for the storage volume (Sv) provided by the practice as well as 100% TSS, TN, and bacteria removal (see Table 4.25).

Table 4.25. Retention and pollutant removal of green roofs.

Retention	= 100%
TSS Removal	= 100%
TN Removal	= 100%
Bacteria Removal	= 100%

The practice must be designed using the guidance detailed in Section 4.4.4 Green Roof Design Criteria.

Green roofs also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) from the total runoff volume for the design storms. The resulting reduced runoff volumes can then be used to calculate a reduced Natural Resource Conservation Service (NRCS) curve number (CN) for the site or site drainage area (SDA). The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

4.6.9 References

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4.7 Rainwater Harvesting

Rainwater Harvesting				
Definition: Rainwater harvesting systems store rainfall and release it for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground tank (also referred to as a cistern) or settling pond, where it is stored for non-potable uses.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		Varies*	Varies*	Varies*
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
Low to Moderate	Moderate	Varies*		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	100% of Available Storage Volume		
Quarterly	Every 3 years			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Reduces runoff rates and volume ▪ Can provide for/supplement irrigation needs		▪ Stored water must be used on regular basis to maintain capacity ▪ Stagnant water can breed mosquitos		
Components		**Design considerations**		
▪ Pretreatment ▪ Conveyance ▪ First flush diverter ▪ Cistern (storage tank) ▪ Overflow ▪ Low water cutoff		▪ Plumbing codes (for indoor tanks) ▪ Size based on CDA, local rainfall patterns, and projected harvest rainwater demand ▪ Location and elevation of cistern ▪ Tank manufacturer's specifications ▪ Irrigation system and application rates		
Maintenance Activities				
▪ Inspect/clean pretreatment devices and first flush diverts ▪ Clear gutter/downspouts		▪ Inspect and clean storage tank ▪ Maintenance log required		

[1]*Credited pollutant load removal*

**Varies according to rainwater harvesting storage capacity and demand*

Rainwater harvesting systems store rainfall for future, non-potable water uses and on-site stormwater disposal/infiltration. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g. increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, supply of water post storm/hurricane in case of failed municipal infrastructure etc.).

Definition

Rainwater harvesting systems store rainfall and release it for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground tank (also referred to as a cistern) or settling pond where it is stored for non-potable uses or for on-site disposal or infiltration as stormwater. Cisterns can be sized for commercial as well as residential purposes (see Figure 4.23). Residential cisterns are commonly called rain barrels.

Figure 4.23. Example cistern application (photo: Marty Morganello).

The design includes the following:

R-1 Rainwater harvesting for non-potable uses

Non-potable uses of harvested rainwater may include the following:

- Landscape irrigation,
- Exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, and fire trucks),
- Flushing of toilets and urinals,
- Fire suppression (e.g., sprinkler systems),
- Supply for cooling towers, evaporative coolers, fluid coolers, and chillers,
- Supplemental water for closed loop systems and steam boilers,
- Replenishment of water features and water fountains,
- Distribution to a green wall or living wall system, and
- Laundry.

Rainwater stored in a settling pond may only be used for landscape irrigation. Pond design criteria in Section 4.10 and landscaping criteria of Section 4.5.5 shall be followed.

The seven primary components of an enclosed rainwater harvesting system are discussed in detail in Section 4.5.4 Rainwater Harvesting Design Criteria. Some are depicted in Figure 4. 25 . The components include the following:

- CDA surface,
- Collection and conveyance system (e.g., gutter and downspouts; number 1 in Figure 4.24)
- Pretreatment, including prescreening and first flush diverters (number 2 in Figure 4.24)
- Cistern (no number, but depicted in Figure 4.24)
- Water quality treatment (as required by Appendix J Rainwater Harvesting Treatment and Management Requirements)
- Distribution system
- Overflow, filter path, or secondary stormwater retention practice (number 8 in Figure 4.24)

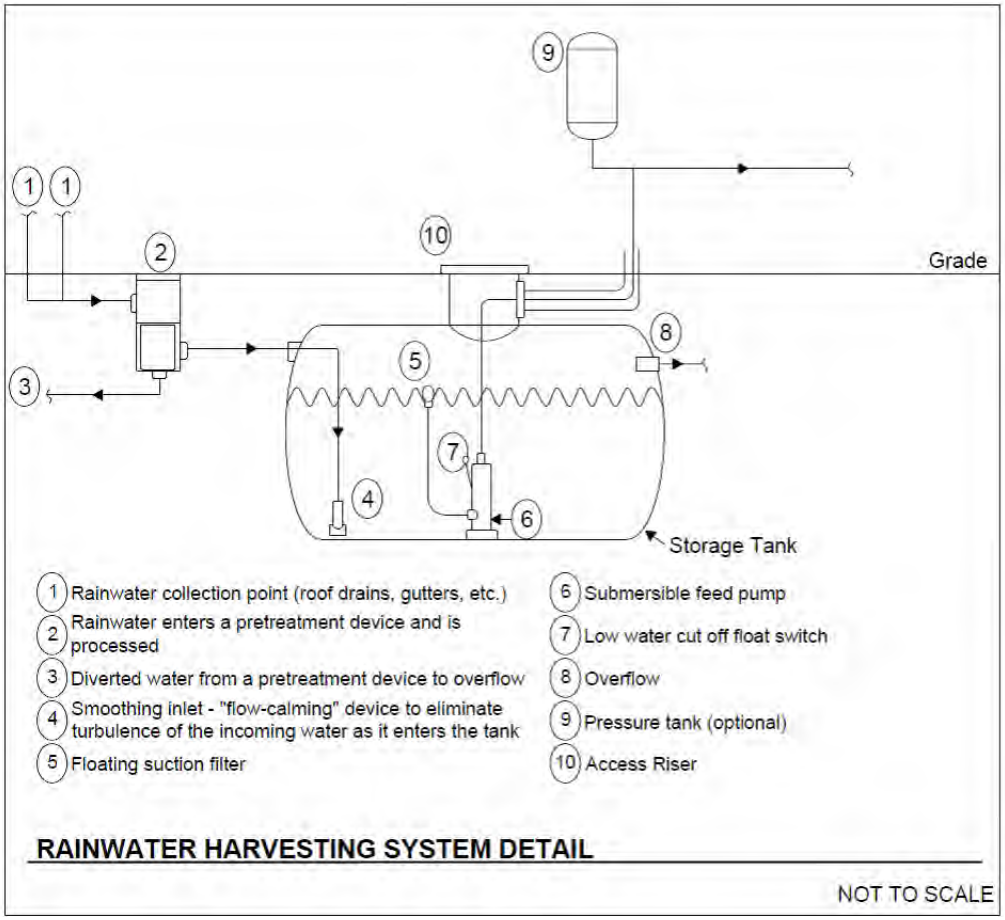

Figure 4.24. Example of a rainwater harvesting system detail.

4.7.1 Rainwater Harvesting Feasibility Criteria

Several site-specific features influence how rainwater harvesting systems are designed and/or utilized. The following are key considerations for rainwater harvesting feasibility. They are not comprehensive or conclusive; rather, they are recommendations to consider during the planning process to incorporate rainwater harvesting systems into the site design.

Plumbing Code

Designers and plan reviewers should consult with local construction codes to determine the allowable indoor uses and required treatment for harvested rainwater. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should refer to the 2012 Uniform Plumbing Code - Chapter 17 Non-potable Rainwater Catchment Systems, or local plumbing codes, as applicable.

Mechanical, Electrical, Plumbing

For systems that call for indoor use of harvested rainwater, the seal of a mechanical, electrical, and plumbing engineer is required.

Water Use

When rainwater harvesting will be used, the requirements in Appendix J Rainwater Harvesting Treatment and Management Requirements must be followed. This will outline the design assumptions and provide water quality end use standards.

Available Space
Adequate space is needed to house the cistern and any overflow. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Cisterns can be placed underground, indoors, adjacent to buildings, and on rooftops that are structurally designed to support the added weight. Designers can work with architects and landscape architects to creatively site the cisterns. Underground utilities or other obstructions should always be identified prior to final determination of the cistern location.

Site Topography
Site topography and cistern location should be considered as they relate to every inlet and outlet invert elevation in the rainwater harvesting system.

The final invert of the cistern outlet pipe at the discharge point must match the invert of the receiving mechanism (e.g., natural channel, storm drain system) and be sufficiently sloped to adequately convey this overflow. The elevation drops associated with the various components of a rainwater harvesting system and the resulting invert elevations should be considered early in the design, to ensure that the rainwater harvesting system is feasible for the particular site.

Site topography and cistern location will also affect pumping requirements. Locating cisterns in low areas will make it easier to get water into the cisterns; however, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing cisterns at higher elevations may require larger diameter pipes with smaller slopes but will generally reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building or SDA, to limit the amount of pipe needed.

Available Hydraulic Head
The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern may be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building, which then serves the internal water demands. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure.

Water Table
Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that does not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from floating) and conducting buoyancy calculations when the tank is empty. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The combined weight of the tank and hold-down ballast must meet or exceed the buoyancy force of the cistern. The cistern must also be installed according to the cistern manufacturer’s specifications.

Soils
Cisterns should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could

cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete foundation, may be appropriate depending on the soils and cistern characteristics. Where the installation requires a foundation, the foundation must be designed to support the cistern's weight when the cistern is full, consistent with the bearing capacity of the soil and good engineering practice. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities

All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems, treating all of the rainwater harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground cisterns and piping associated with the system.

Contributing Drainage Area

The CDA to the cistern is the area draining to the cistern. Rooftop surfaces are what typically make up the CDA, but paved areas can be used with appropriate treatment (oil/water separators and/or debris excluders).

Contributing Drainage Area Material

The quality of the harvested rainwater will vary according to the roof material or CDA over which it flows. Water harvested from certain types of rooftops and CDAs, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal, or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such surfaces should be avoided. If harvesting from a sealed or painted roof surface is desired, it is recommended that the sealant or paint be certified for such purposes to the NSF International NSF Protocol P151 standard.

Water Quality of Rainwater

Designers should also note that the pH of rainfall in the State tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from roof surfaces, cistern lining, or water laterals, to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Limestone or other materials may be added in the cistern to buffer acidity, if desired.

Pollutant Hotspot Land Uses

Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from its mixing with ground-level runoff from a stormwater hotspot operation.

Setbacks from Buildings

Cistern overflow devices must be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. While most systems are generally sited underground and more than 10 feet laterally from the building foundation wall, some cisterns are incorporated into the basement of a building or underground parking areas. In any case, cisterns must be designed to be watertight to prevent water damage when placed near building foundations.

Vehicle Loading

Whenever possible, underground rainwater harvesting systems should be placed in areas without vehicle traffic or other heavy loading, such as deep earth fill. If site constraints dictate otherwise, systems must be designed to support the loads to which they will be subjected.

Feasibility
Rainwater harvesting systems are very well suited to the warm environment of South Carolina and may help to relieve some of the pressure on drinking water aquifers, if applied on a wide scale. In areas with a high-water table, above ground installations will often be more appropriate.

Economic Considerations
Rainwater harvesting systems can provide cost savings by replacing or augmenting municipal water supply needs.

4.7.2 Rainwater Harvesting Conveyance Criteria

Collection and Conveyance
The collection and conveyance systems consist of the gutters, downspouts, and pipes that channel rainfall into cisterns. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system.

Pipes, which connect downspouts to the cistern, should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Overflow
An overflow mechanism must be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the cistern. The overflow pipe(s) must have a capacity greater than or equal to the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe(s) must be screened to prevent access to the cistern by small mammals and birds and must include a backflow preventer if it connects directly to the combined sewer or storm sewer. All overflow from the system must be directed to an acceptable flow path that will not cause erosion during a 2-year storm event.

4.7.3 Rainwater Harvesting Pretreatment Criteria

Prefiltration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for prefiltration of small systems, although direct water filtration is preferred. The purpose of prefiltration is to significantly cut down on maintenance by preventing organic buildup in the cistern, thereby decreasing microbial food sources.

Various pretreatment devices are described below. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the cistern. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the cistern at all. A design intensity of 1 inch per hour (for design storm = SWRv) must be used for the purposes of sizing pre-cistern conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004). If the system will be used for channel and flood protection, the 2- to 25-year storm intensities must be used for the design of the conveyance and pretreatment portion of the system. The Appendix K Rainwater Harvesting Storage Volume Calculator, discussed in Section 4.5.4 Rainwater Harvesting Design Criteria, allows for input of variable filter efficiency rates for the

design storm. To meet the requirements to manage the 2- to 25-year storms, a minimum filter efficiency of 90% must be met.

- **First Flush Diverters.** First flush diverters (see Figure 4.25) direct the initial pulse of rainfall away from the cistern. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces.
- **Leaf Screens.** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the cisterns. Built-up debris can also harbor bacterial growth within gutters or downspouts (Texas Water Development Board, 2005).
- **Roof Washers.** Roof washers are placed just ahead of cisterns and are used to filter small debris from harvested rainwater (see Figure 4.26). Roof washers consist of a cistern, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30 microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.
- **Hydrodynamic Separator.** For large-scale applications, hydrodynamic separators and other devices can be used to filter rainwater from larger CDAs.

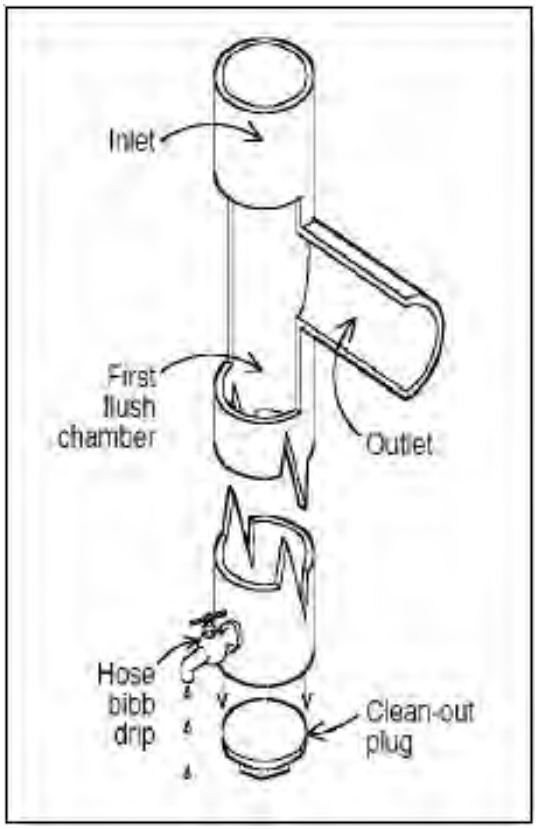

Figure 4.25. Diagram of a first flush diverter (photo: Texas Water Development Board, 2005).

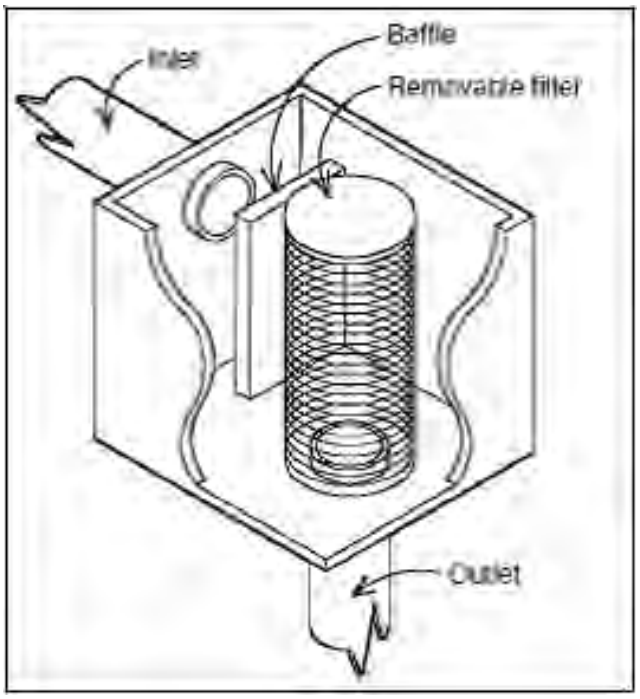

Figure 4.26. Diagram of a roof washer (photo: Texas Water Development Board, 2005).

4.7.4 Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system require special considerations:

- CDA or CDA surface
- Collection and conveyance system (i.e., gutter and downspouts)
- Cisterns (Storage Tank)
- Pretreatment, including prescreening and first flush diverters
- Water quality treatment (as described in Appendix J Rainwater Harvesting Treatment and Management Requirements)
- Distribution systems
- Overflow, filter path, or secondary stormwater retention practice

The system components are discussed below:

CDA Surface

When considering CDA surfaces, smooth, non-porous materials will drain more efficiently. Slow drainage of the CDA leads to poor rinsing and a prolonged first flush, which can decrease water quality.

Rainwater can also be harvested from other impervious surfaces, such as parking lots and driveways; however, this practice requires more extensive pretreatment and treatment prior to use.

Collection and Conveyance System
See Section 4.7.2 Rainwater Harvesting Conveyance Criteria.

Pretreatment
See Section 4.7.3 Rainwater Harvesting Pretreatment Criteria.

Cisterns (Storage Tank)
Also known as the storage tank, the cistern is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities generally range from 250 to 30,000 gallons, but they can be as large as 100,000 gallons or more for larger projects. Multiple cisterns can be placed adjacent to each other and connected with pipes to balance water levels and to tailor the storage volume needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Cistern volumes are calculated to meet the water demand and stormwater storage volume retention objectives, as described further below in this specification.

While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the cisterns can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the cisterns will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site. The following factors should be considered when designing a rainwater harvesting system and selecting a cistern:

- Aboveground cisterns should be ultraviolet and impact resistant.
- Underground cisterns must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic).
- Underground rainwater harvesting systems must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. The access opening must be installed in such a way as to prevent surface- or groundwater from entering through the top of any fittings, and it must be secured/locked to prevent unwanted entry. Confined space safety precautions/requirements should be observed during cleaning, inspection, and maintenance.
- All rainwater harvesting systems must be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. Table 4. 26 compares the advantages and disadvantages of different cistern materials.
- Cisterns must be opaque or otherwise protected from direct sunlight to inhibit growth of algae, and they must be screened to discourage mosquito breeding.
- Dead storage below the outlet to the distribution system and an air gap at the top of the cistern must be included in the total cistern volume. For gravity-fed systems, a minimum of 6 inches of dead storage must be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

Table 4.26. Advantages and Disadvantages of Typical Cistern Materials

Cistern Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below-ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of watertight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20–50 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable, and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast-in-Place Concrete	Durable, immoveable, and versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or Concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009

- **Water Quality Treatment**
  Depending upon the collection surface, method of dispersal, and proposed use for the harvested rainwater, a water quality treatment device may be required. Treatment requirements are described in Appendix J Rainwater Harvesting Treatment and Management Requirements.

- **Distribution Systems**
  Most distribution systems require a pump to convey harvested rainwater from the cistern to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary stormwater treatment practice. The rainwater harvesting system should be equipped with an appropriately sized pump that produces sufficient pressure for all end-uses.

The typical pump and pressure tank arrangement consists of a multi-stage, centrifugal pump, which draws water out of the cistern and sends it into the pressure tank, where it is stored for distribution. Some systems will not require this two-tank arrangement (e.g., low-pressure and gravel systems). When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

A drain plug or cleanout sump must be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter if winter use is planned.

- **Overflow**
  See Section 4.7.2 Rainwater Harvesting Conveyance Criteria.

Rainwater Harvesting Material Specifications

The basic material specifications for rainwater harvesting systems are presented in Table 4.27. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated cisterns and other system components.

Table 4.27. Design Specifications for Rainwater Harvesting Systems

Item	Specification
Gutters and Downspouts	Materials commonly used for gutters and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum, and galvanized steel. Lead must not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. ▪ The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the cisterns. ▪ Include needed bends and tees.
Pretreatment	At least one of the following (all rainwater to pass through pretreatment): ▪ First flush diverter ▪ Hydrodynamic separator ▪ Roof washer ▪ Leaf and mosquito screen (1 mm mesh size)
Cisterns	▪ Materials used to construct cisterns must be structurally sound. ▪ Cisterns should be constructed in areas of the site where soils can support the load associated with stored water. ▪ Cisterns must be watertight and sealed using a water-safe, non-toxic substance. ▪ Cisterns must be opaque or otherwise shielded to prevent the growth of algae. ▪ The size of the rainwater harvesting system(s) is determined through design calculations.

Note: This table does not address indoor systems or pumps.

Design Objectives and System Configuration

Rainwater harvesting systems can have many design variations that meet user demand and stormwater objectives. This specification provides a design framework to achieve the SWRv objectives that are required to comply with the regulations, and it adheres to the following concepts:

- Give preference to use of rainwater as a resource to meet on-site demand or in conjunction with other stormwater retention practices.
- Reduce peak flow by achieving volume reduction and temporary storage of runoff.

Based on these concepts, this specification focuses on system design configurations that harvest rainwater for internal building uses, seasonal irrigation, and other activities, such as cooling tower use and vehicle washing. While harvested rainwater will be in year-round demand for many internal building uses, some other uses will have varied demand depending on the time of year (e.g., cooling towers and seasonal irrigation). Thus, a lower retention volume is assigned to a type of use that has reduced demand.

Design Objectives & Cistern Design Set-Ups

Prefabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. Three basic cistern designs meet the various rainwater harvesting system configurations in this section.

Cistern Design 1. The first cistern set-up (Figure 4.27) maximizes the available storage volume to meet the desired level of stormwater retention. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the cistern as the only gravity release outlet device (not including the pump, manway, or inlets). It should be noted that it is possible to address 2- to 25-year storm volumes with this cistern configuration, but the primary purpose is to address the smaller SWRv design storm.

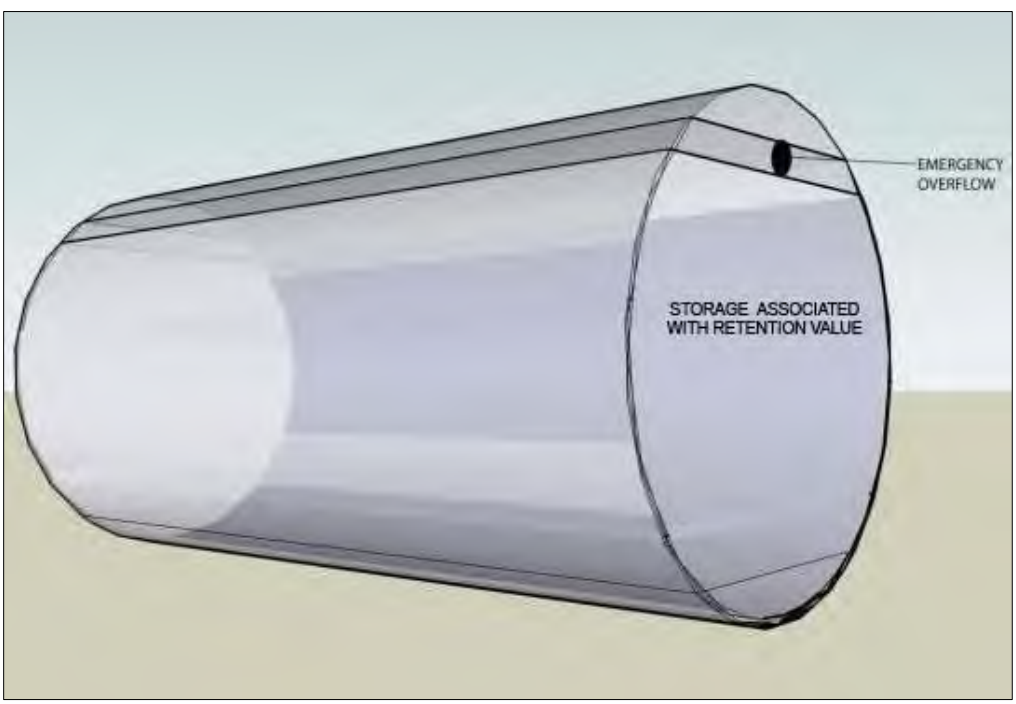

Figure 4.27. Cistern Design 1: Storage associated with the design storm volume only.

Cistern Design 2. The second cistern set-up (Figure 4.28) uses cistern storage to meet the SWRv retention objectives and also uses additional detention volume to meet some or all of the 2- to 25-year storm volume requirements. An orifice outlet is provided at the top of the design storage for the SWRv level, and an emergency overflow is located at the top of the detention volume level.

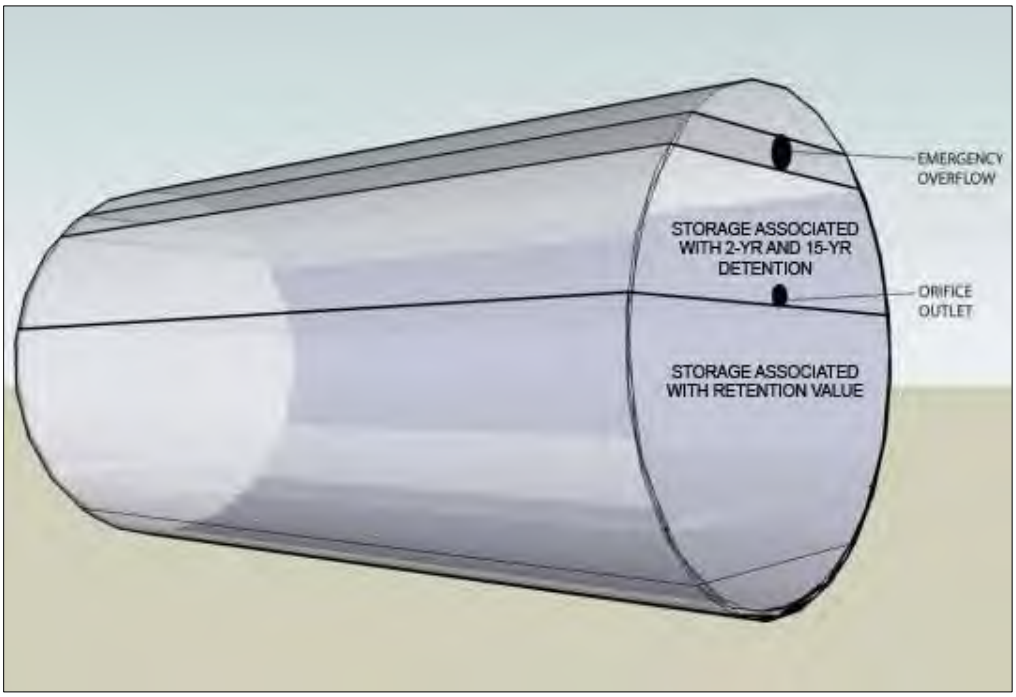

Figure 4.28. Cistern Design 2: Storage associated with design storm, channel protection, and flood volume.

Cistern Design 3. The third cistern set-up (Figure 4.29) creates a constant drawdown within the system. The small orifice at the bottom of the cistern needs to be routed to an appropriately designed secondary practice (i.e., bioretention, stormwater infiltration) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release must not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

While a small orifice is shown at the bottom of the cistern in Figure 4.29, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

For this design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the storage volume calculated in the General Retention Compliance Calculator in Appendix H. In other words, the storage volume associated with the secondary practice must not be included as a separate BMP because the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown.

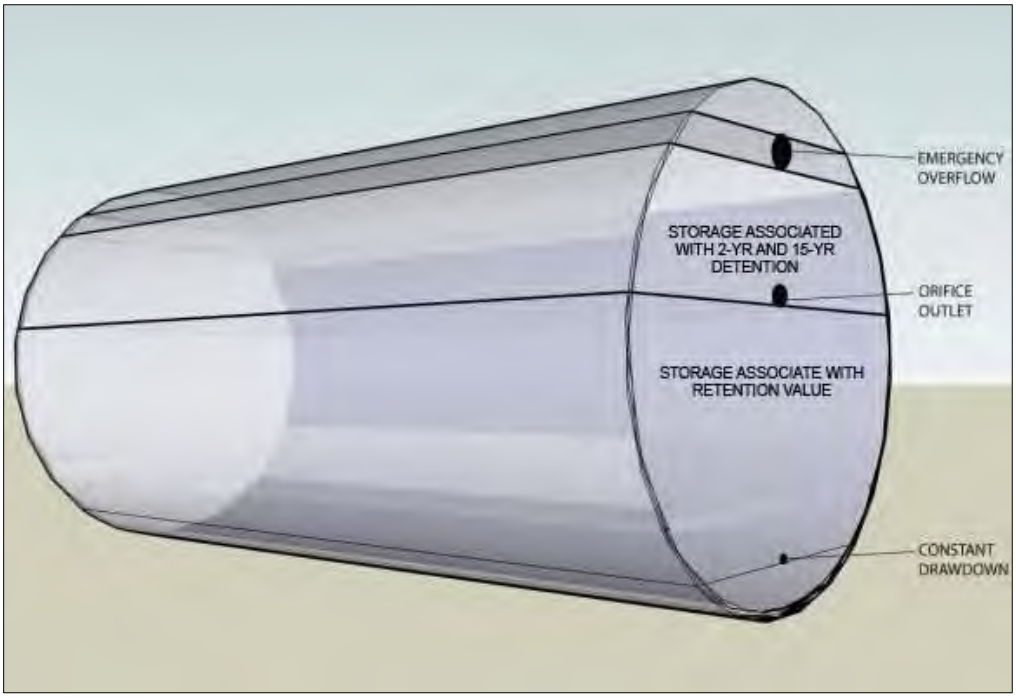

Figure 4.29. Cistern Design 3: Constant drawdown version where storage is associated with design storm, channel protection, and flood volume.

Sizing of Rainwater Harvesting Systems

The rainwater harvesting cistern sizing criteria presented in this section were developed using a spreadsheet model that used best estimates of indoor and outdoor water demand, long-term rainfall data, and CDA capture area data (Forasté 2011). The Rainwater Harvesting Storage Volume Calculator in Appendix J1 is used for cistern sizing guidance and to quantify the available storage volume achieved. This storage volume value is required for input into the General Retention Compliance Calculator and is part of the submission of a SWMP using rainwater harvesting systems for compliance. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource.

Rainwater Harvesting Storage Volume Calculator

The design specification provided in this section is follows the Rainwater Harvesting Storage Volume Calculator Appendix J1. The spreadsheet uses daily rainfall data from January 1, 2007 to December 31, 2019 to model performance parameters of the cistern under varying CDAs, demands on the system and cistern size.

The size of ponds used for irrigation, their irrigation area and characteristics of soil and land use can be entered in the calculator to determine stormwater volume retained. The runoff that reaches the cistern each day is added to the water level that existed in the cistern the previous day, with all of the total demands subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the cistern runs dry (reaches the cut-off volume level), then the volume in the cistern is fixed at the low level. A summary of the water balance for the system is provided below.

Incremental Design Volumes within Cistern

Rainwater cistern sizing is determined by accounting for varying precipitation levels, captured CDA runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for the design storm (permanent storage), storage needed for 2- to 25-year volume (temporary detention storage), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See Figure 4. 30 for a graphical representation of these various incremental design volumes.

The design specification described in this section does not provide guidance for sizing larger storms, but rather provides guidance on sizing for the 85th and 95th percentile design storms.

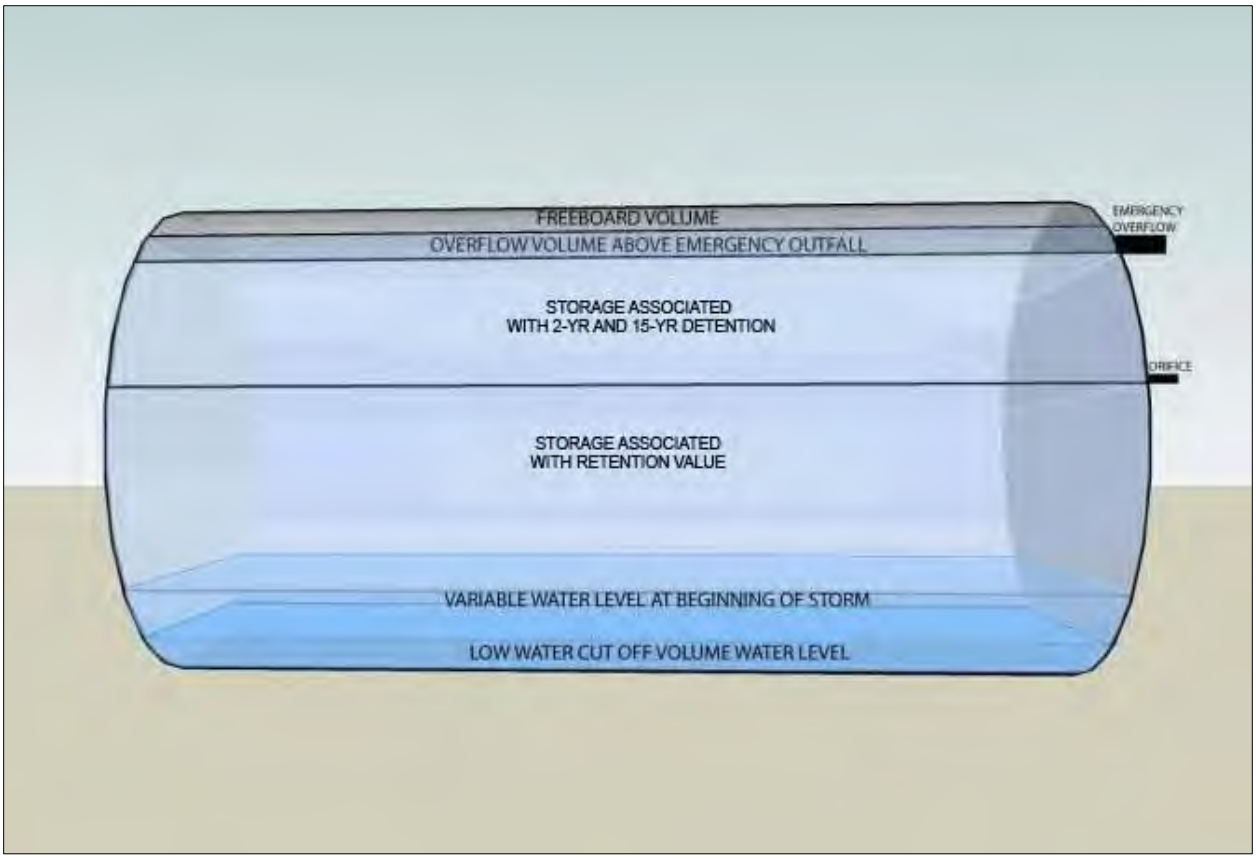

Figure 4.30. Incremental design volumes associated with cistern sizing.

The "Average Available Storage Volume" is the average storage within the cistern that is modeled and available to retain rainfall. While the SWRv will remain the same for a specific CDA, the "Average Available Storage Volume" is dependent on demand and cistern volume. It is the available space in the cistern between the average level at the beginning of a storm and the orifice outflow.

Water Contribution

- **Precipitation**
  The volume of water contributing to the rainwater harvesting system is a function of the rainfall and CDA, as defined by the designer.
- **Municipal Backup (optional)**
  In some cases, the designer may choose to install a municipal backup water supply to supplement cistern levels. Note that municipal backups may also be connected post-cistern (i.e., a connection is made to the non-potable water line that is used for pumping water from the cistern for reuse), thereby not contributing any additional volume to the cistern. Municipal backup designs that supply water directly to the cistern are not accounted for in the Rainwater Harvesting Storage Volume Calculator.

Water Losses

- **Contributing Drainage Area Runoff Coefficient**
  The CDA is assumed to convey 95% of the rainfall that lands on its surface (i.e., $Rv = 0.95$).
- **First Flush Diversion**
  The first 0.02 to 0.06 inches of rainfall that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is assumed to be contained within the filter efficiency rate.
- **Filter Efficiency**
  It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the design storm will be captured successfully. For the 85th or 95th percentile storms, a minimum of 95% of the runoff should be conveyed into the cistern. The minimum values are included as the filter efficiencies in the Rainwater Harvesting Storage Volume Calculator, although they can be altered (increased) if appropriate. The Rainwater Harvesting Storage Volume Calculator applies these filter efficiencies, or interpolated values, to the daily rainfall record to determine the volume of runoff that reaches the cistern. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1 inch per hour shall be used when the design storm is the SWRv. The appropriate rainfall intensity values for the 2- to 25-year storms shall be used when designing for larger storm events.
- **Drawdown (Storage Volume)**
  This is the stored water within the cistern that is reused or directed to a secondary stormwater practice. It is the volume of runoff that is reduced from the CDA. This is the water loss that translates into the achievable storage volume retention.

