Rhode Island Stormwater Design and Installation Standards Manual

Amended March 2015

Rhode Island Department of Environmental management and

Coastal Resources Management Council

Amended March 2015

Effective Date

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Janet Coit, Director
Department of Environmental Management

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Rhode Island Stormwater Design and Installation Standards Manual

Amended March 2015

Written, Compiled, Designed and Illustrated

by

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TABLE OF CONTENTS

Chapter Seven – Storage Practices for Stormwater Quantity Control

List of Figures

List of Tables

APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE OF THE MANUAL

Stormwater management has evolved dramatically throughout the country since it was first adopted and applied in several regions as early as the late 1970s. In September 1993, the Rhode Island Department of Environmental Management (DEM) and the Rhode Island Coastal Resources Management Council (CRMC) published the Rhode Island Stormwater Design and Installation Standards Manual. That original manual was intended to provide guidance in planning and designing effective stormwater best management practices (BMPs) to persons developing properties subject to state and local regulatory review.

Since that manual was completed, stormwater and water quality management programs have been expanded to address the advanced scientific understanding of the water quality impacts of stormwater runoff. The US Environmental Protection Agency (EPA) has documented widespread impairments in surface water quality largely attributable to nonpoint sources, with stormwater runoff being a common source. Effective management of stormwater now demands attention to both the quantity (volume and peak rate) and quality of stormwater runoff. During this same period, new methodologies have been developed to provide treatment of stormwater runoff. Additionally, advances in site planning and design have made available techniques for minimizing the generation of runoff via low impact development (LID) methods. LID is both a site planning process and an application of small-scale management practices that minimizes stormwater runoff, disperses runoff across multiple locations, and utilizes a more naturalized system approach to runoff management.

The development of this manual is also a requirement of Rhode Island General Law, Section 45, Chapter 61.2, entitled “The Smart Development for a Cleaner Bay Act of 2007” (hereafter, the Bay Act of 2007), which states the following:

§ 45-61.2-1 Findings.

(a) The general assembly hereby recognizes and declares that:

(1) Stormwater, when not properly controlled and treated, causes pollution of the waters of the state, threatens public health, and damages property. Stormwater carries pollutants into rivers, streams, ponds, coves, drinking water aquifers and Narragansett Bay;
(2) Stormwater reaches the state's waters by streets, roads, lawns and other means. As a result, public use of the state's natural resources for drinking water, swimming, fishing, shellfishing and other forms of recreation is limited and in some cases prohibited;
(3) Development often results in increased stormwater runoff by increasing the size and number of paved and other impervious surfaces within the

state, and decreasing the amount of natural surface areas that naturally control stormwater runoff through natural filtration and groundwater recharge systems;

(4) Rhode Island's State Land Use Policies and Plan "Land Use 2025" predicts under the "Current Trend Scenario" that by 2025 an area comprising over one hundred eight thousand (108,000) acres, or sixteen percent (16%) of the state's total area, could be developed with twenty (20) more years of building to current plans; and

(5) Rhode Island's stormwater design and installation standards manual has been developed to describe mandatory and suggested stormwater design and performance criteria for applicants to the Department of Environmental Management (DEM), Coastal Resources Management Council (CRMC) and Rhode Island's cities and towns.

(6) To prevent the future degradation of the state's waters the general assembly finds that Rhode Island should update the stormwater design and installation standards manual to implement comprehensive stormwater standards for development that will maintain natural hydrological systems and reduce pollution to the maximum extent possible by requiring the use of modern non-structural low impact design practices and techniques.

§ 45-61.2-2 Implementation. – The Department of Environmental Management (DEM), in conjunction with the Coastal Resources Management Council (CRMC) shall, by July 1, 2008, amend the Rhode Island Stormwater Design & Installation Standards manual. The changes shall include, but not be limited to, incorporation into existing regulatory programs that already include the review of stormwater impacts the following requirements:

(a) Maintain pre-development groundwater recharge and infiltration on site to the maximum extent practicable;

(b) Demonstrate that post-construction stormwater runoff is controlled, and that post-development peak discharge rates do not exceed pre-development peak discharge rates[1]; and

(c) Use low impact-design techniques as the primary method of stormwater control to the maximum extent practicable[2].

To effectively manage the impacts of stormwater and prevent adverse impacts to water quality, habitat and flood storage capacity, as well as meet the requirements of the Bay Act of 2007, CRMC and DEM are updating the 1993 manual to reflect current science and engineering practice concerning stormwater management and to incorporate LID

[1] Specific exemptions are available for peak flow attenuation criteria in certain situations, as described in Chapter Three of the manual.

[2] For all references to "maximum extent practicable" in this manual, an applicant must demonstrate the following: (1) all reasonable efforts have been made to meet the standard in accordance with current local, state, and federal regulations, (2) a complete evaluation of all possible management measures has been performed, and (3) if full compliance cannot be achieved, the highest practicable level of management is being implemented.

methods throughout. This revised manual provides appropriate guidance for stormwater management on new development, redevelopment, and infill projects and, most importantly, incorporates LID as the "industry standard" for all sites, representing a fundamental shift in how development projects are planned and designed.

1.2 APPLICABILITY OF THE MANUAL

This manual has been prepared to assist property owners, developers, engineers, consultants, contractors, municipal staff and others in planning, designing and implementing effective stormwater best management practices for the development and redevelopment of properties in Rhode Island. DEM currently administers a number of programs that require stormwater management. CRMC also requires stormwater management for projects located within that agency's jurisdiction. Readers are advised to refer to specific permit requirements of the applicable agencies to determine if a given project is regulated and whether this manual is applicable. Applicants to these agencies should consult this manual for guidance on required and recommended elements to achieve stormwater management goals for their projects. The stormwater management standards and performance criteria outlined in the manual should be applied to the maximum extent practicable for single-family lots of record.[1] In reviewing stormwater retrofit designs to improve water quality, as compared to existing conditions, the approving agencies may approve designs that do not meet the minimum standards or performance criteria herein due to existing site constraints.

Municipal officials may also use this manual to support local storm water management programs by incorporating or referencing the manual into local ordinances. Please note that most municipalities and large operators of stormwater systems (e.g., Rhode Island Department of Transportation - RIDOT) are regulated under the Rhode Island Pollutant Discharge Elimination System (RIPDES) Municipal Separate Storm Sewer System (MS4) program and are required by their MS4 permits to have applicants who apply for local permits adhere to this manual. Because MS4 program requirements vary somewhat and are subject to change, users of the manual who are applying for local permits are encouraged to consult the RIPDES MS4 Program regulations and the local MS4 Operator ordinances or procedures, as part of developing a stormwater management plan for their project.

The design practices described in this manual shall be implemented by an individual with a demonstrated level of professional competence, such as a professional engineer licensed to practice in the State of Rhode Island. Design engineers, as well as those accountable for operation and maintenance, are ultimately responsible for the long-term performance and success of these practices. However, this manual is also meant to be used as a guide for non-technical individuals interested in implementing or recommending LID and practices at their home or in their community.

[1] For further guidance on small site stormwater BMPs, designers are encouraged to consult the State of Vermont, Department of Environmental Conservation "Small Sites Guide for Stormwater Management" at http://www.vtwaterquality.org/stormwater.htm.

Designers are required to adhere to the stormwater management standards and performance criteria in this manual. Various words are used to indicate the importance of a particular design standard or criterion in meeting the objectives in this manual. These terms and their meanings in this context are as follows:

- Must, shall, required: The design standard or criterion is essential; it is not optional. A written technical justification that is acceptable to the approving agency must be provided if the standard or criterion is not used or achieved.
- Should: A well-accepted practice; a satisfactory and advisable option or method. It is optional, but subject to review and consent by the approving agency.
- May: It is recommended for consideration by the designer; it is optional.

Designers should be aware that the figures and photographs included in Chapters Five, Six, and Seven are schematic graphics only. Design plans should be consistent with the schematic figures when using the method or practice described, but must be completely detailed by the designer for site-specific conditions and construction purposes. In addition, Appendices C, E, and F present technical information that supports the design, construction, and maintenance of effective BMPs. These sections are all entitled as “guidance,” meaning that readers can rely on the information to provide recommended approaches for the topic; reliance on this guidance shall not relieve the reader from compliance with sound engineering judgment or compliance with the required criteria listed elsewhere, nor shall the authors be liable for the use or misuse of this information.

1.3 Organization of the Manual

Descriptions of each chapter and each appendix in this manual are included below:

Chapter 1: Introduction
Chapter One describes the purpose of the manual and its applicability as well as the general organization of the manual. The final section in this chapter explains how to use the manual.

Chapter 2: Why Stormwater Matters - The Impacts of Development
Chapter Two describes stormwater runoff and its impact on watershed hydrology, water quality, runoff volumes, and ecology.

Chapter 3: Stormwater Management Standards and Performance Criteria
Chapter Three presents the standards and performance criteria for stormwater management in the State of Rhode Island. Eleven minimum standards are presented, followed by specific criteria for the site planning process, groundwater recharge, water quality, channel protection, and peak flow control requirements.

Chapter 4: Low Impact Development (LID) Site Planning and Design Strategies

This manual more fully incorporates LID and complies with the 2007 Smart Development for a Cleaner Bay Act (R.I.G.L. § 45-61.2). This chapter describes a three-step LID site planning and design process that must be used to meet the performance standards in Chapter Three.

Chapter 5: Structural Stormwater Treatment Practices for Meeting Water Quality Criteria
Chapter Five outlines the acceptable structural BMPs that can be used to meet the water quality criteria outlined in Chapter Three and presents specific design criteria and guidelines for their design. The five groups of structural BMPs include (1) Wet Vegetated Treatment Systems (WVTS), (2) Infiltration Practices, (3) Filtering Systems, (4) Green Roofs, and (5) Open Channel Practices.

Chapter 6: Pretreatment Practices
There is a suite of stormwater management practices that cannot be used alone to treat the water quality volume, but may be useful to provide pretreatment. Pretreatment BMPs are designed to improve water quality and enhance the effective design life of practices by consolidating sedimentation location. Pretreatment practices must be combined with an acceptable water quality BMP from Chapter Five to meet the water quality criterion.

Chapter 7: Storage Practices for Stormwater Quantity Control
Certain "storage" practices included in this chapter (e.g., dry detention ponds) are explicitly designed to provide stormwater detention; these practices can be used to meet channel protection and flood protection, but must be combined with other BMPs to meet water quality and, in some cases, recharge criteria.

Glossary of Terms
A glossary of terms used in the manual is provided.

References
A list of references used in the manual are provided; these references provide additional guidance on a number of recommended stormwater management practices and related topics.

Appendices include supplemental information on the design, construction, and maintenance of structural stormwater management practices.

Appendix A: Stormwater Management Checklist
The Stormwater Management Checklist outlines the components that must be included in an applicant's stormwater management plan. This includes documentation of LID design methods, procedures, and practices and detailed information for applicable LID credits as well as the structural practices used to meet stormwater criteria.

Appendix B: Vegetation Guidelines and Planting List

Plantings can often be an important factor in the performance and community acceptance of many stormwater BMPs. The Planting Guide provides general background on how to determine the appropriate vegetation for BMPs in Rhode Island. General planting guidance for all BMPs is discussed, as well as specific guidance for each of the BMP groups, focusing on native, non-invasive species.

Appendix C: Guidance for Retrofitting Existing Development for Stormwater Management
This appendix provides guidance for retrofitting existing developed sites to improve or enhance the water quality mitigation functions of the sites. It also discusses the conditions for which stormwater retrofits are appropriate and the potential benefits of stormwater retrofits.

Appendix D: Site Specific Design Examples
Step-by-step design examples based on Rhode Island projects are provided to help designers and plan reviewers better understand the new criteria in this manual. The examples demonstrate how the site planning and stormwater criteria are applied, as well as some of the design procedures and performance criteria that should be considered when siting and designing a stormwater BMP. A stormwater design for a typical single-lot/small-scale house is also included.

Appendix E: Guidance for Developing Operation and Maintenance Plans
On-going maintenance is vital to ensure that BMPs continue to function as designed. Appendix E includes guidance on creating an appropriate operation and maintenance plan and example checklists that can be incorporated in the plan. There are two key components to adequately maintaining a stormwater management infrastructure: Periodic and scheduled inspections, and maintenance scheduling and performance.

Appendix F: Guidance on BMP Construction Specifications
Good designs only work if careful attention is paid to proper construction techniques and materials. Appendix F contains guidance on material specifications for constructing WVTSs, infiltration practices, filters, bioretention areas, and open channels. While these specifications are provided as guidance, if no other specifications are submitted with an application, it will be assumed that the specifications in Appendix F will be met.

Appendix G: Pollution Prevention and Source Controls
Pollution prevention techniques must, to the maximum extent practicable, be incorporated into all site designs, especially at commercial and light industrial sites, to minimize the potential impact those activities may have on stormwater runoff quality. Preventative source controls, while more limited, must also be applied in residential development, particularly in preventing floatables (trash and debris) from entering storm sewer drainage systems. Pollution prevention techniques are provided for solid waste containment; roads and parking areas;

hazardous materials containment; septic system management; and lawn, garden, and landscape management.

Appendix H: Assorted Design Tools
Appendix H provides additional information to help designers with the incorporation of stormwater BMPs at their site, including approved testing requirements (e.g., soils testing for infiltration), miscellaneous design details, pollutant loading analysis methods and information, and TR-55 “short-cut” sizing.

Appendix I: Rhode Island River and Stream Order
This appendix includes a list and map of the rivers and streams in Rhode Island that are 4^{th}-order or larger.

Appendix J: Technology Assessment Protocol (TAP) for Innovative and Emerging Technologies
The TAP describes testing and reporting procedures to evaluate the effectiveness of emerging stormwater treatment technologies and existing BMPs. The protocol requires an independent third-party verification that will ensure treatment facilities meet the stormwater performance goals for new development, redevelopment, infill, and retrofit situations established in this manual.

Appendix K: Hydrologic & Hydraulic Modeling Guidance
This appendix includes DEM Guidance that has been designed to help engineers produce the best possible applications.

1.4 How to Use this Manual

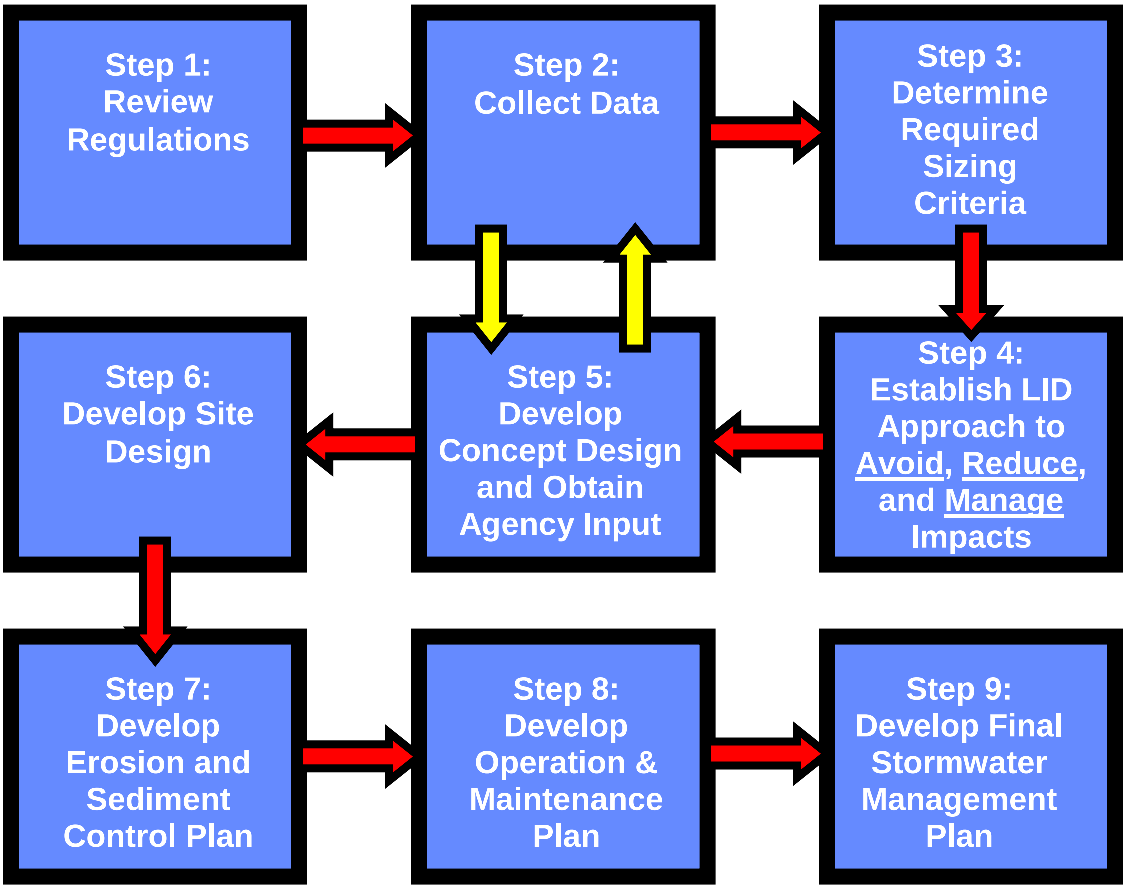
This manual can be used for many purposes and by many different parties. The four most common users are likely designers, municipal officials, property owners, and regulatory program reviewers.

Engineers and designers who are designing the stormwater management system for a development will likely be the most frequent users of the manual. The first thing that designers should do before even beginning a project is to make sure they are familiar with the 11 minimum standards listed in Chapter Three that their project will have to meet. Next, designers should review the LID site planning and design process described in Chapter Four as well as the LID techniques and management practices in Chapters Five - Seven to determine which would work best at their site. Finally, the designer should refer to any applicable appendix or other noted reference for technical guidance. A more detailed discussion for how to meet the 11 minimum standards is illustrated and described below:

Step 1 – Review local ordinances and DEM/CRMC regulations to determine specific regulatory requirements for development site and contact local officials and/or DEM/CRMC staff to clarify uncertainties. At a minimum, designers are required to adhere to the stormwater management standards and performance criteria in this manual.

Step 2 – Collect needed data: designers will need to acquire the necessary information to advance site design concepts and develop the stormwater management approach, concepts, and designs. At a minimum, they will need to acquire appropriate level of topographic detail; define and delineate drainage areas and study points; identify off-site land uses; establish soil, groundwater and geologic constraints (e.g., consult NRCS soil maps to determine hydrologic soil groups); identify natural resource and threatened and endangered species constraints; evaluate alternative roadway configurations; locate existing utilities including onsite

Figure 1-1 Steps to Designing the Stormwater Management System



wastewater treatment systems (OWTS) and drinking water wells (private and public); assess existing contamination potential; evaluate receiving water conditions; establish where in a drainage area discharges will occur; determine zoning restrictions, and identify property lines and rights of way limits. A full list of data to be collected is included in Appendix A. All this basic information will allow planners and designers to make the decisions necessary to develop effective stormwater management plans.

Step 3 – Confirm required design criteria for development site (Recharge, Re_v; Water Quality, WQ_v; Channel Protection, CP_v; and Overbank Flood Protection, Q_p). Projects may cross multiple subwatersheds, discharge to different receiving waters, and create varying amounts of new or replaced impervious cover. Planners and designers should develop a simple, straightforward stormwater management design criteria report that quantifies the level of controls needed, the types of BMPs that can or cannot be used, and the basic pollutant removal targets for the project. The criteria for both quality and quantity controls should be established at this stage.

Step 4 - Establish the basic stormwater management approach utilizing the LID planning and site design process described in Chapter Four. Before building layouts are finalized, street numbers are established, and required rights-of-way are identified, planners and stormwater designers must determine how the project will avoid, reduce, and manage impacts.

The first objective in the LID planning and design process is to avoid disturbance of natural features. This includes identification and preservation of natural areas; it is important to understand that minimizing the hydrologic alteration of a site is just as important as stormwater treatment for resource protection. Once sensitive resource areas and site constraints have been avoided, the next objective is to reduce the impact of land alteration by minimizing impervious areas to reduce the volume of stormwater runoff, increase groundwater recharge, and reduce pollutant loadings generated from a site. Runoff comes primarily from impervious surfaces, such as rooftops, roadways or any hard surface that prevents water from absorbing into the ground. Impervious surfaces can often be reduced with thoughtful site planning.

After making every effort to avoid and reduce potential development impacts, the next step is to determine the basic approach for effectively managing the remaining stormwater runoff at the source. Will the project employ enclosed drainage, open drainage, or a combination? The choice will dictate, in a large part, the stormwater conveyance and treatment practices. Are there existing flooding and erosion problems? Is spill containment and response a primary concern? What soils and/or geologic conditions affect BMP selection? Are there special permitting requirements that may affect the stormwater design?

Answers to these questions, and likely others, will help designers establish what practices will be utilized where, what pretreatment will be needed, and will there be enough space for certain selections. Will off-site be a better approach to meeting resource protection objectives for a redevelopment or infill site? Open section roads (roads that use shoulders and side ditches to redirect stormwater runoff) may utilize a “treatment train” approach consisting of open channel practices, bioretention, before draining to a stormwater pond and/or WVTS. A site immediately adjacent to a drinking water supply reservoir will likely need spill containment and management added to the treatment approach. Enclosed drainage systems will likely need to have pretreatment practices such as underground hydrodynamic separators or oil/grit separators to pretreat runoff prior to a bioretention or other practice. Poor soils or significant presence of bedrock can prohibit the successful application of infiltration practices. Planners and designers should select the basic approach for managing stormwater runoff as early in the site planning process as possible.

Step 5 – Stormwater designers should use the approach determined in Step 4 to develop a conceptual design plan at approximately the 25% design stage that utilizes LID site planning and design techniques to the maximum extent practicable as required by Standard 1; identifies the location and types of BMPs to be utilized, the approximate footprint needed, and construction and maintenance access requirements; and establishes the basic profile to verify physical constraints and the overall feasibility of each BMP practice. This plan can then be used to ensure adequate land area is under the control of the owner and whether easements and/or right-of-way acquisition is necessary. At this stage, designers should coordinate with approving agencies to address potential constraints prior to final design. If additional data is determined to be necessary, designers can collect it and revise the concept before moving forward with full design. Field testing of soils or other physical characteristics should also occur at this time.