Overflow

For the purposes of addressing the SWRv (not for addressing larger storm volumes), orifice outlets for both detention and emergency overflows are treated the same. This is the volume of water that may be lost during large storm events or successive precipitation events.

Storage Volume Results

The Rainwater Harvesting Storage Volume Calculator determines the average daily volume of water in the cistern for a range of cistern sizes. From this value, the available storage volume for the 85th and 95th percentile storm can be calculated; it is simply the difference between the cistern size and the average daily volume. The available storage volume for the selected cistern size should be used as an input to the General Retention Compliance Calculator. Similarly, the pond used for irrigation stormwater volume is entered in the General Retention Compliance Calculator in the rainwater harvesting row rather than the stormwater pond row to produce runoff reduction and pollutant removal credit with the other BMPs for the stormwater plan.

- **Available Storage Volume (Sv)**
  The volume available for storage of the 85th and 95th percentile storm is calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the retention achieved versus cistern size. While larger cisterns yield more retention, they are more expensive. The curve helps the user to choose the appropriate cistern size, based on the design objectives and site needs.

- **Overflow Volume**
  The volume of the overflows resulting from the 85th or 95th percentile precipitation event is also reported in this sheet. The overflow volume is also plotted to illustrate the effects of cistern size on overflow volume. An example chart is shown in Figure 4.31. The effect of diminishing returns is clear. Beyond a cistern size of 9,000 gallons, the overflow volume drops to zero. So, while the available storage continues to increase, the 85th or95th percentile storm is entirely retained, and no additional retention will be possible.

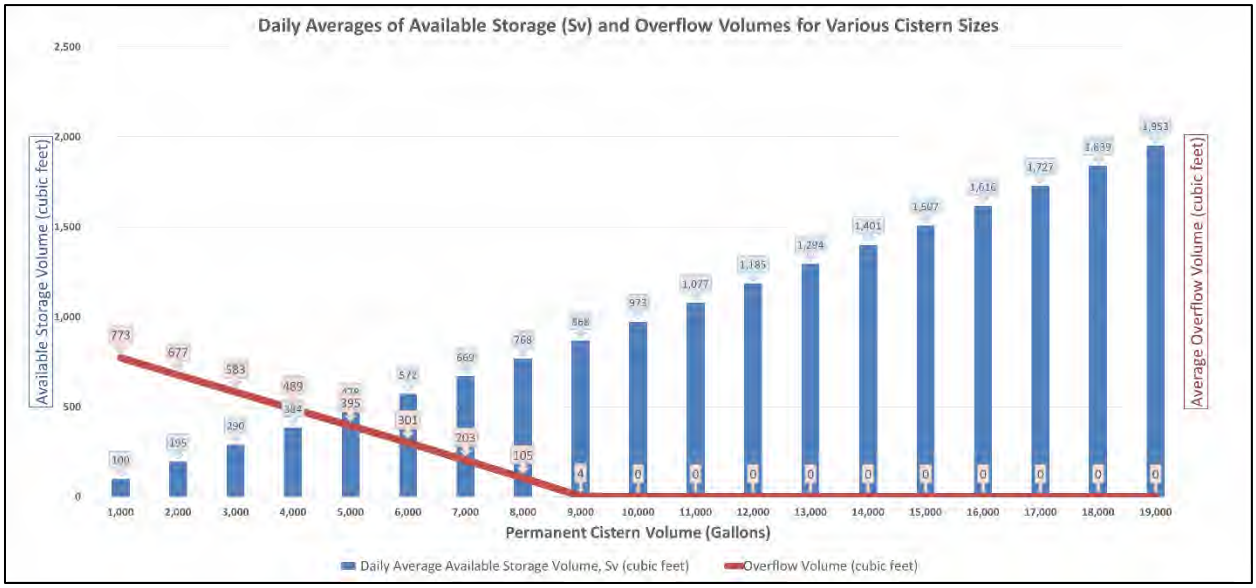

Figure 4.31. Example of graph showing Average Available Storage Volume and Overflow Volume for an example cistern design.

<u>Results from the Rainwater Harvesting Storage Volume Calculator to be Transferred to the Compliance Calculator</u>

There are two results from the Rainwater Harvesting Storage Volume Calculator that are to be transferred to the Compliance Calculator as follows:

- **Contributing Drainage Area**
  Enter the CDA that was used in the Rainwater Harvesting Storage Volume Calculator into the appropriate columns in the "Rainwater Harvesting" row of the Compliance Calculator BMP sheet.

- **Available Storage Volume**
  Once a cistern has been selected, enter the Available Storage Volume (ft^3) associated with that cistern into the Compliance Calculator column called "Storage Volume Provided by BMP" in the "Rainwater Harvesting" row of the BMP sheet.

<u>Completing the Sizing Design of the Cistern</u>

The total size of the cistern is the sum of the following four volume components:

- **Low Water Cutoff Volume (Included)**
  A dead storage area must be included so the pump will not run the cistern dry. This volume is included in the Rainwater Harvesting Storage Volume Calculator's modeled volume.

- **Cistern Storage Associated with Design Volume (Included)**
  This is the cistern design volume from the Rainwater Harvesting Storage Volume Calculator.
- **Adding Channel Protection and Flood Volumes (Optional)**
  Additional detention volume may be added above and beyond the cistern storage associated with the design storm volumes for the 2- to 25-year events. Typical routing software programs may be used to design for this additional volume.
- **Adding Overflow and Freeboard Volumes (Required)**
  An additional volume above the emergency overflow must be provided in order for the cistern to allow very large storms to pass. Above this overflow water level, there will be an associated freeboard volume that should account for at least 5% of the overall cistern size. Sufficient freeboard must be verified for large storms, and these volumes must be included in the overall size of the cistern.

4.7.5 Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan elements must include the proposed delineation of planting areas to be irrigated, the planting plan, and quantification of the expected water demand. The default water demand for irrigation is 1.0 inches per week over the area to be irrigated during the months of May through October only. Justification must be provided if larger volumes are to be used.

4.7.6 Rainwater Harvesting Construction Sequence

Installation

It is advisable to have a single contractor to install the rainwater harvesting system, outdoor irrigation system, and secondary retention practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions.

1. Choose the cistern location on the site.
2. Route all downspouts or pipes to prescreening devices and first flush diverters.
3. Properly install the cistern.
4. Install the pump (if needed) and piping to end uses (indoor, outdoor irrigation, or cistern dewatering release).
5. Route all pipes to the cistern.
6. Stormwater must not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.

Construction Supervision

The following items should be inspected by a qualified professional in the mechanical, electrical, or plumbing fields prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed

- Mosquito screens are installed on all openings
- Overflow device is directed as shown on plans
- Rainwater harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary stormwater treatment practice(s) is installed as shown on plans
- System commissioning

Construction phase inspection checklist for rainwater harvesting practices and the Stormwater Facility Leak Test form can be found in Appendix E Construction Inspection Checklists.

4.7.7 Rainwater Harvesting Maintenance Criteria

Maintenance Inspections

Periodic inspections and maintenance shall be conducted for each system by a qualified professional.

Maintenance inspection checklists for rainwater harvesting systems and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Maintenance Schedule

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table 4.28 describes routine maintenance tasks necessary to keep rainwater harvesting systems in working condition. It is recommended that maintenance tasks be performed by an “Inspector Specialist,” certified by the American Rainwater Catchment Association. Maintenance tasks must be documented and substantially comply with the maintenance responsibilities outlined in the maintenance agreement.

Table 4.28. Typical Maintenance Tasks for Rainwater Harvesting Systems

Responsible Person	Frequency	Activity
Owner	Four times a year	Inspect and clean prescreening devices and first flush diverters
	Twice a year	Keep gutters and downspouts free of leaves and other debris
	Once a year	▪ Inspect and clean storage cistern lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately ▪ Inspect condition of overflow pipes, overflow filter path, and/or secondary stormwater treatment practices
	Every third year	Clear overhanging vegetation and trees over roof surface
Qualified Third-Party Inspector	According to Manufacturer	Inspect water quality devices
	As indicated in Appendix J Rainwater Harvesting Treatment and Management Requirements	Field verification and data logs must be available at all times and semiannual reports must be uploaded to the SW database annually.
	Every third year	▪ Inspect cistern for sediment buildup ▪ Check integrity of backflow preventer ▪ Inspect structural integrity of cistern, pump, pipe and electrical system ▪ Replace damaged or defective system components

Mosquitoes

In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding. Designers must provide screens on above- and below-ground cisterns to prevent mosquitoes and other insects from entering the cisterns. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

Waste Material

Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.7.8 Rainwater Harvesting Stormwater Compliance Calculations

Rainwater harvesting practices are credited with 100% retention for the average available storage volume (Sv) available in the cistern as well as 100% TSS, TN, and bacteria removal (see Table 4.29). This average available storage volume is determined by using the Rainwater Harvesting Storage Volume Calculator, as described in Section 4.5.4 Rainwater Harvesting Design Criteria.

Table 4.29. Rainwater Harvesting Retention and Pollutant Removal

Retention	= 100%
TSS Removal	= 100%
TN Removal	= 100%
Bacteria Removal	= 100%

Rainwater harvesting practices also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume from the total runoff volume for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

4.7.9 References

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4.8 Impervious Surface Disconnection

Impervious Surface Disconnection				
Definition: This strategy involves managing runoff close to its source by directing it from rooftops and other impervious surfaces to pervious areas.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Suburban ▪ Rural	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		80%	40%	40%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
Low	Low	Low		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	**40%**		
At least annually	As needed			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Low cost construction and maintenance ▪ Reduces runoff volume ▪ Helps restore pre-development hydrologic conditions		▪ Only applicable to small drainage areas ▪ Difficult to apply to treatment trains ▪ Requires pervious receiving area		
Components		**Design considerations**		
▪ Conveyance ▪ Receiving area ▪ Vegetation ▪ Receiving soils		▪ Maximum CDA of 1,000 ft^2 per disconnection ▪ Disconnection area should be at least 35 feet long and 10 feet wide. ▪ Slope of receiving area should be < 2% (with turf reinforcement, <5%) ▪ Building setback for areas with < 1% slope		
Maintenance Activities				
▪ Typical lawn/landscaping maintenance		▪ Ensure receiving area remains uncompacted and pervious		

[1]*Credited pollutant load removal*

In this practice, runoff from a rooftop or other small impervious surface is directed to a pervious surface or small practice to provide infiltration, filtering, or reuse (Figure 4.32)

Figure 4.32. Rooftop disconnection (photo: Center for Watershed Protection, Inc.)

Definition

This strategy involves managing runoff close to its source by directing it from rooftops and other impervious surfaces to pervious areas. Disconnection practices can be used to reduce the volume of runoff that enters the combined or separate sewer systems. Applicable practices include the following:

D-1 Disconnection to pervious areas with the compacted cover designation

D-2 Disconnection to conservation areas

Disconnection practices reduce a portion of the SWRv. In order to fully meet retention requirements, , disconnection practices must be combined with additional practices.

4.8.1 Impervious Surface Disconnection Feasibility Criteria

Impervious surface disconnections are ideal for use on commercial, institutional, municipal, multi-family residential, and single-family residential buildings. Key constraints with impervious surface disconnections include available space, soil permeability, and soil compaction. These and other feasibility criteria are described below and summarized in Table 4. 30.

- **Contributing Drainage Area.** For rooftop impervious areas, the maximum impervious area treated cannot exceed 1,000 square feet per disconnection. For impervious areas other than rooftop, the longest contributing impervious area flow path cannot exceed 75 feet.
- **Sizing.** The available disconnection area must be at least 10 feet wide and 35 feet long. For sheet flow from impervious areas, the disconnection area must be as wide as the area draining to it.
- **Site Topography.** Disconnection is best applied when the grade of the receiving pervious area is less than 2%, or less than 5% with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations. Turf reinforcement may include erosion control matting or other appropriate reinforcing materials that are confirmed by the designer to be erosion resistant for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan-approving authority.

- **Soils.** Impervious surface disconnection can be used on any post-construction hydrologic soil group (HSG). The disconnection area must be kept well-vegetated with minimal bare spots—at least 95% soil cover.
- **Building Setbacks.** If the grade of the receiving area is less than 1%, downspouts must be extended 5 feet away from building.

Discharge Across Property Lines. Disconnection areas must be designed such that runoff is not directed across property lines toward other sites.

Economic Considerations. Disconnection is one of the least expensive BMPs available.

Table 4.30. Feasibility Criteria for Disconnection

Design Factor	Disconnection Design
Contributing Drainage Area	1,000 square feet per rooftop disconnection. For impervious areas other than rooftop, the longest contributing impervious area flow path cannot exceed 75 feet.
Sizing	The available disconnection area must be at least 10 feet wide and 35 feet long. For sheet flow from impervious areas, the disconnection area must be as wide as the area draining to it.
Site Topography	Grade of the receiving pervious area is less than 2%, or less than 5% with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations.
Soils	Impervious surface disconnection can be used on any post-construction HSG. The disconnection area must be kept well-vegetated with minimal bare spots.
Building Setbacks	5 feet away from building if the grade of the receiving area is less than 1%.

4.8.2 Impervious Surface Disconnection Conveyance Criteria

Receiving areas in disconnection practices (D-1, D-2, and D-3) require a design that safely conveys the 2- to 25-year storm events over the receiving area without causing erosion. In some applications, erosion control matting or other appropriate reinforcing materials may be needed to control flow rates anticipated for these larger design storms.

4.8.3 Impervious Surface Disconnection Pretreatment Criteria

Pretreatment is not needed for impervious surface disconnection.

4.8.4 Impervious Surface Disconnection Design Criteria

If the feasibility criteria presented in Section 4.6.1 are met for a disconnection area, the storage volume is equal to the SWRv for the impervious area draining to it. The disconnection area itself should be considered Compacted Cover or Open Space rather than BMP area and should not be considered as part of the contributing drainage area to the impervious surface disconnection.

The following additional design criteria apply to Disconnection to Conservation Areas:

- **(D-2) Disconnection to a Conservation Area.** Disconnection area cannot include regulated wetlands and buffer areas.

- Inflow must be conveyed via sheet flow or via a level spreader.
- If inflow is conveyed via a level spreader, the maximum flow path is 150 feet, and the level spreader must be designed with an appropriate width as specified below.

Level Spreaders. A level spreader can be used to disperse or "spread" concentrated flow thinly over a vegetated or forested area to promote greater runoff infiltration in the receiving area. A level spreader consists of a permanent linear structure constructed at a 0% grade that transects the slope. The influent concentrated runoff must be spread over an area wide enough area so that erosion of the receiving area does not result. Detailed information on the design and function of level spreaders can be found in Hathaway and Hunt (2006) and NCDWQ (2010).

The minimum required width of the level spreader is

- 13 linear feet per each 1 cubic foot/second of inflow if the receiving conservation area has a minimum 90% ground cover
- 40 linear feet per 1 cubic foot/second of inflow if the receiving conservation area is forested

4.8.5 Impervious Surface Disconnection Landscaping Criteria

All receiving disconnection areas must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems according to the Erosion and Sediment Control seeding and vegetation requirements. Designers must ensure that the maximum flow velocities do not exceed the acceptable values for the selected grass species and the specific site slope.

4.8.6 Impervious Surface Disconnection Construction Sequence

Construction Sequence for Disconnection to Pervious Areas. For disconnection to a pervious area, the pervious area can be within the limits of disturbance (LOD) during construction. The following procedures should be followed during construction:

- Before site work begins, the receiving pervious disconnection area boundaries should be clearly marked.
- Construction traffic in the disconnection area should be limited to avoid compaction. The material stockpile area shall not be located in the disconnection area.
- Construction runoff should be directed away from the proposed disconnection area, using perimeter silt fence, or, preferably, a diversion dike.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- The disconnection area may require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction.
- Topsoil and or compost amendments should be incorporated evenly across the disconnection area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater must not be diverted into any topsoil or compost amended areas until the area is stabilized (establishment of 95% or greater groundcover).

Construction Sequence for Disconnection to Conservation Areas. For disconnection to a conservation area, the conservation area must be fully protected during the construction stage of development and kept outside the LOD on the soil erosion and sediment control plan.

- No staging, parking, clearing, grading, or heavy equipment access is allowed in the conservation area except temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation. Incidental utility construction includes protecting existing utilities, removing abandoned utilities, rearranging service lines, temporarily rearranging utilities, and adjusting utility appurtenances.
- Any conservation areas shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent sediment discharge consistent with soil erosion and sediment control standards and specifications.
- The LOD must be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence or other protective barrier.
- If a level spreader is to be used in the design, construction of the level spreader shall not commence until the CDA has been stabilized and perimeter soil erosion and sediment control measures have been removed and cleaned out. Stormwater must not be diverted into the disconnection area until the level spreader is installed and stabilized.

Construction Supervision. Construction supervision is recommended to ensure compliance with design standards. A qualified professional should evaluate the performance of the disconnection after the first significant rainfall event to look for evidence of gullies, outflanking, undercutting, or sparse vegetative cover. Spot repairs should be made as needed.

Construction phase inspection checklist for impervious cover disconnection can be found in Appendix E Construction Inspection Checklists.

4.8.7 Impervious Surface Disconnection Maintenance Criteria

Maintenance of disconnected downspouts usually involves regular lawn or landscaping maintenance in the filter path from the roof to the street. In some cases, runoff from a disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected). Typical maintenance activities include erosion control of the receiving area and ensuring the receiving area remains uncompacted and pervious.

Maintenance inspection checklists for disconnection can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.8.8 Impervious Surface Disconnection Stormwater Compliance Calculations

Disconnection practices are credited with 40% retention for the SWRv as well as 80% TSS, 40% TN, and 40% bacteria removal (see Table 4.31).

Table 4.31. Disconnection Retention and Pollutant Removal

Retention	= 40%
TSS Removal	= 80%
TN Removal	= 40%
Bacteria Removal	= 40%

Impervious surface disconnection also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume from the total runoff volume for the 2- to 25-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

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Virginia DCR Stormwater Design Specification No. 1: Rooftop (Impervious Surface) Disconnection Version 1.8. 2010.

4.9 Open Channel Systems

Open Channel Systems						
Definition: Vegetated open channels that are designed to capture and treat or convey the design storm volume (SWRv).						
Site Applicability		**BMP Performance Summary**				
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High				
▪ Suburban ▪ Rural	Moderate	**TSS[1]**	**Total N[1]**	**Bacteria[1]**		
		50-80%	25-70%	30-80%		
		Runoff Reduction				
Construction Costs	**Maintenance Burden**	**Volume**				
Low	Low	Low				
Maintenance Frequency:		***SWRv***				
Routine	**Non-Routine**	**O-1a**	**O-1b**	**O-2**	**O-3**	**O-4**
Quarterly	Every 10-15 years	10%	20%	60%	0%	0%
Advantages/Benefits		**Disadvantages/Limitation**				
▪ Less expensive than curb and gutter ▪ Relatively low maintenance requirements ▪ Provides pretreatment if used as part of runoff conveyance system ▪ Provides partial infiltration of runoff in some soils ▪ Good for small drainage areas		▪ Must be carefully designed to achieve low flow rates in the channel (< 1.0 ft/s) ▪ May re-suspend sediment ▪ May not be acceptable for some areas because of standing water in channel				
Components		**Design considerations**				
▪ Channel geometry ▪ Dense vegetation ▪ Check dams, as needed)		▪ Maximum drainage area of 2.5 acres ▪ Slopes (<4% unless using O-4) ▪ Runoff velocities must be non-erosive ▪ Vegetation must withstand both relatively high velocity flows and wet/dry periods.				
Maintenance Activities						
▪ Mow grass to 3 or 4 inches high ▪ Inspect for, and correct, formation of rills and gullies		▪ Clean out sediment accumulation in channel ▪ Ensure that vegetation remains well established				

[1]*Credited pollutant load removal*

Often found along roadsides, parking lots, and property boundaries, open channels can provide stormwater conveyance, capture and/or treatment (Figure 4.33). One of the most visible stormwater BMPs, they are often part of stormwater conveyance systems.

Figure 4.33. Open channel (photo: Center for Watershed Protection, Inc.)

Definition. Vegetated open channels that are designed to capture and treat or convey the design storm volume (SWRv). Design variants include the following:

O-1 Grass channels

O-2 Dry swales/bioswales

O-3 Wet swales

O-4 Regenerative stormwater conveyance (RSC)

Open channel systems shall not be designed to provide stormwater detention except under extremely unusual conditions. Open channel systems must generally be combined with a separate facility to meet detention requirements.

Grass channels (O-1) can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes (see Figure 4.34). The performance of grass channels will vary depending on the underlying soil permeability. Grass channels, however, are not capable of providing the same stormwater functions as dry swales as they lack the storage volume associated with the engineered filter media. Their retention performance can be boosted when compost amendments are added to the bottom of the swale (see Appendix C Soil Compost Amendment Requirements). Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography, and soils permit.

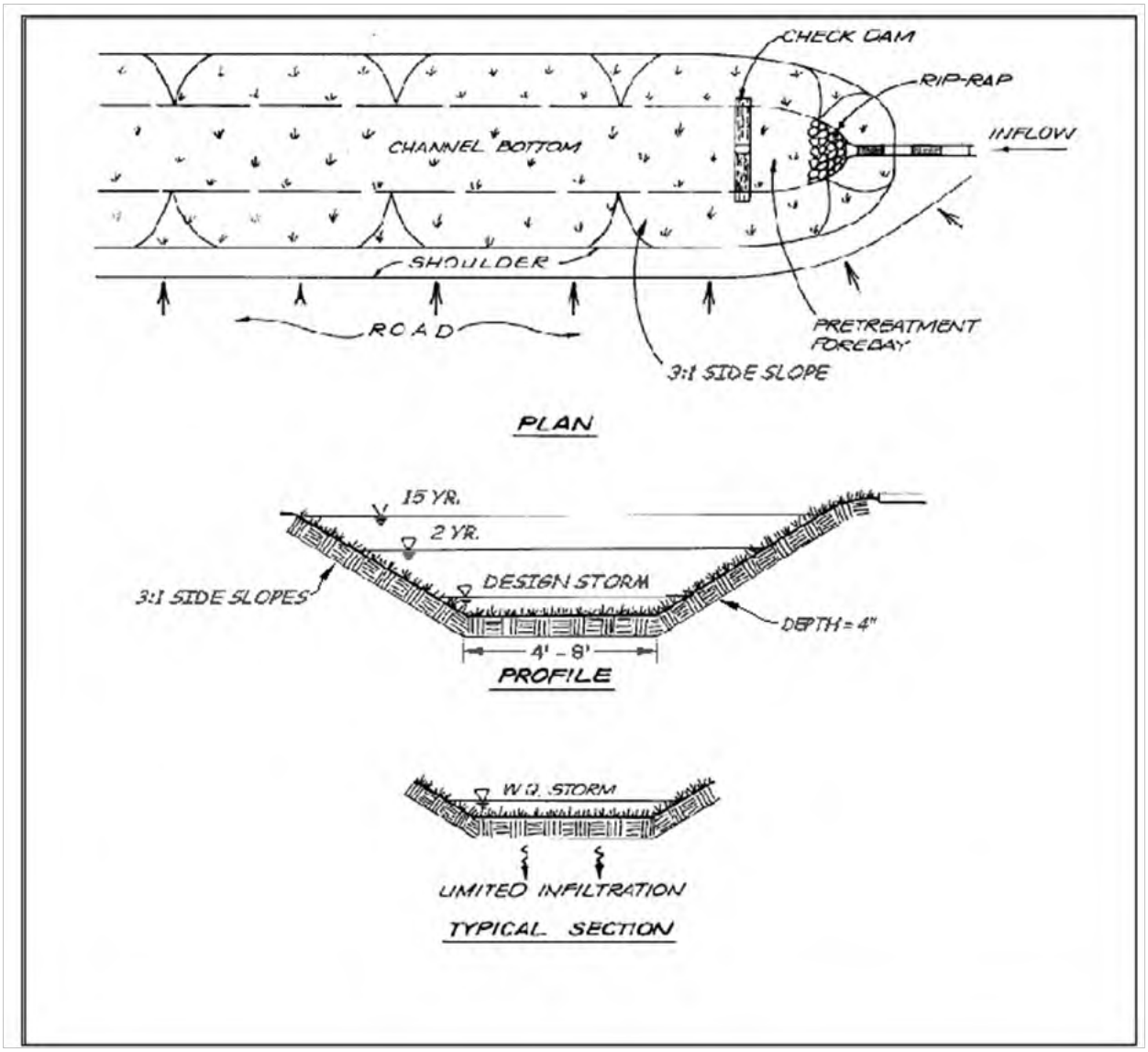

Figure 4.34. Grass channel typical plan, profile, and section views (O-1).

Dry swales (O-2), also known as bioswales, are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants; see Figure 4.35. Example of a dry swale/bioswale (O-2).). The dry swale is a soil filter system that temporarily stores and then filters the desired design storm volume. Dry swales rely on a premixed filter media below the channel that is identical to that used for bioretention. In most cases, the runoff treated by the filter media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. However, if soils are permeable, runoff infiltrates into underlying soils and the dry swale can be designed without an underdrain as if it were an enhanced bioretention. In either case, check dams should be constructed to encourage ponding (see Site Topography). Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

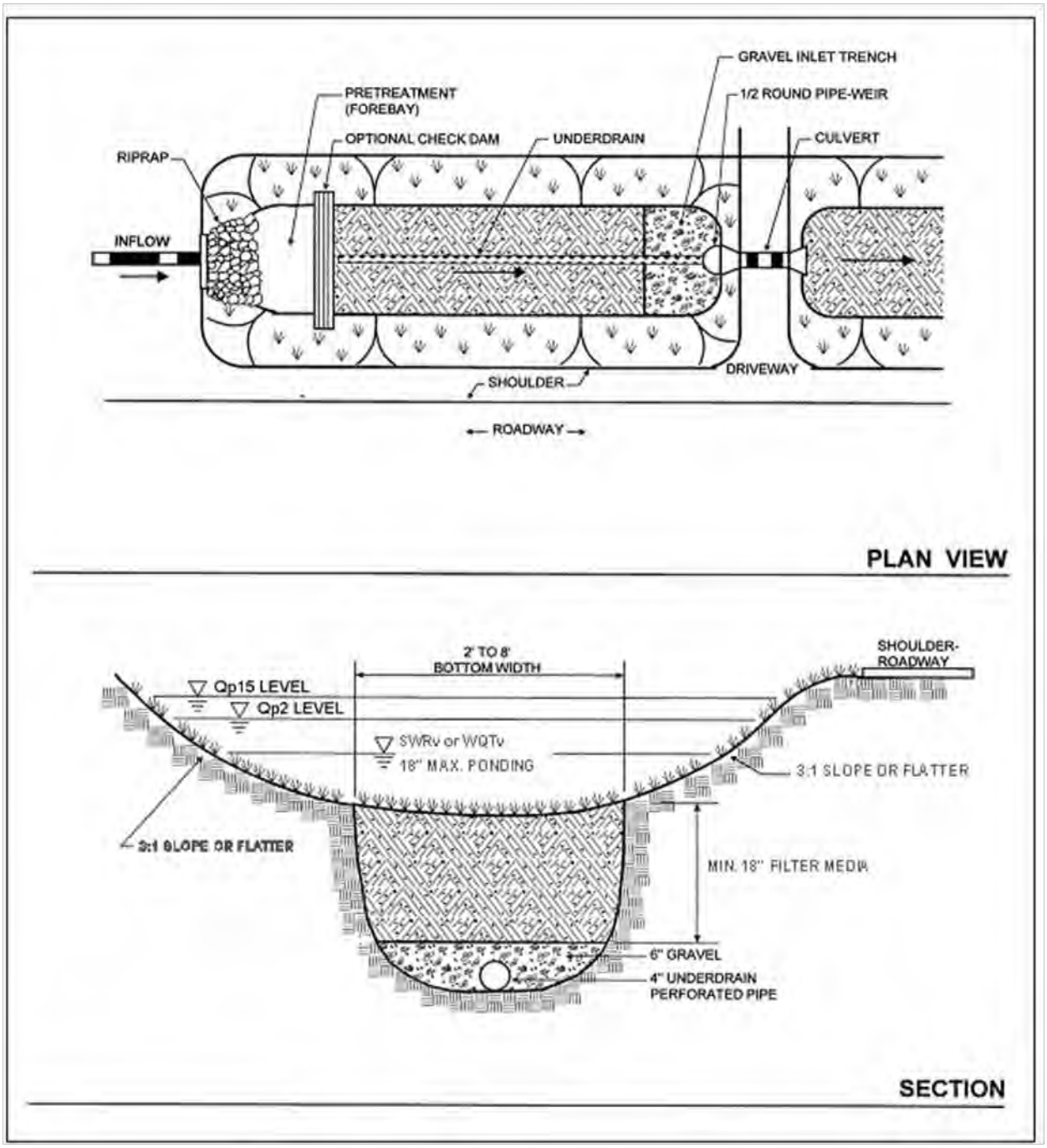

Figure 4.35. Example of a dry swale/bioswale (O-2).

Wet swales (O-3) can provide a modest amount of runoff filtering within the conveyance (see Figure 4.36). These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. On-line or off-line cells are formed within the channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).

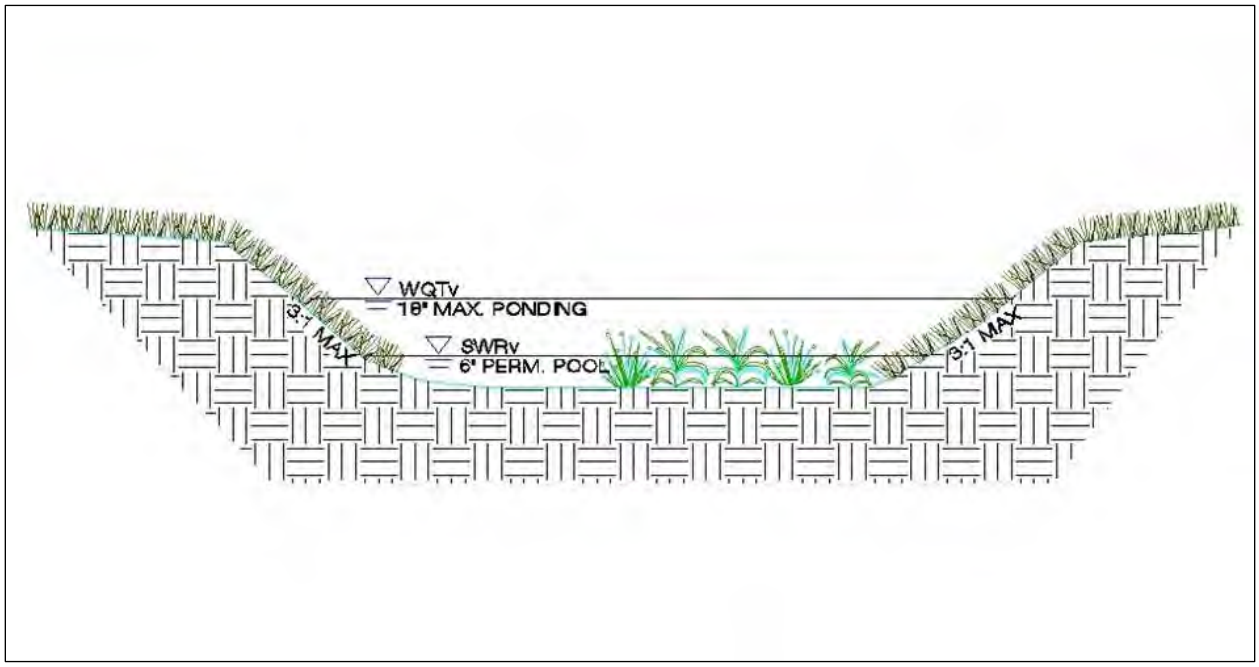

Figure 4.36. Example of a wet swale (O-3).

Regenerative Stormwater Conveyance (O-4). RSC is a unique conveyance practice that can be used in locations where other conveyance practices are infeasible, or as a restoration practice for eroded or degraded outfalls and drainage channels (Figure 4.37). RSC utilizes a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand and woodchip beds to treat, detain, and convey storm flow. It can be used in places where grades make traditional stormwater practices difficult to implement. Because of the regional topography and waters of the state limitations, RSC Systems will have limited application in the Southern Lowcountry. RSC Systems combine features and treatment benefits of Swales, Infiltration, Filtering and Wetland practices. In addition, they are designed to convey flows associated with larger storm events in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

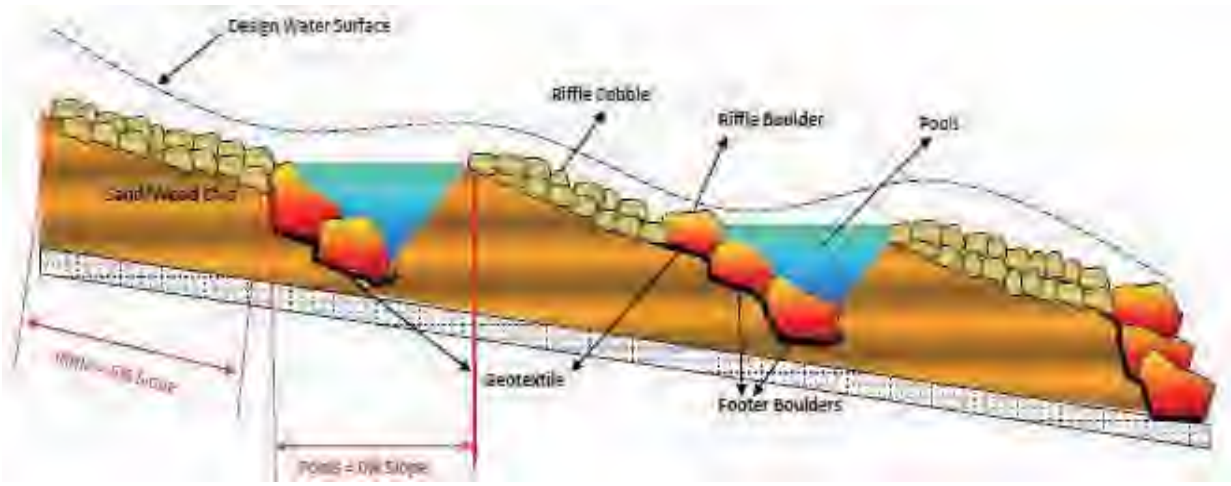

Figure 4.37. Example of Regenerative Stormwater Conveyance (O-4).

4.9.1 Open Channel Feasibility Criteria

Open channel systems are primarily applicable for land uses, such as roads, highways, and residential development. Some key feasibility issues for open channels include the following:

Contributing Drainage Area. The maximum CDA to an open channel should be 2.5 acres, preferably less. When open channels treat and convey runoff from CDAs greater than 2.5 acres, the velocity and flow depth through the channel often becomes too great to treat runoff or prevent erosion in the channel. The design criteria for maximum channel velocity and depth are applied along the entire length (see Section 4.9.4 Open Channel Design Criteria). Dry Swales should be approximately 3%–10% of the size of the CDA, depending on the amount of impervious cover. Wet swale footprints usually cover about 5%–15% of their CDA.

Available Space. Open channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Grass channels can be incorporated into linear development applications (e.g., roadways) by utilizing the footprint typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel. However, the benefit of the retention may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Grass channels and wet swales should be used on sites with longitudinal slopes of less than 4%. Check dams can be used to reduce the effective slope of the channel and lengthen the contact

time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade so as to avoid flat areas with pockets of standing water.

For dry swales, check dams will be necessary regardless of the longitudinal slope to create the necessary ponding volume.

Land Uses. Open channels can be used in residential, commercial, or institutional development settings.

When open channels are used for both conveyance and water quality treatment, they should be applied only in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas. The linear nature of open channels makes them well-suited to treat highway or low- and medium-density residential road runoff, if there is adequate right-of-way width and distance between driveways. Typical applications of open channels include the following, as long as CDA limitations and design criteria can be met:

- Within a roadway or bicycle path right-of-way;
- Along the margins of small parking lots;
- Oriented from the roof (downspout discharge) to the street;
- Disconnecting small impervious areas; and
- Used to treat the managed turf areas of parkland, sports fields, golf courses, and other turf-intensive land uses, or to treat CDAs with both impervious and managed turf cover (such as residential streets and yards).

Open channels are not recommended when residential density exceeds more than four (4) dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel.

Open channels can also provide pretreatment for other stormwater treatment practices.

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement open channels in order to ensure positive drainage and conveyance through the channel. The hydraulic head for wet swales and grass channels is measured as the elevation difference between the channel inflow and outflow point. The hydraulic head for dry swales is measured as the elevation difference between the inflow point and the storm drain invert (unless an infiltration-based design will be used). Dry swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and underdrain.

Hydraulic Capacity. Open channels are typically designed as on-line practices that must be designed with enough capacity to (1) convey runoff from the 25-year design storm at non-erosive velocities, and (2) contain the 25-year flow within the banks of the swale. This means that the swale's surface dimensions are more often determined by the need to pass the 25-year storm events, which can be a constraint in the siting of open channels within existing rights-of-way (e.g., constrained by sidewalks).

Depth to Water Table. The bottom of dry swales and grass channels must be at least 0.5 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the filter bed, since this could lead to groundwater contamination or practice failure. It is permissible for wet swales to intersect the water table.

Soils. Soil conditions do not constrain the use of open channels, although they do dictate some design considerations:

- Dry swales in soils with low infiltration rates may need an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in Appendix B Geotechnical Information Requirements for Underground BMPs to eliminate the requirements for a dry swale underdrain.
- Grass channels situated on low-permeability soils may incorporate compost amendments to improve performance (see Appendix C Soil Compost Amendment Requirements).
- Wet swales work best on the more impermeable HSG C or D soils.
- At infill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary for open channel designs.

Utilities. Typically, utilities can cross linear channels if they are specially protected (e.g., double-casing). Interference with underground utilities should be avoided, if possible. When large site development is undertaken, the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the PROW. Where conflicts cannot be avoided, these guidelines shall be followed:

- Consult with each utility company on recommended offsets that will allow utility maintenance work with minimal disturbance to the BMP.
- Whenever possible, coordinate with utility companies to allow them to replace or relocate their aging infrastructure while BMPs are being implemented.
- BMP and utility conflicts will be a common occurrence in PROW projects. However, the standard solution to utility conflict should be the acceptance of conflict provided sufficient soil coverage over the utility can be assured.
- Additionally, when accepting utility conflict into the BMP design, it is understood that the BMP will be temporarily impacted during utility maintenance but restored to its original condition.

Avoidance of Irrigation or Baseflow. Open channels should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other dry weather flows.

Setbacks. To avoid the risk of seepage, stormwater cannot flow from the open channel reservoir layer or via baseflow to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties Open channels should be set back at least 10 feet down-gradient from building foundations and property lines, 50 feet from septic system fields and 150 feet from public or private drinking water wells. The 10-foot building setback may be relaxed if an impermeable building liner is installed.

Pollutant Hotspot Land Use. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil- water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the channel and subsequent water bodies.

Runoff from hotspot land uses must not be treated with infiltrating dry swales due to the potential interaction with the water table and the risk that hydrocarbons, trace metals, and other toxic pollutants could migrate into the groundwater. An impermeable liner must be used for filtration of hotspot runoff for dry swales.

Grass channels can typically be used to convey runoff from stormwater hotspots, but they do not qualify as a hotspot treatment mechanism. Wet swales are not recommended to treat stormwater hotspots, due to the potential interaction with the water table and the risk that hydrocarbons, trace metals, and other toxic pollutants could migrate into the groundwater.

On sites with existing contaminated soils, infiltration is not allowed; dry and wet swales on these hotspots must include an impermeable liner.

Feasibility. Open channels are ideally suited to the Southern Lowcountry environment, since open channel drainage is often the norm due to the flat topography. Depending on underlying soil and other characteristics, however, a specific open channel option may be the most appropriate. For example, the wet swale design option is most suited to areas with elevated groundwater tables, while dry swales and grassed channels are best suited for sandy soils of the coastal plain.

Economic Considerations. While most open channel designs provide relatively small water quality credits when compared with other stormwater practices, they nevertheless provide greater quality benefits than traditional conveyance designs, such as curb and gutter.

4.9.2 Open Channel Conveyance Criteria

The bottom width and slope of a grass channel must be designed such that the velocity of flow from the design storm provides a minimum hydraulic residence time (average travel time for a particle of water through a waterbody) of 9 minutes for the peak flows from the SWRv or design storm. Check dams may be used to achieve the needed retention volume, as well as to reduce the flow velocity. Check dams must be spaced based on channel slope and ponding requirements, consistent with the criteria in Section 4.7.4 Open Channel Design Criteria.

Open channels must also convey the 25-year storm at non-erosive velocities (generally less than 6 feet per second) for the soil and vegetative cover provided. The final designed channel shall provide 6 inches minimum freeboard above the designated water surface profile of the channel. The analysis must evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

RSC systems are typically designed to convey larger storm events, up to and including the 100- year storm event.

4.9.3 Open Channel Pretreatment Criteria

Pretreatment is required for open channels to dissipate energy, trap sediments, and slow down the runoff velocity.

The selection of a pretreatment method depends on whether the channel will experience sheet flow or concentrated flow. Several options are as follows:

- **Check Dams (channel flow).** These energy dissipation devices are acceptable as pretreatment on small open channels with CDAs of less than 1 acre. The most common form is the use of wooden or stone check dams. The pretreatment volume stored must be 15% of the design volume.
- **Tree Check Dams (channel flow).** These are street tree mounds that are placed within the bottom of grass channels up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow runoff to percolate through (Cappiella et al, 2006). The pretreatment volume stored must be 15% of the design volume.
- **Grass Filter Strip (sheet flow).** Grass filter strips extend from the edge of the pavement to the bottom of the open channel at a slope of 5H:1V or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20H:1V) cross slope and 3H:1V or flatter side slopes on the open channel.
- **Gravel or Stone Diaphragm (sheet flow).** The gravel diaphragm is located at the edge of the pavement or the edge of the roadway shoulder and extends the length of the channel to pretreat lateral runoff. This requires a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The stone must be sized according to the expected rate of discharge.
- **Gravel or Stone Flow Spreaders (concentrated flow).** The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.
- **Initial Sediment Forebay (channel flow).** This grassed cell is located at the upper end of the open channel segment with a recommended 2:1 length to width ratio and a storage volume equivalent to at least 15% of the total design storm volume. If the volume of the forebay will be included as part of the dry swale storage volume, the forebay must de-water between storm events. It cannot have a permanent ponded volume.

4.9.4 Open Channel Design Criteria

Channel Geometry. Design guidance regarding the geometry and layout of open channels is provided below:

- Open channels should generally be aligned adjacent to and the same length as the CDA identified for treatment.
- Open channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance, and hydraulic reasons.
- The bottom width of the channel should be between 4 to 8 feet wide to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a channel will be wider than 8 feet, the designer must incorporate benches, check dams, level spreaders, or multi-level cross sections to prevent braiding and erosion along the channel bottom.
- Open-channel side slopes should be no steeper than 3H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to enhance pretreatment of sheet flows entering the channel.
- RSC has several specific geometry requirements, which are outlined in RSC Sizing below.

Check dams. Check dams may be used for pretreatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- Check dams should be spaced based on the channel slope, as needed to increase residence time, provide design storm storage volume, or any additional volume attenuation requirements. In typical spacing, the ponded water at a downhill check dam should not touch the toe of the upstream check dam. More frequent spacing may be desirable in dry swales to increase the ponding volume.
- The maximum desired check dam height is 12 inches, for maintenance purposes. However, for some sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils.
- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the channel design storm peak flow (25-year storm event for man-made channels).
- For grass channels, each check dam must have a weep hole, or similar drainage feature, so it can dewater after storms. This is not appropriate for dry swales.
- Check dams should be composed of wood, concrete, stone, compacted soil, or other non-erodible material, or should be configured with elevated driveway culverts.
- Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

Check dams for grass channels must be spaced to reduce the effective slope to less than 2%, as indicated in Table 4.32.

Table 4.32. Typical Check Dam Spacing to Achieve Effective Channel Slope

Channel Longitudinal Slope (%)	**Check Dam Spacing to Achieve Effective Slope [a, b, c]**	
	Effective Slope of 2% (ft)	**Effective Slope of 0%–1% (ft)**
0.5	–	
1.0	–	
1.5	–	67–200
2.0	–	50–100
2.5	200	40–67
3.0	100	33–50
3.5	67	30–40
4.0	50	25–33
4.5[d]	40	20–30
5.0[d]	40	20–30

[a] All check dams require a stone energy dissipator at the downstream toe.
[b] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.
[c] Assumed check dam height is 12 inches. The spacing dimension is half of the above distances if a 6-inch check dam is used.
[d] Open channels with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.

Ponding Depth. Check dams must be used in dry swales to create ponding cells along the length of the channel. The maximum ponding depth in a dry swale must not exceed 18 inches. Minimum surface ponding depth is 3 inches (averaged over the surface area of the open channel). In order to increase the ponding depth, it may be necessary or desirable to space check dams more frequently than is shown in Table 4.32.

Dry Swale Filter Media. Dry swales require replacement of native soils with a prepared filter media. The filter media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the dry swale. At least 18 inches of filter media must be added above the choker stone layer (and no more than 6 feet) to create an acceptable filter. The recipe for the filter media is identical to that used for bioretention and is provided in Section 4.1 Bioretention. The batch receipt confirming the source of the filter media must be submitted to the *<local jurisdiction>* inspector. One acceptable design adaptation is to use 100% sand for the first 18 inches of the filter and add a combination of topsoil and compost, as specified in Appendix C Soil Compost Amendment Requirements, for the top 4 inches, where turf cover will be maintained.

Dry Swale Drawdown. Dry swales must be designed so that the desired design storm volume is completely filtered within 72 hours, using the equations specified in Section 4.7.6 Open Channel Construction Sequence.

Dry Swale Underdrain. Some dry swale designs will not use an underdrain (where soil infiltration rates meet minimum standards). See Section 4.9.1 Open Channel Feasibility Criteria for more details. When underdrains are necessary, they should have a minimum diameter of 4 to 6 inches and be encased in a 12-inch deep gravel bed. Two layers of stone should be used. A choker stone layer, consisting of No. 8 or No. 89 stone at least 3 inches deep, must be installed immediately below the filter media. Below the choker stone layer, the underdrain must be encased (a minimum of 2 inches above and below the underdrain) in a layer of clean, double-washed ASTM D448 No.57 or smaller (No. 68, 8, or 89) stone. The maximum depth of the underdrain stone layer combined with the choking layer is 12 inches, and it cannot extend beyond the surface dimensions of the dry swale filter media.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a PVC geomembrane liner or an equivalent of an appropriate thickness (follow manufacturer's instructions for installation). Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Dry Swale Observation Well. A dry swale must include well-anchored, 4- to 6-inch diameter PVC pipe observation wells along the length of the swale. For a dry swale with an underdrain, the wells should be

tied into any Ts or Ys in the underdrain system and must extend upward above the surface of the ponding. These observation wells may double as clean outs. For an infiltrating dry swale, the observation well should be perforated in the gravel layer only.

Grass Channel Material Specifications. The basic material specifications for grass channels are outlined in Table 4.33.

Table 4.33. Grass Channel Material Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: ▪ A deep root system to resist scouring; ▪ A high stem density with well-branched top growth; ▪ Water-tolerance; ▪ Resistance to being flattened by runoff; ▪ An ability to recover growth following inundation; and
Check Dams	Check dams should be constructed of a non-erodible material such as wood, gabions, riprap, or concrete. Wood used for check dams should consist of pressure-treated logs or timbers or water-resistant tree species such as cedar, hemlock, swamp oak, or locust. Computation of check dam material is necessary, based on the surface area and depth used in the design computations.
Diaphragm	Pea gravel used to construct pretreatment diaphragms must consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter.
Erosion Control Fabric	Where flow velocities dictate, biodegradable erosion control netting or mats that are durable enough to last at least two growing seasons must be used.

Dry Swale Material Specifications. For additional material specifications pertaining to dry swales, designers should consult Section 4.1.4 Bioretention Design Criteria and Table 4.34.

Table 4.34. Dry Swale Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain: 80%–90% sand 10%–20% soil fines Maximum 10% clay 3%–5% organic matter	To account for settling/compaction, it is recommended that 110% of the plan volume be utilized.
Filter Media Testing	P content = 5 to 15 mg/kg (Mehlich I) or 18 to 40 mg/kg (Mehlich III) CEC > 5 milliequivalents per 100 grams	See Section 4.3.4 Bioretention, for additional filter media information.
Geotextile	Geotextile fabric meeting the following specifications: AASHTO M-288 Class 2, latest edition Has a permeability of at least an order of magnitude (10 times) higher than the soil subgrade permeability. Apply along sides of the filter media only and do not apply along the swale bottom.	
Choking Layer	A 2- to 4-inch layer of choker stone (typically No. 8 or No. 89 washed gravel) laid above the underdrain stone.	
Underdrain Stone Layer	Stone must be double-washed and clean and free of all fines (ASTM D448 No. 57 or smaller stone).	
Underdrains and Cleanouts	4-inch or 6-inch rigid schedule 40 PVC pipe, with 3 or 4 rows of 3/8-inch perforations at 6 inches on center.	Install perforated pipe for the full length of the dry swale cell. Use non-perforated pipe, as needed, to connect with the storm drain system.
Observation Wells	4-inch or 6-inch rigid schedule 40 PVC pipe	For dry swales with underdrains, tie the non-perforated observation well to the underdrain via T or Y connection. This observation well can double as a cleanout. For dry swales without an underdrain, the pipe should only be perforated in the gravel layer. The observation wells should extend to the top of ponding.
Impermeable Liner	Where appropriate, use a PVC geomembrane liner or equivalent.	
Vegetation	Plant species as specified on the landscaping plan.	
Check Dams	Use non-erosive material, such as wood, gabions, riprap, or concrete. Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species, such as cedar, hemlock, swamp oak, or locust.	
Erosion Control Fabric	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats (EC2) that are durable enough to last at least 2 growing seasons.	

RSC Material Specifications. RSC has several design elements that are unique to this practice. The practice includes riffle and pool segments, underlain with a sand/ wood chip bed, and with a top dressing of compost and plant material. Table 4.35 outlines the materials needed for this practice.

Table 4.35. Regenerative Stormwater Conveyance System Material Specifications

Material	Specification
Footer Boulders	Should have a natural appearance and be equivalent in size to Class 3 Rip Rap (aver- age diameter 26.4 inches)
Cobble	Should have a natural appearance and a minimum diameter of 6”
Sand/ Woodchip Bed	The sand component of the sand/wood chip bed should meet the AASHTO- M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand shall be a silica-based coarse aggregate. Substitutions such as Diabase and Gray- stone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No “rock dust” can be used for sand. Locally-approved pulverized glass may be substituted if the local authority undertakes testing to verify compliance with the particle size specification. No art glass shall be used for a pulverized glass material. For woodchips, use aged, shredded hardwood chips/mulch. The woodchips should be added to the sand mix, approximately 20 percent by volume, to increase the organic content and promote plant growth and sustainability.
Choker Stone	The choker stone layer between the sand bed and the bank run gravel should be clean, washed #8 or #78 stone.
Bank Run Gravel	The bank run gravel layer that is placed beneath and above the sand bed/choker stone layers should be constructed using clean, washed # 5 or # 57 coarse aggregate.
Compost	The compost used as a top dressing over the RSC System should consist of a 100% organic compost, with a pH of between 6.0 and 7.0, a moisture content of between 30 and 55%, and a particle size of 0.25 inches or less. (See Appendix C for compost specifications)
Wood Chips	The wood chips used within the sand bed should consist of double-shredded or double-ground hardwood mulch that is free of dyes, chromated copper arsenate and other preservatives.
Plant Materials	Plants should be native species, appropriate to the planting/wetness zone where they are located.

Wet Swale Design Issues. The following criteria apply to the design of wet swales:

- The average normal pool depth (dry weather) throughout the swale must be 6 inches or less.
- The maximum temporary ponding depth in any single wet swale cell must not exceed 18 inches at the most downstream point (e.g., at a check dam or driveway culvert).
- Check dams should be spaced as needed to maintain the effective longitudinal slope.
- Individual wet swale segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

- Wet swale side slopes should be no steeper than 4H:1V to enable wetland plant growth. Flatter slopes are encouraged where adequate space is available, to enhance pretreatment of sheet flows entering the channel. Under no circumstances are side slopes to steeper than 3H:1V.

Grass Channel Enhancement using Compost Soil Amendments. Soil compost amendments serve to increase the retention capability of a grass channel. The following design criteria apply when compost amendments are used:

- The compost-amended strip must extend over the length and width of the channel bottom, and the compost must be incorporated to a depth as outlined in Appendix C Soil Compost Amendment Requirements.
- For grass channels on steep slopes, it may be necessary to install a protective biodegradable erosion control mat to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate erosion control mat.

Grass Channel Sizing. Unlike other BMPs, grass channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance.
- The flow depth for the peak flow generated by the SWRv must be maintained at 4 inches or less.
- Manning's "n" value for grass channels is 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches and above, which would apply to the 2- to 25-year storms if an on-line application (Haan et. al, 1994).
- Peak flow rates for the 25-year frequency storm must be non-erosive, in accordance with Table 4. 37 (see Section 4.9.5 Open Channel Landscaping Criteria), or subject to a site-specific analysis of the channel lining material and vegetation; and the 25-year peak flow rate must be contained within the channel banks (with a minimum of 6 inches of freeboard).
- Calculations for peak flow depth and velocity must reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet must be used.
- The hydraulic residence time (e.g., the average travel time for a particle of water through a waterbody) must be a minimum of 9 minutes for the peak flows from the SWRv or design storm (Mar et al., 1982; Barrett et al., 1998; Washington State Department of Ecology, 2005). If flow enters the swale at several locations, a 9-minute minimum hydraulic residence time must be demonstrated for each entry point, using Equation 4.13 through Equation 4.17.

The bottom width of the grass channel is therefore sized to maintain the appropriate flow geometry as follows:

Equation 4.13 Manning's Equation

$$V = (\frac{1.49}{n}) \times D^{2/3} \times S^{1/2}$$

Where:

V	=	flow velocity (ft/s)
n	=	roughness coefficient (0.2, or as appropriate)
D	=	flow depth (ft) (Note: D approximates hydraulic radius for shallow flows)
S	=	channel slope (ft/ft)

Equation 4.14 Continuity Equation

$$Q = V \times (W + 3 \times D) \times D$$

Where:

Q	=	design storm peak flow rate (cfs)
V	=	design storm flow velocity (ft/s)
W	=	channel bottom width (ft)
D	=	flow depth (ft)

(Note: Channel width (W) plus 3 times the depth (D) represents the average width of a trapezoidal channel with 3H:1V side slopes. Average width multiplied by depth equals the cross-sectional flow area.)

Combining Equation 4.13 and Equation 4.14, and rewriting them provides a solution for the minimum width (Equation 4.15):

Equation 4.15 Minimum Width

$$W = \frac{n \times Q}{1.49 \times D^{5/3} \times S^{1/2}} - (3 \times D)$$

Where:

W	=	channel bottom width (ft)
n	=	roughness coefficient (0.2, or as appropriate)
Q	=	design storm peak flow rate (cfs)
D	=	flow depth (ft)
S	=	channel slope (ft/ft)

Equation 4.16 provides the corresponding velocity:

Equation 4.16 Corresponding Velocity

$$V = \frac{Q}{(W + 3 \times D) \times D}$$

Where:

V	=	design storm flow velocity (ft/s)
Q	=	design storm peak flow rate (cfs)
W	=	channel bottom width (ft)
D	=	flow depth (ft)

The width, slope, or Manning's "n" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "n" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that the denser vegetation is actually established. Equation 4.17 can then be used to ensure adequate hydraulic residence time.

Equation 4.17 Grass Channel Length for Hydraulic Residence Time of 9 minutes (540 seconds)

$$L = 540 \times V$$

Where:

L	=	minimum swale length (ft)
V	=	flow velocity (ft/s)

The storage volume (Sv) provided by the grass channel is equal to the total runoff from the design storm (typically SWRv) used to size the channel (conveyed at a depth of 4 inches or less), as shown in Equation 4.18.

Equation 4.18 Grass Channel Storage Volume

$$Sv = DesignStorm$$

Where:

Sv	=	total storage volume of grass channel (ft^3)
DesignStorm	=	SWRv or other design storm volume (ft^3) (e.g., portion of the SWRv)

Dry Swale Sizing. Dry swales are typically sized to capture the SWRv or larger design storm volumes in the surface ponding area, filter media, and gravel reservoir layers of the dry swale.

Total storage volume of the BMP is calculated using Equation 4.19.

Equation 4.19 Dry Swale Storage Volume

$$Sv = SA_{bottom} \times \left[(d_{media} \times \eta_{media}) + \left(d_{gravel} \times \eta_{gravel}\right)\right] + (SA_{average} \times d_{ponding})$$

Where:

Sv	=	total storage volume of dry swale (ft^3)
SA_{bottom}	=	bottom surface area of dry swale (ft^2)
d_{media}	=	depth of the filter media, including mulch layer (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer, including choker stone (ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	average surface area of the dry swale (ft^2) typically, where SA_{top} is the top surface area of dry swale, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	the maximum ponding depth of the dry swale (ft)

Equation 4.19 can be modified if the storage depths of the filter media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the dry swale must not exceed 18 inches. If storage practices will be provided off-line or in series with the dry swale, the storage practices should be sized using the guidance in Section 0 Storage Practices.

Dry swales can be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The Sv can be counted as part of the 2- to 25-year runoff volumes to satisfy stormwater quantity control requirements.

Note: To increase the storage volume of a dry swale, the ponding surface area may be increased beyond the filter media surface area. However, the top surface of the BMP (at the top of the ponding elevation) may not be more than twice the size of surface area of the filter media (SA_{bottom}).

Wet Swale Sizing. Wet swales can be designed to capture and treat the SWRv remaining from any upstream stormwater retention practices. The storage volume is made up of the temporary and permanent storage created within each wet swale cell. This includes the permanent pool volume and up to 12 inches of temporary storage created by check dams or other design features that has 24 hours extended detention.

The storage volume (Sv) of the practice is equal to the volume provided by the pond permanent pool plus the 24-hour extended detention (ED) volume provided by the practice (Equation 4.20). The total Sv cannot exceed the design SWRv.

Equation 4.20 Wet Swale Storage Volume

$$Sv = Pond\ permanent\ pool\ volume + 24\ hour\ ED\ volume$$

RSC Sizing. RSC design is an iterative process in which the channel is sized to convey the 100-year storm event, using manning's equation for parabolic channels as described in detail by Anne Arundel County, MD (2011). The following description provides an overview of this process, but designers should consult Anne Arundel County (2011) or the latest design variation for RSC for additional design guidelines. The

Anne Arundel County guidance can be found at http://www.aacounty.org/DPW/Watershed/StepPoolStorm-Conveyance.cfm.

Some key RSC sizing considerations include the following:

- One control structure and pool (riffle-pool) combination is needed for each foot of elevation difference along the channel.
- The length of each grade control structure or pool is determined by Equation 4.21

Equation 4.21 Riffle Pool Length

$$L_{pool} = \frac{L_{riffle}}{(Elevation\ Change) \times 2}$$

Where:

L_{pool}	=	surface length of each pool (ft)
L_{riffle}	=	total length of riffle pool (ft)
Elevation Change	=	difference in elevation between pool and bottom pool (ft)

- In areas with steep slopes (10% or greater) the length of the pool or riffle may be small (<10'). In these locations, cascades may be needed as a part of the system design.
- The minimum width of grade control structures should be 8 ft and the width should be equal to 10 times the channel depth (Figure 4.38).
- The depth of flow in the riffle sections should be less than 4 inches.
- Cobbles in the riffle section should be sized so that the velocity of the 100-year storm is non-erosive (Table 4.36).

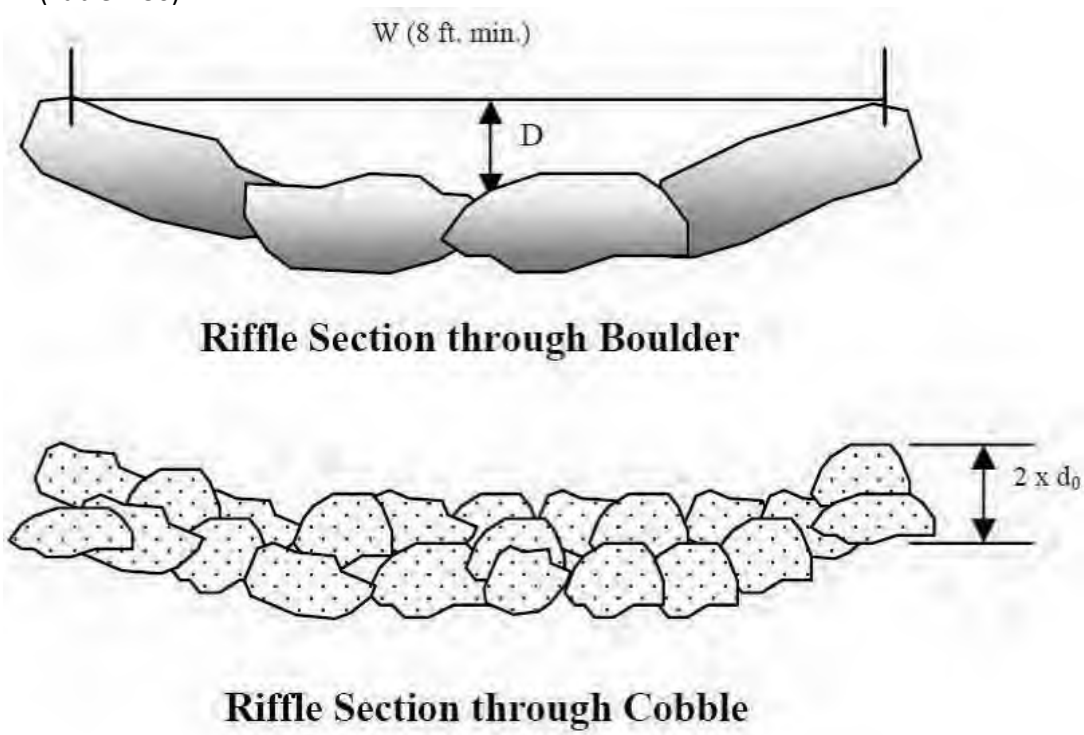

Figure 4.38. Typical Width and Depth of Riffle Sections (Anne Arundel County, 2011).

Table 4.36. Maximum Allowable Velocity

Cobble size (in)	Allowable velocity (ft/s)
4	5.8
5	6.4
6	6.9
7	7.4
8	7.9
9	8.4
10	8.8
11	9.2
12	9.6
15	10.4

- Pools should be between 1.5 and 3 feet deep, and equal to the width of the riffle sections.
- The RSC system is underlain with a sand bed with a 1–5 foot depth and a width between 4 and 14 feet.
- The downstream edge of the riffle should incorporate a series of boulders in a parabolic shape.
- Place a cobble apron below the riffle section to allow for a stable transition between the riffle section and the downstream pools when the pools are dry. The cobble apron should be approximately 5 feet wide and 3 feet long.

The total Sv in the RSC system (available for water quality treatment) is determined by Equation 4.22.

Equation 4.22 RSC Systems Storage Volume

$$Sv = V_{pool} + V_{sandbed}$$

Where:

Sv	=	total storage volume of RSC system (ft^3)
V_{pool}	=	volume in pools (ft^3)
$V_{sandbed}$	=	volume in sand bed (ft^3), use effective porosity of 0.25

4.9.5 Open Channel Landscaping Criteria

All open channels must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. There are several types of grasses appropriate for dry open channels (grass channels and dry swales). These are listed in Table 4.37. Designers should choose plant species that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Designers should ensure that the maximum flow velocities do not exceed the values listed in the table for the selected grass species and the specific site slope. For more information on stabilization seeding, see the Charleston County Stabilization Specifications.

Table 4.37. Recommended Vegetation for Open Channels

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion Resistant Soil	Easily Eroded Soil
Bermuda Grass	0–5	8	6
	5–10	7	5
	>10	6	4
Kentucky Bluegrass	0–5	7	5
	5–10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0–5	6	4
	5–10	4	3
Annual and Perennial Rye	0–5	4	3
Sod		4	3

Source: USDA, TP-61, 1954; Roanoke Virginia, Stormwater Design Manual, 2008

Wet swales should be planted with grass and wetland plant species that can withstand both wet and dry periods as well as relatively high velocity flows within the channel. For a list of wetland plant species suitable for use in wet swales, refer to the wetland panting guidance and plant lists provided in Section 0 Stormwater Wetlands.

Landscape design shall specify proper grass species based on site-specific soils and hydric conditions present along the channel.

Open channels should be seeded at such a density to achieve a 90% vegetated cover after the second growing season. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover.

Grass channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration. Grass channels should be protected by a biodegradable erosion control fabric to provide immediate stabilization of the channel bed and banks.

4.9.6 Open Channel Construction Sequence

Design Notes. Channel invert and tops of banks are to be shown in plan and profile views. A cross sectional view of each configuration and completed limits of grading must be shown for proposed channels. For proposed channels, the transition at the entrance and outfall is to be clearly shown on plan and profile views.

Open Channel Installation. The following is a typical construction sequence to properly install open channels, although steps may be modified to reflect different site conditions or design variations. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation. For more specific information on the installation of wet swales, designers should consult the construction criteria outlined in Section 0 Stormwater Wetlands.

1. Protection During Site Construction. Ideally, open channels should remain outside the limits of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these

cases, temporary soil erosion and sediment controls such as dikes, silt fences, and other erosion control measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel. Dry swales that lack underdrains (and rely on infiltration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

2. Installation. Installation may only begin after the entire CDA has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross section. Soil erosion and sediment controls for construction of the channel must be installed as specified in the soil erosion and sediment control plan. Stormwater flows must not be permitted into the channel until the bottom and side slopes are fully stabilized.

3. Grading. Grade the grass channel to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the open channels to the appropriate design dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the open channel area. If constructing a dry swale, the bottom of the swale should be ripped, rototilled or otherwise scarified to promote greater infiltration.

4. Placing Stone Layer (for dry swales). If constructing a dry swale, place an acceptable geotextile fabric on the underground (excavated) sides of the dry swale with a minimum 6-inch overlap. Place the stone needed for storage layer over the filter bed. Add the perforated underdrain pipe. Add the remaining stone jacket, and then pack No. 57 stone (clean, double-washed) to 3 inches above the top of the underdrain, and then add 3 inches of pea gravel as a filter layer. Add the filter media in 12-inch lifts until the desired top elevation of the dry swale is achieved. Water thoroughly and add additional media as needed where settlement has occurred.

5. Add Amendments (optional, for grass channels). Add soil amendments as needed. Till the bottom of the grass channel to a depth of 1 foot and incorporate compost amendments according to Appendix C Soil Compost Amendment Requirements.

6. Install Check Dams. Install check dams, driveway culverts and internal pretreatment features as shown on the plan. Fill material used to construct check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam must be constructed level at the design elevation.

7. Hydro-seed. Hydro-seed the bottom and banks of the open channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming the South Carolina BMP Handbook (SDHEC, 2005).

8. Plant. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

9. Final Inspection. A qualified professional should conduct the final construction inspection and develop a punch list for facility acceptance.

Open Channel Construction Supervision. Supervision during construction is recommended to ensure that the open channel is built in accordance with these specifications.

Construction phase inspection checklist is available in Appendix E Construction Inspection Checklists.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry swale installation:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pretreatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- For dry swale designs:

  Check the filter media to confirm that it meets specifications and is installed to the correct depth.

  Check elevations, such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.

  Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.

  Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of an open channel occurs after its first big storm. The post-storm inspection should focus on whether the desired sheetflow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams). Also, a qualified professional should check that dry swale practices drain completely within the 72-hour drawdown period.

4.9.7 Open Channel Maintenance Criteria

Maintenance is a crucial and required element that ensures the long-term performance of open channels. Once established, grass channels have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams, and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover. Dry swale designs may require regular pruning and management of trees and shrubs. The surface of dry swale filter beds can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pretreatment cells. Table 4.38 provides a schedule of typical maintenance activities required for open channels.

Table 4.38.Typical Maintenance Activities and Schedule for Open Channels

Schedule	Maintenance Activity
As needed	▪ Mow grass channels and dry swales during the growing season to maintain grass heights in the 4- to 6-inch range.
Quarterly	▪ Ensure that the CDA, inlets, and facility surface are clear of debris. ▪ Ensure that the CDA is stabilized. Perform spot-reseeding if where needed. ▪ Remove accumulated sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ▪ Repair undercut and eroded areas at inflow and outflow structures.
Annual inspection	▪ Add reinforcement planting to maintain 90% turf cover. Reseed areas of dead vegetation. ▪ Remove any accumulated sand or sediment deposits behind check dams. ▪ Inspect upstream and downstream of check dams for evidence of undercutting or erosion. Remove and trash or blockages at weep holes. ▪ Examine channel bottom for evidence of erosion, braiding, excessive ponding, or dead grass. ▪ Check inflow points for clogging and remove any sediment. ▪ Inspect side slopes and grass filter strips for evidence of any rill or gully erosion and repair. ▪ Look for any bare soil or sediment sources in the CDA and stabilize immediately.

Maintenance Inspections. Annual inspections by a qualified professional are used to trigger maintenance operations, such as sediment removal, spot revegetation, and inlet stabilization. Maintenance inspection checklists for disconnection and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.9.8 Open Channel Stormwater Compliance Calculations

Grass channels are credited with 10% retention for the storage volume (Sv) provided by the practice as well as 50% TSS, 25% TN, and 30% bacteria removal (see Table 4.39).

Table 4.39. Grass Channel Retention and Pollutant Removal

Retention	= 10%
TSS Removal	= 50%
TN Removal	= 25%
Bacteria Removal	= 30%

Grass channels with amended soils are credited with 20% retention for the storage volume (Sv) provided by the practice as well as 50% TSS, 35% TN, and 30% bacteria removal (Table 4.40).

Table 4.40. Grass Channel on Amended Soils Retention and Pollutant Removal

Retention	= 20%
TSS Removal	= 50%
TN Removal	= 35%
Bacteria Removal	= 30%

Dry swales are credited with 60% retention for the storage volume (Sv) provided by the practice as well as 85% TSS, 70% TN, and 80% bacteria removal (Table 4.41).

Table 4.41. Dry Swale Retention and Pollutant Removal

Retention	= 60%
TSS Removal	= 85%
TN Removal	= 70%
Bacteria Removal	= 80%

Wet Swales are credited with 0% retention, but they do receive 80% TSS, 25% TN, and 60% bacteria removal for the storage volume (Sv) provided by the practice (Table 4.42).

Table 4.42. Wet Swale Retention and Pollutant Removal

Retention	= 0%
TSS Removal	= 80%
TN Removal	= 25%
Bacteria Removal	= 60%

RSCs are credited with 0% retention, but they do receive 80% TSS, 40% TN, and 80% bacteria removal for the storage volume (Sv) provided by the practice (Table 4.43).

Table 4.43. RSC Retention and Pollutant Removal

Retention	= 0%
TSS Removal	= 80%
TN Removal	= 40%
Bacteria Removal	= 80%

All practices must be sized using the guidance detailed in Section 4.7.4 Open Channel Design Criteria.

Open channels also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume from the total runoff volume for the 2-year through the 50-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

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Virginia DCR Stormwater Design Specification No. 10: Dry Swales Version 1.8. 2010.

Virginia DCR Stormwater Design Specification No. 11: Wet Swales Version 1.8. 2010.

Washington State Department of Ecology. 2005. Stormwater Manual for Western Washington. State of Washington Department of Ecology. Available online at: https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals

4.10 Filtering Systems

Filtering Systems				
Definition: Practices that capture and temporarily store the design storm volume and pass it through a filter bed of sand media. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate into the soil.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		80%	30%	80%
		Runoff Reductions		
Construction Costs	**Maintenance Burden**	**Volume**		
High	High	Low		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	0%		
At least annually	Every 5 years			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Applicable to small drainage areas ▪ Good for highly impervious areas ▪ Good for water quality retrofits to existing developments		▪ High maintenance burden ▪ Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas ▪ Relatively costly ▪ Possible odor problems, if not maintained ▪ Limited volume and rate control		
Components		**Design considerations**		
▪ Conveyance ▪ Pretreatment ▪ Sand bed (or Filtration) chamber ▪ Spillway/outlet system(s) ▪ Liner, as needed		▪ Typically requires 2 to 10 feet of head ▪ Maximum CDA of 2-5 acres ▪ Must drain within 40 hours ▪ In karst areas, watertight structure required ▪ Maintenance access		
Maintenance Activities				
▪ Inspect for clogging—rake first inch of sand ▪ Remove sediment from pretreatment areas		▪ Replace filter media as needed ▪ Clean spillway/outlet system(s)		

[1]*Credited pollutant load removal*

Stormwater filters are a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. Stormwater filters are a versatile option because they consume very little surface land and have few site restrictions. They provide moderate pollutant removal performance at small sites where space is limited.