Step 6 – Move forward with site design, ensuring that the proposed stormwater management system meets Minimum Standards 2 – 9, as stated below.

- Standard 2: Designers must recharge stormwater as required based on soils at the site. This can be achieved by using a Stormwater Credit (see Chapter Four) and/or one or more of the approved BMPs listed in Table 3-5 and further described in Chapter Five.
- Standard 3: Designers must provide water quality volume treatment. This can be achieved by using a Stormwater Credit (see Chapter Four) and/or one or more of the approved BMPs from Chapter Five. In addition, pretreatment must be provided for water quality BMPs; pretreatment practices are described throughout Chapter Five, as well as in Chapter Six.
- Standard 4: Designers must provide adequate stormwater conveyance systems for at least the 10-year, 24-hour Type III design storm event. Channel protection must be supplied by providing 24-hour extended detention of the one-year, 24-hour Type III design storm event runoff volume. If a stormwater discharge is proposed in a watershed draining to a cold-water fishery, additional restrictions apply for surface detention practices based on the distance from the discharge point to streams (and any contiguous natural or vegetated wetlands) as described in Section 3.3.4. To achieve this standard, designers should refer to the design requirements and guidelines for the BMPs in Chapter Five, as well as Chapter Seven, which describes additional storage practices.
- Standard 5: Designers must provide attenuation for the 10-year and 100-year, 24-hour Type III design storm events to predevelopment rates. In addition, designers must demonstrate that runoff from the site for storms up to the 100-year, 24-hour Type III design storm events actually reach proposed structural practices designed to meet this criterion. To achieve this standard, designers should refer to the design requirements and guidelines for the BMPs in Chapter Five, as well as Chapter Seven, which describes additional storage practices.

- Standard 6: For sites meeting the definition of a redevelopment or infill project, modified stormwater management requirements (Section 3.2.6) will apply. Designers should discuss redevelopment and infill projects with approving agency staff to discuss options for specific sites and check agency websites and other information sources for more specific programmatic guidance. Appendix C includes a variety of retrofit opportunities that a designer could consider on a redevelopment site or for an approved off-site location in the same watershed.
- Standard 7: Designers must implement pollutant prevention practices and have a stormwater pollution prevention plan. Guidance for this standard is included in Appendix G.
- Standard 8: A land use with higher potential pollutant loads (LUHPPL) requires specific BMPs to ensure protection of water resources from the higher expected pollutant loads from those sites. Designers should refer to the list of LUHPPLs in Table 3-2, as well as the list of allowable BMPs for LUHPPLs, which are included in Table 3-3.
- Standard 9: All illicit discharges to stormwater management systems are prohibited, including discharges from OWTSs, and sub-drains and French drains near OWTSs that do not meet the State's OWTS Rules (Setbacks vary depending on the capacity of the OWTS, the type of conveyance system, and the sensitivity of the receiving waters).

Designers will need to work with the other project planners and engineers to develop the detailed plans, specifications, and construction quantity estimates for the stormwater management system. These plans will be of sufficient detail for construction of the proposed facilities and will include specifications, notes, tables, alignment, vertical controls, and all other features in sufficient detail for construction of the proposed measures.

Step 7 – Ensure that the erosion and sediment control (ESC) plan utilizes ESC practices that meet the minimum design criteria from Standard 10: temporary sediment trapping practices must be sized for 1 inch of runoff, and temporary conveyance practices must be sized to handle flow from the 10-year, 24-hour Type III design storm. Refer to the guidelines in the most recent edition of the "Rhode Island Soil Erosion and Sediment Control Handbook," published by the USDA NRCS, RIDEM, and the Rhode Island Conservation Committee when developing the ESC plan. Stormwater designers must also consider at a minimum construction staging, sequencing, and traffic control.

Step 8 – The stormwater management system, including all structural stormwater controls and conveyances, must have an operation and maintenance plan to ensure that it continues to function as designed, as required by Standard 11. To meet this standard, designers should refer to the BMP-specific operation and maintenance requirements and guidance included in Chapters Five, Six, and Seven, as well as the Maintenance Plan information included in Appendix E. Planners and designers must establish and define maintenance and operation requirements, including frequency, access locations, staging areas and sediment disposal options, among others. The ability of BMPs to function successfully is not only related to good design and successful construction, but must account for the long term maintenance burden. Designers should consider ease of access, identify where maintenance equipment might be temporarily stored, how sediments might be stockpiled, and whether traffic control will be needed during maintenance operations as key considerations in the design process.

Step 9 – All development proposals must include a stormwater management site plan for review by the approving agency. The final plan must address all of the minimum standards through compliance with the requirements of this manual. Designers must complete the Stormwater Management Plan Checklist in Appendix A to document compliance with all 11 standards.

In addition to designers and developers, local officials will find this manual helpful. For example, a Planning Department may be looking for retrofits to recommend for a redevelopment project in their town and could refer to Appendix C for guidance. Also, while generally not required, a property owner may be interested in practices that he/she could implement on his/her lot. Chapter Four would be helpful for non-structural ways to reduce a parcel's stormwater impact, Appendix B includes a list of native plants that are appropriate for a variety of site conditions, and Appendix D offers a design example that focuses on a single-family house.

Finally, a project reviewer could turn to this manual to ensure applicants have followed appropriate steps in developing their stormwater management plan and designing individual stormwater practices. Approving agencies may also use this manual for guidance on how to evaluate and approve new proprietary stormwater devices; these topics are discussed in Appendix J.

Contact Information

To ensure that the project meets the State's regulatory requirements, applicants should consult the following offices at DEM Office of Water Resources:

- Freshwater Wetlands Program
- Water Quality Certification Program
- RIPDES Program
- TMDL Program
- Underground Injection Control Program
- Applicants are encouraged to contact DEM's Office of Technical and Customer assistance to schedule a pre-application meeting.

DEM
Rhode Island Department of Environmental Management 401-222-4700
235 Promenade Street
Providence, RI 02908

If the project is located in CRMC jurisdiction, consult the *Rhode Island Coastal Resources Management Program* and applicable Special Area Management Plans. See: www.crmc.ri.gov

CRMC
Rhode Island Coastal Resources Management Council 401-783-3370
Oliver Stedman Government Center
Tower Hill Road
Wakefield, RI 02879

Local Officials
In addition, applicants should consult with their local building official and planning or zoning office in order to identify any local stormwater management or erosion and sediment control ordinances.

Table 1-1 Key Abbreviations and Acronyms Cited in the Manual

Acronym	Term
A	Area
A_s	Sediment forebay surface area
AASHTO	American Association of State Highway and Transportation Officials
ac	Acre
ac-ft	Acre-feet
ACI	American Concrete Institute
ASTM	American Society of Testing and Materials
BMP	Best management practice
BOD	Biological Oxygen Demand
C	Flow-weighted mean concentration of the pollutant in urban runoff (mg/L)
C’	Flow-weighted mean bacteria concentration (#col/100 ml)
cfs	Cubic feet per second
CN	Curve number
COD	Chemical Oxygen Demand
col/100 ml	Bacteria colonies/100 milliliters
CP_v	Channel protection storage volume
CRMC	Rhode Island Coastal Resources Management Council
csm/in	cfs per square mile per inch
Cu	Copper
CWP	Center for Watershed Protection

Acronym	Term
DEM	Rhode Island Department of Environmental Management
DO	Dissolved Oxygen
DOH	Rhode Island Department of Health
DOT	Department of Transportation
E	Removal efficiency
E_{TSS}	Removal efficiency of total suspended solids
ED	Extended detention
EIC	Effective impervious area
EOEA	Executive office of Environmental Affairs
EPA	U.S. Environmental Protection Agency
ESC	Erosion and Sediment Control
ETV	EPA's Environmental Technology Verification Program
F	Recharge Factor
f_c	Soil infiltration rate
FC	Fecal coliforms
fps	Feet per second
GW	Groundwater
h:v	Horizontal to Vertical
HDPE	High Density Polyethelene
HECRAS	Hydraulic Engineering Center - River Analysis System
HSG	Hydrologic soil group
I	Impervious area
%I	Percent impervious area
I_a	Initial abstraction
K	Coefficient of permeability
L	Stormwater pollutant export load (pounds or billion colonies)
LID	Low impact development
LUHPPL	Land use with higher potential pollutant loads
MASTEP	Massachusetts Stormwater Technology Evaluation Project
µg/l	Micrograms per liter
mg/l	Milligrams per liter
MS4	Municipal separate storm sewer system

Acronym	Term
MSGP	Multi-sector General Permit
n	Porosity
N/A	Not applicable
NAPA	National Asphalt Pavement Association
NCDC	National Climatic Data Center
ND	No data
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NT	No treatment
o.c.	On-center
O/M	Operation and maintenance
OSHA	Occupational Safety and Health Administration
OWTS	Onsite wastewater treatment system
P	Precipitation depth
Pb	Lead
Pj	Rainfall correction factor
PCB	Polychlorinated biphenyls
PE	Professional Engineer
ppm	Parts per million
PVC	Polyvinyl chloride
Q	Flow rate
q_I	Peak inflow discharge
q_O	Peak outflow discharge
Q_p	Overbank flood protection storage volume
Q_{peak}	Peak discharge flow rate
q_u	Unit peak discharge (csm/inch)
QPA	Qualifying Pervious Area
Re_a	Recharge area
Re_v	Recharge volume
Rv	Runoff coefficient expressing the fraction of rainfall converted to runoff
RIDOT	Rhode Island Department of Transportation
RIPDES	Rhode Island Pollutant Discharge Elimination System

Acronym	Term
ROW	Right-of-way
SAMP	Special Area Management Plan
SCS	Soil Conservation Service
SD	Separation distance
sf	Square feet
SHGT	Seasonal high groundwater table
SMP	Stormwater Management Plan
SWMM	Stormwater Management Model
SWPPP	Stormwater Pollution Prevention Plan
T	Extended detention time
t_c	Time of concentration
TAP	Technology Assessment Protocol
TARP	Technology Acceptance and Reciprocity Partnership
TER	Technology Evaluation Report
TMDL	Total Maximum Daily Load
TN	Total nitrogen
TP	Total phosphorus
TR-20	NRCS Technical Release No. 20 Project Formulation - Hydrology
TR-55	NRCS Technical Release No. 55 Urban Hydrology for Small Watersheds
TSS	Total suspended solids
UIC	Underground Injection Control
UNHSC	University of New Hampshire Stormwater Center
USDA	United States Department of Agriculture
V_r	Runoff volume from a given storm event
V_s	Required storage volume for facility sizing
VOCs	Volatile organic compounds
WQ_f	Water quality flow
WQ_v	Water quality storage volume
WSE	Water surface elevation
WT	Water table
WVTS	Wet vegetated treatment system
Zn	Zinc

2.0 WHY STORMWATER MATTERS - THE IMPACTS OF DEVELOPMENT

Historically, stormwater has been viewed as strictly a drainage (flooding) issue, a waste to be disposed, and has generally been routed to the nearest discharge location, infiltrated with little or no pretreatment, or conveyed directly to receiving waters as channel-flow. This chapter describes how this type of stormwater management greatly alters the natural hydrology and water quality of a watershed. Rhode Island started moving away from this approach with the stormwater manual developed in 1993, which required water quality treatment and quantity control. The goal of this manual is to not only address water quality and quantity issues, but also to require that designers maintain a site's pre-development hydrology. In the sections below, stormwater runoff is defined and water quality and quantity issues related to stormwater are discussed, as well as methods for preventing and mitigating stormwater impacts.

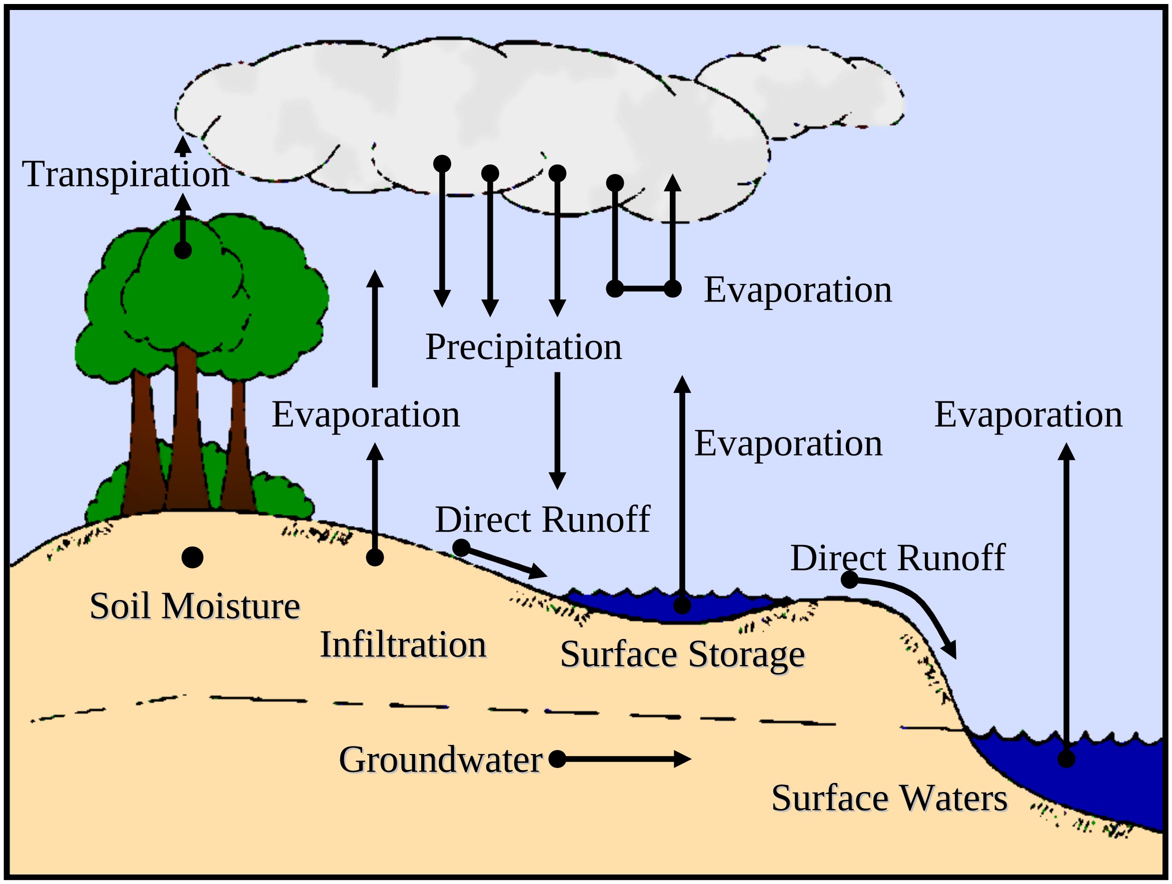
2.1 WHAT IS STORMWATER RUNOFF?

Stormwater runoff is precipitation that washes over the land (i.e., runs off) and discharges to nearby streams, lakes, wetlands, estuaries and other waters. Stormwater runoff is a part of the hydrologic cycle, which is the distribution and movement of water between the earth's atmosphere, land, and waterbodies (see Figure 2-1). Water that does not runoff includes the following: (a) atmospheric evaporation; (b) transpiration or uptake by plants, which in combination with evaporation, is referred to as evapotranspiration; and (c) infiltration into underlying soils, which is responsible for groundwater recharge. Thus, stormwater runoff is essentially the remaining water after evapotranspiration and infiltration.

Land development has a profound influence on the quality of the waters of Rhode Island. To start, land development dramatically alters the local hydrologic cycle. The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the native soil that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff. In addition, the construction process exposes soils to rainfall, which increases the potential for erosion and sedimentation.

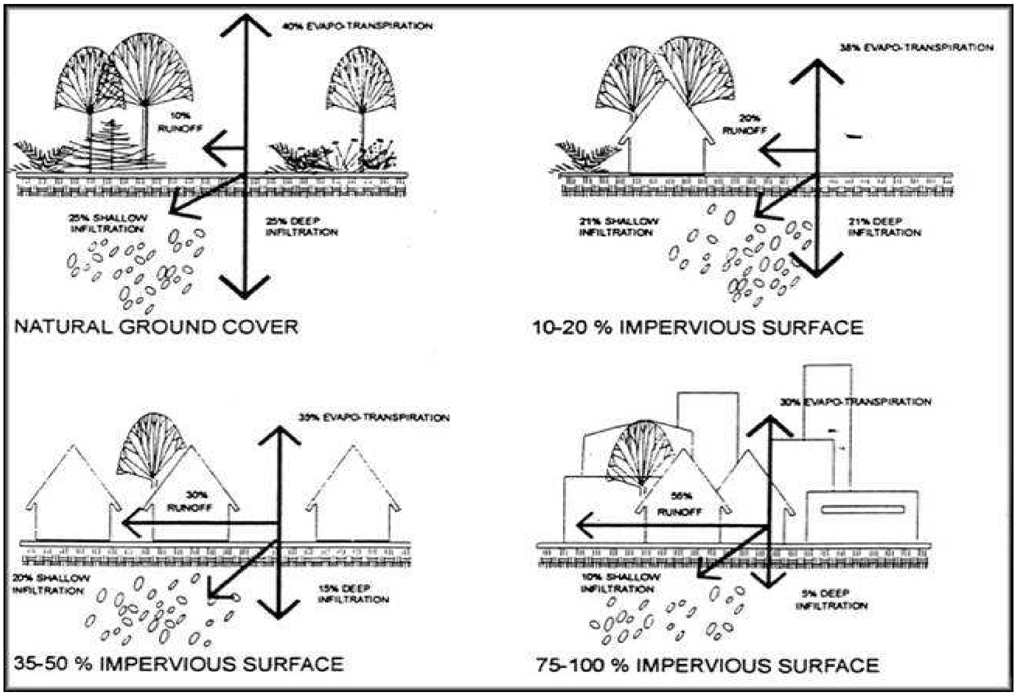
Additional impacts occur after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces interrupt infiltration mechanisms by not allowing rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in Figure 2-2, which shows the increase in runoff (along with a decrease in groundwater recharge) as a function of site imperviousness. As can be seen by the relative size of the arrows, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre parking lot can produce 16 times more stormwater runoff each year than a one-acre meadow (Schueler, 1994).

Figure 2-1 Hydrologic Cycle



While adding impervious area on a small residential lot might not seem significant, the cumulative effect of several such increases in site imperviousness throughout a watershed can drastically change the hydrology and overall ecological health of the whole system. Studies have shown that once impervious cover in a watershed reaches between 10 and 25 percent, ecological health is greatly stressed. Some studies have shown that water resources health is impacted at percentages as low as 5 to 7 percent. At 25 percent impervious cover and greater, stream stability decreases, habitat disappears, water quality declines, and biological diversity dwindles (NRDC, 1999). Development not only increases runoff quantity, but can also introduce new sources of pollutants from everyday activities associated with residential, commercial, and industrial land uses (CTDEP, 2004). When it rains, stormwater flowing over pavement and disturbed areas carries these pollutants directly into nearby wetlands and surface waters, either by direct runoff or via storm drains, bypassing any treatment that would naturally occur when rainwater infiltrates into the ground.

Figure 2-2 Water Balance at Varying Stages of Development (adapted from Prince George's County, 1999)



To put these thresholds into perspective, typical imperviousness in medium-density residential areas ranges from 25 to nearly 60 percent (SCS, 1986). Table 2-1 indicates typical percentages of impervious cover for various land uses according to TR-55. While most watersheds are developed with land uses of varied intensity, significant residential, commercial and industrial development suggests an expanse of impervious cover that exceeds ecological stress thresholds.

Table 2-1 Typical Amounts of Impervious Cover Associated with Different Land Uses

Land Use	**Percent Impervious Cover**
Commercial and Business District	85%
Industrial	72%
High Density Residential (1/8 ac zoning)	65%
Medium-High Density Residential (1/4 ac zoning)	38%

Land Use	Percent Impervious Cover
Medium-Low Density Residential (1/2 ac zoning)	25%
Low Density Residential:	
1 ac zoning	20%
2 ac zoning	12-16%
3 ac zoning	8%
5 ac zoning	5-8%
10 ac zoning	2.4%

Source: Adapted from USDA Soil Conservation Service, 1986 and the Scituate Reservoir Watershed Greenspace Protection Strategy (DEM, 2008).

2.2 Development and Stormwater Impacts

Stormwater from urban development can cause severe impacts to downstream waters and waterways. These impacts can be broken down into four types, which include:

- Impacts to Natural Stream Channels;
- Impacts to Water Quality;
- Impacts to Receiving Waters; and
- Impacts to Aquatic Habitat.

The following discussion lists and describes these impacts to illustrate why effective stormwater management is needed to address and mitigate them.

2.2.1 Impacts to Natural Stream Channels

As pervious meadows and forests are converted into less pervious urban soils or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, there are changes to both stream flow and geometry.

2.2.1.1 Changes to Stream Flow

Urban development disrupts the natural water cycle and tends to alter watershed response to precipitation events. Watershed response becomes “flashier,” and runoff is “intensified,” meaning:

Increased Runoff Volumes

Replacement of natural features (e.g., woodlands) with buildings, pavement and lawns can dramatically increase the total volume of water running off into streams of developed watersheds.

Increased Peak Runoff Discharge Rates

Increased runoff volumes result in increased peak discharges. Peak discharges for a developed watershed can be two to five times higher than those for an undisturbed watershed.

Greater Runoff Velocities

Impervious surfaces, compacted soils and storm sewers are more hydraulically efficient than natural landscapes and increase the speed at which rainfall runs off land surfaces within a watershed.

Reduced Time of Concentration

As runoff velocities increase, runoff takes less time to reach streams or other waterbodies.

Increased Frequency of Bank-Full and Near Bank-Full Events

Increased runoff volumes and peak flows increase the frequency and duration of flows that lead to degradation of (i.e., widen and deepen) stream channels. The bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975).