Definition. Practices that capture and temporarily store the design storm volume and pass it through a filter bed of sand media. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate into the soil. Design variants include the following:

F-1 Nonstructural sand filter

F-2 Surface sand filter

F-3 Three-chamber underground sand filter

F-4 Perimeter sand filter

Filters have no retention capability, so designers should consider using up-gradient retention practices, which have the effect of decreasing the design storm volume and size of the filtering practices. Filtering practices are also suitable to provide special treatment at designated stormwater hotspots.

Filtering systems are typically not designed to provide stormwater detention, but they may be in some circumstances. Filtering practices are generally combined with separate facilities to provide this type of control. However, the three-chamber underground sand filter can be modified by expanding the first (or settling) chamber, or by adding an extra chamber between the filter chamber and the clear well chamber to handle the detention volume, which is subsequently discharged at a predetermined rate through an orifice and weir combination.

A nonstructural or surface sand filter is depicted in Figure 4.39, while Figure 4.40 through Figure 4.45 depict three-chamber underground sand filters.

Perimeter sand filters (Figure 4.46) are enclosed stormwater management practices that are typically located just below grade in a trench along the perimeter of parking lot, driveway, or other impervious surface. Perimeter sand filters consist of a pretreatment forebay and a filter bed chamber. Stormwater runoff is conveyed into a perimeter sand filter through grate inlets located directly above the system

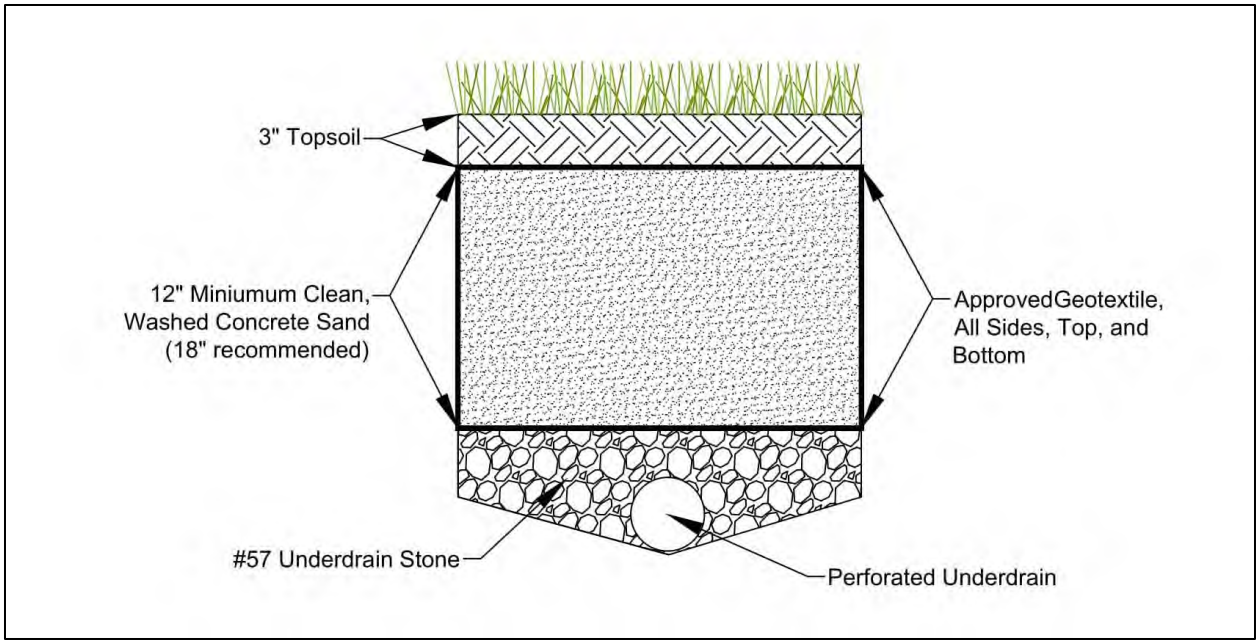

Figure 4.39. Typical schematic for a nonstructural or surface sand filter (note: material specifications are found in Table 4.44).

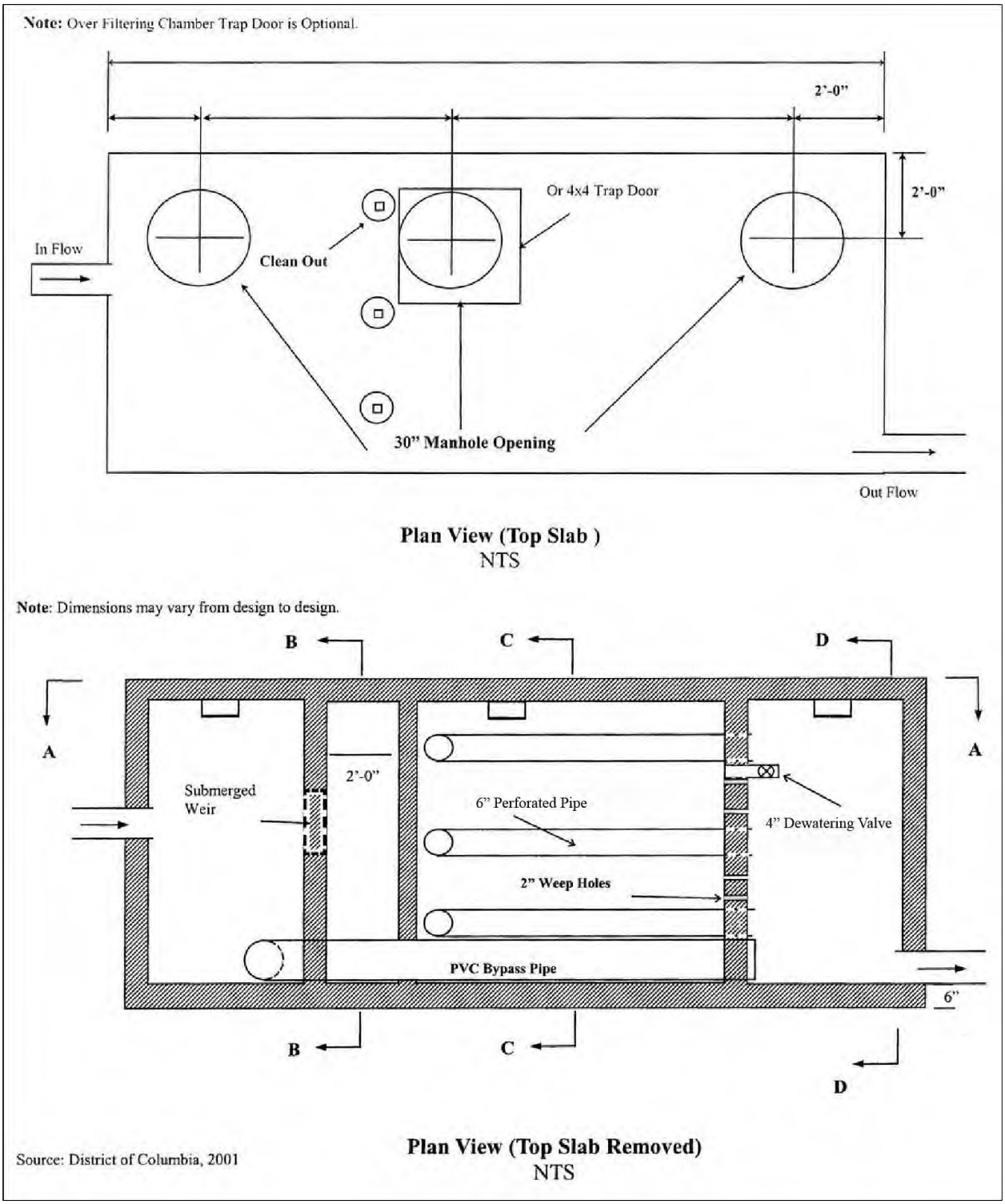

Figure 4.40. Example of a three-chamber underground sand filter (F-3) for separate sewer options. Part A. Note: material specifications are indicated in Table 4.44.

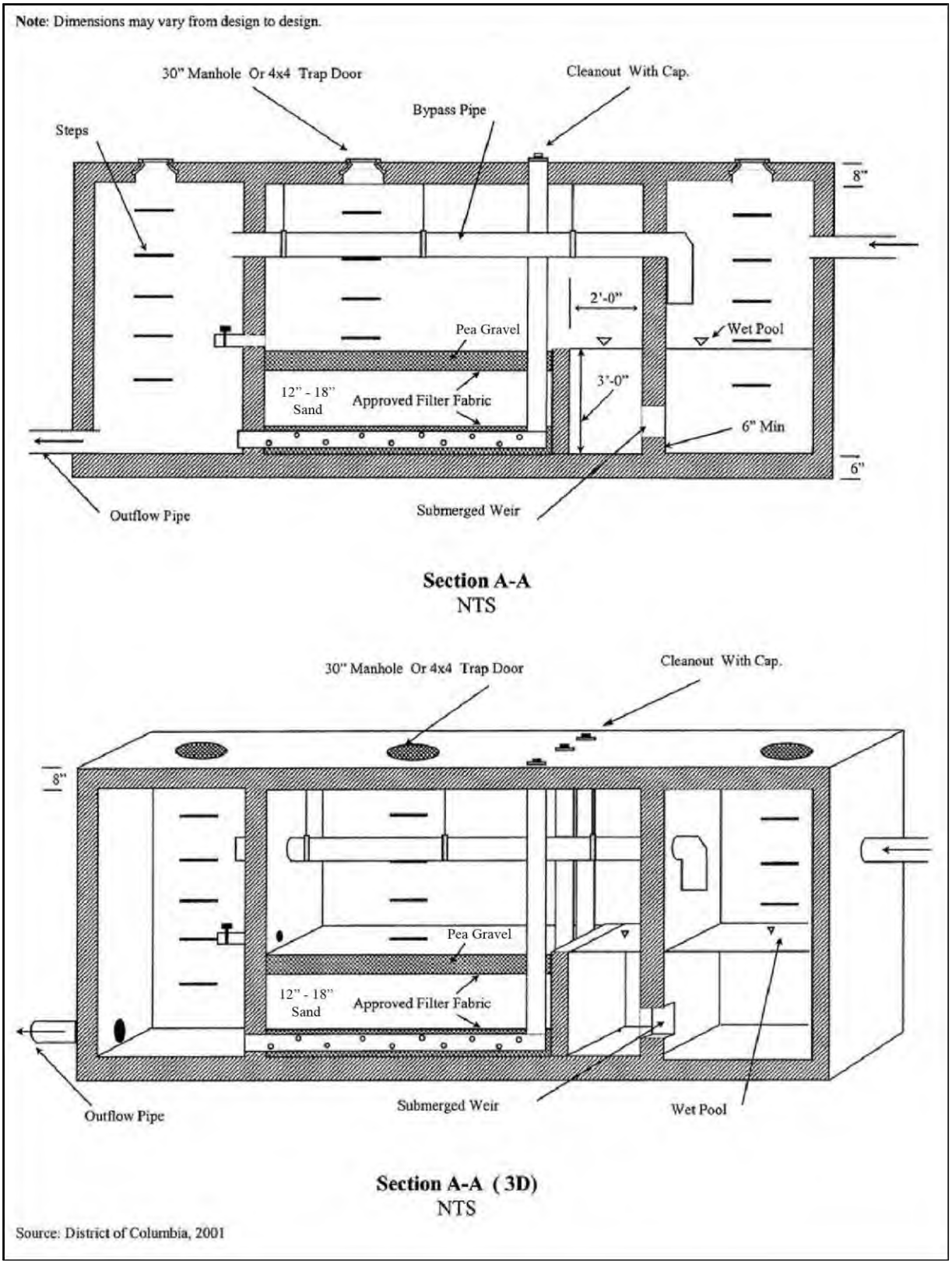

Figure 4.41. Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Part B. Note: material specifications are indicated in Table 4.44.

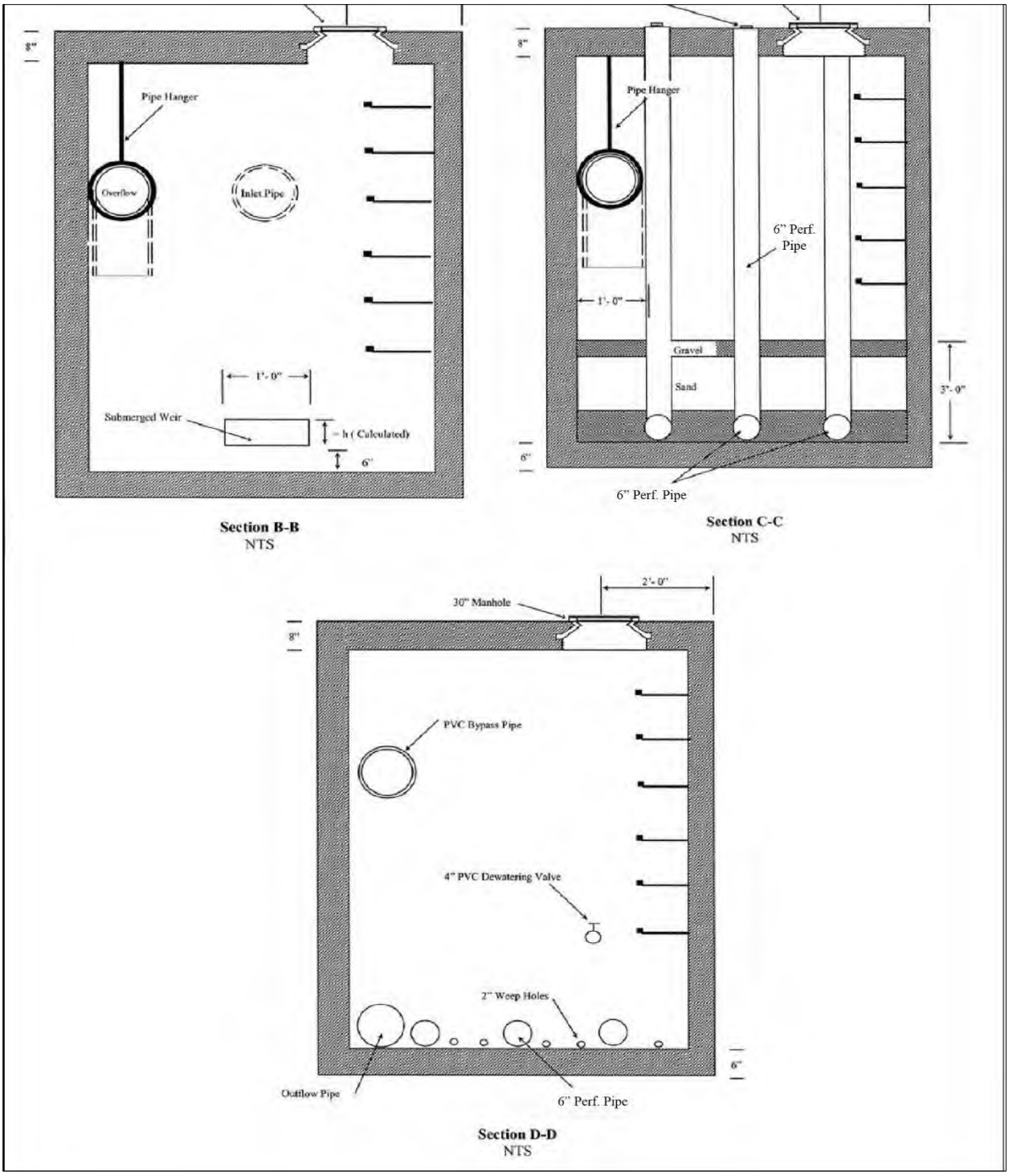

Figure 4.42. Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Part C. Note: material specifications are indicated in Table 4.44.

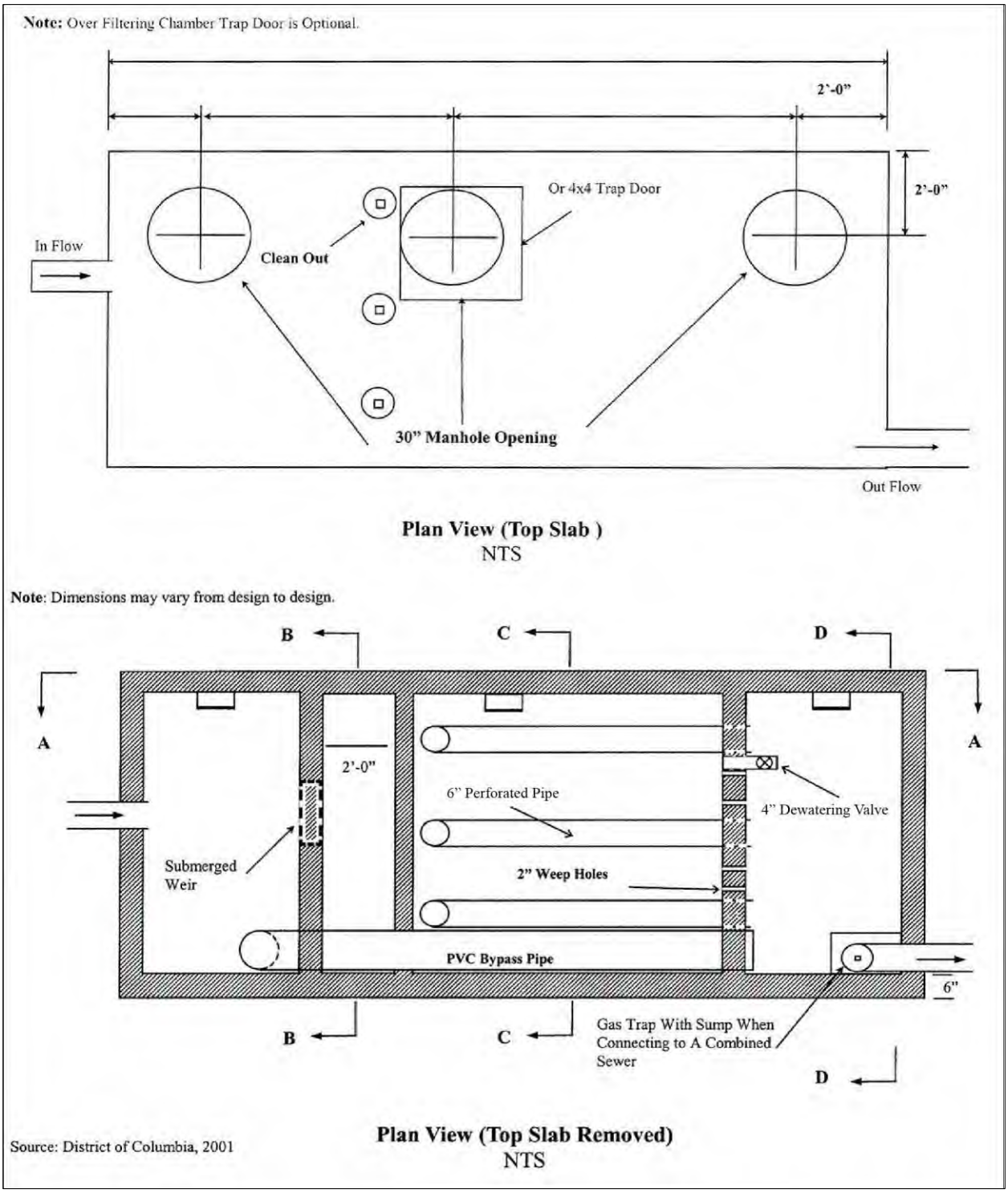

Figure 4.43. Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Part A. Note: Material specifications are indicated in Table 4.44.

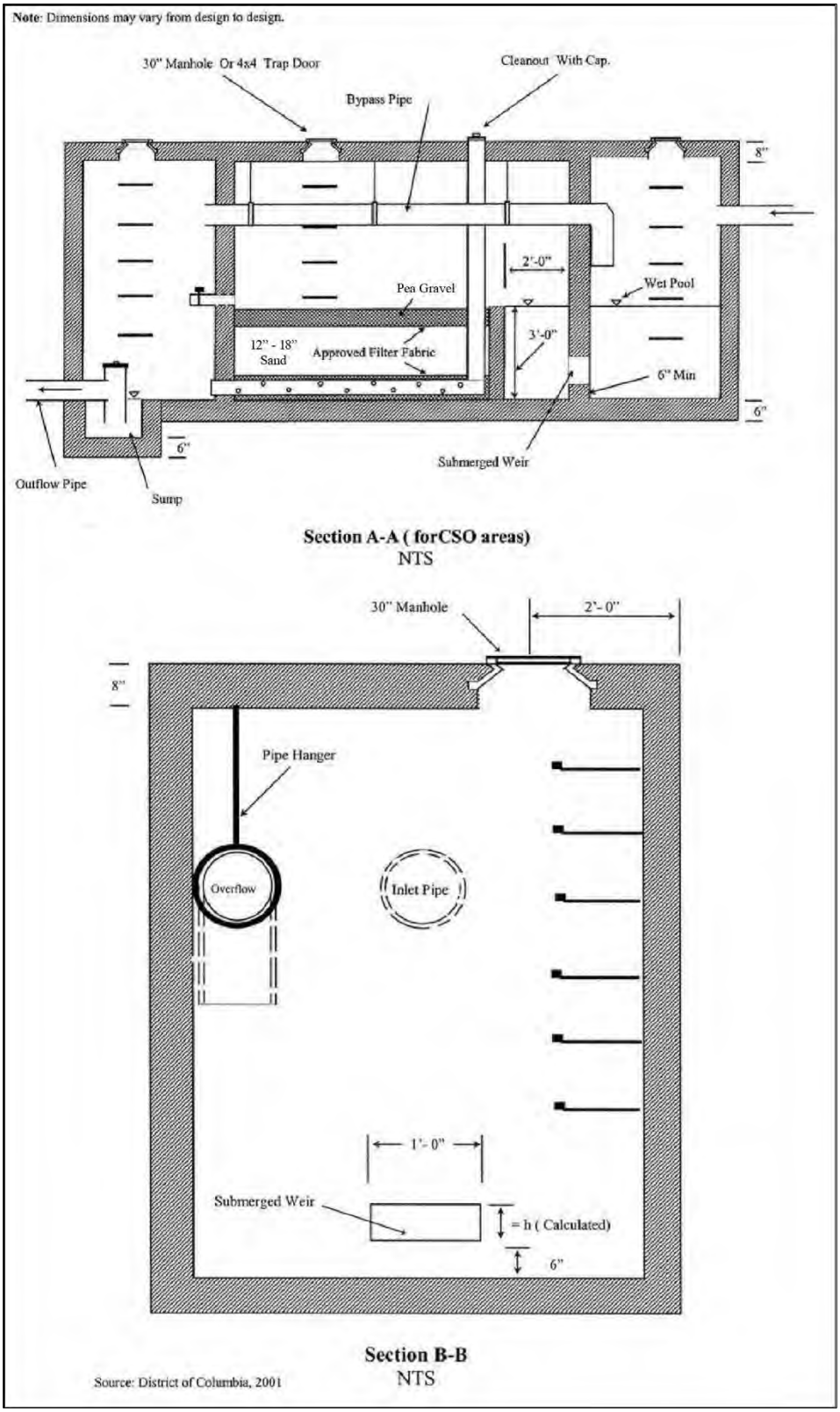

Figure 4.44. Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Part B. Note: Material specifications are indicated in Table 4.44.

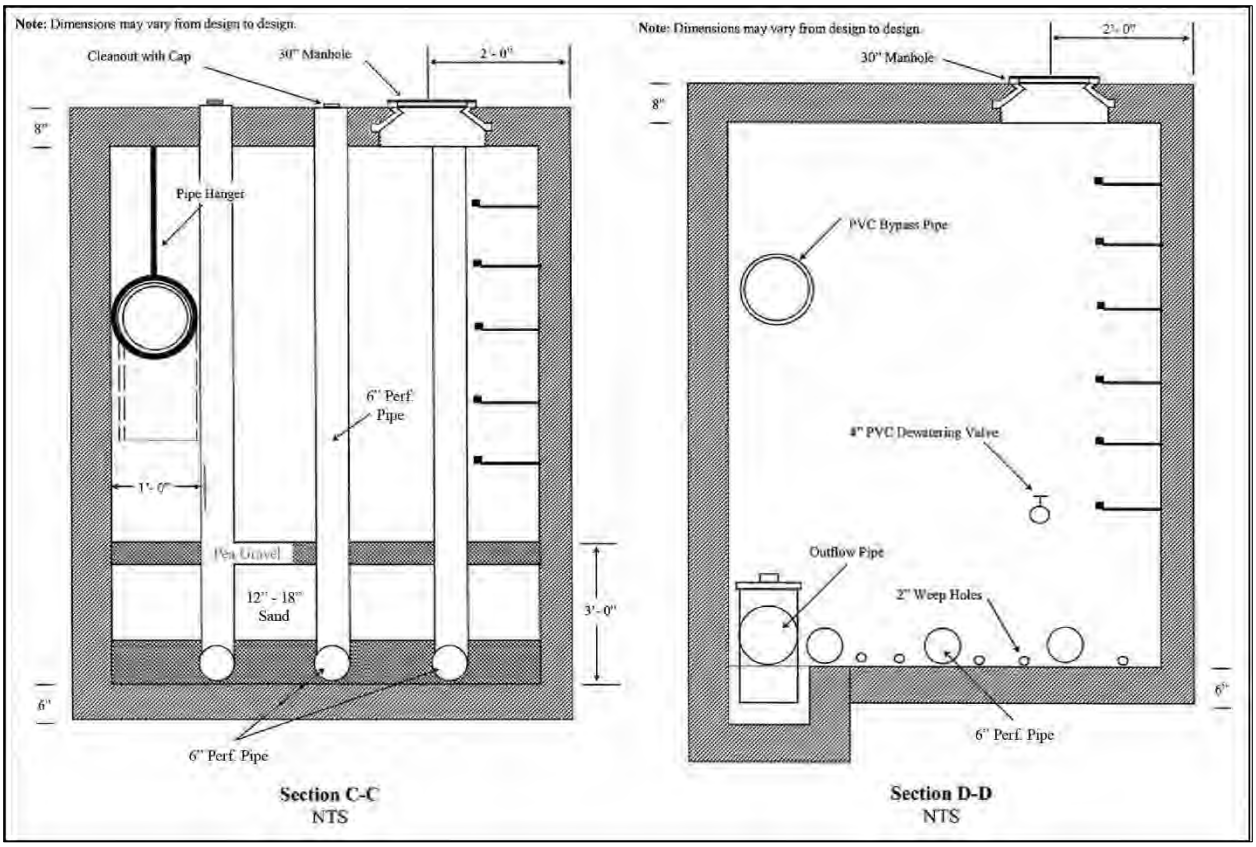

Figure 4.45. Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Part C. Note: Material specifications are indicated in Table 4.44.

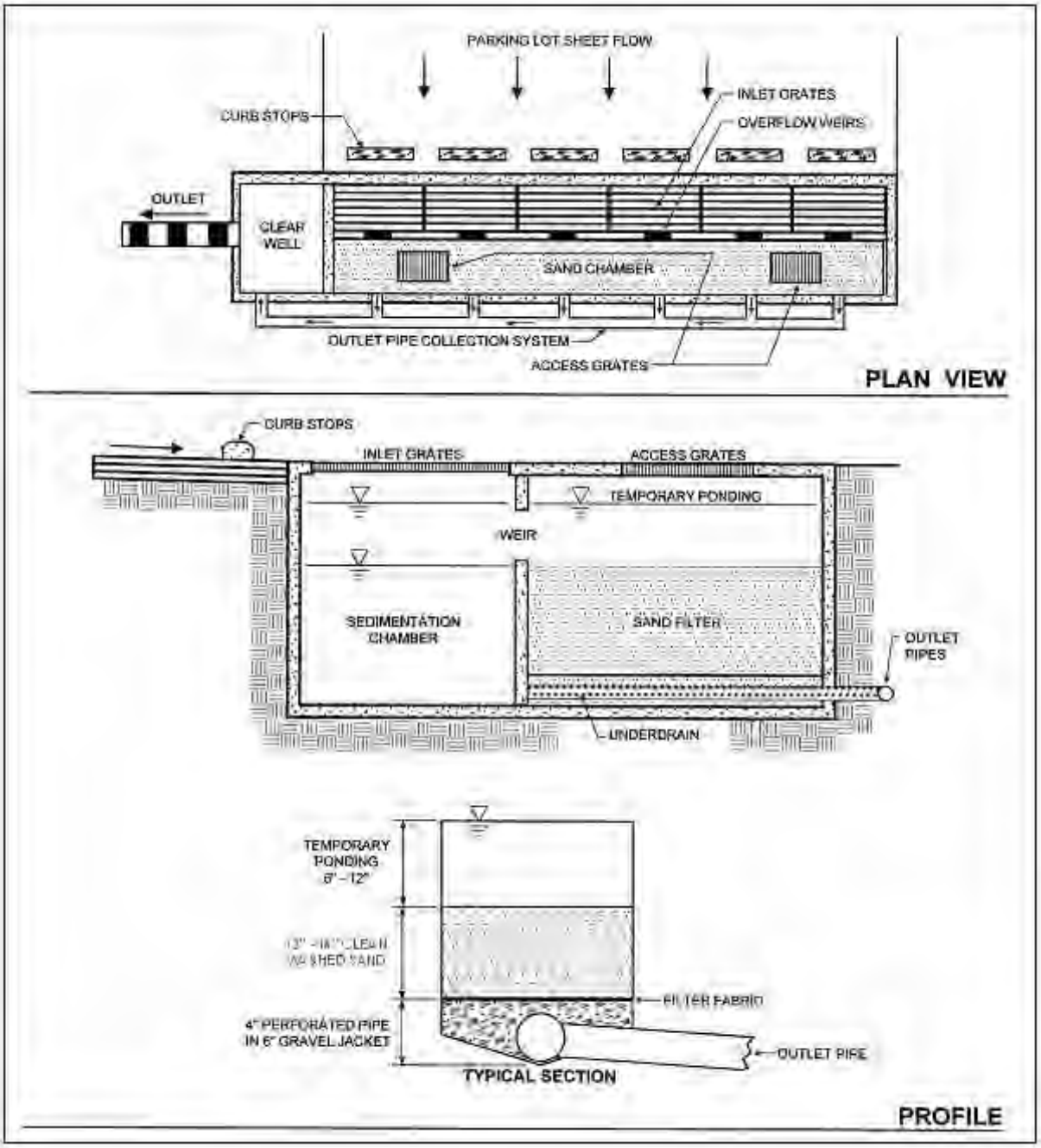

Figure 4.46. Example of a perimeter sand filter (F-4). Note: material specifications are indicated in Table 4.44.

4.10.1 Filtering System Feasibility Criteria

Stormwater filters can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they may clearly be the best option for stormwater treatment (e.g., hotspot runoff treatment, small parking lots, ultra-urban areas, etc.). The following criteria apply to filtering practices:

Available Hydraulic Head. The principal design constraint for stormwater filters is available hydraulic head, which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the existing storm drain system that receives its discharge. The head required for stormwater filters ranges from 2 to 10 feet, depending on the design variant. It is difficult to employ filters in extremely flat terrain, since they require gravity flow through the filter. The only exception is the perimeter sand filter, which can be applied at sites with as little as 2 feet of head.

Depth to Water Table. The designer must assure a standard separation distance of at least 0.5 feet between the groundwater table and the bottom invert of the filtering practice.

Contributing Drainage Area. Filters are best applied on small sites where the CDA is as close to 100% impervious as possible to reduce the risk that eroded sediment will clog the filter. If the CDA is pervious, then the vegetation must be dense and stable. Turf is acceptable (see Section 4.10.5 Filtering Landscaping Criteria). A maximum CDA of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for perimeter or underground filters. Filters have been used on larger CDAs in the past, but greater clogging problems have typically resulted.

Space Required. The amount of space required for a filter practice depends on the design variant selected. Surface sand filters typically consume about 2%–3% of the CDA, while perimeter sand filters typically consume less than 1%. Underground stormwater filters generally consume no surface area except their manholes.

Land Use. As noted above, filters are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Filters can work on most commercial, industrial, institutional, or municipal sites and can be located underground if surface area is not available.

Site Topography. Filters shall not be located on slopes greater than 6%.

Utilities. All utilities shall have a minimum 5-foot, horizontal clearance from the filtering practice.

Facility Access. All filtering systems shall be located in areas where they are accessible for inspection and for maintenance (by vacuum trucks).

Soils. Soil conditions do not constrain the use of filters. At least one soil boring must be taken at a low point within the footprint of the proposed filtering practice to establish the water table and evaluate soil suitability. A geotechnical investigation is required for all underground stormwater BMPs, including underground filtering systems. Geotechnical testing requirements are outlined in Appendix B Geotechnical Information Requirements for Underground BMPs.

Setbacks. Filters should be set back at least 10 feet from the property line, and the bottom of the practice should be separated from groundwater by at least 0.5 feet.

Economic Considerations. Perimeter sand filters are expensive relative to other treatment practices, but may be the only option to treat small hotspot drainage areas.

4.10.2 Filtering System Conveyance Criteria

Most filtering practices are designed as off-line systems so that all flows enter the filter storage chamber until it reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an

outlet chamber and are not treated. Runoff from larger storm events must be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Some underground filters will be designed and constructed as on-line BMPs. In these cases, designers must indicate how the device will safely pass larger storm events (e.g., the 25-year event) to a stabilized water course without resuspending or flushing previously trapped material.

All stormwater filters must be designed to drain or dewater within 40 hours (1.67 days) after a storm event to reduce the potential for nuisance conditions.

4.10.3 Filtering System Pretreatment Criteria

Adequate pretreatment is needed to prevent premature filter clogging and ensure filter longevity. Dry or wet pretreatment shall be provided prior to filter media. Pretreatment devices are subject to the following criteria:

- Sedimentation chambers are typically used for pretreatment to capture coarse sediment particles before they reach the filter bed.
- Sedimentation chambers may be wet or dry but must be sized to accommodate at least 25% of the total design storm volume (inclusive).
- Sediment chambers should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.
- Non-structural and surface sand filters may use alternative pretreatment measures, such as a grass filter strip, forebay, gravel diaphragm, check dam, level spreader, or a combination of these. The grass filter strip must be a minimum length of 15 feet and have a slope of 3% or less. The check dam may be wooden or concrete and must be installed so that it extends only 2 inches above the filter strip and has lateral slots to allow runoff to be evenly distributed across the filter surface. Alternative pretreatment measures must contain a non-erosive flow path that distributes the flow evenly over the filter surface. If a forebay is used, it must be designed to accommodate at least 25% of the total design storm volume (inclusive).

4.10.4 Filtering System Design Criteria

Detention time. All filter systems must be designed to drain the design storm volume from the filter chamber within 40 hours (1.67 days) after each rainfall event.

Structural Requirements. If a filter will be located underground or experience traffic loads, a licensed structural engineer must certify the structural integrity of the design.

Geometry. Filters are gravity flow systems that normally require 2 to 5 feet of driving head to push the water through the filter media through the entire maintenance cycle; therefore, sufficient vertical clearance between the inverts of the inflow and outflow pipes is required.

Type of Filter Media. The normal filter media consists of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains 0.02 to 0.04 inches in diameter.

Depth of Filter Media. The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. The recommended filter bed depth is 18

inches. An absolute minimum filter bed depth of 12 inches above underdrains is required; although, designers should note that specifying the minimum depth of 12 inches will incur a more intensive maintenance schedule and possibly result in costlier maintenance.

Underdrain and Liner. Stormwater filters are normally designed with an impermeable liner and underdrain system that meet the criteria provided in Table 4. 44 below.

Underdrain Stone. The underdrain should be covered by a minimum 6-inch gravel layer consisting of clean, double washed No. 57 stone.