Increased Flooding

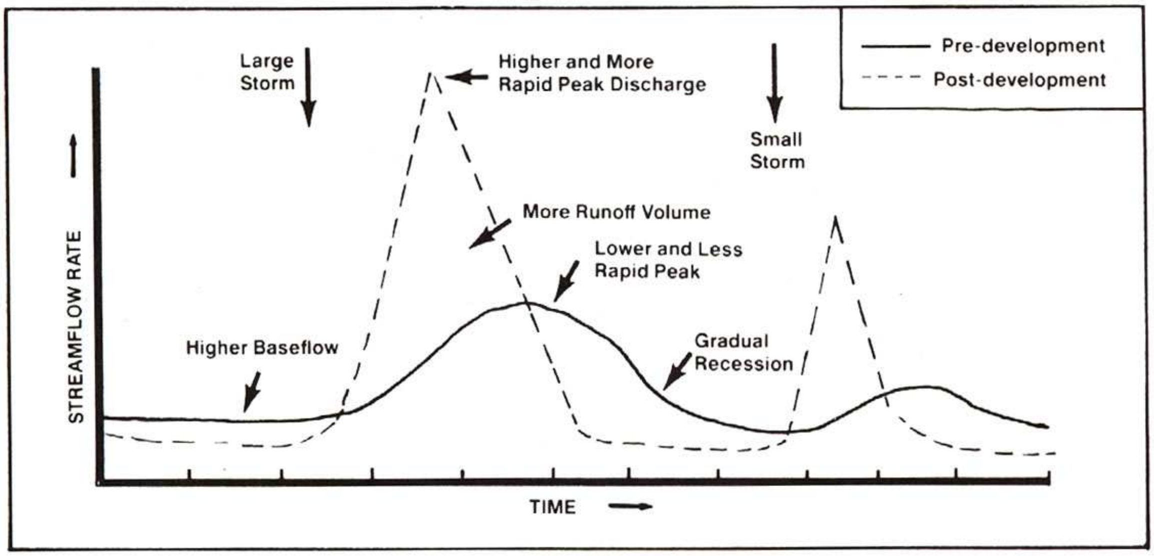
Increased runoff volumes and peaks increase the frequency, duration and severity of flows that overtop stream banks and cause flooding. An example of severe flooding in Rhode Island occurred in the Pocasset River Watershed in 2001. This watershed has lost approximately 700 acres of wetland since 1939, much of which was floodplain loss. As a result, in the highly urbanized and industrial areas of Johnston and Cranston, there is now little natural floodplain storage so during heavy periods of rain, flooding occurs on private properties (Wetland Functions and Values Brochure, DEM, 2008). Another example of severe flooding occurred in October 2005, during which many evacuations were necessary, mainly along the Pawtuxet, Pocasset, Woonasquatucket, and Blackstone Rivers. Damages in Rhode Island from this storm event totaled to $1.6 million (NCDC, 2008).

Lower Dry Weather Flows (Base Flow)

Stream base flow (i.e., the typical level of stream flow during dry weather) is derived primarily from groundwater input. Loss of groundwater recharge due to impervious surfaces artificially lowers the groundwater table and consequently lowers base flow.

The change in post-development peak discharge rates that accompany development is profiled in Figure 2-3.

Figure 2-3 Stream Flow Hydrographs Before and After Development (MDE, 2000)



2.2.1.2 Changes to Stream Geometry

The changes in the rates and amounts of runoff from developed watersheds directly affect the morphology, or physical shape and character, of streams and rivers. Some of the impacts due to urban development include:

Stream Widening and Bank Erosion

Stream channels widen to accommodate and convey the increased volumes and rates of runoff and higher stream flows from developed areas. More frequent small and moderate runoff events undercut and scour stream banks causing steeper banks to slump and collapse during larger storms. A stream can widen many times its original size due to post-development runoff.

Source: R. Claytor File Photo

Streambed Downcutting

Streams may also deepen to accommodate higher flows and become less stable. When streams downcut, their bottom widths may decrease (i.e., become narrower). Loss of width narrows flow and increases flow velocity, triggering further channel erosion at the toe of the bank.

Source: R. Claytor File Photo

Loss of Riparian Trees

Increased flows undercut stream banks and cause them to slump. Trees that protect the banks are exposed at the roots and may eventually topple over.

Root systems support soil structure. Unanchored stream banks erode away more easily.

Sedimentation of Channel Beds

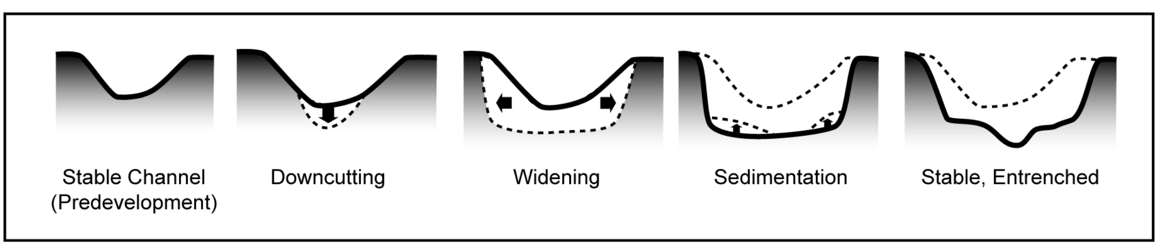
When upstream channels erode, sediment particles are carried and deposited downstream. The deposits replace the natural streambed with shifting sands, silts and muck.

Source: R. Claytor File Photo

Increased Floodplain Elevation

Floodplains are areas adjacent to streams that become inundated during peak storm events. A stream's floodplain can be increasingly isolated from the normal channel with more intense development and increased runoff volume. Increases become more acute when building and filling occurs in floodplain areas where it may displace floodwaters and directly elevate the floodplain.

Figure 2-4 Changes to a Stream's Physical Character Due to Watershed Development



Source: Adapted from Atlanta Regional Commission, 2001

The increase in stormwater runoff can be too much for the natural drainage system to handle. As a result, the drainage system is often "improved" to rapidly collect runoff and quickly convey it away (using curb/gutters, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, lakes, wetlands, estuaries, or near-shore bays.

2.2.2 Impacts to Water Quality

Development concentrates and increases the amount of nonpoint source pollutants. As stormwater runoff moves across the land surface, it picks up and carries away both natural and anthropogenic pollutants, depositing them into Rhode Island's streams, rivers, lakes, wetlands, coastal waters and marshes, and groundwater. Stormwater pollution is one of the leading sources of water quality degradation in Rhode Island – as evidenced in the 2008 Rhode Island list of impaired waters prepared pursuant to Section 303(d) of the Federal Clean Water Act, urban runoff and stormwater discharges are a significant cause of impairment to the state's waterbodies (DEM, 2008). Water quality impacts are numerous, and common pollutants found in stormwater runoff are listed and described below. Table 2-2 summarizes the major stormwater pollutants and their effects.

2.2.2.1 Sediment (Suspended Solids)

Sources of sediment include particles that are deposited on impervious surfaces and subsequently washed off by a storm event, as well as the erosion of streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997). Additionally, significant quantities of sediments are deposited in waterways as a result of winter sanding of roadway surfaces and the infrequent maintenance of catch basins by state and municipal public works departments.

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, ponds, and bays. Turbidity resulting from this sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems and smothering benthic organisms. In addition, sediment transports many other pollutants including nutrients, trace metals and hydrocarbons to water resources. High turbidity due to sediment increases the cost of treating drinking water and reduces the value of surface waters for industrial and recreational use. Sediment also fills ditches and small streams and clogs storm sewers and pipes, causing flooding and property damage. Sedimentation can reduce the capacity of reservoirs and lakes, block navigation channels, fill harbors and silt estuaries.

2.2.2.2 Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, reservoirs, and bays (known as eutrophication). Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, sewage (e.g., from wastewater treatment facilities, overflows, and faulty on-site wastewater treatment systems), animal waste (both domestic and feral), organic matter, detergent, and streambank erosion. Data from studies across the country suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer et al., 1997; Waschbusch et al., 2000; Bannerman et al., 1993). Nutrients are of particular concern to ponds, lakes, and estuaries and are a major source of degradation in some of Rhode Island's waters because they promote weed and algae growth in lakes, streams and estuaries. Algae blooms block sunlight from reaching underwater grasses and deplete oxygen in bottom waters. In addition, nitrification of ammonia by microorganisms can consume dissolved oxygen, while nitrates can contaminate groundwater supplies.

2.2.2.3 Pathogens

Pathogen levels in stormwater runoff routinely exceed public health standards for water contact recreation and shellfish harvesting. Some stormwater sources of fecal contamination include cesspools and failed OWTSs, sanitary and combined sewer overflows, and illicit connections to the storm drain system. Other sources include pet waste and urban wildlife. Pathogens are a leading contaminant in many of the waters of Rhode Island and have led to many beach and shellfishing bed closures in recent years. For example, the Department of Health discourages swimming, surfing and other full body contact activities at Easton's Beach, Atlantic Beach Club Beach, and Scarborough State Beach for a minimum of 24 hours after heavy rainfall due high levels of harmful bacteria from nearby stormwater drains (DOH, 2008).

2.2.2.4 Organic Matter

When organic matter decomposes in a waterbody, the process consumes dissolved oxygen (DO) in the water. As organic matter is washed off by stormwater, dissolved oxygen levels in receiving waters can be rapidly depleted. If the DO deficit is severe enough, fish kills may occur and aquatic life can weaken and die. In addition, oxygen depletion can affect the release of toxic chemicals and nutrients from sediments deposited in a waterway. All forms of organic matter in urban stormwater runoff such as leaves, grass clippings and pet waste contribute to the problem. In addition, there are a number of non-stormwater discharges of organic matter to surface waters such as sanitary sewer leakage and septic tank leaching.

2.2.2.5 Toxic Pollutants

Besides oils and greases, urban stormwater runoff can contain a wide variety of other toxicants and compounds including heavy metals such as lead, zinc, copper, and cadmium, and organic pollutants such as pesticides, PCBs, and phenols. These contaminants are of concern because they are toxic to aquatic organisms and can bioaccumulate in the food chain. In addition, they also impair drinking water sources and human health. Many of these toxicants accumulate in the sediments of streams and lakes. Sources of these contaminants include industrial and commercial sites, urban surfaces such as rooftops and painted areas, vehicles and other machinery, improperly disposed household chemicals, landfills, hazardous waste sites and atmospheric deposition. According to the 2006 Section 305(b) Report State of the

State's Waters (DEM, 2006), toxicants were at elevated levels in 70% of the total acreage of lakes and 44% of the total miles of rivers assessed.

2.2.2.6 Thermal Impacts

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

2.2.2.7 Trash and Debris

Considerable quantities of trash and other debris are washed through storm drain systems and into streams, lakes and bays. The primary impact is the creation of an aesthetic "eyesore" in waterways and a reduction in recreational value. In smaller streams, debris can cause blockage of the channel, which can result in localized flooding and erosion.

Table 2-2 Effects of Stormwater Pollutants

Stormwater Pollutant	**Effects**
Sediments—Suspended Solids, Dissolved Solids, Turbidity	Stream turbidity Habitat changes Recreation/aesthetic loss Contaminant transport Filling of fresh and estuarine water bodies, and freshwater and coastal wetlands
Nutrients—Nitrate, Nitrite, Ammonia, Organic Nitrogen, Phosphate, Total Phosphorus	Algae blooms Eutrophication DO depletion Ammonia and nitrate toxicity Recreation/aesthetic loss
Pathogens—Total and Fecal Coliforms, Fecal Streptococcus (Enterococci), Viruses, E.Coli	Ear/Intestinal infections Shellfish bed closure Recreation/aesthetic loss

Stormwater Pollutant	**Effects**
Organic Matter—Vegetation, Sewage, Other Oxygen Demanding Materials	DO depletion Odors Fish kills
Toxic Pollutants—Heavy Metals (cadmium, copper, lead, zinc), Organics, Hydrocarbons, Deicing Salt, Pesticides/Herbicides	Human & aquatic toxicity Bioaccumulation in the food chain
Thermal Pollution	DO depletion Habitat changes
Trash and debris	Recreation/aesthetic loss

Concentrations of pollutants in stormwater runoff vary considerably between sites and storm events. Typical average pollutant concentrations in urban stormwater runoff in the Northeast United States are summarized in Table 2-3.

Table 2-3 Average Pollutant Concentrations in Urban Stormwater Runoff (All Land Uses)

Constituent	**Units**	**Concentration**
Total Suspended Solids[1]	mg/l	54.5
Total Phosphorous[1]	mg/l	0.26
Soluble Phosphorous[1]	mg/l	0.10
Total Nitrogen[1]	mg/l	2.00
Total Kjeldahl Nitrogen[1]	mg/l	1.47
Nitrite and Nitrate[1]	mg/l	0.53
Copper[1]	µg/l	11.1
Lead[1]	µg/l	50.7

Constituent	Units	Concentration
Zinc[1]	µg/l	129
BOD[1]	mg/l	11.5
COD[1]	mg/l	44.7
Organic Carbon[2]	mg/l	11.9
PAH[3]	mg/l	3.5
Oil and Grease[4]	mg/l	3.0
Fecal Coliform[5]	Colonies/100 ml	15,000
Fecal Streptococcus (Enterococcus)[5]	Colonies/100 ml	35,400
Chloride (snowmelt)[6]	mg/l	116

Source: Adapted from NYDEC, 2001; original sources are listed below.
[1]Pooled NURP/USGS (Smullen and Cave, 1998)
[2]Derived from National Pollutant Removal Database (Winer, 2000)
[3]Rabanal and Grizzard, 1996
[4]Crunkilton et al., 1996
[5]Schueler, 1999
[6]Oberts, 1994
mg/l = milligrams per liter
µg/l= micrograms per liter

2.2.3 Impacts to Receiving Waters

Rhode Island enjoys an abundance of water resources that support vital uses such as drinking water, recreation, habitat and commerce, among others. The state has approximately 1,498 miles of rivers, 20,917 acres of lakes and ponds, and approximately 15,500 acres of shrub swamps, marshes, bogs and fens as well as close to 72,000 acres of forested wetlands. Estuaries, including Narragansett Bay and the coastal ponds, cover 156 square miles. Underlying the state are 22 major stratified drift (sand and gravel) aquifers as well as usable quantities of groundwater in almost all other locations from the bedrock aquifers (DEM, 2008).

These water resources are impacted by both hydrologic and water quality aspects of stormwater runoff, as were discussed above. The sensitivity of the range of water types is described below. Table 2-4 summarizes the effects of urbanization on these receiving environments.

2.2.3.1 Groundwater

As land development occurs, impervious surfaces preclude the natural infiltration of rainwater, thereby reducing the recharge rate. This results in a lowering of the water table. Ultimately, development can lead to a depletion of aquifers, reduced baseflows for streams and rivers, and increased concentrations of other pollutants derived from urban runoff in groundwater. Aquifer levels and clean groundwater are very important in Rhode Island, where as of September 2005, there were 647 public wells in the state, with approximately 30% of the state's residents depending on wells for drinking water (DEM, 2006).

Source: NRCS photo

One potential remedy for this "de-watering" impact is to collect stormwater runoff and to infiltrate it to help restore (or enhance) natural recharge rates. It is possible to collect and infiltrate enough stormwater to match the natural (pre-development) recharge rates. This is a viable option to mitigate and compensate for other sources of water consumption and groundwater de-watering, such as groundwater withdrawals for drinking water and irrigation purposes.

However, the infiltration of stormwater raises some important water quality issues. As discussed previously, stormwater is commonly degraded with a broad range of pollutants collected from the land surface or accompanying precipitation. Secondly, aquifers can be highly permeable and, therefore, very susceptible to contamination. Thus, depending on the land use, stormwater can require significant pre-treatment prior to infiltration to protect the quality of groundwater resources. This may be accomplished with certain stormwater BMPs that provide effective treatment. Wellhead protection areas that have been delineated showing the specific groundwater contribution areas require the highest level of protection to ensure a safe drinking water supply. Infiltration issues are discussed further in Chapters Three and Five.

2.2.3.2 Freshwater Streams, Ponds, Wetlands, and Estuaries

There are numerous streams (perennial and intermittent), ponds, wetlands, and estuaries throughout Rhode Island. They provide important aquatic habitat for a broad range of fish, amphibian, mammal and bird species, and as recreational resources for humans. In addition, surface water provides approximately 70% of the drinking water in Rhode Island. The Scituate Reservoir alone provides more than 50% of the state's residents with drinking water (DEM, 2008).

Stream flow is derived from overland runoff and baseflow from groundwater, which discharges into streambeds. If baseflow is continuous throughout the year, the stream is perennial. If groundwater elevations fall below the natural stream bed elevation, the stream is intermittent. In either case, stream ecosystems are very dependent upon the maintenance of natural groundwater levels and corresponding groundwater discharges to the streams.

Each stream ecosystem is adapted to its natural flow regime, which is a mixture of surface runoff events and groundwater baseflow. Stormwater management practices associated with land development within watersheds can significantly alter the timing and rates of surface flow and groundwater discharge, thereby impacting stream ecosystems. In some cases, naturally occurring perennial streams may dry up seasonally in a developed watershed, significantly altering the habitat. Similarly, water quality impacts caused by increased nutrients and sedimentation can significantly impact stream ecosystems. Finally, streams, particularly small first- and second-order streams, are especially susceptible to increased channel erosion associated with altered hydrology and land development.

Ponds provide unique habitats and are also sensitive to stormwater discharges within their watersheds. Eutrophication is a common problem in freshwater ponds, and is the result of excessive phosphorus loading, which can cause excessive weed or algal growth and ultimately can cause depleted oxygen levels, fish kills, and noxious odors. Although both phosphorus and nitrogen contribute to excessive plant growth, phosphorus is the limiting nutrient of freshwater pond environments. Common sources of phosphorus include phosphate-containing cleaners or detergents, human and animal waste, and lawn fertilizers.

Wetlands provide a broad range of habitat and recreational values. They too are susceptible to impacts from stormwater in terms of both hydrology and water quality changes. Wetlands are defined and entirely dependent upon surface and near surface hydrologic conditions (water levels to within 12 inches of the surface of the ground), which support hydrophytes (wetland vegetation) and hydric soils. Similar to the other freshwater resource areas discussed above, wetlands are very sensitive to water level changes and to alterations in water inputs. Therefore, stormwater must be managed within the watersheds to wetlands in a manner that minimizes impacts to natural flow regimes. Wetlands are also susceptible to pollutant loading increases, particularly phosphorus.

2.2.3.3 Coastal Waters

Coastal waters are valuable for the support and propagation of fish, shellfish, and other marine life, and serve as a very significant commercial and recreational resource for humans. Coastal water quality issues include eutrophication, damage to wildlife habitat (including sedimentation), and bacterial/viral pollution of swimming beaches and shellfish harvesting areas. Sediments cause physical damage, including decreased water clarity and smothering of benthic habitat. Nutrients (typically nitrogen for coastal environments) cause eutrophication, which results in excessive algae growth, depleted DO levels, and foul odors.

Table 2-4 Effects of Development on Receiving Waters

Receiving Environment	**Impacts**
Wetlands	• Changes in hydrology and hydrogeology • Increased nutrient and other contaminant loads • Changes in atmospheric inputs through increased air emissions to the urban airshed • Compaction and destruction of wetland soil • Changes in wetland vegetation • Changes in or loss of habitat • Changes in the community (diversity, richness, and abundance) of organisms • Loss of particular biota • Permanent loss of wetlands
Lakes and Ponds	• Impacts to biota on the lake bottom due to sedimentation • Contamination of lake sediments • Water column turbidity • Aesthetic impairment due to floatables and trash • Increased algal blooms and depleted oxygen levels due to nutrient enrichment, resulting in an aquatic environment with decreased diversity • Contaminated drinking water supplies

Receiving Environment	Impacts
Estuaries	• Sedimentation in estuarial streams and submerged aquatic vegetation beds • Altered hydroperiod of brackish and tidal wetlands, which results from larger, more frequent pulses of fresh water and longer exposure to saline waters because of reduced baseflow • Increased algal blooms and depleted oxygen levels due to nutrient enrichment, resulting in an aquatic environment with decreased diversity • Turbidity • Bio-accumulation • Scour of tidal wetlands • Short-term salinity swings in small estuaries caused by the increased volume of runoff which can impact key reproduction areas for aquatic organisms • Alteration of salt marsh vegetation communities caused by freshwater inputs; increased occurrence of invasive species such as *Phragmites australis*

Source: Adapted from WEF and ASCE, 1998.

2.2.4 Impacts to Aquatic Habitat

Along with changes in stream hydrology and morphology, the habitat value of streams may diminish due to development. Aquatic habitat impacts include those in the following sections:

2.2.4.1 Degradation of Habitat Structure

High velocity flows scour channels and may wash away entire biological communities. Stream bank erosion and the loss of riparian vegetation reduce habitat for fish and other aquatic life, while sediment deposits may smother bottom-dwelling organisms.

2.2.4.2 Loss of Pool Riffle Structure

Streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with “riffles” or shoals of shallower, fast-flowing water. These pools and riffles provide valuable habitat for fish and aquatic insects. As a result of the increased flows and sediment loads from urban watersheds, the pools and riffles disappear and are replaced with more uniform, and often shallower, streambeds that provide less varied habitat and may fail to support a native diversity of species.

2.2.4.3 Reduced Base flows

Urbanization reduces the groundwater recharge and consequently the base flow to streams. Loss of flow stresses habitat and may eliminate many species. During periods of drought, streams may dry up completely, extirpating even the hardiest plants and animals.

2.2.4.4 Increased Stream Temperature

Pavement tends to absorb light energy as heat. Precipitation over pavement absorbs the heat as it runs off into nearby streams and raises stream temperature. Increased temperatures can reduce DO levels and disrupt the food chain. Some aquatic species such as certain trout can only survive within a narrow temperature range.

2.2.4.5 Changes in Water Chemistry

In addition to causing changes in temperature and DO, stormwater contributes other pollutants such as heavy metals, petroleum products, road salts, and excess nutrients to receiving water bodies, which may adversely affect aquatic organisms. In estuarine systems, stormwater inputs may significantly alter salinity levels, which can cause shifts in plant and animal species composition.