Type of Filter. There are several design variations of the basic filter that enable designers to use filters at challenging sites or to improve pollutant removal rates. The choice of which filter design to apply depends on available space, hydraulic head, and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. Surface and perimeter filters are often a more economical choice when adequate surface area is available. The most common design variants include the following:

- **Non-Structural Sand Filter (F-1).** The non-structural sand filter is applied to sites less than 2 acres in size and is very similar to a bioretention practice (see Section 4.3 Bioretention), with the following exceptions:
    - The bottom is lined with an impermeable liner and always has an underdrain.
    - The surface cover is sand, turf, or pea gravel.
    - The filter media is 100% sand.
    - The filter surface is not planted with trees, shrubs, or herbaceous materials.
    - The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.
    - The non-structural sand filter is the least expensive filter option for treating hotspot runoff. The use of bioretention areas is generally preferred at most other sites.
- **Surface Sand Filter (F-2).** The surface sand filter is designed with both the filter bed and sediment chamber located at ground level. The most common filter media is sand; however, a peat/sand mixture may be used to increase the removal efficiency of the system. In most cases, the filter chambers are created using precast or cast-in-place concrete. Surface sand filters are normally designed to be off-line facilities, so that only the desired design volume is directed to the filter for treatment. However, in some cases they can be installed on the bottom of a dry pond (see Section 4.11 Storage Practices).
- **Underground Sand Filter.** The underground sand filter is modified to install the filtering components underground and is often designed with an internal flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter. Underground sand filters are expensive to construct, but they consume very little space and are well suited to ultra-urban areas.
- **Three-Chamber Underground Sand Filter (F-3).** The three-chamber underground sand filter is a gravity flow system. The facility may be precast or cast-in-place. The first chamber acts as a pretreatment facility removing any floating organic material such as oil, grease, and tree leaves. It should have a submerged orifice leading to a second chamber, and it should be designed to minimize the energy of incoming stormwater before the flow enters the second chamber (i.e., filtering or processing chamber).

  The second chamber is the filtering or processing chamber. It should contain the filter material consisting of gravel and sand and should be situated behind a weir. Along the bottom of the

structure should be a subsurface drainage system consisting of a parallel perforated PVC pipe system in a stone bed. A dewatering valve should be installed at the top of the filter layer for safety release in cases of emergency. A bypass pipe crossing the second chamber to carry overflow from the first chamber to the third chamber is required.

The third chamber is the discharge chamber. It should also receive the overflow from the first chamber through the bypass pipe when the storage volume is exceeded.

Water enters the first chamber of the system by gravity or by pumping. This chamber removes most of the heavy solid particles, floatable trash, leaves, and hydrocarbons. Then the water flows to the second chamber and enters the filter layer by overtopping a weir. The filtered stormwater is then picked up by the subsurface drainage system that empties it into the third chamber.

Whenever there is insufficient hydraulic head for a three-chamber underground sand filter, a well pump may be used to discharge the effluent from the third chamber into the receiving storm or combined sewer. For three-chamber sand filters in combined-sewer areas, a water trap shall be provided in the third chamber to prevent the back flow of odorous gas.

- **Perimeter Sand Filter (F-4).** The perimeter sand filter also includes the basic design elements of a sediment chamber and a filter bed. The perimeter sand filter typically consists of two parallel trenches connected by a series of overflow weir notches at the top of the partitioning wall, which allows water to enter the second trench as sheet flow. The first trench is a pretreatment chamber removing heavy sediment particles and debris. The second trench consists of the sand filter layer. A subsurface drainage pipe must be installed at the bottom of the second chamber to facilitate the filtering process and convey filter water into a receiving system.

  In this design, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber. One major advantage of the perimeter sand filter design is that it requires little hydraulic head and is therefore a good option for sites with low topographic relief.

Surface Cover. The surface cover for non-structural and surface sand filters should consist of a 3-inch layer of topsoil on top of the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. The pea gravel may be located where sheet flow enters the filter, around the margins of the filter bed, or at locations in the middle of the filter bed.

Underground sand filters should have a pea gravel or No. 57 stone layer on top of the sand layer. This gravel layer helps to prevent bio-fouling or blinding of the sand surface.

Maintenance Reduction Features. The following maintenance issues should be addressed during filter design to reduce future maintenance problems:

- **Observation Wells and Cleanouts.** Non-structural and surface sand filters must include an observation well consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe must be provided for every 2,000 square feet of filter surface area.

- **Access.** Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts. Direct maintenance access shall be provided to the pretreatment area and the filter bed. For underground structures, sufficient headroom for maintenance should be provided. A minimum head space of 5 feet above the filter is recommended for maintenance of the structure. However, if 5 feet of headroom is not available, manhole access must be installed.
- **Manhole Access (for underground filters).** Access to the headbox and clearwell of Underground Filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.
- **Visibility.** Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can easily find them. Adequate signs or markings must be provided at manhole access points for Underground Filters.
- **Confined Space Issues.** Underground filters are often classified as a confined space. Consequently, special OSHA rules apply, and training may be needed to protect the workers that access them. These procedures often involve training about confined space entry, venting, and the use of gas probes.

Filter Material Specifications. The basic material specifications for filtering practices that utilize sand as a filter media are outlined in Table 4.44.

Table 4.44. Filtering Practice Material Specifications

Material	Specification
Surface Cover	Non-structural and surface sand filters: 3-inch layer of topsoil on top of the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. Underground sand filters: Clean, double-washed pea gravel or No. 57 stone on top of the sand layer.
Sand	Clean AASHTO M-6/ASTM C-33 medium aggregate concrete sand with a particle size range of 0.02–0.04 inches in diameter.
Choker Stone and/or Geotextile/Filter Fabric	For choker stone, a 2- to 4-inch layer of choker stone (e.g., typically ASTM D448 No. 8 or No. 89 washed gravel) should be placed between the sand layer and the underdrain stone. Alternatively, if available head is limited, an appropriate geotextile fabric that meets AASHTO M-288 Class 2, latest edition, requirements may be used. The geotextile fabric must have a flow rate of > 125 gpm/ft^2 (ASTM D4491) and an Apparent Opening Size (AOS) equivalent to a US No. 70 or No. 80 sieve.
Underdrain/Perforated Pipe	4- or 6-inch perforated schedule 40 PVC pipe, with three or four rows of 3/8-inch perforations at 6 inches on center.
Underdrain Stone	Use No. 57 stone or the ASTM equivalent (1-inch maximum).
Impermeable Liner	Where appropriate, use a PVC Geomembrane liner or equivalent.

Filter Sizing. Filtering devices are sized to accommodate a specified design storm volume (typically SWRv). The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given design volume, Equation 4.23 is used to determine the required filter surface area.

Equation 4.23 Minimum Filter Surface Area for Filtering Practices

$$SA_{filter} = \frac{DesignVolume \times d_f}{k \times (h_{avg} + d_f) \times t_d}$$

Where:

SA_{filter}	=	area of the filter surface (ft^2)
DesignVolume	=	design storm volume, typically the SWRv (ft^2)
d_f	=	filter media depth (thickness) (ft), with a minimum of 1 ft
k	=	coefficient of permeability (ft/day) (3.5 ft/day for partially clogged sand)
h_f	=	height of water above the filter bed (ft), with a maximum of 5 ft
h_{avg}	=	average height of water above the filter bed (ft), one half of the filter height (h_f)
t_d	=	allowable drawdown time (1.67 days)

The coefficient of permeability (ft/day) is intended to reflect the worst-case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Filtering practices are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

The entire filter treatment system, including pretreatment, shall temporarily hold at least 50% of the design storm volume prior to filtration (see Equation 4.24). This reduced volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation 4.24 Required Ponding Volume for Filtering Practices

$$V_{ponding} = 0.50 \times DesignVolume$$

Where:

$V_{ponding}$	=	storage volume required prior to filtration (ft^3)
DesignVolume	=	design storm volume, typically the SWRv (ft^2)

The total storage volume for the practice (Sv) can be determined using Equation 4. 25 below.

Equation 4.25 Storage Volume for Filtering Practices

$$Sv = 2.0 \times V_{ponding}$$

Where:

Sv	=	total storage volume for the practice (ft^3)
$V_{ponding}$	=	storage volume required prior to filtration (ft^3)

4.10.5 Filtering System Landscaping Criteria

A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Filtering practices should be incorporated into site landscaping to increase their aesthetics and public appeal.

Surface filters (e.g., surface and non-structural sand filters) can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

4.10.6 Filtering System Construction Sequence

Soil Erosion and Sediment Control. No runoff shall be allowed to enter the filter system prior to completion of all construction activities, including revegetation and final site stabilization. Construction runoff shall be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials must be removed and replaced with new clean filter materials before a regulatory inspector approves its completion. The approved soil erosion and sediment control plan shall include specific measures to provide for the protection of the filter system before the final stabilization of the site.

Filter Installation. The following is the typical construction sequence to properly install a structural sand filter. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity, and configuration of the proposed filtering application.

1. Stabilize Contributing Drainage Area

Filtering practices should only be constructed after the CDA to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility will be dewatered, dredged, and regraded to design dimensions for the post-construction filter.

2. Install Soil Erosion and Sediment Control Measures for the Filtering Practice

Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is extremely important to keep runoff and eroded sediment away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch, or other method.

3. Assemble Construction Materials on Site

Inspect construction materials to ensure they conform to design specifications and prepare any staging areas.

4. Clear and Strip

Bring the project area to the desired subgrade.

5. Excavate and Grade

Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the filtering practice.

6. Install Filter Structure

Install filter structure in design location and check all design elevations (i.e., concrete vaults for surface, underground, and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets must be temporarily plugged and the structure filled with water to the brim to demonstrate water tightness. Maximum allowable leakage is 5% of the water volume in a 24-hour period. See Appendix E Construction Inspection Checklists for the Stormwater Facility Leak Test form. If the structure fails the test, repairs must be performed to make the structure watertight before any sand is placed into it.

7. Install Base Material Components

Install the gravel, underdrains, and choker layers of the filter.

8. Install Top Sand Component

Spread sand across filter bed in 1-foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the filter bed.

9. Install Surface Layer (Surface Sand Filters only)

Add a 3-inch topsoil layer and pea gravel inlets and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.

10. Stabilize Surrounding Areas

Stabilize exposed soils on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the normal pool should be permanently stabilized by hydroseed, sod, or seeding and mulch.

11. Final Inspection. Conduct the final construction inspection

Multiple construction inspections by a qualified professional are critical to ensure that stormwater filters are properly constructed. Inspections are recommended during the following stages of construction:

- Initial site preparation, including installation of soil erosion and sediment control measures;
- Excavation/grading to design dimensions and elevations;
- Installation of the filter structure, including the water tightness test;
- Installation of the underdrain and filter bed;
- Check that turf cover is vigorous enough to switch the facility on-line; and

- Final inspection after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance. Log the filtering practice's GPS coordinates and submit them for entry into the BMP maintenance tracking database.

Construction phase inspection checklist for filters and the Stormwater Facility Leak Test form can be found in Appendix E Construction Inspection Checklists.

4.10.7 Filtering System Maintenance Criteria

Maintenance of filters is required and involves several routine maintenance tasks, which are outlined in Table 4.45. A cleanup should be scheduled at least once a year to remove trash and floatables that accumulate in the pretreatment cells and filter bed. Frequent sediment cleanouts in the dry and wet sedimentation chambers are recommended every 1 to 3 years to maintain the function and performance of the filter. If the filter treats runoff from a stormwater hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. Petroleum hydrocarbon contaminated sand or filter cloth must be disposed of according to State solid waste disposal regulations. Testing is not needed if the filter does not receive runoff from a designated stormwater hotspot, in which case the media can be safely disposed of in a landfill.

Table 4.45. Typical Annual Maintenance Activities for Filtering Practices

Frequency	Maintenance Tasks
At least 4 times per growing season	▪ Mow grass filter strips and perimeter turf around surface sand filters. Maximum grass heights should be less than 12 inches.
2 times per year (may be more or less frequently depending on land use)	▪ Check to see if sediment accumulation in the sedimentation chamber has exceeded 6 inches. If so, schedule a cleanout.
Annually	▪ Conduct inspection and cleanup. ▪ Dig a small test pit in the filter bed to determine whether the first 3 inches of sand are visibly discolored and need replacement. ▪ Check to see if inlets and flow splitters are clear of debris and are operating properly. ▪ Check concrete structures and outlets for any evidence of spalling, joint failure, leakage, corrosion, etc. ▪ Ensure that the filter bed is level and remove trash and debris from the filter bed. Sand or gravel covers should be raked to a depth of 3 inches.
Every 5 years	▪ Replace top sand layer. ▪ Till or aerate surface to improve infiltration/grass cover.
As needed	▪ Remove blockages and obstructions from inflows. Trash collected on the grates protecting the inlets shall be removed regularly to ensure the inflow capacity of the BMP is preserved. ▪ Stabilize CDA and side-slopes to prevent erosion. Filters with a turf cover should have 95% vegetative cover.
Upon failure	▪ Corrective maintenance is required any time the sedimentation basin and sediment trap do not draw down completely after 72 hours (i.e., no standing water is allowed).

Maintenance Inspections. Regular inspections by a qualified professional are critical to schedule sediment removal operations, replace filter media, and relieve any surface clogging. Frequent

inspections are especially needed for underground and perimeter filters, since they are out of sight and can be easily forgotten. Depending on the level of traffic or the particular land use, a filter system may either become clogged within a few months of normal rainfall or could possibly last several years with only routine maintenance. Maintenance inspections should be conducted within 24 hours following a storm that exceeds 0.5 inch of rainfall, to evaluate the condition and performance of the filtering practice.

Note: Without regular maintenance, reconditioning sand filters can be very expensive.

Maintenance inspection checklists for filters and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.10.8 Filtering System Stormwater Compliance Calculations

Filtering practices are credited with 0% retention, but they do receive 80% TSS, 30% TN, and 80% bacteria removal for the storage volume (Sv) provided by the (Table 4.46).

Table 4.46. Filter Retention and Pollutant Removal

Retention	= 0%
TSS Removal	= 80%
TN Removal	= 30%
Bacteria Removal	= 80%

The practice must be sized using the guidance detailed in Section 4.8.4 Filtering Design Criteria.

4.10.9 References

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Virginia DCR Stormwater Design Specification No. 12: Filtering Practices Version 1.7. 2010.

4.11 Storage Practices

Storage Practices				
Definition: Practices that are explicitly designed to provide stormwater detention (2- to 25-year, and/or flood control).				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Low		
▪ Urban ▪ Suburban ▪ Rural	Medium	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		60%	10%	60%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
Moderate	Low	Low		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	0%		
Quarterly	Every 10–15 years			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Flood control ▪ Typically less costly than stormwater (wet) ponds for equivalent flood storage ▪ Provides recreational and other open space opportunities between storm runoff events		▪ Minimal water quality treatment ▪ Best suited to large CDAs (at least 10 acres) ▪ Tends to re-suspend sediment		
Components		**Design considerations**		
▪ Conveyance ▪ Inlets/outlets ▪ Forebay ▪ Ponding area with available storage ▪ Micropool ▪ Spillway system(s) ▪ Liners, as needed		▪ Depth to seasonal high water table must be at least 6 inches below bottom of practice ▪ Drawdown of 24 to 48 hours ▪ Shallow pond with large surface area performs better than deep pond of same volume ▪ Maintenance access		
Maintenance Activities				
▪ Remove debris (inlets/outlets/basin surface) ▪ Remove sediment buildup ▪ Repair and revegetate eroded areas.		▪ Perform structural repairs to inlet and outlets. ▪ Mow unwanted vegetation		

[1]*Credited pollutant load removal*

Storage practices are a common BMP used to temporarily detain runoff to reduce peak flows (Figure 4.47).

Figure 4.47. Dry Extended Detention Pond (Photo: Center for Watershed Protection, Inc.)

Definition. Storage practices are explicitly designed to provide stormwater detention (2- to 25-year, and/or flood control). Design variants include the following:

S-1 Underground detention vaults and tanks

S-2 Dry detention ponds

S-3 Rooftop storage

S-4 Stone storage under permeable pavement or other BMPs

Detention vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Detention tanks are underground storage facilities typically constructed with large diameter concrete or plastic pipe (see Figure 4.44). Both serve as an alternative to surface dry detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area. Prefabricated concrete vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems.

Dry detention ponds are widely applicable for most land uses and are best suited for larger SDAs. An outlet structure restricts stormwater flow, so it backs up and is stored within the basin (see Figure 4. 45). The temporary ponding reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on the bed and banks of the receiving stream.

Storage practices do not receive any stormwater retention or treatment volume and should be considered only for management of larger storm events. Storage practices are not considered an acceptable practice to meet the SWRv. Storage practices must be combined with a separate facility to meet these requirements. Upland practices can be used to satisfy some, or all, of the stormwater retention requirements at many sites, which can help to reduce the footprint and volume of storage practices.

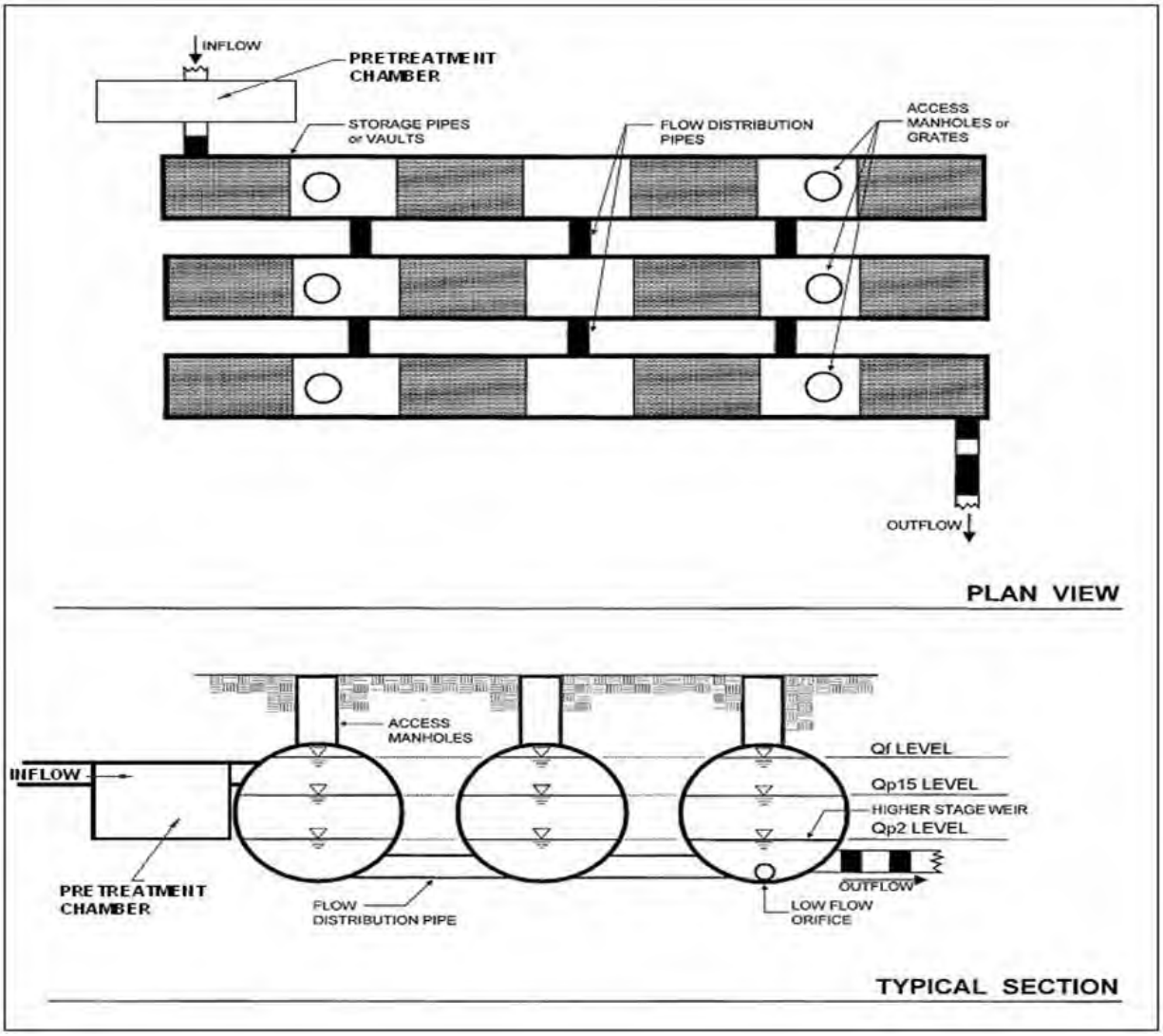

Figure 4.45 Example of an underground detention vault and/or tank (S-1).

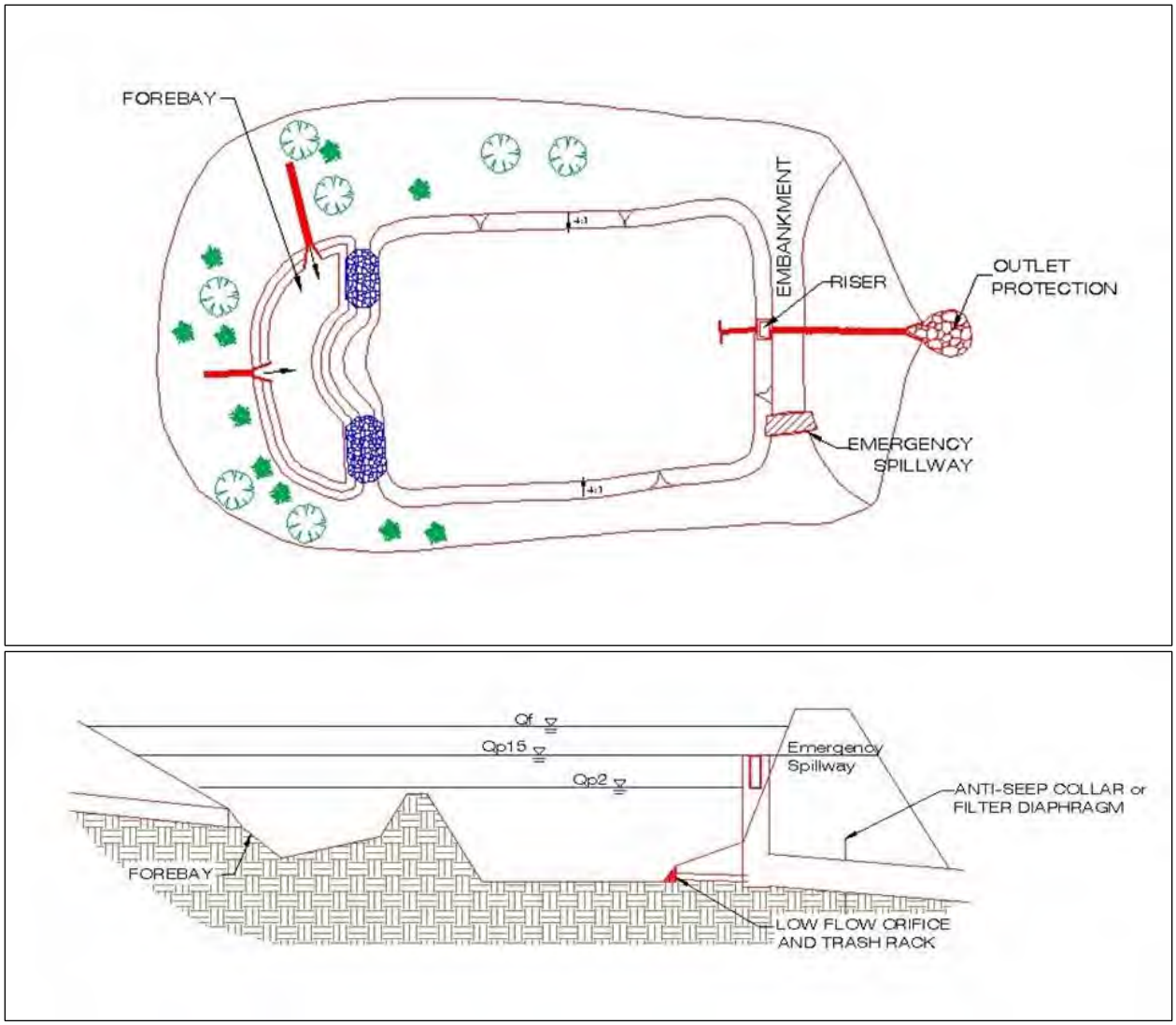

Figure 4.46 Example of a dry detention pond (S-2).

4.11.1 Storage Feasibility Criteria

The following feasibility issues need to be evaluated when storage practices are considered as the final practice in a treatment train:

Space Required. A typical storage practice requires a footprint of 1%–3% of its CDA, depending on the depth of the pond or storage vault (i.e., the deeper the practice, the smaller footprint needed).

Contributing Drainage Area. A CDA of at least 10 acres is preferred for dry ponds in order to keep the required orifice size from becoming a maintenance problem. Designers should be aware that small "pocket" ponds will typically (1) have very small orifices that will be prone to clogging, (2) experience fluctuating water levels such that proper stabilization with vegetation is very difficult, and (3) generate more significant maintenance problems.

Underground detention systems can be located downstream of other structural stormwater controls providing treatment of the design storm. For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or NRCS CN that reflects the volume

reduction of upland practices and likely reduce the size and cost of detention (see Storage Practice Sizing in Section 4.8.4 Storage Design Criteria).

The maximum CDA to be served by a single underground detention vault or tank is 25 acres.

Available Hydraulic Head. The depth of a storage practice is usually determined by the amount of hydraulic head available at the site (dimension between the surface drainage and the bottom elevation of the site). The bottom elevation is normally the invert of the existing downstream conveyance system to which the storage practice discharges. Depending on the size of the development and the available surface area of the basin, as much as 6 to 8 feet of hydraulic head may be needed for a dry detention practice to function properly for storage. An underground storage practice will require sufficient head room to facilitate maintenance—at least 5 feet depending on the design configuration.

Setbacks. Setbacks to structures and property lines must be at least 10 feet, and adequate waterproofing protection must be provided for foundations and basements.

Depth to Water Table. Dry ponds are not allowed if the water table will be within 0.5 feet of the floor of the pond. For underground detention vaults and tanks, an anti-flotation analysis is required to check for buoyancy problems in high water table areas.

Tidal Impacts. The outlet of a dry detention practice should be located above the tidal mean high water elevation. In tidally impacted areas, detention practices may have minimal benefit, and re- questing a variance for detention requirements may be an option.

Tailwater Conditions. The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the dry detention practice. Design tailwater condition elevation shall be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a king tide evaluation shall accompany the tailwater condition evaluation.

Soils. The permeability of soils is seldom a design constraint for storage practices. Soil infiltration tests should be conducted at proposed dry pond sites to estimate infiltration rates and patterns, which can be significant in HSG A soils and some group B soils. Infiltration through the bottom of the pond is typically encouraged unless it may potentially migrate laterally thorough a soil layer and impair the integrity of the embankment or other structure.

Structural Stability. Underground detention vaults and tanks must meet structural requirements for overburden support and traffic loading if appropriate as verified by shop drawings signed by an appropriately licensed professional.

Geotechnical Tests. At least one soil boring must be taken at a low point within the footprint of any proposed storage practice to establish the water table elevations and evaluate soil suitability. A geotechnical investigation is required for all underground BMPs, including underground storage systems. Geotechnical testing requirements are outlined in Appendix B Geotechnical Information Requirements for Underground BMPs.

Utilities. For a dry pond system, no utility lines shall be permitted to cross any part of the embankment where the design water depth is greater than 2 feet. Typically, utilities require a minimum 5-foot horizontal clearance from storage facilities.

Perennial Streams. Locating dry ponds on perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Economic Considerations. Underground detention can be expensive, but often allows for greater use of a development site. Dry detention ponds are generally inexpensive to construct and maintain. Depending upon the type of development, dry detention practices may be required to treat a larger volume of water than other BMPs. Dry detention practices must store 1 inch of runoff from the site, whereas infiltration practices and other BMPs must capture 1 inch of runoff from only the impervious cover on a site.

4.11.2 Storage Conveyance Criteria

Designers must use accepted hydrologic and hydraulic routing calculations to determine the required storage volume and an appropriate outlet design for storage practices. See Section 3.7.2 Hydrologic and Hydraulic Analysis for a summary of acceptable hydrologic methodologies and models.

For management of the 2-year storm, a control structure with a trash rack designed to release the required predevelopment Qp_2 must be provided. Ideally, the channel protection orifice should have a minimum diameter of 3 inches in order to pass minor trash and debris. However, where smaller orifices are required, the orifice must be adequately protected from clogging by an acceptable external trash rack.

As an alternative, the orifice diameter may be reduced if internal orifice protection is used (i.e., a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves, weir manholes, and other structures designed for simple maintenance can also be used to achieve this equivalent diameter.

For overbank flood protection, an additional outlet is sized for 2- to 25-year frequency storm event control and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure.

Riprap, plunge pools or pads, or other energy dissipators are to be placed at the end of the outlet to prevent scouring and erosion and to provide a non-erosive velocity of flow from the structure to a water course. The design must specify an outfall that will be stable for the 25-year design storm event. The channel immediately below the storage practice outfall must be modified to prevent erosion. This is typically done by calculating channel velocities and flow depths, then placing appropriately sized riprap, over geotextile fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 feet per second depending on the channel lining material). The storage practice geometry and outfall design may need to be altered in order to yield adequate channel velocities and flow.

Flared pipe sections that discharge at or near the stream invert or into a step pool arrangement should be used at the spillway outlet. An outfall analysis shall be included in the SWMP showing discharge velocities down to the nearest downstream water course. Where indicated, the developer/contractor must secure an off-site drainage easement for any improvements to the downstream channel.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge.

If discharge daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of riprap should be avoided.

The final release rate of the facility shall be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow.

The following **additional** conveyance criteria apply to underground detention or ponds:

- **High Flow Bypass (underground detention).** An internal or external high flow bypass or overflow must be included in underground detention designs to safely pass the extreme flood flow.
- **Primary Spillway (dry ponds).** The primary spillway shall be designed with acceptable anti-flotation, anti-vortex, and trash rack devices. The spillway must generally be accessible from dry land. When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O"-ring gaskets (ASTM C361) must be used to create watertight joints, and they should be inspected during installation.
- **Avoid Outlet Clogging (dry ponds).** The risk of clogging in outlet pipes with small orifices can be reduced by the following:

  Providing a micropool at the outlet structure. For more information on micropool extended detention ponds see Section 4.12 Ponds.

  Installing a trash rack to screen the low-flow orifice.

  Using a perforated pipe under a gravel blanket with an orifice control at the end in the riser structure.
- **Emergency Spillway (dry ponds).** Dry ponds must be constructed with overflow capacity to safely pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway unless waived by *<local jurisdiction>*.
- **Inlet Protection (dry ponds).** Inflow points into dry pond systems must be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 25-year storm event).

4.11.3 Storage Pretreatment Criteria

Dry Pond Pretreatment Forebay. A forebay must be located at each major inlet to a dry pond to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to dry pond forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the storage practice's CDA.
- The forebay consists of a separate cell, formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay shall be sized to contain 0.1 inches per impervious acre of contributing drainage. The relative size of individual forebays should be proportional to the percentage of the total inflow to the dry pond.

- The forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main storage cell.
- Exit velocities from the forebay shall be non-erosive or an armored overflow shall be provided. Non-erosive velocities are 4 feet per second for the 2-year event and 6 feet per second for the 25-year event.
- The bottom of the forebay may be hardened (e.g., concrete, asphalt, or grouted riprap) in order to make sediment removal easier.
- Direct maintenance access for appropriate equipment shall be provided to the each forebay.

Underground Detention Pretreatment. A pretreatment structure to capture sediment, coarse trash, and debris must be placed upstream of any inflow points to underground detention. A separate sediment sump or vault chamber sized to capture 0.1 inches per impervious acre of contributing drainage, or a proprietary structure with demonstrated capability of removing sediment and trash, should be provided at the inlet for underground detention systems that are in a treatment train with off-line water quality treatment structural controls. Refer to Section 0 Proprietary Practices for information on approved proprietary practices.

4.11.4 Storage Design Criteria

Dry Pond Internal Design Features. The following apply to dry pond design:

- **No Pilot Channels.** Dry ponds shall not have a low-flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom, to avoid scour, promote attenuation and, where possible, infiltration.
- **Internal Slope.** The maximum longitudinal slope through the pond should be approximately 0.5%–1%.
- **Side Slopes.** Side slopes within the dry pond should generally have a gradient of 3H:1V to 4H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. Ponds with side slopes steeper than 5H:1V must be fenced and include a lockable gate.
- **Long Flow Path.** Dry pond designs should have an irregular shape and a long flow path distance from inlet to outlet to increase water residence time, treatment pathways, pond performance, and to eliminate short-cutting. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al., 2009):

  The overall flow path can be represented as the length-to-width ratio OR the flow path ratio. These ratios must be at least 2L:1W (3L:1W preferred). Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.

  The shortest flow path represents the distance from the closest inlet to the outlet. The ratio of the shortest flow to the overall length must be at least 0.4. In some cases—due to site geometry, storm sewer infrastructure, or other factors—some inlets may not be able to meet these ratios. However, the CDA served by these “closer” inlets must constitute no more than 20% of the total CDA.

Top of Bank. Dry ponds shall be provided with a 20-ft maintenance access at the top of bank with a maximum cross slope of 48:1.

Safety Features. The following safety features must be considered for storage practices:

- The underground spillway access must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced at the top of the wall to prevent a falling hazard.
- Storage practices must incorporate an additional 1 foot of freeboard above the emergency spillway, or 2 feet of freeboard if design has no emergency spillway, for the 100-year storm.
- The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges
- Underground maintenance access should be locked at all times.

Maintenance Access. All storage practices shall be designed so as to be accessible to annual maintenance. Unless waived by *<local jurisdiction>*, a 5H:1V slope and 15-foot-wide entrance ramp is required for maintenance access to dry ponds. Adequate maintenance access must also be provided for all underground detention systems. Access must be provided over the inlet pipe and outflow structure with access steps. Access openings can consist of a standard 30-inch diameter frame, grate and solid cover, a hinged door, or removable panel. Removable panels must be designed with sufficient support so they cannot fall through the opening into the vault when removed.

Outlets. Trash racks shall be provided for low-flow pipes and for risers not having anti-vortex devices.

To reduce maintenance problems for small orifices, a standpipe design can be used that includes a smaller inner standpipe with the required orifice size, surrounded by a larger standpipe with multiple openings, and a gravel jacket surrounding the larger standpipe. This design will reduce the likelihood of the orifice being clogged by sediment.

Detention Vault and Tank Materials. Underground stormwater detention structures shall be composed of materials as approved by *<local jurisdiction>*. All construction joints and pipe joints shall be soil-tight. Cast-in-place wall sections must be designed as retaining walls. The maximum depth from finished grade to the vault invert is 20 feet. The minimum pipe diameter for underground detention tanks is 24 inches unless otherwise approved by *<local jurisdiction>*. Manufacturer's specifications should be consulted for underground detention structures.

Anti-floatation Analysis for Underground Detention. Anti-flotation analysis is required to check for buoyancy problems in high water table areas. Anchors shall be designed to counter the pipe and structure buoyancy by at least a 1.2 factor of safety.

Storage Practice Sizing. Storage facilities should be sized to control peak flow rates from the 2- to 25-year frequency storm event or other design storm. Design calculations must ensure that the post-development peak discharge does not exceed the predevelopment peak discharge. See Section 3.7.2 Hydrologic and Hydraulic Analysis for a summary of acceptable hydrologic methodologies and models.

For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or NRCS CN that reflects the volume reduction of upland practices to compute the 2- 50-year frequency storm event that must be treated by the storage practice.

4.11.5 Storage Landscaping Criteria

No landscaping criteria apply to underground storage practices.

For dry ponds, a landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage within the dry pond. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within the pond.
- Selection of corresponding plant species.
- The planting plan.
- The sequence for preparing the wetland bed, if one is incorporated with the dry pond (including soil amendments, if needed).
- Sources of native plant material.
- The planting plan should allow the pond to mature into a native forest in the right places, but yet keep mowable turf along the embankment and all access areas. The wooded wetland concept proposed by Cappiella et al. (2005) may be a good option for many dry ponds.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.

4.11.6 Storage Construction Sequence

Construction of underground storage systems must be in accordance with manufacturer's specifications. All runoff into the system should be blocked until the site is stabilized. The system must be inspected and cleaned of sediment after the site is stabilized.

The following is a typical construction sequence to properly install a dry pond. The steps may be modified to reflect different dry pond designs, site conditions, and the size, complexity, and configuration of the proposed facility.

1. Use of Dry Pond for Soil Erosion and Sediment Control. A dry pond may serve as a sediment basin during project construction. Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction dry pond in mind. The bottom elevation of the dry pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures must be implemented to prevent discharge of turbid waters when the basin is being converted into a dry pond.

2. Stabilize the Contributing Drainage Area. Dry ponds should only be constructed after the CDA to the pond is completely stabilized. If the propose dry pond site will be used as a sediment trap or basin during the construction phase, the construction notes must clearly indicate that the facility will be dewatered, dredged, and regraded to design dimensions after the original site construction is complete.