2.2.4.6 Decline in Abundance and Biodiversity

Loss of habitat and habitat variety reduces abundance and diversity of organisms.

3.0 STORMWATER MANAGEMENT STANDARDS AND PERFORMANCE CRITERIA

3.1 OVERVIEW

Rhode Island has seen an increase in commercial and residential development over the last several decades. Controlling stormwater from development sites is a priority with regards to impacts to receiving water bodies. This chapter presents performance standards and criteria for all new and redevelopment projects in the State of Rhode Island. Project applicants are required to meet the eleven minimum standards, as well as comply with specific criteria for the site planning process, groundwater recharge, water quality, channel protection, and peak flow control requirements. In the case of restoration or retrofitting, deviation from these standards may be appropriate at the discretion of the approving agency. All applicable development proposals must include a stormwater management site plan for review by State and local government. A plan must address all of the above minimum standards through compliance with the requirements of this manual (see checklist in Appendix A of this document).

All of the minimum standards contribute to protecting the water and habitat quality of receiving waters from the negative impacts of stormwater runoff. This is achieved by using a combination of both structural controls and non-structural practices (such as LID) as part of an effective stormwater management system. In general, when a project's stormwater management system is designed, installed, and maintained in accordance with the requirements of this manual, its runoff impacts will be presumed to be in compliance with applicable state regulatory standards and requirements. In some cases, the permitting agency may require that an applicant prepare and submit a pollutant loading analysis developed in accordance with the provisions of Appendix H in order to ascertain compliance.

This manual often refers to storm events of various kinds. Unless otherwise noted, all storm events are 24 hours in duration and utilize NRCS Type III precipitation distribution. Rainfall amounts for Rhode Island for various return frequencies are provided in Table 3-1 and shall be used for design unless otherwise specified.

Table 3-1 Design Rainfall Amounts for Rhode Island

RI County	24-hour (Type III) Rainfall Amount (inches)*						
	1-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Providence County	2.7	3.3	4.1	4.9	6.1	7.3	8.7
Bristol County	2.8	3.3	4.1	4.9	6.1	7.3	8.6
Newport County	2.8	3.3	4.1	4.9	6.1	7.3	8.6

RI County	24-hour (Type III) Rainfall Amount (inches)*						
	1-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Kent County	2.7	3.3	4.1	4.8	6.2	7.3	8.7
Washington County	2.8	3.3	4.1	4.9	6.1	7.2	8.5

*All Rhode Island County rainfall values were obtained from the Northeast Regional Climate Center (NRCC) using regional rainfall data processed by NRCC from the period of record through December 2008. The NRCC in collaboration with the Natural Resource Conservation Service has under development an interactive web tool at www.precip.net for analysis of precipitation events based on long-term, station-specific data. Applicants may elect to use site-specific data derived from this web tool once the beta site becomes final rather than the RI County values in Table 3-1.

3.2 Minimum Stormwater Management Standards

3.2.1 Minimum Standard 1: LID Site Planning and Design Strategies

LID site planning and design strategies must be used to the maximum extent practicable[1] in order to reduce the generation of the water runoff volume for both new and redevelopment projects. All development proposals must include a completed Stormwater Management Plan checklist (Appendix A) and Stormwater Management Plan for review by the approving agency that shows compliance with this standard. If full compliance is not provided, an applicant must document why key steps in the process could not be met and what is proposed as mitigation. The objective of the LID Site Planning and Design Strategies standard is to provide a process by which LID is considered at an early stage in the planning process such that stormwater impacts are prevented rather than mitigated for.

3.2.2 Minimum Standard 2: Groundwater Recharge

Stormwater must be recharged within the same subwatershed to maintain baseflow at pre-development recharge levels to the maximum extent practicable in accordance with the requirements and exemptions[2] described in Section 3.3.2. In addition, applicants may be required to provide a water budget analysis for proposed groundwater dewatering. Recharge volume is determined as a function of annual pre-development

[1] For all references to "maximum extent practicable" in this manual, an applicant must demonstrate the following: (1) all reasonable efforts have been made to meet the standard in accordance with current local, state, and federal regulations, (2) a complete evaluation of all possible management measures has been performed, and (3) if full compliance cannot be achieved, the highest practicable level of management is being implemented.

[2] Some exemptions to the recharge criteria are necessary to ensure public safety, avoid unnecessary threats of groundwater contamination, and avoid common nuisance issues. Stormwater runoff from LUHPPL is not allowed to infiltrate into groundwater. The stormwater recharge requirement may be specifically waived if an applicant can demonstrate a physical limitation that would make implementation impracticable or where unusual geological or soil features may exist such as significant clay deposits, ledge, fill soils, or areas of documented slope failure.

recharge for site-specific soils or surficial materials, average annual rainfall volume, and amount of impervious cover on a site. The objective of the groundwater recharge standard is to protect water table levels, stream baseflow, wetlands, and soil moisture levels. Infiltrating stormwater may also provide significant water quality benefits such as reduction of bacteria, nutrients, and metals when infiltrated into the soil profile. Maintaining pre-development groundwater recharge conditions may also be used to reduce the volume requirements dictated by other sizing criteria (i.e., water quality, channel protection, and overbank flood control) and the overall size and cost of stormwater treatment practices. Recharge must occur in a manner that protects groundwater quality. Recharge practices may include both structural stormwater controls and nonstructural practices (using the Stormwater Credit in Chapter Four).

3.2.3 Minimum Standard 3: Water Quality

Stormwater runoff must be treated before discharge. The amount that must be treated from each rainfall event is known as the required water quality volume (WQ_v) and is the portion of runoff containing the majority of the pollutants. The required WQ_v is calculated as described in Section 3.3.3 and excludes LID credits allowed under Section 4.6. To provide adequate treatment of stormwater, the WQ_v must be treated by at least one of the structural BMPs listed in Chapter Five at each location where a discharge of stormwater will occur. Structural BMPs are generally required to achieve the following minimum average pollutant removal efficiencies: 85% removal of total suspended solids (TSS), 60% removal of pathogens, 30% removal of total phosphorus (TP) for discharges to freshwater systems, and 30% removal of total nitrogen (TN) for discharges to saltwater or tidal systems. Based upon results published in the scientific literature, the structural BMPs listed in Chapter Five will meet these standards when properly designed, constructed, and maintained. Pretreatment is required for water quality treatment practices where specified in the design guidelines within Chapter Five.

BMPs targeted to remove other pollutant(s) of concern and/or to achieve higher pollutant removal efficiencies may be required for impaired receiving waters, drinking water reservoirs, bathing beaches, shellfishing grounds, Outstanding National Resource Waters, Special Resource Protection Waters, tributaries thereto, and for those areas where watershed plans, including Special Area Management Plans (SAMPs) or Total Maximum Daily Load (TMDLs), have been completed. In some cases, the permitting agencies may require that an applicant prepare and submit a pollutant loading analysis developed in accordance with the provisions of Appendix H.

Applicants or other interested parties may petition the permitting agencies to add one or more BMPs to the list of acceptable structural stormwater controls described in Chapter Five by submitting monitoring results and supporting information developed in accordance with the provisions of the Technology Assessment Protocol (TAP) included in Appendix J.

3.2.4 Minimum Standard 4: Conveyance and Natural Channel Protection

Open drainage and pipe conveyance systems must be designed to provide adequate passage for flows leading to, from, and through stormwater management facilities for at least the peak flow from the 10-year, 24-hour Type III design storm event. Protection for natural channels downstream must be supplied by providing 24-hour extended detention of the one-year, 24-hour Type III design storm event runoff volume. If a stormwater discharge is proposed in a watershed draining to a cold-water fishery, additional restrictions apply for surface detention practices based on the distance from the discharge point to streams (and any contiguous natural or vegetated wetlands) as described in Section 3.3.4. Consult DEM's Water Quality Regulations – Appendix A to determine if a project is in a watershed directly draining to a cold-water fishery. This standard is designed to prevent erosive flow within natural channels and drainageways. For hydrologic and hydraulic modeling guidance, applicants should refer to Appendix K.

3.2.5 Minimum Standard 5: Overbank Flood Protection

Larger storm events also can cause flood damage and other impacts. These impacts can be significantly reduced by storing and releasing stormwater runoff in a gradual manner that ensures pre-development peak discharges are not exceeded. Downstream overbank flood protection must be provided by attenuating the post-development peak discharge rate to the pre-development levels for the 10-year and 100-year, 24-hour Type III design storm events. In addition, designers must demonstrate that runoff from the site for storms up to the 100-year, 24-hour Type III design storm events actually reach proposed structural practices designed to meet this criterion. The objective of this standard is to prevent an increase in the frequency and magnitude of overbank flooding and to protect downstream and abutting structures from flooding. For hydrologic and hydraulic modeling guidance, applicants should refer to Appendix K.

3.2.6 Minimum Standard 6: Redevelopment and Infill Projects

The construction of new impervious areas on undeveloped land is subject to the requirements of this manual even if other portions of the site are currently developed, unless the site meets the definition for an infill project. The purpose of this minimum standard is to establish the alternative requirements for projects or portions of a project where existing impervious areas will be redeveloped or where the site qualifies as infill. In no case on a redevelopment or infill project shall the levels of stormwater treatment and recharge be less than the levels prior to initiation of the proposed project.

Redevelopment

Redevelopment is defined as any construction, alteration, or improvement that disturbs a total of 10,000 square feet or more of existing impervious area where the existing land use is commercial, industrial, institutional, governmental, recreational, or multifamily residential. The permitting authority may take into consideration prior projects or multi-phase projects in determining if the redevelopment threshold has been met. Building demolition is included as an activity defined as “redevelopment,” but building renovation is not. Similarly, removal of roadway materials down to the erodible soil surface is an activity defined as “redevelopment,” but simply resurfacing of a roadway surface is not. Pavement excavation and patching that is incidental to the primary project purpose, such as replacement of a collapsed storm drain, is not classified as redevelopment. In general, the requirements in this manual do not apply to projects or portions of projects when the total existing impervious area disturbed is less than 10,000 square feet. However, specific regulatory programs may impose additional requirements. Any creation of new impervious area over portions of the site that are currently pervious is required to comply fully with the requirements of this manual.

Because redevelopment may present a wide range of constraints and limitations, this minimum standard allows for flexibility and an evaluation of options that can work in conjunction with broader state watershed goals and local initiatives. Stormwater requirements for redevelopment vary based upon the surface area of the site that is covered by existing impervious surfaces.

In order to determine the stormwater requirements for redevelopment projects, the percentage of the site covered by existing impervious areas must be calculated. The term “site” is defined as one or more lots, tracts, or parcels of land to be developed or redeveloped for a complex of uses, units or structures, including but not limited to commercial, residential, institutional, governmental, recreational, open space, and/or mixed uses. When calculating site size, jurisdictional wetland areas defined by DEM or CRMC regulations and undeveloped lands protected by conservation easements should be subtracted from the total site area. Doing so provides incentive to preserve and protect natural resources near redevelopment projects.

For sites with less than 40% existing impervious surface coverage, the stormwater management requirements for redevelopment will be the same as for new development. The applicant, however, can meet those requirements either on-site or at an approved off-site location within the same watershed provided the applicant satisfactorily demonstrates that impervious area reduction, LID strategies, and/or structural BMPs have been implemented on-site to the maximum extent practicable. An approved off-site location must be identified, the specific management measures identified, and an implementation schedule developed in accordance with local review and with DEM/CRMC concurrence, as appropriate. The applicant must also demonstrate that there are no downstream drainage or flooding impacts as a result of not providing on-site management. The intent of this provision is to allow flexibility to meet the goals of improved recharge, water quality, and channel and flood protection to receiving waters while still promoting redevelopment in urban and urban fringe areas.
For redevelopment sites with 40% or more existing impervious surface coverage, only Standards 2, 3, and 7-11 must be addressed. Specifically, recharge and stormwater quality[1] shall be managed for in accordance with one or more of the following techniques:

- Reduce existing impervious area by at least 50% of the redevelopment area; or
- Implement other LID techniques to the maximum extent practicable to provide recharge and water quality management for at least 50% of the redevelopment area; or

[1] For redevelopment sites with 40% or more existing impervious surface coverage, only Standards 2, 3, and 7-11 must be addressed. However, the permitting agency may require peak flow control on a case-by-case basis within a watershed with a history of flooding problems.

- Use on-site structural BMPs to provide recharge and water quality management for at least 50% of redevelopment area; or
- Any combination of impervious area reduction, other LID techniques, or on-site structural BMPs for at least 50% of redevelopment area.
- If none of the above options are practical in terms of water quality management, alternatives may be proposed that would achieve an equivalent pollutant reduction by using a combination of other types of BMPs and strategies, including treating 100% of the redevelopment area by BMPs with a lesser pollutant removal efficiency than stipulated in Standard 3.

Off-site structural BMPs to provide recharge and water quality management for an area equal to or greater than 50% of redevelopment areas may be used to meet these requirements provided that the applicant satisfactorily demonstrates that impervious area reduction, LID strategies, and/or on-site structural BMPs have been implemented to the maximum extent practicable. An approved off-site location must be identified, the specific management measures identified, and an implementation schedule developed in accordance with local review and with DEM/CRMC concurrence, as appropriate. The applicant must also demonstrate that there are no downstream drainage or flooding impacts as a result of not providing on-site management for large storm events.

Infill

For infill[1] sites, the stormwater management requirements will be the same as for new development except that existing impervious area may be excluded from the stormwater management plan (unless subject to local approval or necessary for mitigation by regulation) and only Standards 2, 3, and 7-11 need be applied. The applicant, however, can meet the recharge and water quality requirements either on-site or at an approved off-site location within the same watershed, provided the applicant satisfactorily demonstrates that impervious area reduction, LID strategies, and/or structural BMPs have been implemented on-site to the maximum extent practicable. An approved off-site location must be identified, the specific management measures identified, and an implementation schedule developed in accordance with local review and with DEM/CRMC concurrence, as appropriate. The applicant must also demonstrate that there are no downstream drainage or flooding impacts as a result of not providing on-site management. The intent of this provision is to allow flexibility to meet the goals of improved recharge, water quality, and channel and flood protection to receiving waters while still promoting infill in urban and urban fringe areas.

3.2.7 Minimum Standard 7: Pollution Prevention

All development sites require the use of source control and pollution prevention measures to minimize the impact that the land use may have on stormwater runoff

[1] An infill project is a development site that meets all of the following: the site is currently predominately pervious (less than 10,000 sf of existing impervious cover); it is surrounded (on at least three sides) by existing development (not including roadways); the site is served by a network of existing infrastructure and does not require the extension of utility lines or new public road construction to serve the property; and the site is one (1) acre or less where the existing land use is commercial, industrial, institutional, governmental, recreational, or multifamily residential.

quality. These measures shall be outlined in a stormwater pollution prevention plan. Representative pollution prevention techniques are described in Appendix G. The intent of this standard is to prevent, to the maximum extent practicable, pollutants from coming into contact with stormwater runoff.

3.2.8 Minimum Standard 8: Land Uses with Higher Potential Pollutant Loads

Stormwater discharges from land uses with higher potential pollutant loads (LUHPPLs) require the use of specific source control and pollution prevention measures and the specific stormwater BMPs approved for such use. Allowable BMPs for LUHPPLs are included in Table 3-3 (design details for these practices are provided in Chapter Five). Many LUHPPLs require additional special permits such as a Rhode Island Pollutant Discharge Elimination System (RIPDES) Multi-Sector General Permit (MSGP), and sector-specific required BMPs are included in Section VI of the MSGP. Stormwater runoff from a LUHPPL (classified in Table 3-2) shall not be recharged to groundwater, unless it has been adequately treated for the pollutant of concern as determined by the approving agency. The recharge prohibition at LUHPPLs applies only to stormwater discharges that come into contact with the area or activity on the site that may generate the higher potential pollutant load. In addition, infiltration practices should not be used where subsurface contamination is present from prior land use due to the increased threat of pollutant migration associated with increased hydraulic loading from infiltration systems, unless the contamination is removed and the site has been remediated, or if approved by DEM on a case-by-case basis. In these areas where infiltration is not appropriate, other LID practices can be used, as long as they are lined (e.g., lined bioretention areas). The intent of this standard is to prevent, to the maximum extent practicable, pollution from entering water resources.

Table 3-2 Classification of Stormwater LUHPPLs

The following land uses and activities are considered stormwater LUHPPLs
1. Areas within an industrial site (as defined in RIPDES Rule 31(b)(15)) that are the location of activities subject to the RIPDES Multi-Sector General Permit (except where a No Exposure Certification for Exclusion from RIPDES Stormwater Permitting has been executed); 2. Auto fueling facilities (i.e., gas stations); 3. Exterior vehicle service, maintenance and equipment cleaning areas; 4. Road salt storage and loading areas (if exposed to rainfall); and 5. Outdoor storage and loading/unloading of hazardous substances.

Table 3-3 Acceptable BMPs for Use at LUHPPLs

Group	Practice[1]	Description
Wet Vegetated Treatment Systems (WVTS)	Shallow WVTS	A wet stormwater basin that provides water quality treatment primarily in a shallow vegetated permanent pool. Must be lined for use at LUHPPLs.
	Gravel WVTS	A wet stormwater basin that provides water quality treatment primarily in a wet gravel bed with emergent vegetation. Must be lined for use at LUHPPLs.
	Permeable Paving[2]	A practice that stores the water quality volume in the void spaces of a clean sand or gravel base before it is infiltrated into an underlying constructed filtration media. Must be lined for use at LUHPPLs.
Filtering Practices	Sand Filter	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a surface or underground sand matrix. Must be lined for use at LUHPPLs.
	Organic Filter	A filtering practice that uses an organic medium such as compost in the filter, or incorporates organic material in addition to sand (e.g., peat/sand mixture). Must be lined for use at LUHPPLs.
	Bioretention	A shallow depression that treats stormwater as it flows through a soil matrix, and is returned to the storm drain system, or infiltrated into underlying soils or substratum. Must be lined for use at LUHPPLs.
Green Roofs	Extensive	Rooftop vegetated with low, drought-tolerant plant species and a shallow planting media designed for performance. Not typically designed for public access.
	Intensive	Rooftop vegetated with trees and shrubs with a deeper planting soil and walkways, typically designed for both performance and public access.
Open Channels	Dry Swale	An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix. Must be lined for use at LUHPPLs.

[1] Refer to Chapter Five for detailed descriptions and design criteria for these practices.
[2] Direct infiltration through permeable paving is not permitted for LUHPPL; applicants may use permeable surface materials above a sand or organic filtration media in a lined facility.

3.2.9 Minimum Standard 9: Illicit Discharges

All illicit discharges to stormwater management systems are prohibited, including discharges from OWTS, and sub-drains and French drains near OWTSs that do not meet the State's OWTS Rules (setbacks vary depending on the capacity of the OWTS, the type of conveyance system, and the sensitivity of the receiving waters). The stormwater management system is the system for conveying, treating, and infiltrating stormwater on site, including stormwater best management practices and any pipes intended to transport stormwater to ground water, surface water, or municipal separate storm sewer system (MS4). Illicit discharges to the stormwater management system, i.e., illicit connections, are discharges not entirely comprised of stormwater that are not specifically authorized by a National Pollutant Discharge Elimination System (NPDES) or RIPDES permit. The objective of this standard is to prevent pollutants from being discharged into MS4s and Waters of the State, and to safeguard the environment and public health, safety, and welfare.

3.2.10 Minimum Standard 10: Construction Activity Soil Erosion, Runoff, Sedimentation, and Pollution Prevention Control Measure Requirements

Soil Erosion and Sedimentation Control (SESC) measures must be utilized during the construction phase as well as during any land disturbing activities. The objective of this standard is to reduce mobilization, transport and discharge of pollutants associated with erosion and sedimentation from construction site runoff through implementation of SESC measures that 1) avoid and protect sensitive areas and natural features, 2) minimize disturbances and preserve top soil 3) protect structures, conveyances, receiving waters, and 4) control overland and concentrated stormwater flows.

All soil erosion, runoff, sedimentation, and construction activity pollution prevention control measures must be designed and implemented in accordance with the Soil Erosion and Sediment Control (SESC) Plan requirements outlined in the Performance Criteria in Section 3.3.7 and the most recent edition of the Rhode Island Soil Erosion and Sediment Control Handbook (as amended). The component of the Stormwater Management Plan that addresses this standard is referred to as a Soil Erosion and Sediment Control (SESC) Plan.

For all land disturbance activities that require a permit from the RI DEM or the CRMC, a qualified SESC Plan preparer shall be a Rhode Island Registered Professional Engineer, a Certified Professional in Erosion and Sediment Control (CPESC), a Certified Professional in Storm Water Quality (CPSWQ), or a Rhode Island Registered Landscape Architect who certifies that the SESC Plan meets the Performance Criteria in 3.3.7 and requirements of the Rhode Island Soil Erosion and Sediment Control Handbook (as amended). The Preparer shall have the specific credentials and experience needed to select the appropriate practices for the application. If the project involves significant land grading or requires an engineered site design, then the SESC Plan must be prepared by a Professional Engineer licensed in the State of RI.

For activities that do not require a permit from the RI DEM or the CRMC and are subject to only local ordinances or Municipal Separate Storm Sewer System (MS4) requirements (e.g. site disturbing < 1 acre that is not part of a larger common plan and not subject to CRMC, Freshwater Wetlands, Water Quality, and Groundwater Discharge Regulations) the preparer should consult local ordinances or MS4 requirements as part of developing a stormwater management plan for their project.

3.2.11 Minimum Standard 11: Stormwater Management System Operation and Maintenance

The stormwater management system, including all structural stormwater controls and conveyances, must have an operation and maintenance plan to ensure that it continues to function as designed.

The long-term Operation and Maintenance Plan shall at a minimum include:

1. Stormwater management system(s) owners;
2. The party or parties responsible for operation and maintenance, including how future property owners will be notified of the presence of the stormwater management system and the requirement for proper operation and maintenance;
3. The routine and non-routine maintenance tasks for each BMP to be undertaken after construction is complete and a schedule for implementing those tasks;
4. A plan that is drawn to scale and shows the location of all stormwater BMPs in each treatment train along with the discharge point;
5. A description and delineation of public safety features;
6. An estimated operation and maintenance budget; and
7. Funding source for operation and maintenance activities and equipment.