3. Assemble Construction Materials on Site. Inspect construction materials to ensure they conform to design specifications and prepare any staging areas.

4. Clear and Grade. Bring the project area to the desired subgrade.

5. Soil Erosion and Sediment Controls. Install soil erosion and sediment control measures prior to construction, including temporary stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

6. Install the Spillway Pipe. Ensure the top invert of the spillway pipe is set to design elevation.

7. Install the Riser or Outflow Structure. Once riser and outflow structures are installed, ensure the top invert of the overflow weir is constructed level and at the design elevation.

8. Construct the Embankment and any Internal Berms. Construct the embankment and berms in 8- to 12-inch lifts and compact the lifts with appropriate equipment.

9. Excavate and Grade. Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the dry pond.

10. Construct the Emergency Spillway. The emergency spillway must be constructed in cut or structurally stabilized soils.

11. Install Outlet Pipes. The installation of outlet pipes must include a downstream riprap protection apron.

12. Stabilize Exposed Soils. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

13. Dry Pond Construction Supervision. Ongoing construction supervision is recommended to ensure that stormwater ponds are properly constructed. Supervision/inspection is recommended during the following stages of construction:

- Preconstruction meeting
- Initial site preparation including the installation of soil erosion and sediment control measures
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization
- Immediately seed or install vegetated ground cover upon completion of sloping and grading of each storage practice, where applicable, within a project.
- Inspect within two weeks to ensure vegetation is in fact holding banks and slopes in place.
- Prior to completion of project, mechanically remove erosion deposition from ponds that occurred during the project. Criteria should be based on erosion of designed bank slopes and loss of storage capacity.
- Final inspection (develop a punch list for facility acceptance)

Construction phase inspection checklist for storage practices and the Stormwater Facility Leak Test form can be found in Appendix E Construction Inspection Checklists.

If the dry pond has a permanent pool, then to facilitate maintenance the contractor should measure the actual constructed dry pond depth at three areas within the permanent pool (forebay, mid-pond, and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

4.11.7 Storage Maintenance Criteria

Typical maintenance activities for storage practices are outlined in Table 4.47. Maintenance requirements for underground storage facilities will generally require quarterly visual inspections from the manhole access points by a qualified professional to verify that there is no standing water or excessive sediment buildup. Entry into the system for a full inspection of the system components (pipe or vault joints, general structural soundness, etc.) should be conducted annually. Confined space entry credentials are typically required for this inspection.

Table 4.47. Typical Maintenance Activities for Storage Practices.

Schedule	Maintenance Activity
As needed	▪ Water dry pond side slopes to promote vegetation growth and survival.
Quarterly	▪ Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, storage practices, and overflow structures. ▪ Ensure that the CDA, inlets, and facility surface are clear of debris. ▪ Ensure that the CDA is stabilized. Perform spot-reseeding where needed. ▪ Repair undercut and eroded areas at inflow and outflow structures.
Annual inspection	▪ Measure sediment accumulation levels in forebay. Remove sediment when 50% of the forebay capacity has been lost. ▪ Inspect the condition of stormwater inlets for material damage, erosion or undercutting. Repair as necessary. ▪ Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine pond embankment integrity. ▪ Inspect outfall channels for erosion, undercutting, riprap displacement, woody growth, etc. ▪ Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc. ▪ Inspect condition of all trash racks, reverse sloped pipes, or flashboard risers for evidence of clogging, leakage, debris accumulation, etc. ▪ Inspect maintenance access to ensure it is free of debris or woody vegetation and check to see whether valves, manholes, and locks can be opened and operated. ▪ Inspect internal and external side slopes of dry ponds for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately. ▪ Monitor the growth of wetlands, trees and shrubs planted in dry ponds. Remove invasive species and replant vegetation where necessary to ensure dense coverage.

Maintenance of storage practices is driven by annual inspections that evaluate the condition and performance of the storage practice. Based on inspection results, specific maintenance tasks will be triggered.

Maintenance inspection checklists for extended detention ponds and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.11.8 Storage Stormwater Compliance Calculations

Storage practices are credited with 0% retention, but they do receive 80% TSS, 30% TN, and 80% bacteria removal for the SWRv (Table 4.48).

Table 4.48. Storage Retention and Pollutant Removal

Retention	= 0%
TSS Removal	= 60%
TN Removal	= 10%
Bacteria Removal	= 60%

4.11.9 References

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4.12 Ponds

Ponds				
Definition: Stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake, and microbial activity.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Medium	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		80%	30%	60%
		Runoff Reductions		
Construction Costs	**Maintenance Burden**	**Volume**		
Moderate	Moderate	Low		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	0%		
At least annually	Every 5–7 years			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ Moderate to high pollutant removal ▪ Can be designed as a multi-functional BMP ▪ Cost effective ▪ Good for sites with high water table and/or poorly drained soils ▪ Wildlife habitat potential ▪ High community acceptance when integrated into a development		▪ Requires large amount of flat land (1-3% of CDA) ▪ Must be properly designed, installed, and maintained to avoid nuisance problems ▪ Routine sediment cleanout may be needed ▪ Potential for thermal impacts downstream		
Components		**Design considerations**		
▪ Conveyance ▪ Forebay ▪ Ponding area with available storage ▪ Micropool ▪ Spillway system(s) ▪ Liners, as needed		▪ CDA of at least 10 acres and slopes <15% ▪ Use CN adjustment factor ARC III for CDA that are irrigated with harvested rainwater ▪ Minimum length to width ratio = 3:1 ▪ Maximum depth of permanent pool = 8’ ▪ 3:1 side slopes or flatter around pond perimeter		
Maintenance Activities				
▪ Remove debris from inlet and outlet structures ▪ Maintain side slopes/remove invasive vegetation		▪ Monitor sediment accumulation and remove periodically		

[1]*Credited pollutant load removal*

Stormwater ponds are widely applicable for most land uses and are best suited for larger drainage areas (Figure 4.47); however, they should be considered for use after all other upland retention opportunities have been exhausted and there is still a remaining treatment volume or runoff from larger storms (i.e., 2- to 25-year or flood control events) to manage.

Stormwater ponds receive no retention credit and should be considered mainly for management of larger storm events. Stormwater ponds have both community and environmental concerns (see Section 4.12.1 Pond Feasibility Criteria) that should be considered before choosing stormwater ponds as the appropriate stormwater practice on site.

Figure 4.47 Wet Pond (photo: Denise Sanger)

Definition. Stormwater ponds are stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake, and microbial activity. Ponds are best suited for larger SDAs. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to resuspension of sediments and other pollutants deposited during prior storms. When sized properly, stormwater ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Stormwater ponds can also provide storage above the permanent pool to help meet stormwater management requirements for larger storms. Design variants include the following (see Figure 4. 47 and Figure 4. 48):

C-1 Micropool extended detention pond

C-2 Wet pond

C-3 Wet extended detention pond

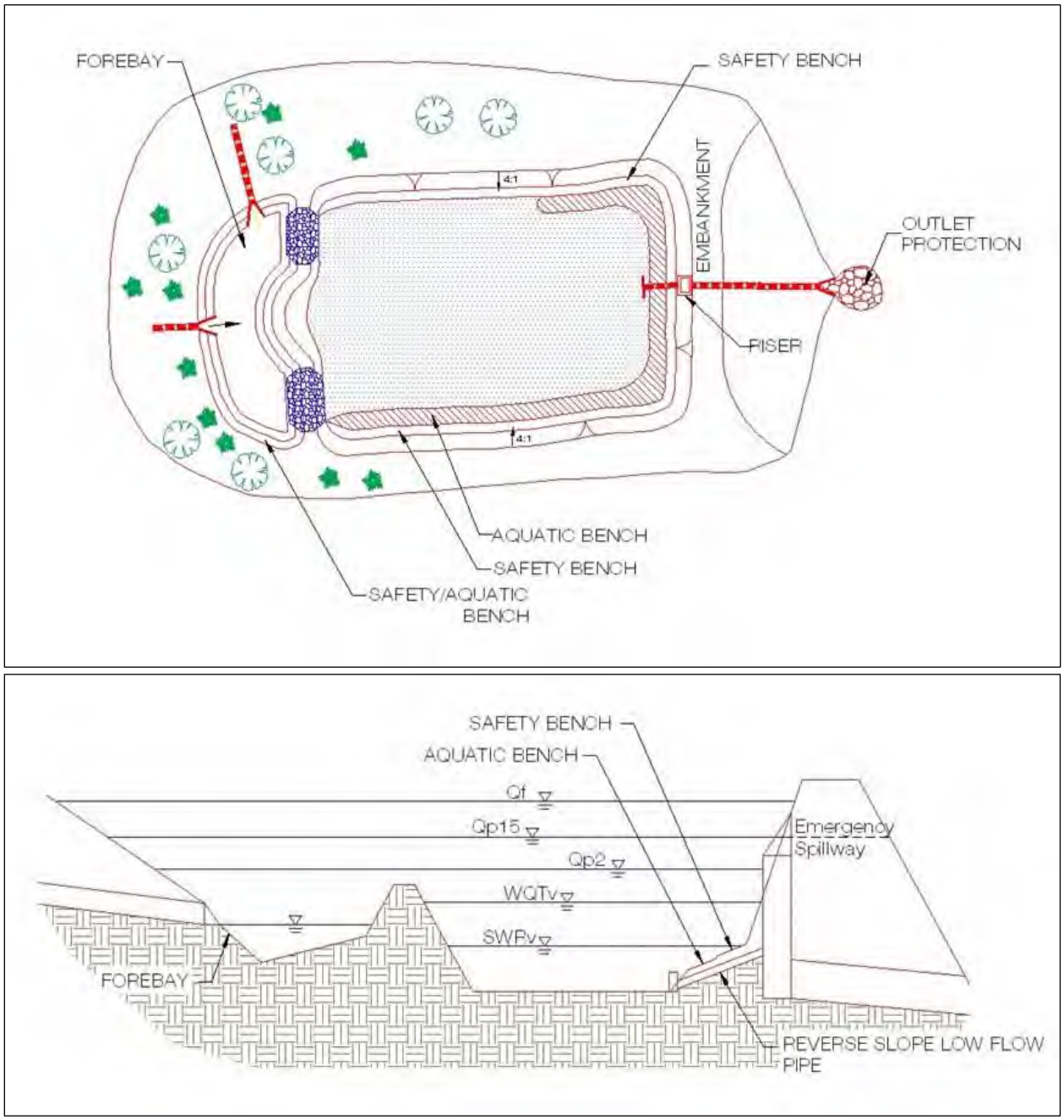

Figure 4.48 Design schematics for a wet pond (C-2).

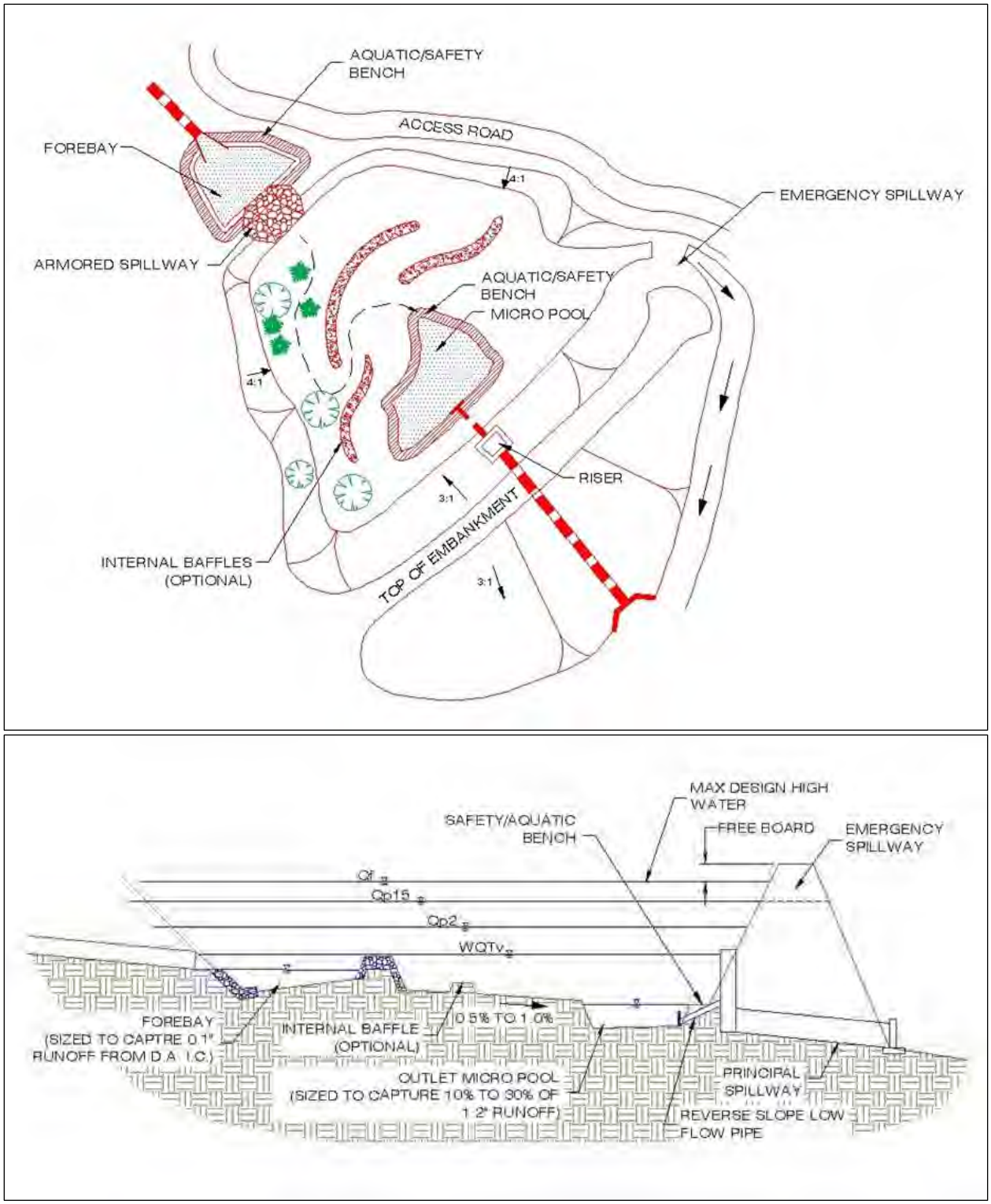

Figure 4.49 Typical extended detention pond (C-3) details.

4.12.1 Pond Feasibility Criteria

The following feasibility issues need to be considered when ponds are considered a final stormwater management practice of the treatment train.

Adequate Water Balance. Wet ponds must have enough water supplied from groundwater, runoff, or baseflow so that the wet pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the Equation 4.27 in Section 4.10.4 Pond Design Criteria.

Contributing Drainage Area. A CDA of 10 to 25 acres is typically recommended for ponds to maintain constant water elevations. Ponds can still function with CDAs less than 10 acres, but designers should be aware that these "pocket" ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions.

Space Requirements. The surface area of a pond will normally be at least 1%–3% of its CDA, depending on the pond's depth.

Site Topography. Ponds are best applied when the grade of contributing slopes is less than 15%.

Available Hydraulic Head. The depth of a pond is usually determined by the hydraulic head available on the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the pond discharges. Typically, a minimum of 6 to 8 feet of head are needed to hold the wet pool and any additional large storm storage or overflow capacity for a pond to function.

Setbacks. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing protection must be provided for foundations and basements.

Proximity to Utilities. For an open pond system, no utility lines shall be permitted to cross any part of the embankment of a wet pool.

Depth to Water Table. The depth to the groundwater table is not a major constraint for stormwater ponds because a high water table can help maintain wetland conditions. However, groundwater inputs can also reduce the pollutant removal rates of ponds. Further, if the water table is close to the surface, it may make excavation difficult and expensive.

Tailwater Conditions. The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from wet pond. Design tailwater condition elevation shall be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a king tide evaluation shall accompany the tailwater condition evaluation.

Soils. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Soil infiltration tests need to be conducted at proposed pond sites to determine the need for a pond liner or other method to ensure a constant water surface elevation. Underlying soils of HSG C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner (see Table 3.42). Geotechnical tests should be conducted to determine the saturated hydraulic conductivity and other subsurface properties of the soils beneath the proposed pond.

Use of or Discharges to Natural Wetlands. Ponds cannot be located within State waters, including wetlands, without obtaining a Section 404 permit or other permissions from the appropriate state or

federal regulatory agency. In addition, the designer should investigate the wetland status of adjacent areas to determine if the discharge from the pond will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006, for guidance on minimizing stormwater discharges to existing wetlands).

Perennial Streams. Locating ponds on perennial streams will require both US Army COE permits under Clean Water Act Section 401 and Section 404 or other permissions from the appropriate state or federal regulatory agency.

Economic Considerations. Wet detention ponds tend to have low construction costs and low space demands (in terms of the land area needed to treat a given volume of water) relative to other LID practices. In addition, the soil excavated to construct ponds can be used as fill, which is often needed for construction on low-lying coastal areas.

Community and Environmental Concerns. Ponds can generate the following community and environmental concerns that need to be addressed during design:

- Aesthetic Issues. Many residents feel that ponds are an attractive landscape feature, promote a greater sense of community and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished where ponds are under-sized or have small CDAs.
- Existing Forests. Construction of a pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction. Consideration of Better Site Design Principles is implicit with permitting decisions related to clearing of existing forest cover.
- Safety Risk. Pond safety is an important community concern, since both young children and adults have perished by drowning in ponds through a variety of accidents, including falling through thin ice cover. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially where ponds are located near residential areas.
- Pollutant Concerns. Ponds collect and store water and sediment to increase residence time that will increase the likelihood for contaminated water and sediments to be neutralized. However, poorly sized, maintained, and/or functioning ponds can export contaminated sediments and/or water to receiving waterbodies (Mallin, 2000; Mallin et al., 2001; Messersmith, 2007). Further, designers are cautioned that recent research on ponds has shown that some ponds can be hotspots or incubators for algae that generate harmful algal blooms (HABs).
- Mosquito Risk. Mosquitoes are not a major problem for larger ponds (Santana et al., 1994; Ladd and Frankenburg, 2003; Hunt et al., 2005). However, fluctuating water levels in smaller or under-sized ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).
- Geese and Waterfowl. Ponds with extensive turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the removal efficiency for those pollutants. Several design and landscaping features can make ponds much less attractive to geese (see Schueler, 1992).

4.12.2 Pond Conveyance Criteria

Internal Slope. The longitudinal slope of the pond bottom should be at least 0.5% to facilitate maintenance.

Primary Spillway. The spillway shall be designed with acceptable anti-flotation, anti-vortex and trash rack devices. The spillway must generally be accessible from dry land. When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O-ring" gaskets (ASTM C361) shall be used to create watertight joints.

Non-Clogging Low-Flow Orifice. A low-flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design to minimize the potential for clogging.

- One option is a submerged reverse-slope pipe that extends downward from the riser to an inflow point 1 foot below the normal pool elevation.
- Alternative methods must employ a broad crested rectangular V-notch (or proportional) weir, protected by a half-round CMP that extends at least 12 inches below the normal pool elevation.

Emergency Spillway. Ponds must be constructed with overflow capacity to pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway unless waived by <*local jurisdiction*>.

Adequate Outfall Protection. The design must specify an outfall that will be stable for the 25-year design storm event. The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is typically done by placing appropriately sized riprap over geotextile fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 feet per second) depending on the channel lining material. Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge.

If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of riprap should be avoided.

The final release rate of the facility shall be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow.

Inlet Protection. Inflow points into the pond must be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 25-year storm event). Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation. A forebay shall be provided at each inflow location, unless the inlet is submerged or inflow provides less than 10% of the total design storm inflow to the pond.

Dam Safety Permits. The designer must verify whether or not Dam Safety permits or approvals are required for the embankment.

4.12.3 Pond Pretreatment Criteria

Sediment forebays are considered to be an integral design feature to maintain the longevity of all ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the pond's CDA.
- The forebay consists of a separate cell, formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be between 4 and 6 feet deep and must be equipped with a variable width aquatic bench for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface. Small forebays may require alternate geometry to achieve the goals of pretreatment and safety within a small area.
- The forebay shall be sized to contain 0.1 inches of runoff from the contributing drainage impervious area. The relative size of individual forebays should be proportional to the percentage of the total inflow to the pond.
- The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- The forebay must be equipped with a metered rod in the center of the pool (as measured lengthwise along the low-flow water travel path) for long-term monitoring of sediment accumulation.
- Exit velocities from the forebay shall be non-erosive or an armored overflow shall be provided. Non-erosive velocities are 4 feet per second for the 2-year event, and 6 feet per second for the 25-year event.
- Direct maintenance access for appropriate equipment shall be provided to each forebay.
- Designers of ponds that are used for irrigation should be mindful of pretreatment provisions that help prevent irrigation system pluggages and operational issues.

4.12.4 Pond Design Criteria

Pond Storage Design. The pond permanent pool must be sized to store a volume equivalent to the SWRv. Volume storage may be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh). Volume storage below the permanent pool is not considered in the detention calculations.

Pond Geometry. Pond designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time and pond performance. The minimum length to width ratio (i.e., length relative to width) for ponds is 1.5:1. Greater flowpaths and irregular shapes are recommended. Internal berms, baffles, or vegetated peninsulas can be used to extend flow paths and/or create multiple pond cells.

Permanent Pool Depth. The maximum depth of the permanent pool should not generally exceed 8 feet unless the pond is designed for multiple uses.

Micropool. A micropool is a 3- to 6-foot-deep pool used to protect the low-flow pipe from clogging and to prevent sediment resuspension. For micropool extended detention ponds, the micropool shall be designed to hold at least 10%–25% of the 85th or 95th percentile storm event.

Side Slopes. Side slopes for ponds should generally have a gradient no steeper than 3H:1V. Mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Maximum Extended Detention Levels. The total storage, including any ponding for larger flooding events (100-year storm) should not extend more than 5 feet above the pond permanent pool unless specific design enhancements to ensure side slope stability, safety, and maintenance are identified and approved.

Top of Bank. Storm ponds shall be provided with a 20-ft maintenance access at the top of bank with a maximum cross slope of 48:1.

Stormwater Pond Benches. The perimeter of all pool areas greater than 4 feet in depth must be surrounded by two benches, as follows:

- **Safety Bench.** This is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. Except when the stormwater pond side slopes are 5H:1V or flatter, provide a safety bench that generally extends 8 to 15 feet outward from the normal water edge to the toe of the stormwater pond side slope. The maximum slope of the safety bench is 5%.
- **Aquatic Bench.** This is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. Incorporate an aquatic bench that generally extends up to 10 feet inward from the normal shoreline, has an irregular configuration, and extends a maximum depth of 18 inches below the normal pool water surface elevation.

Liners. When a stormwater pond is located over highly permeable soils, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include the following:

1. a clay liner following the specifications outlined in Table 4.49;
2. a 30-mil- poly-liner;
3. bentonite;
4. use of chemical additives; or
5. an engineering design, as approved on a case-by-case basis by <*local jurisdiction*>.

A clay liner must have a minimum thickness of 12 inches with an additional 12-inch layer of compacted soil above it, and it must meet the specifications outlined in Table 4.49. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 4.49. Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D2434	cm/s	1×10^{-6}
Plasticity Index of Clay	ASTM D4318	%	Not less than 15
Liquid Limit of Clay	ASTM D2216	%	Not less than 30
Clay Particles Passing	ASTM D422	%	Not less than 30
Clay Compaction	ASTM D2216	%	95% of standard proctor density

Source: VA DCR (1999)

Required Geotechnical Testing. Soil borings must be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the proposed pond treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material, (2) determine its adequacy for use as structural fill or spoil, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine compaction/composition needs for the embankment, (5) determine the depth to groundwater and (6) evaluate potential infiltration losses (and the potential need for a liner).

Non-clogging Low-Flow (Extended Detention) Orifice. The low-flow ED orifice shall be adequately protected from clogging by an acceptable external trash rack. The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point 1 foot below the normal pool elevation. Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool.

Riser in Embankment. The riser should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser is to be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls. The principal spillway opening can be "fenced" with pipe or rebar at 8-inch intervals for safety purposes.

Trash Racks. Trash racks shall be provided for low-flow pipes and for riser openings not having anti-vortex devices.

Pond Drain. Ponds should have a drainpipe that can completely or partially drain the permanent pool. In cases where a low-level drain is not feasible (such as in an excavated pond), a pump well must be provided to accommodate a temporary pump intake when needed to drain the pond.

- The drain pipe must have an upturned elbow or protected intake within the pond to help keep it clear of sediment deposition, and a diameter capable of draining the pond within 24 hours.
- The pond drain must be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Care must be exercised during pond drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. The approving authority shall be notified before draining a pond.

Safety Features.

- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a falling hazard.
- Storage practices must incorporate an additional 1 foot of freeboard above the emergency spillway, or 2 feet of freeboard if design has no emergency spillway, for the 100-year storm.
- The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.
- Warning signs prohibiting swimming must be posted.
- Where permitted, fencing of the perimeter of ponds is discouraged. The preferred method to reduce risk is to manage the contours of the stormwater pond to eliminate drop-offs or other safety hazards. Fencing is required at or above the maximum water surface elevation in the rare situations when the pond slope is a vertical wall.
- Side slopes to the pond shall not be steeper than 3H:1V, and shall terminate on a 15-foot-wide safety bench. Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool. The bench requirement may be waived if slopes are 4H:1V or flatter.

Maintenance Reduction Features. Many maintenance issues can be addressed through well designed access. All ponds must be designed for annual maintenance. Good access is needed so crews can remove sediments, make repairs, and preserve pond-treatment capacity. Design for the following:

  - Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
  - The riser should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
  - Access roads must (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 20 feet, and (3) have a profile grade that does not exceed 5H:1V.
  - A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.
  - No permanent structures (mechanical, electrical, phone, fences) or landscaping are allowed within the 20’ pond maintenance access easement.

- **Material Specifications.** ED ponds are generally constructed with materials obtained on site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and geotextile fabric for lining banks or berms.
- **Pond Sizing.** Stormwater ponds can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm (SWRv). Additionally, stormwater ponds may be sized to control peak flow rates from the 2- to 25-year frequency storm event or other design storms as required. Design calculations must ensure that the post-development peak

discharge does not exceed the predevelopment peak discharge. See Section 3.7.2 Hydrologic and Hydraulic Analysis and Appendix I for a summary of acceptable hydrologic methodologies and models.

For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or NRSC CN that reflects the volume reduction of upland practices to compute the 2- 50-year frequency storm event that must be treated by the stormwater pond.

The pond permanent pool must be sized to store a volume equivalent to the SWRv or design volume.

The storage volume (Sv) of the practice is equal to the volume provided by the pond permanent pool (Equation 4. 26). The total Sv cannot exceed the design SWRv.

Equation 4.26 Pond Storage Volume

$$Sv = Pond\ permanent\ pool\ volume$$

- **Water Balance Testing.** A water balance calculation is recommended to document that sufficient inflows to wet ponds and wet ED ponds exist to compensate for combined infiltration and evapotranspiration losses during a 30-day summer drought without creating unacceptable drawdowns (see Equation 4.27, adapted from Hunt et al., 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

Equation 4.27 Water Balance Equation for Acceptable Water Depth in a Wet Pond

$$DP > ET + INF + RES - MB$$

Where:

DP	=	average design depth of the permanent pool (in.)
ET	=	summer evapotranspiration rate (in.) (assume 8 in.)
INF	=	monthly infiltration loss (assume 7.2 inches at 0.01 in./hour)
RES	=	reservoir of water for a factor of safety (assume 24 in.)
MB	=	measured baseflow rate to the pond, if any convert to pond-inches (in.)

Design factors that will alter this equation are the measurements of seasonal base flow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the base flow conditions over time (e.g., urbanization and increased impervious cover).

Translating the baseflow to inches refers to the depth within the pond. Therefore, Equation 4. 28 can be used to convert the baseflow, measured in cubic feet per second (cfs), to pond-inches:

Equation 4.28 Baseflow Conversion

$$Pond - inches = \frac{MB \times 2.592 \times 10^6 \times 12}{SA}$$

Where:

Pond – inches	=	depth within the pond (in,)
MB	=	measured baseflow rate to the pond (cfs)
2.592 × 106	=	conversion factor, converting cfs to ft^3/month
12	=	conversion factor, converting feet to inches
SA	=	surface area of pond (ft^2)

4.12.5 Pond Landscaping Criteria

Pond Benches. The perimeter of all deep pool areas (4 feet or greater in depth) must be surrounded by two benches:

- A safety bench that extends 8 to 15 feet outward from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 6%.
- An aquatic bench that extends up to 10 feet inward from the normal shoreline and has a maximum depth of 18 inches below the normal pool water surface elevation.

Landscaping and Planting Plan. A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the pond and its buffer (see Section 4.3.5 Bioretention Landscaping Criteria for extended landscaping and planting details). Minimum elements of a landscaping plan include the following:

- Delineation of pondscaping zones within both the pond and buffer.
- Selection of corresponding plant species.
- The planting plan.
- The sequence for preparing the wetland benches (including soil amendments, if needed).
- Sources of native plant material.
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction.
- The soils in the stormwater buffer area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the root ball for bare root and ball-and-burlap stock, and five times deeper and wider for container-grown stock.

- Avoid species that require full shade or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

For more guidance on planting trees and shrubs in pond buffers, consult Cappiella et al. (2006).

4.12.6 Pond Construction Sequence

The following is a typical construction sequence to properly install a stormwater pond. The steps may be modified to reflect different pond designs; site conditions; and the size, complexity and configuration of the proposed facility.

1. Use of Ponds for Soil Erosion and Sediment Control. A pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (soil erosion and sediment control requirement versus storage volume requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction pond in mind. The bottom elevation of the pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures must be implemented to prevent discharge of turbid waters when the basin is being converted into a pond.

Approval from *<local jurisdiction>* must be obtained before any sediment pond can be used as for stormwater management.

2. Stabilize the Contributing Drainage Area. Ponds should only be constructed after the CDA to the pond is completely stabilized. If the proposed pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged, and regraded to design dimensions after the original site construction is complete.

3. Assemble Construction Materials on Site. Inspect construction materials to ensure they conform to design specifications and prepare any staging areas.

4. Clear and Strip. Bring the project area to the desired subgrade.

5. Soil Erosion and Sediment Controls. Install soil erosion and sediment control measures prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

6. Excavate the Core Trench and Install the Spillway Pipe.

7. Install the Riser or Outflow Structure. Once riser and outflow structures are installed ensure the top invert of the overflow weir is constructed level at the design elevation.

8. Construct the Embankment and any Internal Berms. These features must be installed in 8- to 12-inch lifts; compact the lifts with appropriate equipment.

9. Excavate and Grade. Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the pond.

10. Construct the Emergency Spillway. The emergency spillway must be constructed in cut or structurally stabilized soils.

11. Install Outlet Pipes. The installation of outlet pipes must include a downstream riprap protection apron.

12. Stabilize Exposed Soils. Use temporary seed mixtures appropriate for the pond buffer to stabilize the exposed soils. All areas above the normal pool elevation must be permanently stabilized by hydroseeding or seeding over straw.

13. Plant the Pond Buffer Area. Establish the planting areas according to the pondscaping plan (see Section 4.12.5 Pond Landscaping Criteria).

Construction Supervision. Supervision during construction is recommended to ensure that stormwater ponds are properly constructed, especially during the following stages of construction:

- Preconstruction meeting
- Initial site preparation including the installation of soil erosion and sediment control measures
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization
- Immediately seed or install vegetated ground cover upon completion of sloping and grading of each stormwater pond within a project.
- Inspect within two weeks to insure vegetation is in fact holding banks and slopes in place.
- Prior to completion of project, mechanically remove erosion deposition from ponds that occurred during the project. Criteria should be based on erosion of designed bank slopes and loss of storage capacity.
- Final inspection (develop a punch list for facility acceptance)

Construction phase inspection checklist for ponds can be found in Appendix E Construction Inspection Checklists.

To facilitate maintenance, contractors should measure the actual constructed pond depth at three areas within the permanent pool (forebay, mid-pond and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

4.12.7 Pond Maintenance Criteria

Maintenance is needed so stormwater ponds continue to operate as designed on a long-term basis. Ponds normally have fewer routine maintenance requirements than other stormwater control measures. Stormwater pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine stormwater pond maintenance, such as mowing and removing debris and trash, is needed several times each year (see Table 4.50). More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features (e.g., embankments and risers) needs to be performed by a qualified professional (e.g., a structural engineer) who has experience in the construction, inspection, and repair of these features.

Table 4.50. Pond Maintenance Tasks and Frequency.

Frequency	Maintenance Items
During establishment, as needed (first year)	▪ Inspect the site at least twice after storm events that exceed a 1/2 inch of rainfall. ▪ Plant the aquatic benches with emergent wetland species, following the planting recommendations contained in Section 4.11.6 Stormwater Wetland Landscaping Criteria. ▪ Stabilize any bare or eroding areas in the CDA or around the pond buffer. ▪ Water trees and shrubs planted in the pond buffer during the first growing season. In general, consider watering every 3 days for first month, and then weekly during the remainder of the first growing season (April through October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	▪ Mowing (twice a year) ▪ Remove debris and blockages ▪ Repair undercut, eroded, and bare soil areas
Twice a year	▪ Mowing of the buffer and pond embankment
Annually	▪ Shoreline cleanup to remove trash, debris, and floatables ▪ A full maintenance inspection ▪ Open up the riser to access and test the valves ▪ Repair broken mechanical components, if needed
Once—during the second year following construction	▪ Pond buffer and aquatic bench reinforcement plantings
Every 5 to 7 years	▪ Forebay sediment removal
From 5 to 25 years	▪ Repair pipes, the riser, and spillway, as needed

Sediment removal in the pond pretreatment forebay should occur every 5 to 7 years or after 50% of total forebay capacity has been lost. The designer should also check to see whether removed sediments can be spoiled on site or must be hauled away. Sediments excavated from ponds are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the pond serves a pollutant hotspot land use, as the sediment could be potentially toxic or hazardous (Weinstein et al., 2008). In lieu of local regulations for sediment testing, the parameters in Table 4.51 may be used.

Table 4.51. Ceiling Levels Governing Management of Accumulated Sediment[1]

Parameter	Ceiling Level (ppm or mg/kg)
Total Arsenic	8
Total Cadmium	10
Total Chromium	100
Total Lead	250
pH	Less than 5 or greater than 10 standard units
Electrical Conductivity	8 deciSiemens/meter (dS/m) at 25°C

[1] *Excerpt from Wisconsin Administrative Code NR 528.03, Table 2*

Maintenance Plans. Maintenance plans must clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables. For information on chemical control methods for aquatic plants, consult Clemson's fact sheet entitled "Aquatic Weed Control Overview" available online at http://www.clemson.edu/extension/hgic/plants/other/landscaping/hgic1714.html.

Maintenance Inspections. Maintenance of a pond is driven by annual inspections by a qualified professional who evaluates the condition and performance of the pond. Based on inspection results, specific maintenance tasks will be triggered.

Maintenance inspection checklist for stormwater ponds and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law. However, sediment testing may be needed prior to sediment disposal because sediments excavated from ponds could be contaminated.

4.12.8 Pond Stormwater Compliance Calculations

Stormwater ponds are credited with 0% retention, but they do receive 80% TSS, 30% TN, and 60% bacteria removal for the storage volume (Sv) provided by in the permanent pool (Table 4.52).

Table 4.52. Pond Retention and Pollutant Removal

Retention	= 0%
TSS Removal	= 80%
TN Removal	= 30%
Bacteria Removal	= 60%

4.12.9 References

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4.13 Stormwater Wetlands

Stormwater Wetlands				
Definition: Practices that create shallow marsh areas to treat urban stormwater, which often incorporate small permanent pools and/or extended detention storage. Stormwater wetlands are explicitly designed to provide stormwater detention for larger storms (2- to 25-year, or flood control events) above the design storm (SWRv) storage.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Medium	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		80%	25%	60%
		Runoff Reduction		
Construction Costs	**Maintenance Burden**	**Volume**		
Moderate	Moderate	Low		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	**0%**		
At least annually	Every 2 years			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ High removal of typical stormwater pollutants ▪ Provides habitat for wildlife ▪ Attractive when integrated into site development ▪ Good for sites with high water table and/or poorly drained soils		▪ Requires large amount of flat land (3% of CDA) ▪ Must be properly designed, installed, and maintained to avoid nuisance problems ▪ Needs constant source of water ▪ Routine sediment cleanout may be needed ▪ Potential for thermal impacts downstream		
Components		**Design considerations**		
▪ Conveyance ▪ Forebay ▪ Deep ponding area ▪ High marsh and transition zones ▪ Micropool ▪ Spillway system(s)		▪ CDA must be large enough to sustain permanent water level ▪ Flow path through the wetland system should be at least 2L:1W ▪ 25% of pool depth should be 18-48 inches ▪ Water balance must be maintained		
Maintenance Activities				
▪ Reinforce plantings as needed ▪ Remove accumulated sediments ▪ Remove invasive vegetation		▪ Thin/harvest vegetation every 2 years on embankments and access areas; elsewhere every 5–10 years		

[1]*Credited pollutant load removal*

Stormwater wetlands, sometimes called constructed wetlands, are shallow depressions that receive stormwater inputs for water quality treatment. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity. Wetlands include various design adaptations to allow them to be applied in specific settings. For example, some designs incorporate trees within the wetland area.