The Operation and Maintenance Plan shall identify measures for implementing maintenance activities in a manner that minimizes stormwater runoff impacts.

3.3 PERFORMANCE CRITERIA

3.3.1 LID Site Planning and Design Criteria

The LID Site Planning and Design Criteria requires that the site planning process be documented and include how the proposed project will meet the following measures and/or methods to:

1. Protect as much undisturbed open space as possible to maintain pre-development hydrology and allow precipitation to naturally infiltrate into the ground;

2. Maximize the protection of natural drainage areas, streams, surface waters, wetlands, and other regulated areas;
3. Minimize land disturbance, including clearing and grading, and avoid areas susceptible to erosion and sediment loss;
4. Minimize soil compaction and restore soils compacted as a result of construction activities or prior development;
5. Provide low-maintenance, native vegetation that encourages retention and minimizes the use of lawns, fertilizers, and pesticides;
6. Minimize impervious surfaces;
7. Minimize the decrease in the "time of concentration" from pre-construction to post construction, where "time of concentration" means the time it takes for runoff to travel from the hydraulically most distant point of the drainage area to the point of interest within a watershed;
8. Infiltrate precipitation as close as possible to the point it reaches the ground using vegetated conveyance and treatment systems;
9. Break up or disconnect the flow of runoff over impervious surfaces; and
10. Provide source controls to prevent or minimize the use or exposure of pollutants into stormwater runoff at the site in order to prevent or minimize the release of those pollutants into stormwater runoff.

Applicants need to document that the full list of approved LID methods and/or procedures were explored at the site and need to supply a specific rationale in the event LID strategies are rejected as infeasible. More detail on LID site planning and design is included in Chapter Four, and the Stormwater Management Checklist is included in Appendix A.

3.3.2 Groundwater Recharge (Re_v)

The recharge criterion (Re_v) requires that the following volume of stormwater be recharged based on the amount of impervious area. **The groundwater recharge requirement may be waived or reduced by applying the LID Stormwater Credit outlined in Section 4.6 of this document.** Recharge requirements are based on hydrologic soil group (HSG) as follows:

$$Re_v = (1")\,(F)\,(I)/12$$

Where:

Re_v = groundwater recharge volume (ac-ft)
F = recharge factor, see Table 3-4
I = impervious area (acres)

Table 3-4 Recharge Factors Based on Hydrologic Soil Group (HSG)

HSG	Recharge Factor (F)
A	0.60
B	0.35
C	0.25
D	0.10

An example calculation using the HSG method is provided below.

Example: A 30-acre site is to be developed as a residential subdivision in the Town of Westerly. The impervious area for the development will be 10 acres. Half of the impervious area overlays HSG "B" soils and half of the impervious area overlays HSG "C" soils. The recharge requirement would be calculated as follows:

Re_v for B soils = (1") (F) (I)/12 = [(1 in) (0.35) (5 ac)] / (12 in/ft) = 0.15 ac-ft
Re_v for C soils = (1") (F) (I)/12 = [(1 in) (0.25) (5 ac)] / (12 in/ft) = 0.10 ac-ft

Total recharge requirement for site = 0.15 ac-ft + 0.10 ac-ft = 0.25 ac-ft

The recharge volume is considered as part of the total water quality volume that must be provided at a site (i.e., Re_v is contained within WQ_v) and must be achieved by disconnection of impervious areas (see LID Credit, Chapter Four), a structural practice included in Table 3-5 which are described in detail in Chapter Five, or a combination of the two. Recharge should be provided in each applicable drainage area where impervious cover is proposed (e.g., a designer with a large site that has six separate drainage areas should not propose to recharge the site's entire Re_v in just one of the drainage areas; recharge should be calculated separately for each study point). Roof runoff may be infiltrated without pretreatment unless the roof is deemed to have a higher potential pollution load as per Table 3-2 (e.g., industrial buildings with pollutant exhaust vent fallout or with highly erodible roofing materials). Recharged roof runoff can be subtracted from WQ_v but not from larger storm calculations, unless applicant verifies that the drywells are sized for the 100-year, 24-hour Type III storm event.

Some exemptions to the recharge criteria are necessary to ensure public safety, avoid unnecessary threats of groundwater contamination, and avoid common nuisance issues. Stormwater runoff from a LUHPPL is not allowed to infiltrate into groundwater. The stormwater recharge requirement may be specifically waived if an applicant can demonstrate a physical limitation that would make implementation impracticable or where unusual geological or soil features may exist such as significant clay deposits or ledge, where recharge does not currently occur; fill soils; or areas of documented slope failure.

Table 3-5 List of BMPs Acceptable for Recharge

Group	Practice	Description
Infiltration	Infiltration Trenches/Chambers/ Dry Wells	An infiltration practice that stores the water in the void spaces of a trench or open chamber filled with or embedded in clean gravel before it is infiltrated into underlying soils or substratum.
	Infiltration Basin	An infiltration practice that stores the water in a surface depression before it is infiltrated into the underlying soils or substratum.
	Permeable Paving	A practice that stores the water in the void spaces of a clean gravel base before it is infiltrated into the underlying soils or substratum.
Filtering Practices	Sand Filter	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a surface or underground sand matrix. Only counts for recharge when unlined so that stormwater is infiltrated into underlying soils or substratum.
	Organic Filter	A filtering practice that uses an organic medium such as compost in the filter, or incorporates organic material in addition to sand (e.g., peat/sand mixture). Only counts for recharge when unlined so that stormwater is infiltrated into underlying soils or substratum.
	Bioretention	A shallow depression that treats stormwater as it flows through a soil matrix. Only counts for recharge when unlined so that stormwater is infiltrated into underlying soils or substratum.
Open Channels	Dry Swale	An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix. Only counts for recharge when unlined so that stormwater is infiltrated into underlying soils or substratum.

3.3.3 Water Quality Volume (WQ_v)

The water quality volume (WQ_v) is the amount of stormwater runoff from any given storm that must be captured and treated in order to remove a significant fraction of stormwater pollutants on an average annual basis. The required WQ_v, which results in the capture and treatment of the entire runoff volume for 90 percent of the average annual storm events, is equivalent to the runoff associated with the first 1.2 inches of rainfall over the impervious surface (i.e., 1 inch of runoff) (CWP, 2007). **The water quality volume requirement may be waived or reduced by applying the LID Stormwater Credit outlined in Section 4.6 of this document.** The WQ_v is calculated using the following equation:

$$WQ_v = (1") (I) / 12$$

Where:
WQ_v = water quality volume (in acre-feet)
I = impervious area (acres)

A minimum WQ_v value of 0.2 watershed inches (0.2" over the entire disturbed area) is required, which requires the calculation of the total site disturbance. This minimum treatment volume is necessary to fully treat the runoff from pervious surfaces on sites with low impervious cover, i.e., less than 20% of the disturbed area. However, this requirement does not imply that every pervious subarea of disturbance must be treated with a structural water quality BMP. For example, the minimum WQ_v value ensures that developments such as golf courses with low impervious areas receive the appropriate treatment for their stormwater runoff.

Example: The same 30-acre residential subdivision site in the Town of Westerly is to be developed. The impervious area for the development will be 10 acres. The water quality volume requirement would be calculated as follows:

$$I = 10 \text{ ac}$$
$$WQ_v = [(1.0 \text{ in}) (I)]/12 \text{ in/ft} = [(1.0 \text{ in}) (10 \text{ ac})]/12 \text{ in/ft} = 0.83 \text{ ac-ft}$$

3.3.3.1 Rationale

The above approach was adopted by Rhode Island in 1993 and is similar to water quality sizing criteria that have been adopted elsewhere in the United States for the design of stormwater treatment practices. These criteria are intended to remove the majority of pollutants in stormwater runoff at a reasonable cost by capturing and treating runoff from small, frequent storm events that account for a majority of the annual pollutant load, while bypassing larger, infrequent storm events that account for a small percentage of the annual pollutant load. This approach is based on the "first flush" concept, which assumes that the majority of pollutants in urban stormwater runoff are contained in the first half-inch to one-inch of runoff primarily due to pollutant washoff during the first portion of a storm event. Early studies in Florida determined that the first flush generally carries 90 percent of the pollution from a storm (Novotny, 1995). As a result, treatment of the first half-inch of runoff was adopted as a water quality volume sizing criterion requirement throughout much of the United States. More recent research has shown that pollutant removal achieved using the half-inch rule drops off considerably as site imperviousness increases.

For facility sizing criteria, the basis for hydrologic and hydraulic evaluation of development sites should be as follows:

- Impervious cover is measured from the site plan and includes all impermeable surfaces (e.g., paved or gravel roads, driveways and parking lots, sidewalks, and rooftops).
- Off-site areas shall be assessed based on their "pre-development condition" for computing the water quality volume (i.e., treatment of only on-site areas is required). However, if an off-site area drains to a proposed BMP, flow from that area must be accounted for in the sizing of a specific practice.

Table 3-6 includes a list of the acceptable water quality treatment BMPs, which are described in detail in Chapter Five. Other practices may be used to meet other criteria, such as recharge or flood control, but only the practices in this list may be used to meet the water quality criterion. In addition, disconnection of impervious areas (see LID Credit, Chapter Four) may be used to meet some or all of the WQ_v, including the minimum WQ_v.

Table 3-6 Acceptable BMPs for Water Quality Treatment

Group	Practice	Description
Wet Vegetated Treatment Systems (WVTS)	Shallow WVTS	A surface wet stormwater basin that provides water quality treatment primarily in a shallow vegetated permanent pool.
	Gravel WVTS	A wet stormwater basin that provides water quality treatment primarily in a wet gravel bed with emergent vegetation.
Infiltration	Infiltration Trenches/Chambers/ Dry Wells	An infiltration practice that stores the water quality volume in the void spaces of a trench or open chamber filled with or embedded in clean gravel before it is infiltrated into underlying soils.[1]
	Infiltration Basin	An infiltration practice that stores the water quality volume in a shallow surface depression before it is infiltrated into the underlying soils.[1]
	Permeable Paving	A practice that stores the water quality volume in the void spaces of a clean sand or gravel base before it is infiltrated into the underlying soils.[1]
Filtering Practices	Sand Filter	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a surface or underground sand matrix.
	Organic Filter	A filtering practice that uses an organic medium such as compost in the filter, or incorporates organic material in addition to sand (e.g., peat/sand mixture).

[1] The bottom of infiltration practices must be in the natural soil profile, i.e., must not be located in bedrock. Where a TMDL or CRMC goal requires maximum treatment of runoff, the bottom of infiltration practices shall be within the uppermost soil horizons (A or B) or another BMP would be required.

Group	Practice	Description
	Bioretention	A shallow depression that treats stormwater as it flows through a soil matrix, and is returned to the storm drain system, or infiltrated into underlying soils or substratum.
Green Roofs	Extensive	Rooftop vegetated with low, drought-tolerant plant species and a shallow planting media designed for performance. Not typically designed for public access.
	Intensive	Rooftop vegetated with trees and shrubs with a deeper planting soil and walkways, typically designed for both performance and public access.
Open Channels	Dry Swale	An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix.
	Wet Swale	An open vegetated channel or depression designed to retain water or intercept groundwater for water quality treatment.

3.3.3.2 Water Quality Flow (WQ_f)

The water quality flow (WQ_f) is the peak flow rate associated with the water quality design storm or WQ_v. Although most of the stormwater treatment practices in this manual are sized based on WQ_v, flow diversion structures for off-line stormwater treatment practices must be designed to bypass flows greater than the WQ_f. The WQ_f shall be calculated using the WQ_v described above and a modified curve number (CN) for small storm events. This is more appropriate than the traditional NRCS CN Methods and the Rational Formula, which have been widely used for peak runoff calculations and drainage design. The traditional NRCS TR-55 CN methods are valuable for estimating peak discharge rates for large storms (i.e., greater than 2 inches), but can significantly underestimate runoff from small storm events (Claytor and Schueler, 1996). This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the water quality practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels. Similarly, the Rational Formula is highly sensitive to the time of concentration and rainfall intensity, and therefore should only be used with reliable intensity, duration, and frequency (IDF) tables or curves for the storm and region of interest (Claytor and Schueler, 1996).

The following equation shall be used to calculate a modified CN. This modified CN can then be used in a traditional TR-55 model or spreadsheet in order to estimate peak discharges for small storm events.

Using the water quality volume (WQ_v), a corresponding CN is computed utilizing the following equation:

$$CN = 1000 / [10 + 5P + 10Q - 10(Q^2 + 1.25\ QP)^{1/2}]$$

Where:

P = rainfall, in inches (use 1.2 inches for the Water Quality Storm that produces 1 inch of runoff)

Q = runoff volume, in watershed inches (equal to WQ_v ÷ total drainage area)

When using a hydraulic/hydrologic model for facility sizing and WQ_f determination, designers must use this adjusted CN for the drainage area to generate runoff equal to the WQ_v for the 1.2-inch precipitation event.

Designers can also use a TR-55 spreadsheet to find the WQ_f. Using the computed CN from the equation above, the time of concentration (t_c), and drainage area (A); the peak discharge (WQ_f) for the water quality storm event can be computed with the following steps:

1. Read initial abstraction (I_a) from TR-55-Table 4.1 or calculate using $I_a = 200/CN – 2$
2. Compute I_a/P (P = 1.2 inches)
3. Approximate the unit peak discharge (q_u) from TR-55 Exhibit 4-III using t_c and I_a/P
4. Compute the peak discharge (WQ_f) using the following equation:

$$WQ_f = q_u * A * Q$$

Where:
WQ_f = the peak discharge for water quality event, in cfs
q_u = the unit peak discharge, in cfs/mi²/inch
A = drainage area, in square miles
Q = runoff volume, in watershed inches (equal to WQ_v ÷ A)

3.3.4 Channel Protection (CP_v)

The channel protection volume (CP_v) is the 24-hour extended detention of the post-development runoff volume from the 1-year, 24-hour Type III design storm event. If a stormwater discharge is proposed within 200 feet of streams and any contiguous natural or vegetated wetlands in watersheds draining to cold-water fisheries, surface detention practices are prohibited (underground detention or infiltration practices will be required). Discharges beyond 200 feet shall be designed to discharge up to the CP_v through an underdrained gravel trench outlet, as described in Chapter Five and depicted in Figure 5-4.

For facility sizing criteria, the basis for hydrologic and hydraulic evaluation of development sites are as follows:

- The models TR-55 or TR-20 (or approved equivalent) shall be used for determining the CP_v.
- The Rational Method may be used for sizing the conveyance system.
- Off-site areas draining to proposed facility shall be modeled as “present condition” for the one-year storm event.

- The length of sheet flow used in time of concentration (t_c) calculations is limited to no more than 100 feet for post-development conditions.
- The required minimum CP_v shall be computed using the methodology developed in 1987 by Harrington (See Appendix H.4) or by calculating 65% of the direct runoff volume from the post-development 1-year, 24-hour Type III storm based on one of the approved models listed above, using the following equation:

$$V_s = 0.65 * V_r$$

where $V_s = CP_v$ = required channel protection storage volume; and
V_r = runoff volume from 1-year, 24-hour Type III storm.

- The CP_v shall be released at roughly a uniform rate over a 24-hour duration (see example sizing calculations in Appendix D). To determine the average release rate, use the following equation:

$$\text{Average release rate} = V_r / T$$

where V_r = defined above; and
T = extended detention time (24 hours).

The CP_v criterion can be waived for sites that:

- Direct discharge to a large river (i.e., 4th-order stream or larger. See Appendix I for State-wide list and map of stream order), bodies of water > 50.0 acres in surface area (i.e., lakes, ponds, reservoirs), or tidal waters.
- Small facilities with impervious cover less than or equal to 1 acre.
- Projects when the post-development peak discharge from the facility without attenuation is less than 2 cfs for the 1-year, 24-hour Type III design storm event.

3.3.5 Overbank Flood Protection (Q_p)

Peak flow attenuation is required for the 10-year and 100-year, 24-hour Type III design storm events. The primary purpose of this sizing criterion is to prevent an increase in the frequency and magnitude of out-of-bank flooding (i.e., flow events that exceed the bankfull capacity of the channel, and therefore, must spill over to the floodplain). One of the key objectives of an out-of-bank flooding requirement is to protect downstream structures (houses, businesses, culverts, bridge abutments, etc.) from increased flows and velocities from upstream development. The intent of this criterion is to prevent increased flood damage from infrequent but very large storm events, maintain the boundaries of the predevelopment floodplain, and protect the physical integrity of a stormwater management practice itself.

For facility sizing criteria, the basis for hydrologic and hydraulic evaluation of development sites are as follows:

- The models TR-55 and TR-20 (or approved equivalent) will be used for determining the required storage and outlet structures for attenuating the peak flows from the 10-year and 100-year, 24-hour Type III design storms.
- The standard for characterizing pre-development land use for on-site areas shall be woods, meadow, or rangeland. For agricultural land, use a CN representing rangeland.
- For purposes of computing runoff, all pervious lands prior to development shall be assumed to be in good condition regardless of conditions existing at the time of computation.
- Off-site areas that drain to a proposed facility should be modeled as "present condition" for peak-flow attenuation requirements.
- If an off-site area drains to a facility, an applicant must also demonstrate safe passage of the 100-year event, based on actual conditions upstream.
- The length of sheet flow used in t_c calculations is limited to no more than 150 feet for pre-development conditions and 100 feet for post-development conditions.
- An applicant must demonstrate that flows from the 100-year event will be safely conveyed to a practice designed to manage the 100-year event.

The Q_p criterion can be waived for sites that:

- Direct discharge to a large river (i.e., 4th-order stream or larger. See Appendix I for State-wide list and map of stream order), bodies of water > 50.0 acres in surface area (i.e., lakes, ponds, reservoirs), or tidal waters.
- A Downstream Analysis indicates that peak discharge control would not be beneficial or would exacerbate peak flows in a downstream tributary of a particular site (i.e., through coincident peaks).

3.3.6 Downstream Analysis

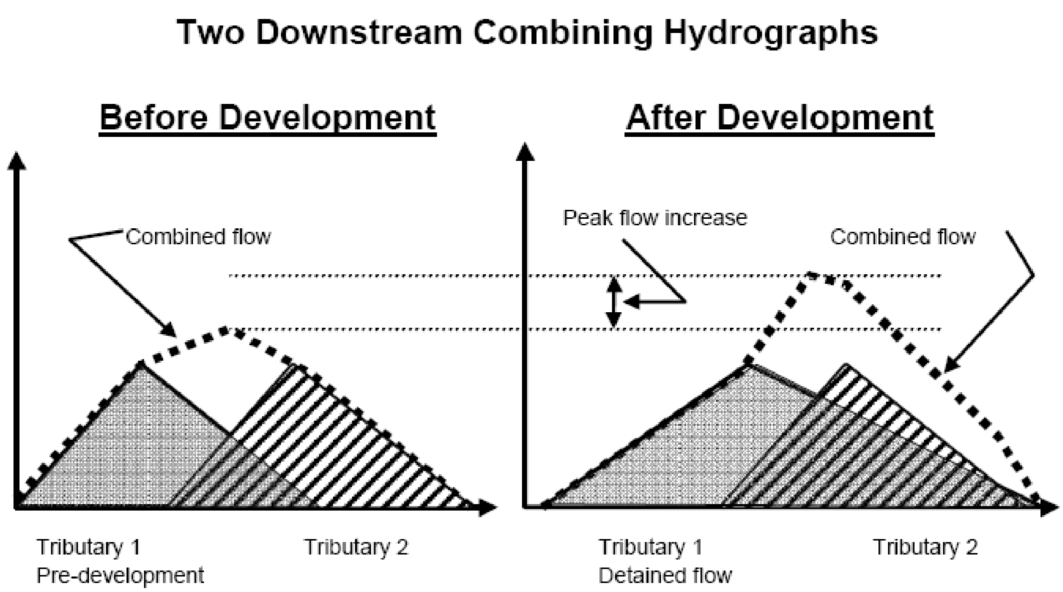
A downstream analysis is required for projects meeting the project size and impervious cover characteristics in the table below, or when deemed appropriate by the approving agency when existing conditions are already causing a problem (e.g., known drainage or flooding conditions or existing channel erosion is evident), to determine whether peak flow impacts are fully attenuated by controlling the 10- and 100-year events. The criterion used for the limit of the downstream analysis is referred to as the “10% rule.” Under the 10% rule, a hydrologic and hydraulic analysis is extended downstream to the point where the site represents 10% of the total drainage area. For example, a 10-acre disturbed area within the same subwatershed would be analyzed to the point downstream with a drainage area of 100 acres.

Table 3-7 Projects for which a Downstream Analysis is required

Area of Disturbance Within the Subwatershed (acres)	Impervious Cover (%)[1]
>5 to10	>75
>10 to 25	>50
>25 to 50	>25
>50	all projects

A number of hydrologists have noted that overbank and extreme flood control approaches do not always provide full downstream control from the out-of-bank events, due to differences in timing of individual peak discharges in the downstream portion of the watershed. Depending on the shape and land use of a watershed, it is possible that upstream peak discharge may arrive at the same time a downstream structure is releasing its peak discharge, thus increasing the total discharge (see Figure 3-1). As a result of this "coincident peaks" problem, it is often necessary to evaluate conditions downstream from a site to ensure that effective out-of-bank control is being provided.

Figure 3-1 Graphical Representation of Coincident Peaks (Ogden, 2000)



[1] Percent Impervious Cover = I / disturbed area contributing to discharge locations

As a minimum, the analysis should include the hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel and assess whether an increase in water surface elevations will impact existing buildings or other structures. The analysis should compute flow rates and velocities (for the overbank flood control storms) downstream to the location of the 10% rule for pre-developed conditions and proposed conditions both with and without detention facility(ies). If flow rates and velocities (for Q_p) with the proposed detention facility increase by less than 5% from the pre-developed condition, and no existing structures are impacted, then no additional analysis is necessary. If the flow rates and velocities increase by more than 5%, then the designer must redesign the detention structure, evaluate the effects of no detention structure, or propose corrective actions to the impacted downstream areas. Additional investigations may be required by the approving agency on a case-by-case basis depending on the magnitude of the project, the sensitivity of the receiving water resource, or other issues such as past drainage or flooding complaints.