Stormwater wetlands should be considered for use after all other upland retention opportunities have been exhausted and there is still a remaining treatment volume or runoff from larger storms (i.e., 2- to 25-year or flood control events) to manage. Stormwater wetlands receive no stormwater retention credit and should be considered mainly for management of larger storm events. Stormwater wetlands have both community and environmental concerns (see Section 4.13.1 Stormwater Wetland Feasibility Criteria) that should be considered before choosing stormwater ponds for the appropriate stormwater practice on site.

Figure 4.50 Stormwater Wetland at Carolina Forest Recreation Center, Myrtle Beach (photo: Kathryn Ellis).

Definition. Practices that create shallow marsh areas to treat urban stormwater, which often incorporate small permanent pools and/or extended detention storage. Stormwater wetlands are explicitly designed to provide stormwater detention for larger storms (2 – 25-year, or flood control events) above the design storm (SWRv) storage. Wetlands are typically less than 1 foot deep (although they have greater depths at the forebay and in micropools) and possess variable microtopography to promote dense and diverse wetland cover. Design variants include the following:

W-1 Shallow wetland

W-2 Extended detention shallow wetland

Several stormwater wetland design features are illustrated in Figure 4. 48 through Figure 4. 52.

Note: All of the pond performance criteria presented in Section 4.10 Ponds also apply to the design of stormwater wetlands. Additional criteria that govern the geometry and establishment of created wetlands are presented in this section.

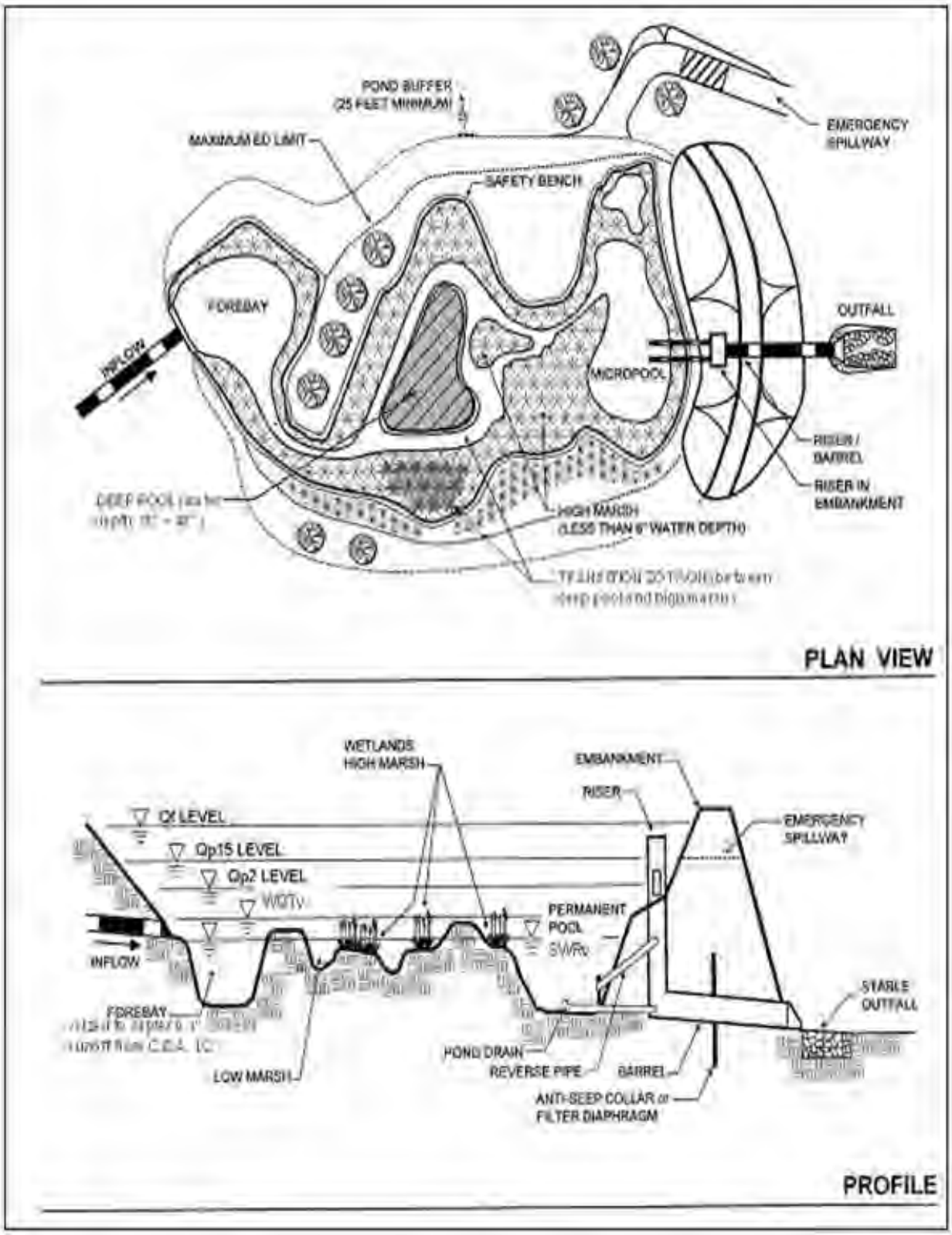

Figure 4.51 Example of extended detention shallow wetland.

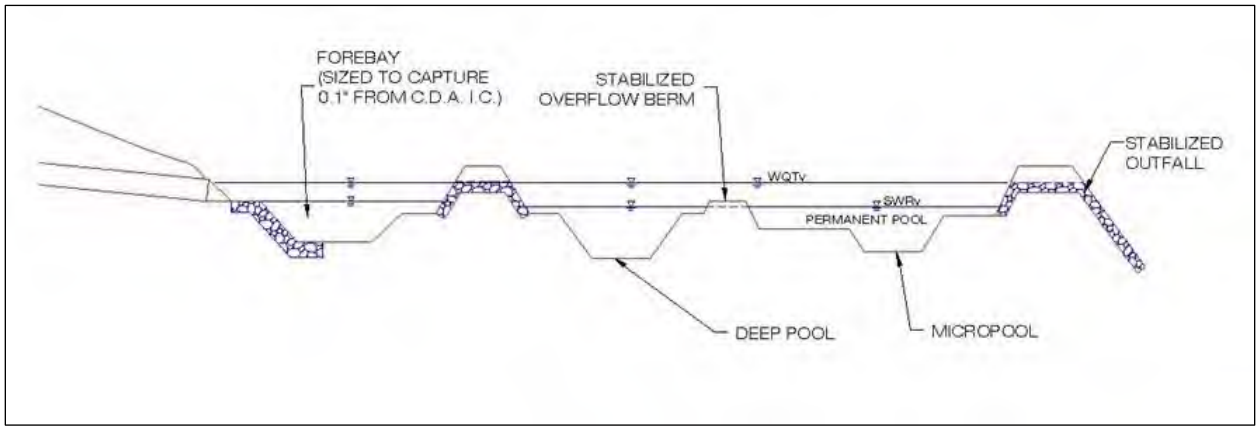

Figure 4.52 Cross section of a typical stormwater wetland.

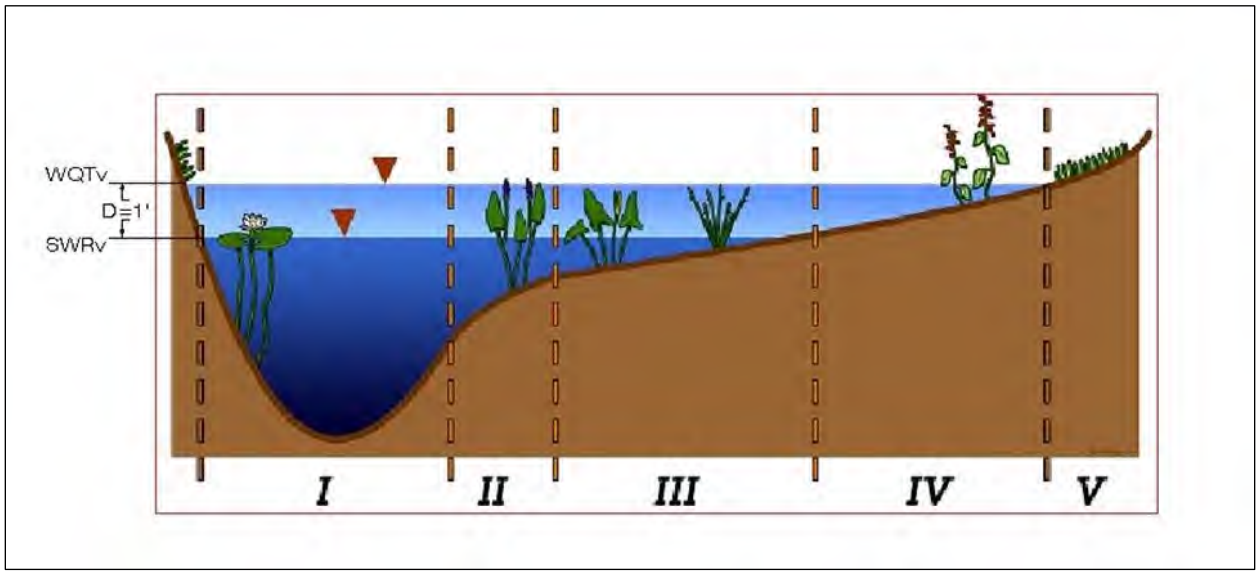

Figure 4.53 Interior wetland zones. Adapted from Hunt et al. (2007).

(I) Deep Pool (depth -48 to -18 inches),

(II) Transition Zone (depth -18 to -6 inches),

(III and IV) High Marsh Zone (depth -6 to +6 inches),

(IV) Temporary Inundation Area, and

(V) Upper Bank

4.13.1 Stormwater Wetland Feasibility Criteria

Constructed wetland designs are subject to the following site constraints:

Adequate Water Balance. Stormwater wetlands must have enough water supplied from groundwater, runoff, or baseflow so that the permanent pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in Section 4.11.4 Stormwater Wetland Design Criteria.

Contributing Drainage Area. The CDA must be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of CDA are typically needed to maintain constant water elevations. Smaller CDAs are acceptable if the bottom of the stormwater wetland intercepts the groundwater table or if the designer or approving agency is willing to accept periodic wetland drawdown.

Space Requirements. Constructed wetlands normally require a footprint that takes up about 3% of the CDA, depending on the average depth of the wetland and the extent of its deep pool features.

Site Topography. Stormwater wetlands are best applied when the grade of contributing slopes is less than 8%.

Steep Slopes. A modification of the constructed wetland (and linear wetland or wet swale system) is the regenerative stormwater conveyance (RSC) or step pool storm conveyance channel. The RSC can be used to bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down outfalls where steep drops on the edge of the tidal receiving system can create design challenges. A description of this practice is provided in Section 4.7 Open Channel Systems. For more detailed information on RSC systems, designers can consult Maryland's Anne Arundel County Design Specifications, available at http://www.aacounty.org/departments/public-works/wprp/watershed-assessment-and-planning/step-pool-conveyance-systems/index.html

Available Hydraulic Head. The depth of a constructed wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because constructed wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Setbacks. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing protection must be provided for foundations and basements.

Depth to Water Table. The depth to the groundwater table is not a major constraint for constructed wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may increase excavation costs (refer to Section 0 Ponds).

Soils. Soil tests should be conducted to determine the saturated hydraulic conductivity and other subsurface properties of the soils underlying the proposed stormwater wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of HSG C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner (see Table 4.49 in Section 4.10 Ponds).

Use of or Discharges to Natural Wetlands. Constructed wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a Section 404 permit from the appropriate federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland. See Cappiella et al. (2006) for guidance on minimizing stormwater discharges to existing wetlands.

Regulatory Status. Constructed wetlands built for the express purpose of stormwater treatment are generally not considered jurisdictional wetlands, but designers should check with their wetland regulatory authorities to ensure the status.

Perennial Streams. Locating a constructed wetland along or within a perennial stream will require both Section 401 and Section 404 permits from the state or federal regulatory authority.

Economic Considerations. If space is available, wetlands can be a very cost-effective stormwater practice.

Community and Environmental Concerns. In addition to the community and environmental concerns that exist for stormwater ponds, the following must be addressed during design of stormwater wetlands:

Aesthetics and Habitat. Constructed wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted.

Existing Forests. Given the large footprint of a constructed wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout and may consider creating a wooded wetland (see Cappiella et al., 2006).

Safety Risk. Constructed wetlands are safer than other types of ponds, although forebays and micropools must be designed with aquatic benches to reduce safety risks.

Mosquito Risk. Mosquito control can be a concern for stormwater wetlands if they are under-sized or have a small CDA. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well-designed, properly sized, and frequently maintained constructed wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within constructed wetlands (e.g., constant inflows, benches that create habitat for natural predators, and constant pool elevations—MSSC, 2005).

4.13.2 Stormwater Wetland Conveyance Criteria

The slope profile within individual stormwater wetland cells should generally be flat from inlet to outlet (adjusting for microtopography). The recommended maximum elevation drop between wetland cells is 1 foot or less.

Since most constructed wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 25-year and 100-year design storms). While the ponding depths for the more frequent 2-year storm are limited in order to avoid adverse impacts to the planting pallet, the overflow for the less frequent 25-100-year storms must likewise be carefully designed to minimize the depth of ponding. A maximum depth of 4 feet over the wetland pool is recommended.

While many options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al., 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

4.13.3 Stormwater Wetland Pretreatment Criteria

Sediment regulation is critical to sustain stormwater wetlands. Consequently, a forebay shall be located at the inlet and a micropool shall be located at the outlet. A micropool is a 3- to 6-foot-deep pool used to protect the low-flow pipe from clogging and to prevent sediment resuspension. Forebays are designed in the same manner as stormwater ponds (see Section 4.12.3 Pond Pretreatment Criteria). The design of forebays should consider the possibility of heavy trash loads from public areas.

4.13.4 Stormwater Wetland Design Criteria

Internal Design Geometry. Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Stormwater wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are required for stormwater wetlands:

Multiple-Cell Wetlands. Stormwater wetlands can be divided into at least four internal sub-cells of different elevations: the forebay, a micro-pool outlet, and two additional cells. Cells can be formed by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 95% of the wetland width). The vegetative target is to ultimately achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

The first cell (the forebay) is deeper and is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it as sheetflow into successive wetland cells. The surface elevation of the second cell is the normal pool elevation. It may contain a forested island or a sand wedge channel to promote flows into the third cell, which is 3 to 6 inches lower than the normal pool elevation. The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize pollutant removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

Extended Detention Ponding Depth. When extended detention is provided for management of larger storm events, the total ED volume shall not comprise more than 50% of the total volume stored by the stormwater wetland, and its maximum water surface elevation shall not extend more than 3 feet above the normal pool.

Deep Pools. Approximately 25% of the stormwater surface area must be provided in at least three deeper pools—located at the inlet (forebay), center, and outlet (micropool) of the wetland—with each pool having a depth of from 18 to 48 inches. Refer to the sizing based on water balance below for additional guidance on the minimum depth of the deep pools.

High Marsh Zone. Approximately 70% of the stormwater wetland surface area must exist in the high marsh zone (-6 inches to +6 inches, relative to the normal pool elevation).

Transition Zone. The low marsh zone is no longer an acceptable wetland zone, and is only allowed as a short transition zone from the deeper pools to the high marsh zone (-6 to -18 inches below the normal pool elevation). In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Flow Path. In terms of the flow path, there are two design objectives:

- The overall flow path through the stormwater wetland can be represented as the length-to-width ratio OR the flow path ratio. A minimum overall flow path of 2:1 must be provided across the stormwater wetland.
- The shortest flow path represents the distance from the closest inlet to the outlet. The ratio of the shortest flow path to the overall length must be at least 0.5. In some cases—due to site geometry, storm sewer infrastructure, or other factors—some inlets may not be able to meet these ratios. However, the CDA served by these "closer" inlets must constitute no more than 20% of the total CDA.

Side Slopes. Side slopes for the stormwater wetland should generally have gradients of 4H:1V or flatter. These mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

Micro-Topographic Features. Stormwater wetlands must have internal structures that create variable micro-topography, which is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover.

Stormwater Wetland Material Specifications. Stormwater wetlands are generally constructed with materials obtained on site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and geotextile fabric for lining banks or berms. Plant stock should be nursery grown, unless otherwise approved (e.g. by the local regulatory authority), and must be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined during the local plan review.

Stormwater Wetland Sizing. Stormwater wetlands can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm (SWRv). Additionally, stormwater wetlands can be sized to control peak flow rates from the 2- 50-year frequency storm event or other design storm. Design calculations must ensure that the post-development peak discharge does not exceed the predevelopment peak discharge. See Section 3.7.2 Hydrologic and Hydraulic Analysis for a summary of acceptable hydrologic methodologies and models.

For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or NRCS CN that reflects the volume reduction of upland practices to compute the 2- 50-year frequency storm event that must be treated by the stormwater wetland.

The wetland permanent pools (volume stored in deep pools and pool depths) must be sized to store a volume equivalent to the SWRv or design volume.

The storage volume (Sv) of the practice is equal to the volume provided by the wetland permanent pool (Equation 4.29). The total Sv cannot exceed the SWRv.

Equation 4.29 Stormwater Wetland Storage Volume

$$Sv = Stormwater\ wetland\ permanent\ pool\ volume$$

Sizing for Minimum Pool Depth. Initially, it is recommended that there be no minimum CDA requirement for the system, although it may be necessary to calculate a water balance for the wet pond cell when its CDA is less than 10 acres (Refer to Section 4.10 Ponds).

Similarly, if the hydrology for the constructed wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using Equation 4.30 (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30-day summer drought.

Equation 4.30 Water Balance for Acceptable Water Depth in a Stormwater Wetland

$$DP = \left(RF_m \times EF \times \frac{WS}{WL}\right) - (ET - INF - RES)$$

Where:

DP	=	depth of pool (in.)
RF_m	=	monthly rainfall during drought (in.)
EF	=	fraction of rainfall that enters the stormwater wetland (in.) (CDA × Rv)
WS/WL	=	ratio of contributing drainage area to stormwater wetland surface area
ET	=	summer evapotranspiration rate (in.) (assume 8 in.)
INF	=	monthly infiltration loss (assume 7.2 inches at 0.01 in./hr)
RES	=	reservoir of water for a factor of safety (assume 6 in.)

Using Equation 4.30, setting the groundwater and (dry weather) base flow to zero and assuming a worst-case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows (Equation 4.31):

Equation 4.31 Minimum Depth of the Permanent Pool

$$DP = RF_m - ET - INF - RES = 21.2$$

Where:

DP	=	depth of pool (in.)
RF_m	=	monthly rainfall during drought (in.)
ET	=	summer evapotranspiration rate (in.) (assume 8 in.)
INF	=	monthly infiltration loss (assume 7.2 inches at 0.01 in./hr)
RES	=	reservoir of water for a factor of safety (assume 6 in.)

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool should be at least 22 inches (rather than the 18-inch minimum depth noted in Section 4.11.4 Stormwater Wetland Design Criteria).

4.13.5 Stormwater Wetland Construction Sequence

The construction sequence for stormwater wetlands depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line stormwater wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

1. Stabilize Contributing Drainage Area. Stormwater wetlands should only be constructed after the CDA to the wetland is completely stabilized. If the proposed stormwater wetland site will be used as a sediment trap or basin during the construction phase, the construction notes must clearly indicate that

the facility will be de-watered, dredged, and re-graded to design dimensions after the original site construction is complete.

2. Assemble Construction Materials on Site. Inspect construction materials to ensure they conform to design specifications and prepare any staging areas.

3. Clear and Strip. Bring the project area to the desired subgrade.

4. Install Soil Erosion and Sediment Control Measures prior to construction, including sediment basins and stormwater diversion practices. All areas surrounding the stormwater wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials, or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the stormwater wetland. During construction, the stormwater wetland must be separated from the CDA so that no sediment flows into the wetland areas. In some cases, a phased or staged soil erosion and sediment control plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

5. Excavate the Core Trench for the Embankment and Install the Spillway Pipe.

6. Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al., 2007).

7. Construct the Embankment and any Internal Berms in 8- to 12-inch lifts and compact them with appropriate equipment.

8. Excavate and Grade. Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the stormwater wetland. This is normally done by “roughing up” the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

9. Install Micro-Topographic Features and Soil Amendments within the stormwater wetland area. Since most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil, or wetland mulch to all depth zones in the stormwater wetland. The importance of soil amendments in excavated stormwater wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

10. Construct the Emergency Spillway in cut or structurally stabilized soils.

11. Install Outlet Pipes. The installation of outlet pipes must include a downstream riprap protection apron.

12. Stabilize Exposed Soils with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

1. Finalize the Stormwater Wetland Landscaping Plan. At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the stormwater wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following:

- Where the inundation zones are located in and around the stormwater wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the stormwater wetland.

2. Open Up the Stormwater Wetland Connection. Once the final grades are attained, the pond and/or CDA connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the stormwater wetland to avoid erosion of unplanted features. Inundation must occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

3. Measure and Stake Planting Depths at the onset of the planting season. Depths in the stormwater wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field, using stakes or flags.

4. Propagate the Stormwater Wetland. Two techniques are used in combination to propagate the emergent community over the wetland bed:

5. Initial Planting of Container-Grown Wetland Plant Stock. The transplanting window extends from early March through May. Planting after these dates can decrease the chance of survival, since emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. It is recommended that plants be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.

6. Broadcasting Wetland Seed Mixes. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.

7. Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a crisscross pattern over the surface area of the stormwater wetland, above the level of the emergent plants.

8. Plant the Stormwater Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm). Consequently, plants in this zone are infrequently inundated (5 to 10 times per year) and must be able to tolerate both wet and dry periods.

Construction Supervision. Supervision during construction is recommended to ensure that stormwater wetlands are properly constructed and established. Multiple site visits and inspections by a qualified professional are recommended during the following stages of the stormwater wetland construction process:

- Preconstruction meeting
- Initial site preparation including the installation of soil erosion and sediment control measures
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization
- Immediately seed or install vegetated ground cover upon completion of sloping and grading, where applicable, of each stormwater wetland within a project.
- Inspect within two weeks to ensure vegetation is in fact holding banks and slopes in place.
- Prior to completion of project, mechanically remove erosion deposition from ponds that occurred during the project. Criteria should be based on erosion of designed bank slopes and loss of storage capacity.
- Final inspection (develop a punch list for facility acceptance)

Construction inspection checklist for Stormwater Wetlands can be found in Appendix E Construction Inspection Checklists.

4.13.6 Stormwater Wetland Landscaping Criteria

An initial stormwater wetland landscaping plan is required for any stormwater wetland and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance, and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. At a minimum, the plan should contain the following:

- Plan view(s) with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the stormwater wetland configuration, different planting zones (e.g., high marsh, deep water, upland), microtopography, grades, site preparation, and construction sequence.
- A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the constructed wetland should contain plants found in similar local wetlands.

The following general guidance is provided:

- **Use Native Species Where Possible.** Table 4.53 provides a list of common native shrub and tree species and Table 4.54 provides a list of common native emergent, submergent, and perimeter plant species, all of which have proven to do well in stormwater wetlands in the mid-Atlantic region and are generally available from most commercial nurseries. Other native species can be used that appear in state-wide plant lists. The use of native species is strongly encouraged, but in some cases,

non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails (*Typha latifolia*), common reed (*Phragmites australis*), and purple loosestrife (*Lythrum salicaria*) must not be planted.

- **Match Plants to Inundation Zones.** The various plant species shown in Table 4.53 and Table 4.54 should be matched to the appropriate inundation zone. The first four inundation zones are particularly applicable to stormwater wetlands, as follows:

  Zone 1 -6 inches to -12 inches below the normal pool elevation

  Zone 2 -6 inches to the normal pool elevation

  Zone 3 From the normal pool elevation to +12 inches above

  Zone 4 +12 inches to +36 inches above the normal pool elevation (i.e., above ED Zone)

  Note: The Low Marsh Zone (-6 to -18 inches below the normal pool elevation) has been dropped since experience has shown that few emergent wetland plants flourish in this deeper zone.

- **Aggressive Colonizers.** To add diversity to the stormwater wetland, five to seven species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers (shown in bold in Table 4.54). No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire stormwater wetland should be colonized within 3 years. Individual plants should be planted 18 inches on center within each single species "cluster."

- **Suitable Tree Species.** The major shift in stormwater wetland design is to integrate trees and shrubs into the design, in tree islands, peninsulas, and fringe buffer areas. Deeper-rooted trees and shrubs that can extend to the stormwater wetland's local water table are important for creating a mixed wetland community. Table 4. 53 above presents some recommended tree and shrub species for different inundation zones. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container or bare root stock is usually the most successful approach if planting in the spring. It is recommended that buffer planting areas be over-planted with a small stock of fast-growing successional species to achieve quick canopy closure and shade out invasive plant species. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.

- **Pre- and Post-Nursery Care.** Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when in transporting them to the planting location. As much as 6 to 9 months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries. Consult local regulatory authorities for information on area suppliers.

Table 4.53. Popular, Versatile, and Available Native Trees and Shrubs for Stormwater Wetlands

Shrubs		Trees	
Common and *Scientific* Names	**Zone[1]**	**Common and *Scientific* Names**	**Zone[1]**
Button Bush *(Cephalanthus occidentalis)*	2, 3	Atlantic White Cedar *(Charnaecyparis thyoides)*	2, 3
Common Winterberry *(Ilex verticillatta)*	3, 4	Bald Cypress *(Taxodium distichum)*	2, 3
Elderberry *(Sambucus canadensis)*	3	Black Willow *(Salix nigra)*	3, 4
Indigo Bush *(Amorpha fruticosa)*	3	Box Elder *(Acer Negundo)*	2, 3
Inkberry *(Ilex glabra)*	2, 3	Green Ash *(Fraxinus pennsylvanica)*	3, 4
Smooth Alder *(Alnus serrulata)*	2, 3	Grey Birch *(Betula populifolia)*	3, 4
Spicebush *(Lindera benzoin)*	3, 4	Red Maple *(Acer rubrum)*	3, 4
Swamp Azalea *(Azalea viscosum)*	2, 3	River Birch *(Betula nigra)*	3, 4
Swamp Rose *(Rosa palustris)*	2, 3	Swamp Tupelo *(Nyssa biflora)*	2, 3
Sweet Pepperbush *(Clethra ainifolia)*	2, 3	Sweetbay Magnolia *(Magnolia virginiana)*	3, 4
		Sweetgum *(Liquidambar styraciflua)*	3, 4
		Sycamore *(Platanus occidentalis)*	3, 4
		Water Oak *(Quercus nigra)*	3, 4
		Willow Oak *(Quercus phellos)*	3,4

[1] Zone 1: -6 to -12 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone
Source: Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

Table 4.54. Popular, Versatile, and Available Native Emergent and Submergent Vegetation for Stormwater Wetlands

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Arrow Arum *(Peltandra virginica)*	2	Emergent	Up to 1 ft	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrowhead (Duck Potato) *(Saggitaria latifolia)*	2	Emergent	Up to 1 ft	Moderate; tubers and seeds eaten by ducks	Aggressive colonizer
Blueflag Iris* *(Iris versicolor)*	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge *(Andropogon virginianus)*	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating water levels and partial shade
Bulltongue Arrowhead *(Sagittaria lancifolia)*	2, 3	Emergent	0 to 24 in.	Waterfowl, small mammals	Full sun to partial shade
Burreed *(Sparganium americanum)*	2, 3	Emergent	0 to 6 in.	Waterfowl, small mammals	Full sun to partial shade
Cardinal Flower* *(Lobelia cardinalis)*	3	Perimeter	Periodic inundation	Attracts hummingbirds	Full sun to partial shade
Common Rush *(Juncus spp.)*	2, 3	Emergent	Up to 12 in.	Moderate; small mammals, waterfowl, songbirds	Full sun to partial shade
Common Three Square *(Scipus pungens)*	2	Emergent	Up to 6 in.	High; seeds, cover, waterfowl, songbirds	Fast colonizer; can tolerate periods of dryness; full sun; high metal removal
Duckweed (*Lemna sp.)*	1, 2	Submergent / Emergent	Yes	High; food for waterfowl and fish	May biomagnify metals beyond concentrations found in the water
Joe Pye Weed *(Eupatorium purpureum)*	2, 3	Emergent	Drier than other Joe-Pye Weeds; dry to moist areas; periodic inundation	Butterflies, songbirds, insects	Tolerates all light conditions
Lizard's Tail *(Saururus cernus)*	2	Emergent	Up to 1 ft	Low; except for wood ducks	Rapid growth; shade-tolerant
Marsh Hibiscus *(Hibiscus moscheutos)*	2, 3	Emergent	Up to 3 in.	Low; nectar	Full sun; can tolerate periodic dryness

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Pickerelweed *(Pontederia cordata)*	2, 3	Emergent	Up to 1 ft	Moderate; ducks, nectar for butterflies	Full sun to partial shade
Pond Weed *(Potamogeton pectinatus)*	1	Submergent	Yes	Extremely high; waterfowl, marsh and shore birds	Removes heavy metals from the water
Rice Cutgrass *(Leersia oryzoides)*	2, 3	Emergent	Up to 3 in.	High; food and cover	Prefers full sun, although tolerant of shade; shoreline stabilization
Sedges *(Carex spp.)*	2, 3	Emergent	Up to 3 in.	High; waterfowl, songbirds	Wetland and upland species
Softstem Bulrush *(Scipus validus)*	2, 3	Emergent	Up to 2 ft	Moderate; good cover and food	Full sun; aggressive colonizer; high pollutant removal
Smartweed *(Polygonum spp.)*	2	Emergent	Up to 1 ft	High; waterfowl, songbirds; seeds and cover	Fast colonizer; avoid weedy aliens, such as *P. Perfoliatum*
Spatterdock *(Nuphar luteum)*	2	Emergent	Up to 1.5 ft	Moderate for food, but High for cover	Fast colonizer; tolerant of varying water levels
Switchgrass *(Panicum virgatum)*	2, 3, 4	Perimeter	Up to 3 in.	High; seeds, cover; waterfowl, songbirds	Tolerates wet/dry conditions
Sweet Flag* *(Acorus calamus)*	2, 3	Perimeter	Up to 3 in.	Low; tolerant of dry periods	Tolerates acidic conditions; not a rapid colonizer
Waterweed *(Elodea canadensis)*	1	Submergent	Yes	Low	Good water oxygenator; high nutrient, copper, manganese, and chromium removal
Wild celery *(Valisneria americana)*	1	Submergent	Yes	High; food for waterfowl; habitat for fish and invertebrates	Tolerant of murkey water and high nutrient loads
Wild Rice *(Zizania aquatica)*	2	Emergent	Up to 1 ft	High; food, birds	Prefers full sun
Woolgrass Bulrush *(Scirpus cyperinus)*	3, 4	Emergent	Yes	High: waterfowl, small mammals	Fresh tidal and non-tidal, swamps, forested wetlands, meadows, ditches

Aggressive colonizers are shown in bold type

[1] Zone 1: -6 to -12 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone

*Not a major colonizer, but adds color

Source: Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

4.13.7 Stormwater Wetland Maintenance Criteria

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first 2 years:

- **Initial Inspections.** During the first 6 months following construction, the site should be inspected by a qualified professional at least twice after storm events that exceed 0.5 inch of rainfall.
- **Spot Reseeding.** Inspections should include looking for bare or eroding areas in the CDA or around the wetland buffer and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every 3 days for first month, and then weekly during the first growing season (April through October), depending on rainfall.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the stormwater wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, and drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the stormwater wetland that fail to fill in or survive. If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, a reinforcement planting will be required.

Managing vegetation is an important ongoing maintenance task at every constructed wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the stormwater wetland, however, will require some annual maintenance.

Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the stormwater wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

- For more information on invasive plants, consult the South Carolina Exotic Pest Plant Council. Resources are available online at http://www.se-eppc.org/southcarolina/invasivePlants.cfm.

- For more information related to chemical control methods for aquatic plants, please review the fact sheet “Aquatic Weed Control Overview” provided by Clemson’s Cooperative Extension Service and available online at http://www.clemson.edu/extension/hgic/plants/other/landscaping/hgic1714.html.

Thinning or harvesting of excess forest growth may be periodically needed to guide the forested stormwater wetland into a more mature state. Vegetation may need to be harvested periodically if the

constructed wetland becomes overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial stormwater wetland construction. Removal of woody species on or near the embankment and maintenance access areas should be conducted every 2 years.

Designers should refer to Section 4.10.7 Pond Maintenance Criteria for additional maintenance responsibilities associated with stormwater wetlands. Ideally, maintenance of constructed wetlands should be driven by annual inspections by a qualified professional that evaluates the condition and performance of the stormwater wetland. Based on inspection results, specific maintenance tasks will be triggered.

Maintenance inspection checklist for stormwater wetlands and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.13.8 Stormwater Wetland Stormwater Compliance Calculations

Stormwater wetlands are credited with 0% retention, but they do receive 80% TSS, 30% TN, and 60% bacteria removal for the storage volume (Sv) provided by in the permanent pool (Table 4.55).

Table 4.55. Stormwater Wetland Retention and Pollutant Removal

Retention	= 0%
TSS Removal	= 80%
TN Removal	= 25%
Bacteria Removal	= 60%

4.13.9 References

Atlanta Regional Commission (ARC). 2001. Georgia Stormwater Management Manual, First Edition. http://www.georgiastormwater.com

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Hunt, W., M. Burchell, J. Wright and K. Bass. 2007. “Stormwater Wetland Design Update: Zones, Vegetation, Soil and Outlet Guidance.” Urban Waterways. North Carolina State Cooperative Extension Service. Raleigh, NC.

Minnesota Stormwater Steering Committee (MSSC). 2005. Minnesota Stormwater Manual. Emmons & Oliver Resources, Inc. Minnesota Pollution Control Agency. St. Paul, MN.

Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

4.14 Tree Planting & Preservation

Tree Planting and Preservation						
Definition: Existing trees can be preserved or new trees can be planted to reduce stormwater runoff.						
Site Applicability		**BMP Performance Summary**				
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High				
▪ Urban ▪ Suburban ▪ Rural	Small	**TSS[1]**		**Total N[1]**		**Bacteria[1]**
		N/A		N/A		N/A
		Runoff Reductions				
Construction Costs	**Maintenance Burden**	**Volume**				
Low	Low	Low				
Maintenance Frequency:		***SWRv****				
Routine	**Non-Routine**	**T-1 Small**	**T-1 Large**	**T-2 Small**	**T-2 Large**	**T-2 Special**
At least annually	Every 10–15 years	5 ft^3	10 ft^3	10 ft^3	20 ft^3	30 ft^3
Advantages/Benefits		**Disadvantages/Limitation**				
▪ High community acceptance ▪ Relatively low maintenance requirements ▪ Increases property value ▪ Easily incorporated with other practices ▪ Excellent for soils		▪ Preserved trees must be protected during construction ▪ Must be within LOD ▪ Must maintain tree health				
Components		**Design considerations**				
▪ Inventory of existing trees ▪ Identification of trees to preserve or plant ▪ Preference for Special trees ▪ Average tree spread		▪ Inventory of existing trees ▪ Identification of trees to preserve or plant ▪ Preference for Special trees ▪ Slope-steep slopes must be terraced/benched ▪ Maintenance access				
Maintenance Activities						
▪ If staked during establishment, remove stakes within 1 year of planting		▪ Maintain appropriate mulch cover ▪ Ensure tree health				

[1]*Credited pollutant load removal*

**Per planted/preserved tree*

Easily combined with other practices, tree planting and preservation provide stormwater interception, beauty, and shade, thereby increasing aesthetics and property values.