Special caution should be employed where the analysis shows that no detention structure is required. Stormwater designers must be able to demonstrate that runoff will not cause downstream flooding within the stream reach to the location of the 10% rule. The absence of on-site detention shall not be perceived to waive or eliminate groundwater recharge (Re_v), water quality control (WQ_v), or stream channel protection requirements (CP_v).

A typical downstream analysis will require a hydrologic investigation of the disturbed area draining to a proposed detention facility and of the contributory watershed to the location of the 10% rule for the 10- and 100-year, 24-hour Type III storms. The approving agency may also request analysis of the 1-year, 24-hour Type III storm on a case-by-case basis. A hydraulic analysis of the stream channel below the facility to the location of the 10% rule will also be necessary (e.g., a HECRAS water surface profile analysis). Depending on the magnitude of the impact and the specific conditions of the analysis, additional information and data may be necessary such as collecting field run topography, establishing building elevations and culvert sizes or investigating specific drainage concerns or complaints.

Table 3-8 Summary of Stormwater Treatment Practice Criteria

Criteria	Description	Post-Development Storm Magnitude

Criteria	**Description**	**Post-Development Storm Magnitude**
Groundwater Recharge	*Groundwater Recharge Volume (Re_v)** Maintain pre-development annual groundwater recharge volume to the maximum extent practicable through the use of infiltration measures Re_v = (1")(F)(I)/12 Re_v = groundwater recharge volume (ac-ft) F = recharge factor, see Table 3-4 I = Impervious area (acres)	First one inch of runoff
Pollutant Reduction	*Water Quality Volume (WQ_v)** Volume generated by one inch of runoff on the site WQ_v = (1")(I)/12 WQ_v = water quality volume (ac-ft) I = Impervious area (acres) *Water Quality Flow (WQ_f)* Peak flow associated with the water quality volume	First one inch of runoff
Channel and Conveyance Protection	*Channel Protection Volume (CP_v)** CP_v = 24-hour extended detention of the volume of the post-development 1-year, 24-hour Type III storm event *Conveyance Protection* Design the conveyance system leading to, from, and through stormwater management facilities based on the peak flow from the 10-year, 24-hour Type III storm.	1-year, 24-hour Type III rainfall 10-year, 24-hour Type III rainfall

Criteria	**Description**	**Post-Development Storm Magnitude**
Overbank Flood Protection	*Peak Runoff Attenuation (Q_p)** Control the post-development peak discharge rates from the 10- and 100-year storms to the corresponding pre-development peak discharge rates. Calculations must be provided that show how runoff from the 10- and 100-year storms reaches the proposed facilities. *Emergency Outlet Sizing* Size the emergency outlet to safely pass the post-development peak runoff from, at a minimum, the 100-year storm in a controlled manner without eroding the outlet works and downstream drainages. *Downstream Analysis* Downstream analysis of the overbank and extreme flood (10-year and 100-year, respectively) shall be conducted to identify potential detrimental effects of proposed stormwater treatment practices and detention facilities on downstream areas (for applicability, see section 3.3.6).	10- and 100-year, 24-hour Type III rainfall 100-year, 24-hour Type III rainfall 10 and 100-year, 24-hour Type III rainfall

*Note that the Rational Formula is not allowed for determining required volumes to meet the stormwater criteria. The Rational Formula is appropriate for calculating peak discharge rates, and thus for sizing pipes, but not for volume-based requirements.

3.3.7 Soil Erosion, Runoff, and Sedimentation Control Measures

Soil Erosion and Sedimentation Control (SESC) measures must be utilized during the construction phase as well as during any land disturbing activities. Owners and operators must design, install, and maintain effective soil erosion, runoff, and sediment controls. SESC Plans must document how the proposed activities are consistent with the following Performance Criteria:

1. Avoid and Protect Sensitive Areas and Natural Features

Areas of existing and remaining vegetation and areas that are to be protected during construction must be clearly marked on the plans. Throughout planning, design, and construction the Applicant must demonstrate that the activities are consistent with Minimum Standard 1, Low Impact Development (LID) Site Planning and Design Strategies designed to maximize the protection of natural drainage areas, streams, surface waters, and jurisdictional wetland buffers. Section 4.5 LID Site Planning and Design Criteria requires that Applicants avoid the impacts, requiring the preservation of buffers and floodplains by delineating and preserving naturally vegetated riparian buffers and floodplains and implementing measures to ensure that buffers and native vegetation are protected.

2. Minimize Area of Disturbance

Limits of Disturbance (LOD) shall be clearly marked on all SESC plans. The amount of land area disturbed should be minimized. Existing vegetation should be left in place as far as practical. The SESC Plan must identify how the Applicant has minimized the area of disturbance by locating sites in less sensitive areas in accordance with Minimum Standard 1, Low Impact Development Site Planning and Design Strategies, Section 3.3.1.3., Appendix A Checklist 1.D. and Chapter Four – LID Site Planning and Design Strategies, Section 4.5.1.

The total amount of land area disturbed at one time should be minimized. Construction activity shall be phased to minimize the amount of area that is being actively disturbed. Activities disturbing less than one acre or activities that will be completed within six months should consider phasing if located in sensitive or problematic areas. Activities disturbing greater than five acres must include phasing in combination with other controls.

The designer should consider the changes in the type of surface cover as the site is developed. For new development projects that involve the conversion of woods or meadow in good condition to a roof, a road, or a parking lot, it may be important to evaluate the temporary changes in runoff as the site is developed. This is especially important if the development is completed in large phases or is located in a sensitive or problematic area.

Adequate temporary controls must be installed on previous phases prior to initiating the land disturbance in subsequent phases until final site stabilization is achieved and post-construction control measures are brought on-line. Phasing should take into account the requirements to manage temporary changes to runoff volume and peak runoff rates due to changes to runoff characteristics caused by the construction activity.

3. Minimize the Disturbance of Steep Slopes

Construction activities should be avoided on steep slopes (e.g. >15%) to the Maximum Extent Practicable (MEP) to comply with Minimum Standard 1, Low Impact Development Site Planning and Design Strategies, Section 3.3.1.3 and Appendix A Checklist 1.D. Locating Sites in Less Sensitive Areas, and Chapter Four – LID Site Planning and Design Strategies, Section 4.5.1 Avoid the Impacts.

4. Preserve Topsoil

Site owners and operators must preserve existing topsoil on the construction site to the maximum extent feasible and as necessary to support healthy vegetation. If it is determined that preserving native topsoil is infeasible, the reasons why this was determined must be addressed in the SESC Plan.

5. Stabilize Soils

Stabilization of disturbed areas must, at a minimum, be initiated immediately whenever any clearing, grading, excavating or other earth disturbance activities have permanently ceased on any portion of the site, or temporarily ceased on any portion of the site and will not resume for a period exceeding fourteen (14) calendar days. Stabilization must be completed using vegetative stabilization measures or using alternative measures whenever vegetative measures are deemed impracticable or during periods of drought. All disturbed soils exposed prior to October 15th shall be seeded by that date. Any such areas which do not have adequate vegetative stabilization by November 15th must be stabilized through the use of non-vegetative erosion control measures. If work continues within any of these areas during the period from October 15th through April 15th, care must be taken to ensure that only the area required for that day's work is exposed, and all erodible soil must be restabilized within 5 working days. In limited circumstances, stabilization may not be required if the intended function of a specific area of the site necessitates that it remain disturbed (i.e. construction of a motocross track).

6. Protect Storm Drain Inlets

If there is a stormwater discharge from the construction site to a storm drain inlet under the project's control, the site owner and operator must install inlet protection measures that remove sediment from discharge prior to entry into the storm drain inlet.

The operator must clean, or remove and replace, the protection measures as sediment accumulates, the filter becomes clogged, and/or performance is compromised. Accumulated sediment adjacent to the inlet protection measures must be removed by the end of the same work day in which it is found or by the end of the following work day if removal by the same work day is not feasible.

7. Protect Storm Drain Outlets

Outfall protection must be used to prevent scour and erosion at discharge points through the protection of the soil surface, reduction of discharge velocity, and the promotion of infiltration.

8. Establish Temporary Controls for the Protection of Post-Construction Stormwater Control Measures

Temporary measures shall be installed to protect permanent or long-term stormwater control and treatment measures as they are installed and throughout the construction phase of the project so that they will function properly when they are brought online. The plan shall identify areas where infiltration measures are proposed and provide measures to restrict construction activity to prevent compaction of the area. In cases where this is not possible to avoid the area the Plan must include methods to restore the infiltration capacity of the soils.

9. Establish Sediment Barriers

Sediment control measures must be installed along the perimeter areas of the site that will receive stormwater from earth disturbing activities. Maintenance of sediment barriers must be completed in accordance with the maintenance requirements specified by the product manufacturer or the Rhode Island Soil Erosion and Sediment Control Handbook (as amended).

10. Divert or Manage Run-on from Up-gradient Areas

Structural control measures must be used to limit stormwater flow from coming onto the project area, and to divert and slow on-site stormwater flow from exposed soils to limit erosion, runoff, and the discharge of pollutants from the site.

11. Properly Design Constructed Stormwater Conveyance Channels

Temporary conveyance practices must be sized to handle the peak flow from the 10-year, 24-hour Type III design storm. Temporary conveyance measures may be required to be sized to handle the peak flow from larger design storms as determined on a case-by-case basis.

12. Retain Sediment On-Site

The SESC Plan shall contain a combination of practices that control erosion, control run-off, and control sediment. The combination of practices must be designed to prevent discharges of sediment. All plans shall include inlet protection, construction entrances, and containment of stockpiled materials. The designer should consider if conditions warrant the use of sediment traps, sediment basins, or sediment barriers.

For Disturbed Areas <1 Acre – Those areas with a common drainage location that serves an area with less than one (1) acre disturbed at one time, a combination of phasing, stabilization and conveyances that provide run-off control will be sufficient. In some cases, additional controls may be required where site conditions warrant or a specific requirement exists in State regulations or Local ordinances.

For Disturbed Areas 1 to 5 Acres – Those areas with a common drainage location that serves an area between one (1) and five (5) acres disturbed at one time, a temporary sediment trap must be provided where attainable and where the sediment trap is only intended to be used for a period of six (6) months or less. For longer term projects with a common drainage location that serves between one (1) and five (5) acres disturbed at one time, a temporary sediment basin must be provided where attainable. Temporary sediment trapping practices must be designed in accordance with the Rhode Island Soil Erosion and Sediment Control Handbook (as amended) and must be sized to have a total storage volume capable of storing one (1) inch of runoff from the contributing area or one hundred and thirty four (134) cubic yards per acre of drainage area. A minimum of fifty percent (50%) of the total volume shall be storage below the outlet (wet storage).

For Disturbed Areas > 5 Acres – Those areas with a common drainage location that serves an area with greater than five (5) acres disturbed at one time, a temporary (or permanent) sediment basin must be provided where attainable until final stabilization of the site is complete. Temporary sediment basins must be designed in accordance with the Rhode Island Soil Erosion and Sediment Control Handbook (as amended). The volume of wet storage shall be at least twice the sediment storage volume and shall have a minimum depth of two (2) feet. Sediment storage volume must accommodate a minimum of one year of predicted sediment load as calculated using the sediment volume formula in the Rhode Island Soil Erosion and Sediment Control Handbook (as amended). In addition to sediment storage volume and wet storage volume, the sediment basin shall provide adequate residence storage volume to provide a minimum 10 hours residence time for a ten (10) -year frequency, twenty four (24) hour duration, Type III distribution storm. To the maximum extent practicable, outlet structures must be utilized that withdraw water from the surface of temporary sedimentation basins, if required or specified by the designer, for the purpose of minimizing the discharge of pollutants. Exceptions may include periods of extended cold weather, where alternative outlets are required during frozen periods. If such a device is infeasible for portions of or the entire construction period justification must be made in the SESC Plan.

13. Control Temporary Increases in Stormwater Velocity, Volume, and Peak Flows

The Plan must identify all discharge points and propose a combination of practices to ensure control of both peak flow rates and total runoff volume to minimize flooding, channel erosion, and stream bank erosion in the immediate vicinity of discharge points. The plan must identify if discharge points from the site discharge directly to a surface water or to an off-site conveyance. The designer must ensure that the proposed combination of practices are adequate to protect the receiving waters and downstream conveyances from the excessive velocities that would cause scouring or channel erosion.

In most cases, the combination of practices that control erosion, control run-off, and control sediment used to retain sediment on-site will be adequate to control temporary increases in volume and peak flows. However, the designer must evaluate if conditions warrant the use additional retention/detention practices beyond those required to address 3.3.7.12. The evaluation must include a description of site conditions and proposed on-site controls and conveyances for all discharge points. For those projects proposing a common drainage location that serves an area with greater than five (5) acres disturbed at one time, the permitting agency may require peak flow control on a case-by-case basis.

14. Construction Activity Pollution Prevention Control Measures

The SESC Plan must describe the pollution prevention measures that will be implemented to control pollutants in stormwater. The owner and operator must design, install, implement, and maintain effective pollution prevention measures to minimize the discharge of pollutants in accordance with the SESC Plan requirements outlined in the Rhode Island Soil Erosion and Sediment Control Handbook (as amended).

15. Control Measure Installation, Inspections, Maintenance, and Corrective Actions

The installation of temporary erosion, runoff, sediment, and pollution prevention control measures must be completed by the time each phase of earth-disturbance has begun.

Construction sites must be inspected by or under the supervision of the owner and operator at least once every seven (7) calendar days and within twenty-four (24) hours after any storm event which generates at least 0.25 inches of rainfall per twenty-four (24) hour period and/or after a significant amount of runoff.

If an inspection reveals a problem, the operator must initiate work to fix the problem immediately after discovering the problem, and complete such work by the close of the next work day, if the problem does not require significant repair or replacement, or if the problem can be corrected through routine maintenance.

When installation of a new control or a significant repair is needed, site owners and operators must ensure that the new or modified control measure is installed and made operational by no later than seven (7) calendar days from the time of discovery where feasible. If it is infeasible to complete the installation or repair within seven (7) calendar days, the reasons why it is infeasible must be documented in the SESC Plan along with the schedule for installing the stormwater control measure(s) and making it operational as soon as practicable after the 7-day timeframe.

If corrective actions are required, the site owner and operator must ensure that all corrective actions are documented on the inspection report in which the problem was first discovered. Corrective actions shall be documented, signed, and dated by the site operator once all necessary repairs have been completed.

4.0 LOW IMPACT DEVELOPMENT (LID) SITE PLANNING AND DESIGN STRATEGIES

This chapter presents a suite of LID methods that designers and developers can choose from to treat, infiltrate, and reduce the stormwater runoff at a site. The LID site planning process is required to meet Minimum Standard 1, and an LID Credit is available that helps project applicants meet the recharge and treatment requirements of Minimum Standards 2 and 3.

4.1 The Problem with Conventional Stormwater Management

Traditionally, stormwater has been managed using large, structural practices installed at the downstream end of development sites - often as an afterthought - on land segments leftover after developing property. Stormwater is typically conveyed from rooftop to driveway to street, where it is then quickly conveyed via a drainage system to a downstream structural practice such as a dry detention pond. This approach, sometimes referred to as end-of-pipe management, yields the apparent advantages of centralizing control and limiting expenditure of land. These structural drainage systems are designed to be hydraulically efficient for removing stormwater from a site as fast as possible. However, in doing so, these systems limit groundwater recharge, can degrade water quality of receiving waters, and increase runoff volumes, peak discharges, and flow velocities, as described in detail in Chapter Two.

As research, technology, and information transfer have improved over recent years, alternative approaches are being sought by the public and regulators to reduce the environmental impacts from new development and redevelopment. Developers and designers are also seeking alternatives to expedite permitting processes, reduce construction costs, reduce long-term operation and maintenance costs, and increase property values. LID has emerged as an effective way to address these issues by combining a site planning and design process with runoff reduction and treatment practices, resulting in benefits that far surpass the end-of-pipe approach.

Use of LID strategies does not necessarily completely supplant the use of end-of-pipe technology. Hybrid approaches that incorporate both can work effectively. However, the Smart Development for a Cleaner Bay Act (RIGL 45-61.2) and this manual require that permit applicants exhaust all opportunities to use such practices prior to exploring end-of-pipe management, in accordance with Minimum Standard 1. Developers must use site planning and design strategies as their first-line approach and are required to recharge stormwater in accordance with Minimum Standard 2, the groundwater recharge requirement (Re_v).

4.2 Definition of LID

LID is quite different from conventional treatment (pipe-to-pond stormwater management). It is a comprehensive approach to managing stormwater that is integrated into a project design to minimize the hydrologic impacts of development. In the past, the landscape was altered significantly to fit the style of development; whereas the LID process is reversed where development is shaped to fit into the landscape. This new approach to stormwater management focuses on the preservation and use of natural systems to achieve stormwater management objectives to the extent feasible. The primary goal of LID is to reduce runoff and mimic the predevelopment site hydrology by using site planning and design strategies to store, infiltrate, evaporate, and detain runoff as close as possible to the point where precipitation reaches the ground. Stormwater is managed in smaller, cost-effective treatment practices located throughout the development site rather than being conveyed to and managed in one or more centralized facilities located at the bottom of drainage areas. Use of these strategies helps to reduce off-site runoff and ensure adequate groundwater recharge.

4.3 LID GOALS

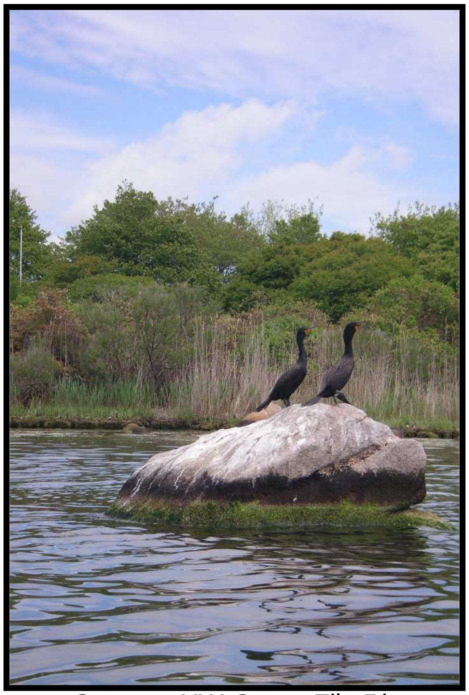
The purpose of LID is to reduce the environmental impact "footprint" of a development site while retaining and enhancing the owner/developer's purpose and vision for the site. Many of the LID concepts employ non-structural, on-site treatment that can reduce the cost of infrastructure while maintaining or even increasing the value of the property relative to conventionally designed developments. The goals of LID include:

- Reduce impervious cover and thus the generation of stormwater runoff volume;
- Prevent impacts to natural drainage ways, surface waters, and wetlands;
- Manage water (quantity and quality) as close to the source as possible and minimize the use of large stormwater collection and conveyance systems;
- Preserve natural areas, native vegetation, and reduce the impact on watershed hydrology;
- Protect natural drainage pathways as a framework for site design;
- Utilize less complex, non-structural methods for stormwater management that are lower cost and lower maintenance than conventional structural controls; and
- Create a multifunctional landscape.

4.4 BENEFITS OF LID

LID provides important benefits to the local municipality, project applicants, and the general public. Less impervious surface creates less surface runoff, which will decrease the burden to municipal infrastructure. Adopting LID strategies can also streamline the review process, saving both the applicants and approving agencies time and money.

The public benefits as a consequence of a healthier environment can translate directly to cost savings through reduced need for future remediation of environmental resources. LID approaches reduce the loading of sediments, nutrients, and pathogens



Source: HW Group File Photo

to streams and other waterbodies. This improves the health of these systems and makes them more attractive for those interested in boating, fishing, or swimming. New development using the old standard approach will continue to threaten these systems, ultimately requiring expensive and difficult fixes if the health of the freshwater and coastal ecosystems is to be restored. If we hope to preserve and restore water quality and aquatic habitat, the use of LID techniques provides a cost-effective tool to accomplish this goal. Furthermore, improved land use strategies contribute to community resiliency and can help mitigate impacts from climate change. For example, increasing rainfall for storm events may have serious impacts to urban infrastructure that is, in many cases, already undersized due to past development. Changes in land use practices can distribute costs across the spectrum of end-users (municipalities, developers, and owners) over a long duration and reduce economic distress from catastrophic events.

Other LID public benefits include:

- Reduced long-term operation and maintenance costs;
- Increased property values;
- Easier compliance with wetland and other resource protection regulations;
- More open space for recreation;
- Neighborhoods that are more pedestrian friendly;
- Fewer safety concerns as LID-based BMPs feature shallow depths and gentle side slopes;
- Protection of sensitive natural resources, forests, wetlands, and habitats;
- More aesthetically pleasing and naturally attractive landscapes; and
- Reduced consumption of land for stormwater management.

There are also significant cost benefits to developers when they follow the LID approach. These benefits are seen in three areas:

- The initial construction cost for a project;
- Operation and maintenance costs for LID-based best management practices; and
- Increased property values for LID sites.

More concentrated (clustered) design, with less impervious area and drainage infrastructure, means significant construction cost savings to developers. Cost savings are found both in residential and commercial designs. A recent study by the EPA (2007) compared the project costs for conventional developments vs. LID developments and found 15-80% total project cost reductions for the LID developments. A study on conservation subdivisions in Rhode Island (Mohamed, 2006) found that conservation developments sold in approximately half the time of conventional subdivisions and at a 17% higher price; yet, they cost approximately 40% less to develop.

In addition, operation and maintenance costs for LID BMPs are similar, and sometimes less, than those for standard drainage systems. In commercial settings where parking lot islands are used for stormwater management, the overall site maintenance costs are likely to be less for an LID-based project. The landscaped islands must be maintained whether or not they are used for stormwater management. The extent of landscape maintenance is not too different for conventional development versus the LID design approach, and if the islands are used for stormwater controls, there is less maintenance for other stormwater structures on the site as well.