Figure 4.54 Tree Planting and Preservation in Bioretention (photo: Center for Watershed Protection, Inc.).

Definition. Existing trees can be preserved or new trees can be planted to reduce stormwater runoff. The design includes the following:

T-1 Tree planting

T-2 Tree preservation

Tree canopy can intercept a significant amount of rainfall before it becomes runoff, particularly if the tree canopy covers impervious surfaces, as in the case of street trees. Through the processes of evapotranspiration and nutrient uptake, trees—even when located on a development site—have the capacity to reduce stormwater runoff volumes and improve water quality. Further, through root growth, trees can improve the infiltration capacity of the soils in which they grow.

Both tree planting and tree preservation can contribute to stormwater management on a site. Note that retention credit is available for preserved trees only when they are within the limits of disturbance of a project. Preserved trees outside of the limits of disturbance may offer an opportunity for additional retention when they constitute an area of natural cover and stormwater is conveyed to that area.

4.14.1 Preserving Existing Trees during Construction

The preferred method for increasing tree cover at a development site is to preserve existing trees during construction, particularly where mature trees are present. Existing trees are preserved during construction through a four-step process:

1. Inventory existing trees.
2. Identify trees to preserve.
3. Protect trees and soil during construction.
4. Protect trees after construction.

Inventory Existing Trees. An inventory of existing trees and forested areas at the development site must be conducted before any site design, clearing, or construction takes place, as specified by the DDOT UFD. The inventory must be conducted by one of the following landscape professionals:

- South Carolina Licensed Forester
- South Carolina Licensed Tree Expert
- South Carolina Experienced Forester
- South Carolina Licensed Landscape Architect
- International Society of Arboriculture (ISA) Certified Arborist

The inventory must include a survey of existing trees and determine their size, species, condition, and ecological value. Locations of trees and forest stands must be recorded.

Identify Trees to Preserve. From the tree inventory, individual trees can be identified for preservation and protection during site development. Preserved trees fall into three categories of retention credit: tree species with an average mature spread less than or equal to 40 feet ("small" trees) receive 10 cubic feet of retention credit; trees species with an average mature spread greater than or equal to 40 feet ("large" trees) receive 20 cubic feet of retention credit; and trees with an existing diameter greater than 14" ("Special" trees receive 30 cubic feet of retention credit, regardless of mature spread size. Additional selection criteria may include tree species, size, condition, and location (see Table 4.56).

Table 4.56. Selecting Priority Trees and Forests for Preservation

Selection Criteria	Examples of Priority Tree and Forests to Conserve
Species	▪ Rare, threatened, or endangered species ▪ Specimen trees ▪ High quality tree species (e.g., white oaks and sycamores because they are structurally strong and live longer than trees such as silver maple and cottonwood) ▪ Species that are tolerant of specific site conditions and soils
Size	▪ Trees over a specified diameter at breast height (DBH) or other size measurement ▪ Trees designated as national, state, or local champions ▪ Contiguous forest stands
Condition	▪ Healthy trees that are structurally sound in “fair” or better condition ▪ High quality forest stands with high forest structural diversity
Location	▪ Trees located where they will provide direct benefits at the site (e.g., shading, privacy, windbreak, buffer from adjacent land use) ▪ Forest stands that are connected to off-site forests that create wildlife habitat and corridors ▪ Trees located in protected natural areas such as floodplains, stream buffers, wetlands, erodible soils, critical habitat areas, and steep slopes. ▪ Forest stands that are connected to off-site non-forested natural areas or protected land (e.g., has potential to provide wildlife habitat)

Trees selected for preservation and protection must be clearly marked both on construction drawings and at the actual site. Flagging or fencing is typically used to protect trees at the construction site. Areas of trees to preserve should be marked on the site map and walked during preconstruction meetings.

Protect Trees and Soil During Construction. Physical barriers must be properly installed around the Critical Root Zone (CRZ) of trees to be preserved. The CRZ shall be determined by a landscape professional from the above list, and in general is equal to 1.5 feet of tree protection (radius of circle) for every 1 inch in tree diameter. For example, a 10-inch diameter tree would have a CRZ radius extending 15 feet from the tree. The barriers must be maintained and enforced throughout the construction process. Tree protection barriers include highly visible, well-anchored temporary protection devices, such as 6-foot-tall chain link fencing.

All protection devices must remain in place throughout construction.

When excavation is proposed immediately adjacent to the CRZ, roots must first be pruned at the edge of the excavation with a trenching machine, vibratory knife or rock saw to a depth of 18 inches.

Protect Trees After Construction. Maintenance covenants, as described below, are required to ensure that preserved trees are protected.

4.14.2 Planting Trees

Considerations at Development Sites. New development sites provide many opportunities to plant new trees. Planting trees at development sites is done in three steps:

1. Select tree species.
2. Evaluate and improve planting sites.
3. Plant and maintain trees.

Tree Species. Planted trees fall into two categories of retention: tree species with an average mature spread less than or equal to 40 feet ("small" trees) receive 5 cubic feet of retention and trees species with an average mature spread greater than or equal to 40 feet ("large" trees) receive 10 cubic feet of retention. Trees to be planted must have a minimum caliper size of 1.5 inches.

Planting Sites. Ideal planting sites within a development are those that create interception opportunities around impervious surfaces. These include areas along pathways, roads, islands and median strips, and parking lot interiors and perimeters. Other areas of a development site may benefit from planting trees (including stream valleys and floodplains, areas adjacent to existing forest, steep slopes, and portions of the site where trees would provide buffers, screening, noise reduction, or shading).

It is important to evaluate and record the conditions, such as soil type, soil pH, soil compaction, and the hydrology of proposed planting sites to ensure they are suitable for planting. These evaluations provide a basis for species selection and determination of the need for any special site preparation techniques.

A minimum of 1,500 cubic feet of rootable soil volume must be provided per large tree. In planting arrangements that allow for shared rooting space amongst multiple trees, a minimum of 1,000 cubic feet of rootable soil volume must be provided for each large tree. Rootable soil volume must be within 3 feet of the surface.

Smaller trees with an average mature spread of less than or equal to 40 feet must have a minimum of 600 cubic feet of rootable soil volume. In planting arrangements that permit shared rooting space amongst multiple trees, a minimum of 400 cubic feet of rootable soil volume must be provided for each tree. Rootable soil volume must be within 3 feet of the surface.

Site characteristics determine what tree species will flourish there and whether any of the conditions, such as soils, can be improved through the addition of compost or other amendments. Table 4.57 presents methods for addressing common constraints to urban tree planting.

Table 4.57. Methods for Addressing Urban Planting Constraints

Potential Impact	Potential Resolution
Limited Soil Volume	▪ Provide 1,500 cubic feet of rootable soil volume per large tree (greater than or equal to 40-foot spread) and 600 cubic feet of rootable soil volume per small tree (less than or equal to 40-foot spread). This soil must be within 3 feet of the surface. • Use planting arrangements that allow shared rooting space. A minimum of 1,000 cubic feet of rootable soil volume must be provided for each tree in shared rooting space arrangements. A minimum of 400 cubic feet of rootable soil volume must be provided for each small tree in shared rooting arrangements.
Poor Soil Quality	▪ Test soil and perform appropriate restoration. ▪ Select species tolerant of soil pH, compaction, drainage, etc. ▪ Replace very poor soils if necessary.
Air Pollution	▪ Select species tolerant of air pollutants.
Damage from Lawnmowers	▪ Use mulch to protect trees.
Damage from Vandalism	▪ Use tree cages or benches to protect trees. ▪ Select species with inconspicuous bark or thorns. ▪ Install lighting nearby to discourage vandalism.
Damage from Vehicles	▪ Provide adequate setbacks between vehicle parking stalls and trees.
Damage from animals such as deer, rodents, rabbits, and other herbivores	▪ Use protective fencing or chemical retardants.
Exposure to pollutants in stormwater runoff	▪ Select species that are tolerant of specific pollutants, such as oils and metals.
Soil moisture extremes	▪ Select species that are tolerant of inundation or drought. ▪ Install underdrains if necessary. ▪ Select appropriate backfill soil and mix thoroughly with site soil. ▪ Improve soil drainage with amendments and tillage if needed.
Increased temperature	▪ Select drought tolerant species.
Increased wind	▪ Select drought tolerant species.
Abundant populations of invasive species	▪ Control invasive species prior to planting. ▪ Continually monitor for and remove invasive species.
Conflict with infrastructure	▪ Design the site to keep trees and infrastructure separate. ▪ Provide appropriate setbacks from infrastructure. ▪ Select appropriate species for planting near infrastructure. ▪ Use alternative materials to reduce conflict.
Disease or insect infestation	▪ Select resistant species

Planting trees at development sites requires prudent species selection, a maintenance plan, and careful planning to avoid impacts from nearby infrastructure, runoff, vehicles or other urban elements.

Trees Along Streets and in Parking Lots. When considering a location for planting, clear lines of sight must be provided, as well as safe travel surfaces, and overhead clearance for pedestrians and vehicles.

Also, ensure enough soil volume for healthy tree growth. Usable soil must be uncompacted and may not be covered by impervious material. Having at least a 6-foot-wide planting strip or locating sidewalks between the trees and street allows more rooting space for trees in adjacent property.

Select tree species that are drought tolerant, can grow in poor or compacted soils, and are tolerant to typical urban pollutants (oil and grease, metals, and chlorides). Additionally, select species that do not produce excessive fruits, nuts, or leaf litter, that have fall color, spring flowers or some other aesthetic benefit, and can be limbed up to 6 feet to provide pedestrian and vehicle traffic underneath.

Planting Techniques. Prepare a hole no deeper than the root ball or mass but two to three times wider than the spread of the root ball or mass. The majority of the roots on a newly planted tree will develop in the top 12 inches of soil and spread out laterally. There are some additional considerations depending on the type of plant material being used (Table 4.58).

Table 4.58. Tree Planting Techniques

Plant Material	Planting Technique	Planting Season
Bare root	Hand plant	Spring or fall when tree is dormant
Container grown	Hand plant or use mechanical planting tools (e.g., auger)	Spring or fall, summer if irrigated
Balled and burlapped	Use backhoe (or other specialized equipment) or hand plant	Spring or fall

Sources: Palone and Todd (1998), WSAHGP (2002)

One of the most important planting guidelines is too make sure the tree is not planted too deeply. The root collar, the lowest few inches of trunk just above its junction with the roots (often indicated by a flare), should be exposed. Trees planted too deeply have buried root collars, and are weakened, stressed, and predisposed to pests and disease. Trees planted too deeply can also form adventitious roots (roots that form from non-root tissue) near the soil surface in an attempt to compensate for the lack of available oxygen to buried roots. Adventitious roots are not usually large enough to provide support for a large tree and may eventually lead to collapse. ISA (2005) provides additional guidance on how to avoid planting too deeply. It is generally better to plant the tree a little high, that is, with the base of the trunk flare 2 to 3 inches above the soil, rather than at or below the original growing level.

Proper handling during planting is essential to avoid prolonged transplant shock and ensure a healthy future for new trees and shrubs. Trees should always be handled by the root ball or container, never by the trunk. Specifications for planting a tree are illustrated in Figure 4.55. Trees must be watered well after planting.

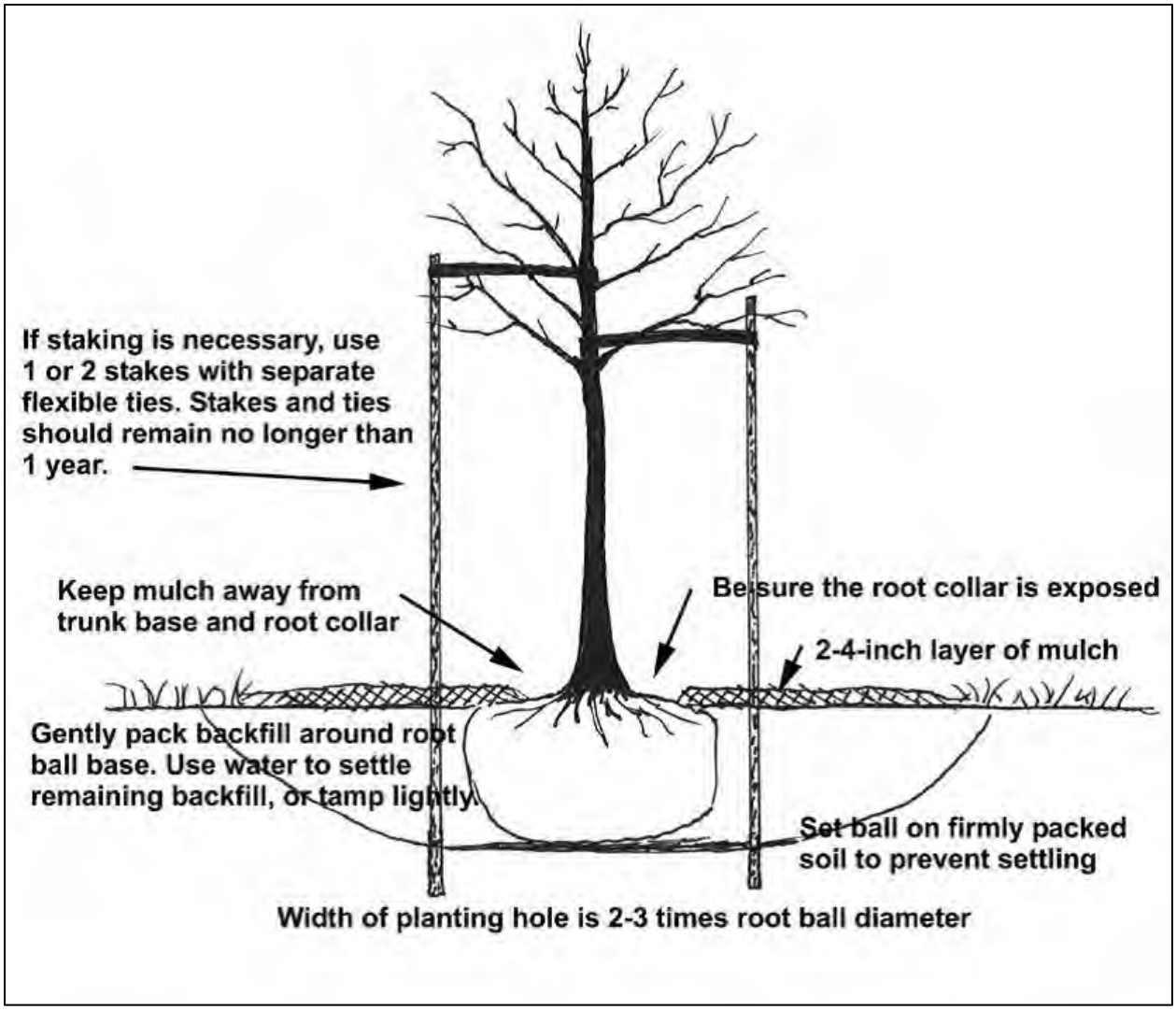

Figure 4.55. Tree planting guidelines. Adapted from Flott, 2004 and ISA, 2003b.

Steep slopes require additional measures to ensure planting success and reduce erosion, especially if the slope receives stormwater runoff from upland land uses. Depending on the steepness of the slope and the runoff volume, rill or gully erosion may occur on these slopes, requiring a twofold approach: controlling the stormwater and stabilizing the slope.

Erosion control blankets are recommended to temporarily stabilize soil on slopes until vegetation is established. Erosion control fabrics come in a variety of weights and types and should be combined with vegetation establishment such as seeding. Other options for stabilizing slopes include applying compost or bark mulch, plastic sheeting, or sodding.

Trees will add stability to slopes because of their deep roots, provided they are not planted by digging rows of pits across a slope. Required maintenance will include mowing (if slopes are not too steep) and establishing cover on bare or eroded areas.

Planting methods for slopes steeper than 3H:1V involve creating a level planting space on the slope (see Figure 4.56). A terrace can be dug into the slope in the shape of a step by cutting into the existing slope

and using the excavated soil as fill to create the step area. A low soil berm (or rock berm) can be formed at the front edge of each step or terrace to slow the flow of water. Trees can also be planted in clusters on slopes (using the above method) to limit potential for desiccation. Staggering tree placement and mulching will prevent water from running straight downhill.

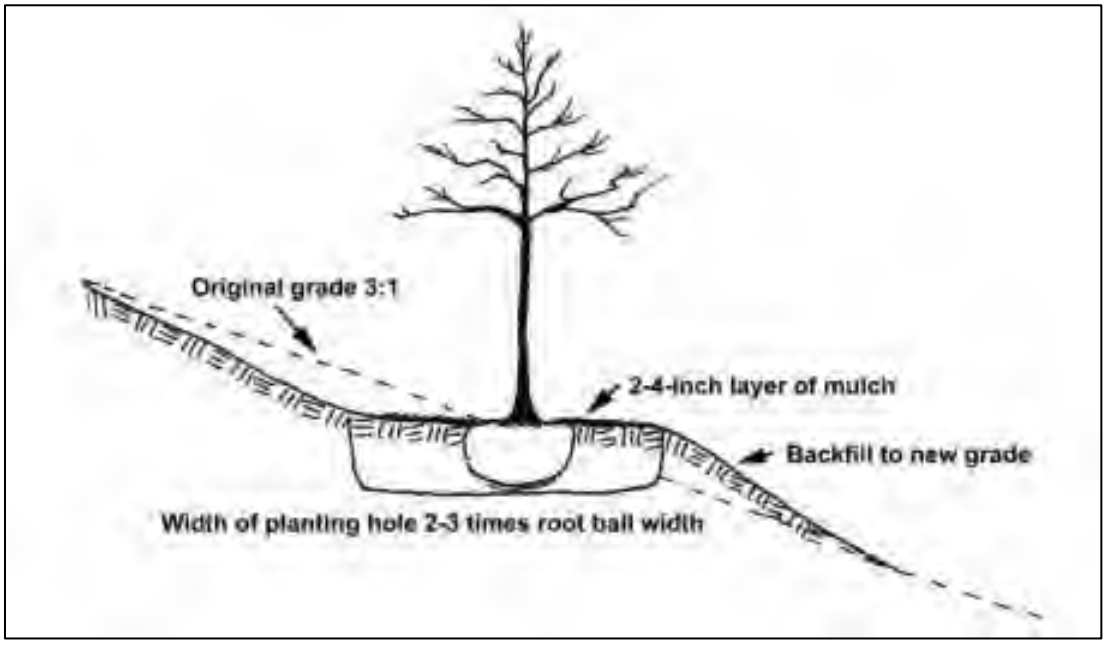

Figure 4.56 Trees planted on steep slopes require a constructed level planting surface.

Post-Planting Tree Protection

Mulching: Once the tree has been properly planted, 2 to 4 inches (maximum) of organic mulch must be spread over the soil surface out to the drip line (the outermost circumference of the tree canopy) of the tree. A mulch-free area, 2 to 3 inches wide at the base of the tree, must be provided to avoid moist bark conditions and prevent decay

If planting a cluster of trees, mulch the entire planting area, ensuring a 2- to 3-inch wide mulch free area at the base of each tree.

Slow-decomposing organic mulches, such as shredded bark, compost, leaf mulch, or wood chips provide many added benefits for trees. Mulch that contains a combination of chips, leaves, bark, and twigs is ideal for reforestation sites. Grass clippings and sawdust are not recommended as mulches because they decompose rapidly and require frequent application, resulting in reduced benefits.

For well-drained sites, up to 4 inches of mulch may be applied. For poorly drained sites, a thinner layer of mulch should be applied. Mulch should never be more than 4 inches deep or applied right next to the tree trunk; however, a common sight in many landscaped areas is the “mulch volcano.” This over-mulching technique can cause oxygen and moisture-level problems, and decay of the living bark at the base of the tree.

Staking: Studies have shown that trees will establish more quickly and develop stronger trunk and root systems if they are not staked at the time of planting. Staking for support may be necessary only for top-heavy trees or at sites where vandalism or windy exposure are a concern.

If staking is necessary for support, two stakes used in conjunction with a wide flexible tie material will hold the tree upright, provide flexibility, and minimize injury to the trunk. To prevent damage to the root ball, stakes should be placed in undisturbed soil beyond the outer edges of the root ball.

Perhaps the most important part of staking is its removal. Over time, guy wires (or other tie material) can cut into the growing trunk bark and interfere with the movement of water and nutrients within the tree. Staking material should be removed within 1 year of planting.

4.14.3 Tree Inspection Criteria

An initial inspection by a qualified professional must be done to ensure the tree has been planted, watered, and protected correctly with locations flagged if appropriate. For newly planted trees, transplant shock is common and causes stress on the tree. For this reason, newly planted trees must be inspected more frequently than established trees. The time it takes for a tree to become established varies with the size at planting, species, stock, and site conditions, but generally, trees should be inspected every few months during the first 3 years after planting, to identify problems and implement repairs or modify maintenance strategies.

After the first 3 years, annual inspections are sufficient to check for problems. Trees must also be inspected after major storm events for any damage that may have occurred. The inspection should take only a few minutes per tree, but prompt action on any problems encountered results in healthier, stronger trees. Inspections should include an assessment of overall tree health, an assessment of survival rate of the species planted, cause of mortality, if maintenance is required, insect or disease problems, tree protection adjustment, and weed control condition.

Construction inspection checklist for tree planting and preservation can be found in Appendix E Construction Inspection Checklists.

4.14.4 Tree Maintenance Criteria

Water newly planted trees regularly (at least once a week) during the first growing season. Water trees less frequently (about once a month) during the next two growing seasons. After 3 growing seasons, water trees only during drought. The exact watering frequency will vary for each tree and site.

A general horticultural rule of thumb is that trees need 1 inch of rainfall per week during the growing season. This means new trees need a minimum of 25 gallons of water a week to stay alive (http://caseytrees.org/get-involved/water/). Water trees deeply and slowly near the roots. Light, frequent watering of the entire plant can encourage roots to grow at the surface. Soaker hoses and drip irrigation work best for deep watering of trees. It is recommended that slow leak watering bags or tree buckets are installed to make watering easier and more effective. Continue watering until mid-fall, tapering off during lower temperatures.

Pruning is usually not needed for newly planted trees but may be beneficial for tree structure. If necessary, prune only dead, diseased, broken or crossing branches at planting. As the tree grows, lower branches may be pruned to provide clearance above the ground, or to remove dead or damaged limbs.

Maintenance inspection checklist for tree planting and preservation and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.14.5 Tree Stormwater Compliance Calculations

Trees receive retention credit, but are not credited with additional TSS, TN, and bacteria removal (Table 4.59). To ensure appropriate stormwater benefits associated with proposed tree preservation or planting, all trees receiving retention credit must be properly maintained until redevelopment of the area occurs. If trees die, they must be replaced with a tree of similar mature spread no longer than 6 months from time of death in an appropriate location.

Preserved trees located within a site's limits of disturbance (LOD) that meet the requirements described above receive a retention credit of 10, 20, or 30 cubic feet each, depending upon the size of the mature spread of the tree and whether the tree is designated as a Special Tree (greater than 14" diameter). Note: To receive the preserved tree retention credit, trees must be left undisturbed in their original location. Trees that are removed and replanted are not considered preserved trees.

Planted trees that meet the requirements described above receive a retention credit of 5 or 10 cubic feet each, depending upon the size of the mature spread of the tree. Note: Trees planted as part of another BMP, such as a bioretention area, also receive the 5 or 10 cubic foot retention credit. Retention credits are shown in Table 4.59 below.

Table 4.59. T-1 Preserved and Planted Tree Retention

Tree Type	Retention Credit
Planted Tree – Small	5 cf per tree
Planted Tree – Large	10 cf per tree
Preserved Tree – Small	10 cf per tree
Preserved Tree – Large	20 cf per tree
Preserved Tree – Special	30 cf per tree

Trees also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the retention credit from the total runoff volume for the 2- to 25-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

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4.15 Proprietary Practices

Proprietary Practices				
Definition: Manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to manage the impacts stormwater runoff. Performance varies based on manufacturer's design.				
Site Applicability		**BMP Performance Summary**		
Land Uses	**Required Footprint**	**WQ Improvement:** Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	Small	**TSS[1]**	**Total N[1]**	**Bacteria[1]**
		Varies*	Varies*	Varies*
		Runoff Reductions		
Construction Costs	**Maintenance Burden**	**Volume**		
Moderate	Moderate	Varies*		
Maintenance Frequency:		***SWRv***		
Routine	**Non-Routine**	Refer to Device Manufacturers Specifications		
At least annually	Variable			
Advantages/Benefits		**Disadvantages/Limitation**		
▪ On- or off-line treatment ▪ Useful in challenging stormwater site designs ▪ Water quality treatment		▪ Devices can be costly ▪ Most devices do not provide retention		
Components		**Design considerations**		
▪ Pretreatment ▪ Conveyance ▪ Bypass mechanism		▪ Must safely overflow or bypass flow from 2- to 25-year design storms. ▪ Manufacturer's specifications ▪ Adequate maintenance access required		
Maintenance Activities				
▪ Based on manufacturer's specifications		▪ Routine inspection for proper function		

[1]*Credited pollutant load removal*

**Varies according to proprietary practice*

Definition. Proprietary practices are manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to manage the impacts stormwater runoff. The design includes the following:

M-1 Proprietary practices

Proprietary practices may be used to achieve treatment compliance, provided they have been approved by the State and meet the performance criteria outlined in this specification. Historically, proprietary practices do not provide retention volume. A proprietary practice will not be valued for retention volume unless the practice can demonstrate the occurrence of retention processes.

4.15.1 Proprietary Practice Feasibility Criteria

Individual proprietary practices will have different site constraints and limitations. Manufacturer's specifications should be consulted to ensure that proprietary practices are feasible for application on a site-by-site basis.

4.15.2 Proprietary Practice Conveyance Criteria

All proprietary practices must be designed to safely overflow or bypass flows from larger storm events to downstream drainage systems. The overflow associated with the 2- to 25-year design storms must be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).

Manufactured treatment devices may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the stormwater quality design storm and conveying the runoff from larger storms through an overflow. In off-line devices, most, or all, of the runoff from storms larger than the stormwater quality design storm bypass the device through an upstream diversion or other mechanism.

4.15.3 Proprietary Practice Pretreatment Criteria

Individual proprietary practices may require pretreatment or may be appropriate for use as pretreatment devices. Manufacturer's specifications should be consulted to determine the device-specific pretreatment requirements.

4.15.4 Proprietary Practice Design Criteria

The basic design parameters for a proprietary practice will depend on the techniques it employs to control stormwater runoff and remove particulate and dissolved pollutants from runoff. In general, the design of devices that treat runoff with no significant storage and flow rate attenuation must be based upon the peak design flow rate. However, devices that do provide storage and flow rate attenuation must be based, at a minimum, on the design storm runoff volume and, in some instances, on a routing of the design runoff hydrograph. Hydrologic design is discussed further in Appendix I Hydrology and Hydraulics Design Requirements.

Proprietary practices approval is contingent on adherence to the New Jersey Department of Environmental Protection Certification (NJDEP) protocols and testing. The NJDEP Certification Process includes details of the verification process and the required data submittals for determination of proprietary practice performance. The current NJDEP version should be followed and is included in the References below.

Adequate maintenance access must be provided for all proprietary practice systems. Access, with access steps, as applicable, must be provided for the inlet pipe, outflow structure, and over any other functional components.

4.15.5 Proprietary Practice Landscaping Criteria

Proprietary devices may or may not require landscaping considerations. Manufacturer's specifications should be consulted to determine any landscaping requirements for the device.

4.15.6 Proprietary Practice Construction Sequence

The construction and installation of individual proprietary practices will vary based on the specific proprietary practice. Manufacturer's specifications should be consulted to determine the device specific construction sequencing requirements.

Construction inspection checklist for generic structural BMPs can be found in Appendix E Construction Inspection Checklists.

4.15.7 Proprietary Practice Maintenance Criteria

In order to ensure effective and long-term performance of a proprietary practice, regular maintenance tasks and inspections are required.

All proprietary practices should be inspected by a qualified professional and maintained in accordance with the manufacturer's instructions and/or recommendations and any maintenance requirements associated with the device's verification by <*Local jurisdiction*>.

Maintenance inspection checklist for generic structural BMPs and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable local, state, and federal law.

4.15.8 Proprietary Practice Stormwater Compliance Calculations

Proprietary practices receive retention credit when explicitly approved by the <*local jurisdiction*>. Pollutant removal (TSS EMC reduction) may be awarded for specific practices provided they meet the performance criteria outlined in Section 4.13.4 Proprietary Practice Design Criteria.

4.15.9 References

The National Environmental Laboratory Accreditation Conference (NELAC) Institute (TNI) Available at: http://www.nelac-institute.org/

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4.16 Conservation Area

If a site includes a Conservation Area which is protected under a conservation easement or equivalent form of protection, a portion of the conservation area may be “removed” from the site for the purposes of calculating the stormwater retention volume (SWRv). There are four scenarios that could qualify for a conservation area credit.

4.16.1 Scenario 1: Natural Conservation Area

Scenario 1 is applicable if a portion of the post-developed area is left in its natural condition and protected, in perpetuity, by a conservation easement or equivalent form of protection. If this scenario is applicable, subtract 100% of the protected natural area from the total site area when calculating the SWRv.

4.16.2 Scenario 2: Reforestation/Revegetation

Scenario 2 is applicable if a portion of the post-developed area employs site reforestation/revegetation and is protected, in perpetuity, by a conservation easement or equivalent form of protection. If this application is used alone, subtract 50% of the reforested/revegetated area from the total site area when calculating the SWRv.

4.16.3 Scenario 3: Soil Restoration

Scenario 3 is applicable if a portion of the post-developed area employs soil restoration and is protected, in perpetuity, by a conservation easement or equivalent form of protection. If this application is used alone, subtract 50% of the soil restoration area from the total site area when calculating the SWRv.

4.16.4 Scenario 4: Reforestation/Revegetation & Soil Restoration

Scenario 4 is applicable if the same portion of the post-developed area employs site reforestation/revegetation as well as soil restoration and is protected, in perpetuity, by a conservation easement or equivalent form of protection, subtract 100% of the acres of development with restored soils in a reforested and revegetated area from the total site area when calculating the SWRv.

Chapter 5. Erosion & Sediment Control

Sedimentation involves three basic geologic processes: erosion, transportation, and deposition. These are natural geologic phenomena; however, land development activities may initiate severe, highly undesirable and damaging alterations in the natural sedimentation cycle by drastically accelerating the erosion and transportation process. Receiving waters are the final destination for sediment transport and deposition. However, natural streams and lakes are not capable of handling the excessive sediments created by this accelerated cycle. Therefore, excessive sediment loads result in turbid waters and heavy deposition over the substrate. The impact of these events directly affects the propagation of aquatic life, which relies on clear substrates and water to feed and reproduce. Sediment-laden waters affect human activities through the degradation of waters used for aquatic recreation and sport fishing and complicate water treatment processes. Consequently, minimizing the occurrence of erosion and effective control of sediment transport is imperative to all.

5.1 Sedimentation Cycle

Soil erosion is usually caused by the impact force of raindrops and by the sheer stress of runoff flowing in rills and streams. Raindrops falling on bare or sparsely vegetated soil detach soil particles; runoff, in the form of sheet flow along the ground, picks up and carries these particles to surface waters. As the runoff gains velocity and concentration, it detaches more soil particles, cuts deeper rills and gullies into the surface of the soil, and adds to its own sediment load. Coalescing rivulets produce streams which have a larger volume and usually an increased velocity. These increasing streams have a greater capacity to remove sediment and transport it downstream. The further the runoff runs uncontrolled, the greater its erosive force and the greater the resulting damage. As the distance and volume of uncontrolled flow increase, the control becomes increasingly difficult. At some point, the energy in the stream dissipates to level that can no longer support the transport of the sediment. At this time, the sediment falls out of the water column and deposits. Over time the sediment will either be incorporated into the substrate or be re-suspended for further transport.

5.2 Factors Influencing Erosion

The erosion potential of a site is principally determined by the soil type, vegetative cover, topography, climate, and season. These factors contribute to the detachment of soil particles and their transport off-site.

- **Soil Type** – Erodibility, the amount of energy needed to break down soil structure, is dependent on soil composition and texture. Soils with high erodibility require less energy to detach soil particles.
- **Vegetative Cover** – Vegetation shields soils from the impact energy of raindrops and traps suspended sediment from runoff.
- **Topography** – Steeper and longer slopes generate runoff with more velocity and energy to erode and transport more sediment.
- **Climate** – Rainfall frequency and intensity cumulatively contribute energy in the form of raindrop impact and runoff volume to detach and transport soil particles.
- **Season** – Seasonal variations in wind, temperature, humidity, and rainfall may create more ideal conditions for erosion.

5.3 Concepts of Erosion & Sediment Control

Principles of erosion and sedimentation control are based on minimizing the effects of the soil and climatologic factors just discussed. None of the following concepts provide a singular solution for controlling those factors, nor can they all be performed at every site. However, the integration of as many concepts as possible provides the most effective erosion and sedimentation control:

A. Compatible Site Planning
- Minimize development within sensitive areas (e.g. highly erosive soils).
- Limit the length and steepness of the designed slopes.
- Maintain natural vegetative cover when possible.

B. Disturbed Areas Reduction
- Minimize the extent of the disturbed area and the duration of exposure.
- Phase or stage development so that only the areas that are actively being developed are disturbed.
- Minimize large or critical area grading during the season of maximum erosion potential.

C. Disturbed Areas Protection
- Complete grading as quickly as possible.
- Establish permanent vegetation as soon as possible on disturbed areas.
- Divert runoff from disturbed areas.

D. Sediment Retention within Site Boundaries
- Filter runoff as it flows from a disturbed area.
- Impound sediment-laden runoff temporarily so that the soil particles are deposited onsite.

The NPDES Phase II storm water regulations enacted by the Clean Water Act of 1972 and promulgated by Stormwater Phase II Final Rule (1999) require that any activity disturbing an acre or greater of land, or a smaller project part of a larger common plan for development or sale, obtain NPDES construction permit coverage. This regulation differs somewhat from the South Carolina state regulations relating to areas of disturbance. Any land disturbing activity in the *<local jurisdiction>* that meets the aforementioned criteria of one acre or more of disturbance will need to will comply with the state process for permitting. Application and issuance of an approved permit under the South Carolina state regulations for erosion and sedimentation control will meet the requirements for coverage under NPDES Phase II as well (DHEC, 2012).

5.4 General Criteria

All construction site activities must adhere the SCDHEC General Permit SC0010000 for Large and Small Site Construction Activities. In addition, the *<local jurisdiction>* will require as a minimum, implementation of the following construction site BMPs:

Single Family Development, not part of a larger common plan of development:

1. Silt Fencing buried a minimum of 6 inches below disturbed grade, where applicable;
2. In areas where more than two feet of fill material has been placed or in areas adjacent to all wetlands, silt fencing meeting the requirements of SCDOT must be used;
3. Temporary gravel driveways a minimum of 15 feet by 10 feet, where applicable; and
4. Sediment barriers surrounding all catch basins or drop inlets on site and sediment socks on all catch basins or drop inlets adjoining to the site.

Single Family and Multi-Family Development, part of a larger common plan of development, and Non-residential Development:

1. Silt Fencing buried a minimum of 6 inches below disturbed grade;
2. Temporary gravel driveways a minimum of 15 feet by 10 feet;

3. Sediment barriers surrounding all catch basins or drop inlets on site and sediment socks on all catch basins or drop inlets adjoining to the site;
4. Flow dissipation devices, such as check dams, in all swales and ditches;
5. Temporary stabilization shall be placed within 7 days after construction activity is complete unless construction activity is going to resume within 21 days;
6. Floating pump suctions for all temporary or permanent ponds or pumping of excavations;
7. Discharge velocities shall be reduced to provide non-erosive flows from dewatering for all temporary or permanent ponds or pumping of excavations;
8. Site inspections must be performed by a <*local jurisdiction*> qualified individual. Copies of inspection reports shall be provided to the <*local jurisdiction*> within 7 days of inspection;
9. Temporary stockpile areas and appropriate BMPs to be identified on plans; and
10. Two rows of silt fence are required between land disturbing activities and adjacent wetlands.

5.5 References

South Carolina Department of Health and Environmental Control (DHEC). 2012. NPDES General Permit for Stormwater Discharges from Construction Activities SCR100000. Retrieved from: https://www.scdhec.gov/sites/default/files/docs/Environment/docs/CGP-permit.pdf

Chapter 6. Enforcement & Violations

[Section Reserved for *<local jurisdiction>* requirements]