4.5 LID Site Planning and Design Criteria

Minimum Standard 1 establishes an approach for measuring compliance with appropriate LID site planning and design and requires that the site planning process be formally documented and address at least the following ten objectives:

Avoid Impacts

1. Protect as much undisturbed open space as possible to maintain pre-development hydrology and allow precipitation to naturally infiltrate into the ground;
2. Maximize the protection of natural drainage areas, streams, surface waters, wetlands, and jurisdictional wetland buffers;
3. Minimize land disturbance, including clearing and grading, and avoid areas susceptible to erosion and sediment loss; and
4. Minimize soil compaction and restore soils compacted as a result of construction activities or prior development.

Reduce Impacts

5. Provide low-maintenance, native vegetation that encourages retention and minimizes the use of lawns, fertilizers, and pesticides;
6. Minimize impervious surfaces; and
7. Minimize the decrease in the "time of concentration" from pre-construction to post construction, where "time of concentration" means the time it takes for runoff to travel from the hydraulically most distant point of the drainage area to the point of interest within a watershed.

Manage Impacts at the Source

8. Infiltrate precipitation as close as possible to the point it reaches the ground using vegetated conveyance and treatment systems;
9. Break up or disconnect the flow of runoff over impervious surfaces; and
10. Provide source controls to prevent or minimize the use or exposure of pollutants into stormwater runoff at the site in order to prevent or minimize the release of those pollutants into stormwater runoff.

These objectives must be formally documented according to the Stormwater Management checklist included in Appendix A using the LID strategies described below. Site planning and design should be done in unison with the design and layout of stormwater and wastewater infrastructure in attaining management and land use goals. The LID site planning and design objectives can be split into three main categories:

1. Avoid the Impacts[1] – Preserve, and where possible restore, natural features;
2. Reduce the Impacts[1] – Reduce impervious cover; and
3. Manage the Impacts at the Source – Design site specific runoff reduction, treatment, and source controls.

These three broad design objectives can be met through the application of a set of specific LID strategies, which are listed below and many of which are further described in "The LID Site Planning and Design Guidance for Rhode Island Communities" *(*DEM*, pending)*.

4.5.1 Avoid the Impacts

The first goal in the LID site planning and design process is to avoid disturbance of natural features. This includes identification and preservation of natural areas that can be used in the protection of water resources. It is important to understand that minimizing the hydrologic alteration of a site is just as important as stormwater treatment for resource protection.

Source: R. Arendt, File Photo

[1] Both avoiding and minimizing the impacts will require more flexibility with community land use ordinances. These steps must be done during the local development review process. Refer to "The LID Site Planning and Design Guidance for Rhode Island Communities" *(*DEM*, pending)* for further details regarding the site planning, design, and development strategies that communities should adopt to encourage LID.

To the extent possible, developers should promote contact between runoff and pervious land surfaces. Technically, this is done by increasing or maintaining natural flow paths and vegetated cover, which increases the time of concentration, t_c (the length of time required for runoff to concentrate and flow off site) and reduces the curve number, CN (a representation of the portion of stormwater that is available to runoff). An in-depth discussion of t_c and CN is contained in Technical Release-55 (SCS, 1986).

Site planning and design strategies that Avoid the Impacts include the following:

- Preservation of Undisturbed Areas – involves delineating and defining natural conservation areas before performing site layout and design and then ensuring that these areas and native vegetation are protected in an undisturbed state throughout the design, construction, and occupancy stages of a project.
- Preservation of Buffers and Floodplains – involves delineating and preserving naturally vegetated riparian buffers and floodplains and implementing measures to ensure that buffers and native vegetation are protected throughout planning, design, construction, and occupancy.
- Reduction of Clearing and Grading – involves strategies that restrict clearing to the minimum area required for building footprints, construction access, and safety setbacks and establishing clearly identified limits of disturbance for all development activities.
- Locating Development in Less Sensitive Areas – involves approaches that avoid sensitive resource areas such as floodplains, steep slopes, erodible soils, wetlands, mature forests, and critical habitat areas.
- Compact Development – is a site development strategy that incorporates smaller lot sizes to reduce overall impervious cover while providing more undisturbed open space and protection of water resources.
- Working with the Natural Landscape Conditions, Hydrology, and Soils – involves delineating natural features and soils and locating buildings, roadways, and parking areas to fit the terrain and in areas that will create the least impact and maintain post-development t_c to mimic pre-development t_c.

4.5.2 Reduce the Impacts

Once sensitive resource areas and site constraints have been avoided, the next goal is to reduce the impact of land alteration by minimizing impervious areas in order to reduce the volume of stormwater runoff, increase groundwater recharge, and reduce pollutant loadings generated from a site. Runoff comes primarily from impervious surfaces, such rooftops, roadways or any hard surface that prevents water from absorbing into the ground. Traditional developments tend to include excessive impervious surfaces, which can often be reduced with thoughtful site planning. Strategies that Reduce the Impacts include the following:

- Reduction of Roadway Area – involves site design techniques where roadway lengths and widths are minimized on a development site to the extent practical to reduce overall imperviousness.
- Reduction of Sidewalk Area – is a design approach where overall sidewalk area is minimized on a development site to the extent possible to reduce overall imperviousness.

Source: R. Claytor, file photo

- Reduction of Driveway Area – employs approaches such as shared driveways that connect two or more homes together, alternative driveway surfaces, and smaller lot front building setbacks to reduce total driveway imperviousness.
- Reduction of Cul-de-Sac Area – involves approaches that minimize the number and size of cul-de-sacs and incorporates landscaped areas to reduce their impervious cover.
- Reduction of Building Footprint Area – is a strategy where residential and commercial building footprint area is reduced by using alternate or taller buildings while maintaining the same floor-to-area ratio.
- Reduction of Parking Lot Area – involves a range of strategies to reduce the overall size of parking lots, including eliminating unneeded spaces, providing some compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, utilizing multi-storied parking decks, using permeable surfaces, and reducing parking ratio requirements.

4.5.3 Manage the Impacts at the Source

After making every effort to avoid and reduce potential development impacts, the next goal is to effectively manage the remaining stormwater runoff. Techniques that manage the impacts include “disconnecting” any necessary impervious surfaces and implementing small-scale, “natural system”-based BMPs close to the source; remaining impacts are managed in accordance with the practices in Chapters Five, Six, and Seven.

Impervious surfaces that are separated from drainage collection systems by pervious surface or infiltrating BMPs contribute less runoff and reduced pollutant loading. Isolating impervious surfaces promotes infiltration and filtration of stormwater runoff. Designers and developers can receive a Stormwater Credit for disconnecting impervious areas to qualified pervious areas. The Credit Approach can be used by project applicants to meet the Recharge (Re_v) and Water Quality Volume (WQ_v) criteria instead of, or in addition to, simply installing structural BMPs. The criteria for receiving a Stormwater Credit are included in Section 4.6.

Small-scale BMPs applied at the source—or as close as practicable—can offer significant advantages over conventional, engineered facilities such as ponds or enclosed conveyances. These small-scale practices can decrease the use of typical engineering materials such as stormwater management measures that rely on pipes and large earthworks. By using materials such as native plants, soil, and gravel, these systems can be more easily integrated into the landscape and appear to be much more natural than these more engineered systems. The natural characteristics may also increase homeowner acceptance and willingness to adopt and maintain such systems. Small, distributed systems also offer a major technical advantage—one or more of the systems can fail without undermining the overall integrity of the site control strategy.

Site planning and design strategies that <u>Manage the Impacts at the Source</u> include the following:

- Disconnecting Impervious Areas – involves a series of strategies that divert runoff over pervious surfaces to foster infiltration, runoff reduction, and pollutant removal.
- Mitigation of Runoff at the Source– is a broad-based strategy involving several techniques such as bioretention, swales, infiltration, and filter strips that generally utilize surface vegetated systems to promote recharge and treatment of runoff.

Source: M. West, file photo

- Stream/Wetland Restoration – involves strategies to restore natural streams/wetlands to increase aquatic habitat and reduce sediment loading from channel erosion. Representative techniques include natural channel design based on geomorphic principles, bioengineering bank stabilization, design of habitat enhancement structures, and modifications to culverts and/or other blockages to improve flushing.
- Reforestation – is the purposeful planting of trees and shrubs in areas previously cleared of native vegetation to help restore a natural hydrologic balance and promote pollutant uptake and habitat enhancement.
- Source Control – involves techniques such as street sweeping and pet waste management. Source control techniques are described in Appendix G.

4.6 LID Stormwater Credit: Rooftop, Roadway, Driveway or Parking Lot Runoff Directed to Qualifying Pervious Areas

The LID Stormwater Credit rewards the use of LID techniques for disconnecting impervious surfaces and preserving natural hydrologic conditions. The Credit allows project applicants to reduce or eliminate the structural stormwater BMPs otherwise required to meet Re_v and WQ_v by directing stormwater runoff to qualifying pervious areas (QPAs) that provide recharge and treatment.

As more fully detailed below, the Credit may be used to reduce the required Re_v and WQ_v provided that any pervious surfaces used to treat and infiltrate stormwater runoff meet the requirements set forth herein.

The application of the Credit does not relieve the design engineer or reviewer from meeting the remaining minimum standards described in Chapter Three or the standard of engineering practice associated with safe conveyance of stormwater runoff and good drainage design.

Credit shall not be applied:

- at sites where stormwater runoff is directed to non-permeable soils, such as bedrock and soils classified as Hydrologic Soil Group (HSG) D; and
- at sites with urban fill, soils classified as contaminated, and soils with a seasonal high groundwater elevation within 18 inches of the land surface.

LUHPPLs are eligible for a Stormwater Credit provided that no runoff from the areas or activities that may generate runoff with a higher potential pollutant load is directed to a QPA, and provided further that the proposal satisfies all the other requirements set forth in this section.

QPAs are defined as natural or landscaped vegetated areas fully stabilized, with runoff characteristics at or lower than the NRCS Curve Numbers in the table set forth below. All QPAs must be shown on site plans, must have a minimum of 4 inches of topsoil or organic material, and must be located outside of regulated wetland areas and regulated buffer to a waterbody or wetland (i.e., the QPA shall not include any wetland resource areas). Excessively fertilized lawn areas are not considered a QPA; in order for lawns to be considered as QPAs, they must consist of low-maintenance grasses adapted to the New England region. Research has shown that lawn areas that are subjected to excessive fertilizer application and excessive irrigation can lead to elevated nutrient export. Property owners and managers can consult the University of Rhode Island, Cooperative Extension for more information on appropriate soil testing and fertilizer application rates for lawn areas (also refer to Appendix G).

Table 4-1 Maximum NRCS Runoff Curve Numbers for QPAs

Cover Type	HSG A	HSG B	HSG C
Natural: Woods Good Condition	30	55	70
Natural: Brush Good Condition	30	48	65
Landscaped: Good Condition (grass cover > 75% or equivalent herbaceous plants)	39	61	74

4.6.1 Stormwater Credit Description

A LID Stormwater Credit is available when rooftop, roadway, driveway, or parking lot runoff is directed to a QPA where it can either infiltrate into the soil or flow over it with sufficient time and reduced velocity to allow for adequate filtering. QPAs are generally flat locations, where the discharge is directed via sheet flow and not as a point source discharge. The credit may be obtained by grading the site to induce sheet flow over specially designed, gently sloped vegetated areas that can treat and infiltrate the runoff. This credit is available for impervious cover associated with all land uses, except for runoff from a LUHPPL.

If runoff from impervious areas is adequately directed to a QPA, the area can be deducted from total impervious area, therefore reducing the *Required* WQ_v and the size of the structural BMPs used to meet the removal requirement of Standard 3. As more fully set forth below, redirected runoff can also be used to meet the recharge requirement as a non-structural practice.

4.6.1.1 Minimum Criteria for Stormwater Credit

The LID Stormwater Credit is subject to the following restrictions:

- To prevent compaction of the soil in the QPA, construction vehicles must not be allowed to drive over the area. If it becomes compacted, the soil must be suitably amended, tilled, and re-vegetated once construction is complete to restore infiltration capacity.
- The QPA must be designed to not cause basement seepage. To prevent basement seepage, at a minimum, runoff must be directed away from the building foundation and be infiltrated at least 10 feet away from the foundation.
- The rooftop area contributing runoff to any one downspout and/or the non-rooftop impervious areas draining to any one discharge location cannot exceed 1,000 ft^2.

- The length of the QPA (in feet) shall be equal to or greater than the contributing rooftop area (in ft^2) divided by 13.3 (e.g., for 1,000 ft^2 roof/13.3 = 75 ft) and the maximum contributing flow path from non-rooftop impervious areas shall be 75 feet.
- For non-rooftop runoff, the length of the QPA must be equal to or greater than the length of the contributing impervious area.
- For roof runoff, the width of the QPA (in feet) shall be equal to or greater than the roof length. For example, if a roof section is 20 feet wide by 50 feet long (1,000 ft^2 roof), the width of the QPA shall be at least 50 feet.
- For non-roof runoff, the width of the QPA shall be no less than the width of the contributing impervious surface. For example, if a driveway is 15 feet wide, the QPA width shall be no less than 15 feet.
- Although they may abut, there shall be no overlap between QPAs. For example, the runoff from two 1,000 ft^2 sections of roof must be directed to separate QPAs. They shall not be directed to the same area.
- The lot must be greater than 6,000 ft^2.
- The slope of the QPA shall be less than or equal to 5.0%.
- Where provided, downspouts must be at least 10 feet away from the nearest impervious surface to prevent reconnection to the stormwater management system.
- Where provided, downspouts must have appropriate provisions to induce sheet flow.
- Where a gutter/downspout system is not used, the rooftop runoff must be designed to sheet flow at low velocity away from the structure housing the roof.
- QPAs should be located on relatively permeable soils (HSG “A” and “B”). A DEM-licensed Class IV soil evaluator or RI-registered PE shall also confirm that the depth to the seasonal high groundwater table is 18 inches or greater. The soil evaluation must identify the soil texture, HSG (from NRCS soil maps), and depth to the seasonal high groundwater table.
- If a QPA is located in less permeable soils (HSG “C”), the water table depth and soil texture shall be evaluated by a DEM-licensed Class IV soil evaluator or RI-registered PE to determine if a level spreading device is needed to sheet flow stormwater over vegetated surfaces (See Appendix H).
- Runoff from driveways, roadways, and parking lots may be directed over soft shoulders, through curb cuts, or level spreaders to QPAs. Measures must be employed at the discharge point to the QPA to prevent erosion and promote sheet flow.
- The flow path through the QPA should comply with the setbacks established for structural infiltration BMPs. See Table 5-2.

- To take credit for rooftop disconnection associated with a LUHPPL, the rooftop runoff must not commingle with runoff from any paved surfaces or activities or areas on the site that may generate higher pollutant loads.
- The Operation and Maintenance Plan required by Minimum Standard 11 must include measures to inspect the QPA at least yearly to remove any deposited sediment (e.g., sand from winter sanding operations), address any ponding, erosion, and replant any vegetation that has died.
- The QPA must be owned or controlled (e.g., drainage easement) by the property owner.
- In locations where there is a history of groundwater seepage and/or basement flooding, the credit shall not be utilized.

The impervious areas contributing runoff to the QPA can be deducted from the impervious surfaces used to calculate the WQ_v, and can meet the Re_v requirement if enough area is disconnected in accordance with the Percent Area Method, described as follows.

4.6.1.2 Percent Area Method

The amount of impervious area that needs to be disconnected to meet the recharge requirement is referred to as the recharge area (Re_a). It is equivalent to the recharge volume but can be achieved by filtration of sheet flow over a QPA. Re_a is calculated according to the equation below:

$Re_a = (F)\ (I)$

Re_a = Required impervious area to be directed to a QPA (acres)
F = Recharge factor based on HSG (dimensionless)
I = Impervious area (acres)

Recharge Factors Based on HSG (from Table 3-4)

HSG	Recharge Factor (F)
A	0.60
B	0.35
C	0.25
D	0.10

If only a portion of the Re_a can be directed to a QPA due to site constraints, a designer must use a structural BMP to recharge the difference. This amount can be determined by the following approach:

- Calculate both the Re_v and Re_a for the site;
- The site impervious area draining to a QPA is subtracted from the Re_a calculation from Credit Step 1, above;

- The remaining Re_a is divided by the original Re_a to calculate a pro-rated percentage that must be directed to structural infiltration BMPs;
- The pro-rated percentage is multiplied by the original Re_v to calculate a new Re_v that must be met by an approved structural practice(s).

4.6.1.3 LID Stormwater Credit - Rooftop Runoff Example

Given the following base data:

- Site Data: 108 Single-Family Residential Lots (~ ½-acre lots)
- Site Area = 45.1 ac
- Original Impervious Area, I = 12.0 ac
- Site drainage flows to one design point[1]
- Site Soils Types: 78% "B", 22% "C"
- Composite Recharge Factor, F = (% HSG B)(0.35) + (% HSG C)(0.25)

  $F = 0.78\ (0.35) + 0.22\ (0.25) = 0.328$
- Original Required Recharge Volume, Re_v = (1") (F) (I)/12

  Re_v = [(1")(0.328)(12.0 ac)]/12 = 0.33 ac ft
- Recharge Area Requiring Treatment, Re_a = (F) (I)

  Re_a = (0.328)(12.0 ac) = 3.94 ac
- Original Required Water Quality Volume, WQ_v = (1") (I) / 12

  WQ_v = [(1.0 in) (12.0 ac)]/12 = 1.0 ac-ft

Rooftop Credit:

42 houses disconnected

Average house area = 2,500 ft^2

Net impervious area disconnected = (# of houses)(average house area, ft^2) / (43,560 ft^2/ac)

Net impervious area disconnected = (42)(2,500 ft^2) / (43,560 ft^2/ac) = 2.41 acres

New impervious area = (Impervious area) – (Net impervious area disconnected)

New impervious area = 12.0 – 2.41 = 9.59 acres;

Re_a is 3.94 acres and 2.41 acres were disconnected; therefore, 1.53 acres of impervious cover need to be met by an approved structural practice.

New Required Recharge Volume, New Re_v = (I / Re_a)(Original Re_v)

[1] If site consists of more than one drainage area with multiple discharge locations, the credit calculations would need to be performed for each drainage area.

New Re_v = (1.53/3.94)(0.33 ac-ft) = 0.128 ac-ft

New Required Water Quality Volume, New WQ_v = (1”) (New impervious area) / 12

New WQ_v = 1.0” (9.59)/12 = 0.80 acre-feet; or a 0.20 acre-foot reduction

Percent Reductions Using Rooftop Disconnection Credit:

Required Re_v = (Original Re_v - New Re_v) / (Original Re_v)

Required Re_v = (0.33-0.128)/0.33 = 0.612 = 61.2% Reduction

Required WQ_v = (Original WQ_v - New WQ_v) / (Original WQ_v)

Required WQ_v = (1.0 – 0.8) /1.0 = 0.20 = 20.0% Reduction

5.0 STRUCTURAL STORMWATER TREATMENT PRACTICES FOR MEETING WATER QUALITY CRITERIA

This chapter outlines the five groups of acceptable structural BMPs that can be used to meet the water quality criteria outlined in Chapter Three and presents specific design criteria and guidelines for their design. The five groups of structural BMPs include the following: (1) Wet Vegetated Treatment Systems, (2) Infiltration Practices, (3) Filtering Systems, (4) Green Roofs, and (5) Open Channel Practices. The figures and photographs included in this chapter are schematic graphics only. Design plans should be consistent with the schematic figures when using the method or practice described, but must be completely detailed by the designer for site-specific conditions and construction purposes. Detailed guidance on construction specifications are provided in Appendix F for the BMPs in this chapter. Note: Sediment volumes do NOT need to be calculated for sizing of the BMPs in this chapter.

5.1 MINIMUM DESIGN CRITERIA FOR BMPS

This section presents two types of criteria for the BMPs listed above—required design elements and design guidelines. Required design elements are features that shall be used in all applications. If required design criteria for a particular BMP cannot be met at a site, an alternative BMP must be selected, or adequate justification must be provided to the approving agency why the particular criteria is not practicable. Design guidelines are features that enhance practice performance, and are therefore optional and might not be necessary for all applications. Design requirements and guidelines are provided for the following six categories:

Feasibility: Identify site considerations that may restrict the use of a practice.

Conveyance: Convey runoff to the practice in a manner that is safe, minimizes erosion and disruption to natural channels, and promotes filtering and infiltration.

Pretreatment: Trap coarse elements before they enter the facility, thus reducing the maintenance burden and ensuring a long-lived practice.

Treatment/Geometry: Provide the required water quality treatment through design elements that provide the maximum pollutant removal.

Environmental/Vegetation: Reduce secondary environmental impacts of facilities through features that minimize disturbance of natural stream systems and comply with environmental regulations. Provide vegetation that enhances the pollutant removal and aesthetic value of the practice.

Maintenance: Maintain the long-term performance of the practice through regular maintenance activities, and through design elements that ease the maintenance burden.

Table 5-1 List of BMPs Acceptable for Water Quality

Group	Practice	Description
Wet Vegetated Treatment Systems (WVTS)	Shallow WVTS	A surface wet stormwater basin that provides water quality treatment primarily in a shallow vegetated permanent pool.
	Gravel WVTS	A wet stormwater basin that provides water quality treatment primarily in a wet gravel bed with emergent vegetation.
Infiltration	Infiltration Trenches/Chambers/ Dry Wells	An infiltration practice that stores the water quality volume in the void spaces of a trench or open chamber filled with or embedded in clean gravel before it is infiltrated into underlying soils.[1]
	Infiltration Basin	An infiltration practice that stores the water quality volume in a shallow surface depression before it is infiltrated into the underlying soils.[1]
	Permeable Paving	A practice that stores the water quality volume in the void spaces of a clean sand or gravel base before it is infiltrated into the underlying soils.[1]
Filtering Practices	Sand Filter	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then by filtering stormwater through a surface or underground sand matrix.
	Organic Filter	A filtering practice that uses an organic medium such as compost in the filter, or incorporates organic material in addition to sand (e.g., peat/sand mixture).
	Bioretention	A shallow depression that treats stormwater as it flows through a soil matrix, and is returned to the storm drain system, or infiltrated into underlying soils or substratum.
Green Roofs	Extensive	Rooftop vegetated with low, drought-tolerant plant species and a shallow planting media designed for performance. Not typically designed for public access.
	Intensive	Rooftop vegetated with trees and shrubs with a deeper planting soil and walkways, typically designed for both performance and public access.
Open Channels	Dry Swale	An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix.
	Wet Swale	An open vegetated channel or depression designed to retain water or intercept groundwater for water quality treatment.

[1] The bottom of infiltration practices must be in the natural soil profile, i.e., shall not be located in bedrock. Where a TMDL or CRMC goal requires maximum treatment of runoff, the bottom of infiltration practices shall be within the uppermost soil horizons (A or B) or another BMP would be required.

5.2 WET VEGETATED TREATMENT SYSTEMS (WVTS)

Source: HW file photo

Description: Shallow WVTS designs are practices that have a permanent pool equivalent to the entire WQ_v and provide treatment via settling and plant/soil treatment processes. Gravel WVTS designs maintain a saturated gravel bed and provide treatment by stormwater movement through the gravel bed and plant/soil treatment processes.

KEY CONSIDERATIONS

FEASIBILITY

- Additional restrictions apply in cold-water fishery watershed based on distance from discharge point to streams (and any contiguous wetlands).

PRETREATMENT

- Sediment forebay at inlet, capturing 10% of the WQ_v

TREATMENT

For a Shallow WVTS:

- Surface area must be minimum of 1.5% of drainage area.
- 35% of the total surface area in depths 6 inches or less, and 65% of the total surface area shallower than 18 inches.
- At least 10% of the WQ_v shall be provided in a sediment forebay or other pretreatment practice, and 25% of the WQ_v in deepwater zones. The remaining 65% of the WQ_v shall be provided in some combination of shallow permanent pool and ED. ED storage volume shall not exceed 50% of the WQ_v and shall drain over 24 hours.

For a Gravel WVTS:

- Surface area must be minimum of 0.35% of drainage area.
- At least 10% of the WQ_v shall be provided in a sediment forebay or other pretreatment practice. The remaining 90% of the WQ_v may be provided in some combination of one or more basins filled with gravel and ED storage above the gravel. ED storage volume shall not exceed 50% of the WQ_v and shall drain over 24 hours.
- Maintain substrate in saturated condition.

STORMWATER MANAGEMENT SUITABILITY

- [x] Water Quality
- [ ] Recharge
- [x] Channel Protection
- [x] Overbank Flood Control

Accepts LUHPPL Runoff: *Yes*

(3 feet of separation distance required to water table)

IMPLEMENTATION CONSIDERATIONS

M Capital Cost

Maintenance Burden:

M Shallow WVTS

M Gravel WVTS

Residential Subdivision Use: Yes

High-Density/Ultra-Urban: *No*

Drainage Area: *Shallow WVTS-10 acres min. and Gravel WVTS-5 acres min., unless intercepting groundwater*

Soils: *Highly permeable soils/karst geology may require liner*

Key : L=Low M=Moderate H=High

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GEOMETRY

- For a Shallow WVTS: Minimum flowpath of 2:1 (length to width).
- For a Gravel WVTS: Minimum flowpath of 1:1 (L:W) for each treatment cell with a minimum flow path (L) within the gravel substrate of 15 ft.

VEGETATION

- Planting plan that indicates methods to establish and maintain coverage. Minimum elements include: delineation of pondscaping zones, selection of species, planting plan, and sequence for planting bed preparation.
- WVTS setback 25 ft from maximum surface elevation.
- Donor plant material must not be from natural wetlands.

MAINTENANCE REQUIREMENTS

- Operation and Maintenance Plan to specify reinforcement plantings after second season if 50% coverage not achieved
- A maintenance right of way or easement shall extend to a WVTS from a public or private road.

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POLLUTANT REMOVAL

G	Phosphorus
G	Nitrogen
F	Metals - Cadmium, Copper, Lead, and Zinc removal
G	Pathogens - Coliform, Streptococci, E. coli removal

Key: G=Good F=Fair P=Poor

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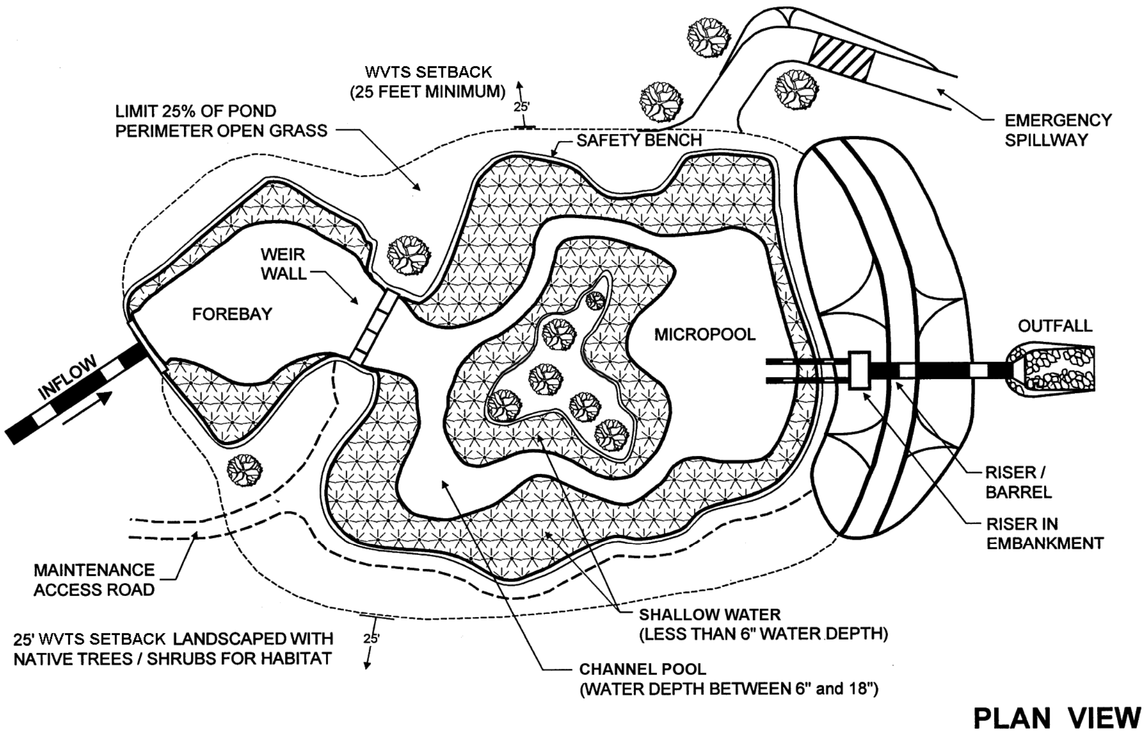
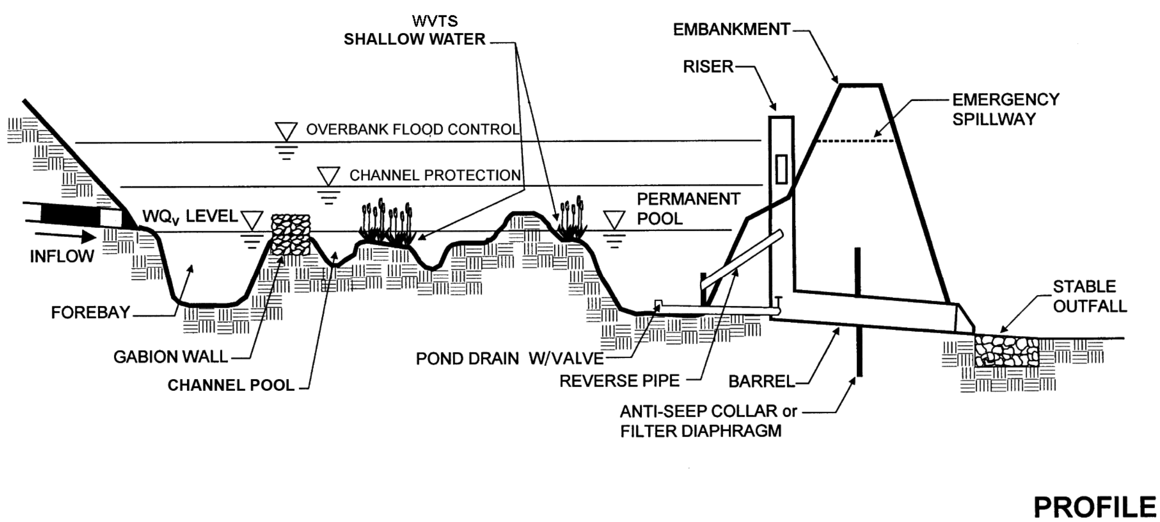
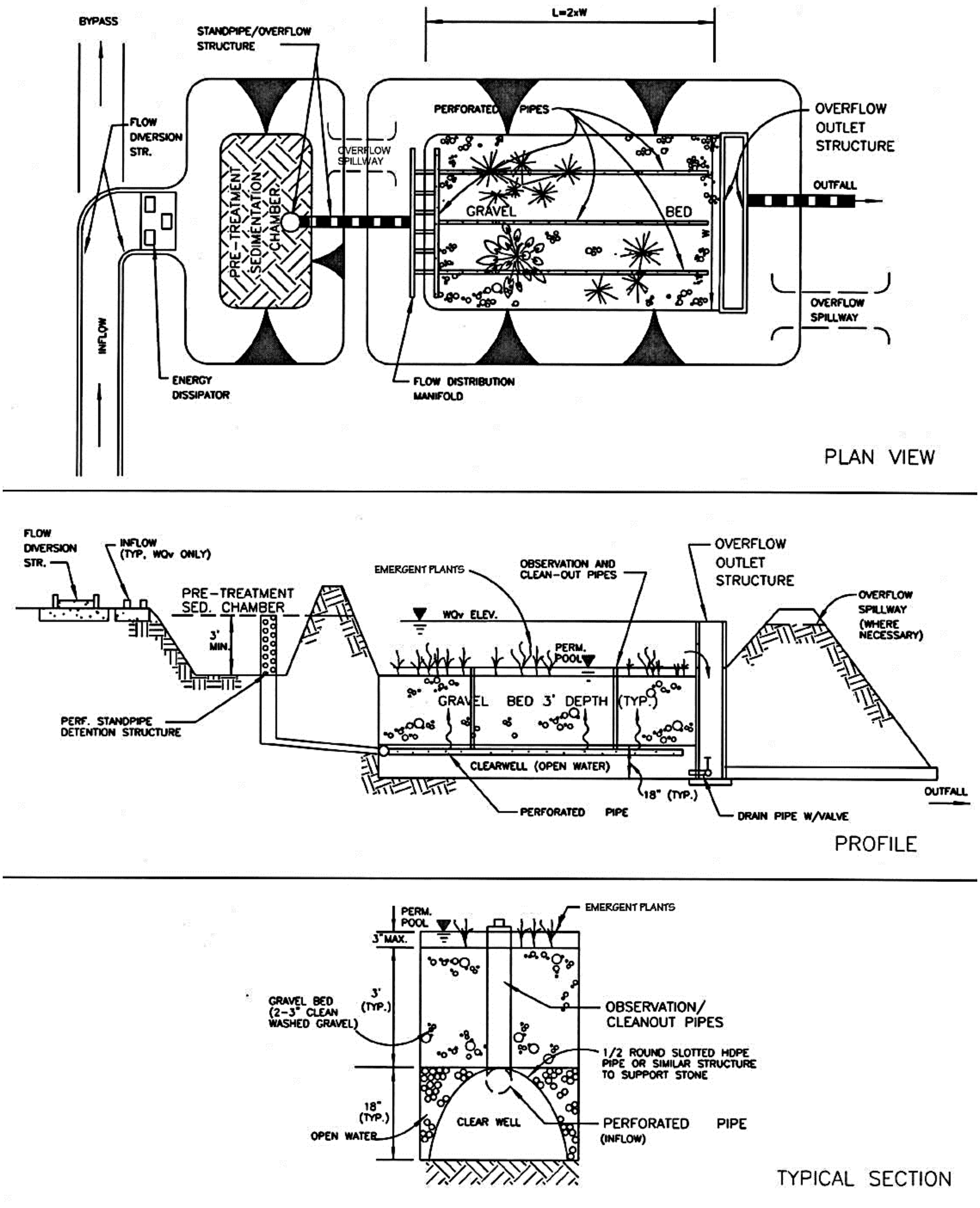
Figure 5-1 Shallow WVTS





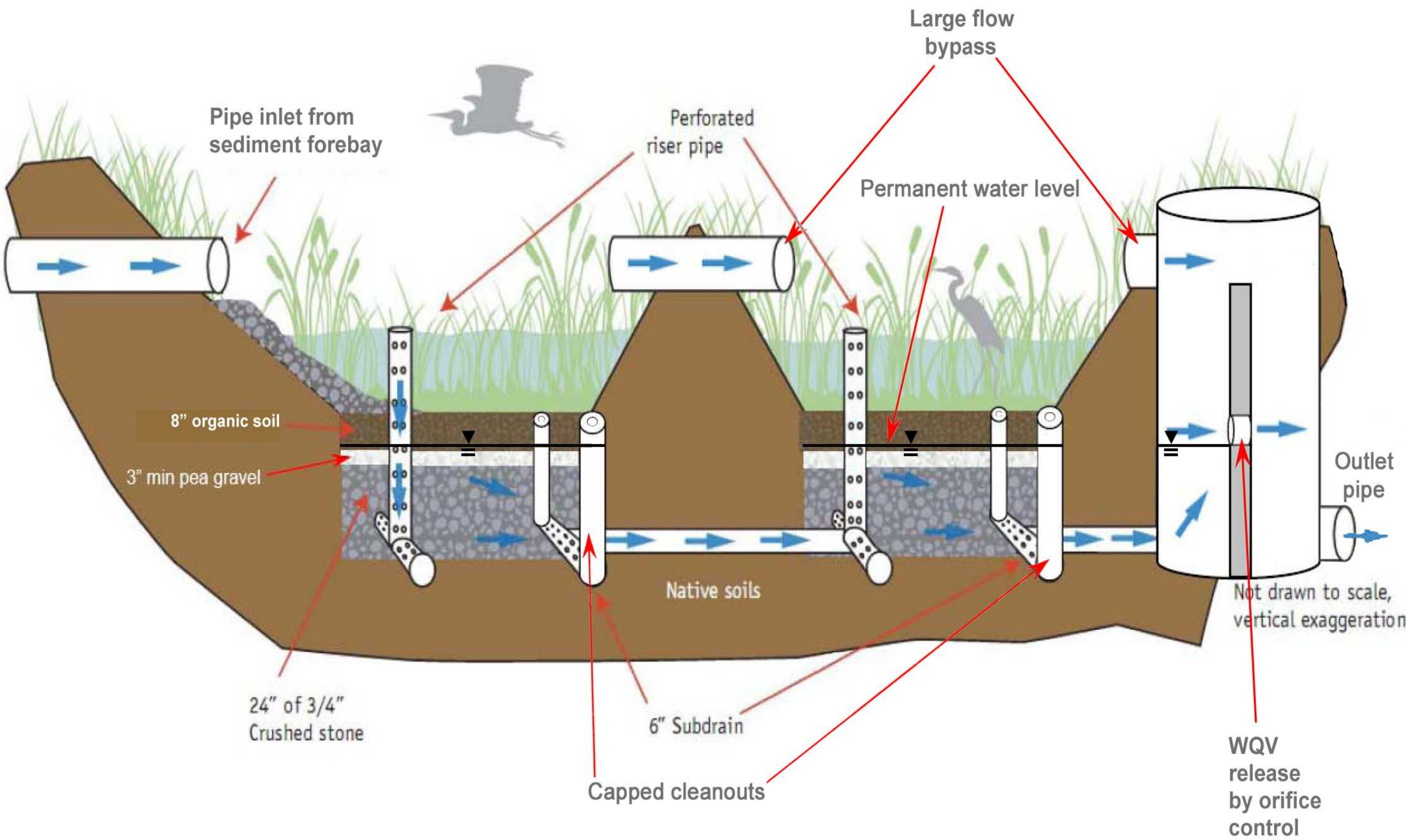
Adapted from MDE, 2000

Figure 5-2 Gravel WVTS – Alternative 1



Adapted from VTANR, 2002

Figure 5-3 Gravel WVTS – Alternative 2



Adapted from UNHSC, 2009

5.2.1 Feasibility

Required Elements

- WVTS designs shall not be located within jurisdictional waters, including wetlands; except that on already developed sites, WTVS designs may be allowed in jurisdictional upland buffers in areas already altered under existing conditions, if acceptable to the approving agency.
- WVTS designs shall not be located within stream channels, to prevent habitat degradation caused by these structures.
- Assess the hazard classification[1] of the structure and consider alternative placement and/or design refinements to reduce or eliminate the potential for designation as a significant or high hazard dam.
- The use of WVTS designs in watersheds draining to cold-water fisheries is restricted to prohibit discharges within 200 feet of streams and any contiguous natural or vegetated wetlands. Discharges beyond 200 feet shall be designed to discharge up to and including the CP_v through an underdrained gravel trench outlet, as depicted in Figure 5-4. Additional storage for Q_p may be discharged through traditional outlet structures.
- WVTS designs specified to manage LUHPPL runoff require a 3-foot separation to groundwater. All other land uses do not require groundwater separation.
- The volume below the surface elevation of the permanent pool shall not be included in storage calculations for peak flow management (CP_v/Q_p).
- Setbacks for WVTS designs from OWTSs shall be consistent with the setbacks in DEM's Onsite Wastewater Treatment System Rules.

Design Guidance

- Generally, shallow WVTS designs require a minimum drainage area of 10 acres to maintain a permanent pool, unless the practice intercepts groundwater. Likewise, a gravel WVTS design generally requires a minimum drainage area of 5 acres unless the practice intercepts groundwater.

5.2.2 Conveyance

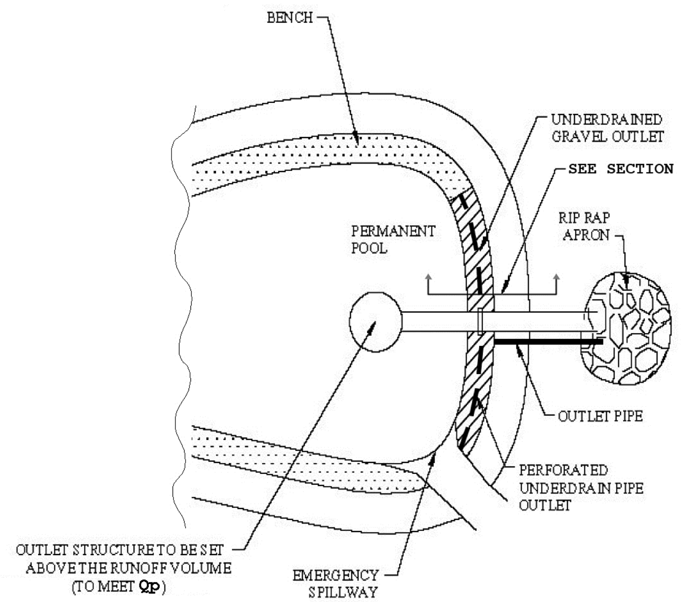
Inlet Protection

Required Elements

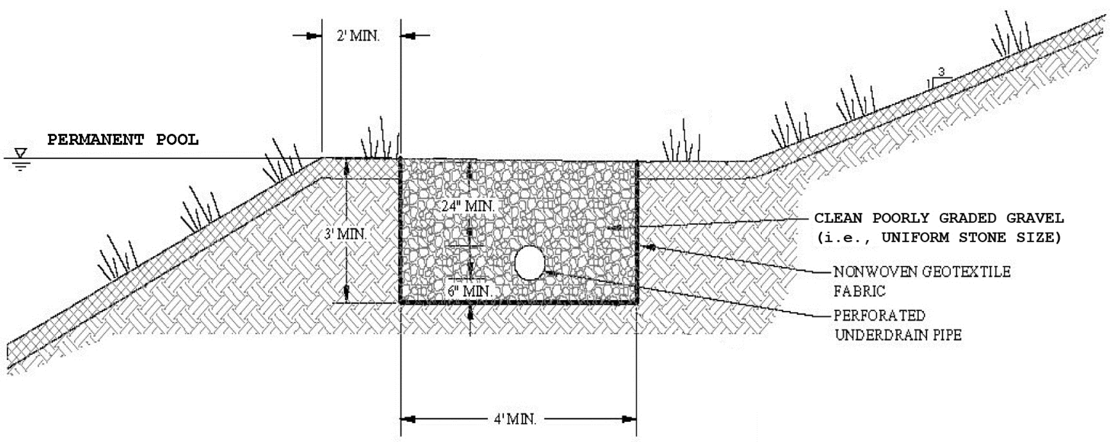
- Flow paths from the inflow points to the outflow points of WVTS shall be maximized through the use of BMP geometry and features such as berms and islands.

[1] "Hazard classification" is a rating for a dam that relates to the probable consequences of failure or misoperation based on an assessment of loss of human life and damages to properties or structures located downstream of an impoundment. A proposal to construct an impoundment having a dam 6 feet in height or more, or a capacity of 15 acre-feet or more, or that is a significant or high hazard dam may subject the applicant to additional requirements in accordance with the RIDEM Dam Safety Program and the State's Dam Safety Regulations.

Figure 5-4 (A) Generalized Plan View of Underdrained Gravel Trench Outlet for a WVTS or Basin (B) Profile of Underdrained Gravel Trench



A



B

Adapted from Maine Stormwater Manual (2006)

Design Guidance

- Inlet areas should be stabilized to ensure that non-erosive conditions exist for at least the 1-year frequency storm event.
- For a Shallow WVTS, inlet pipes should be set at the permanent pool or slightly above to limit erosive conditions. For a Gravel WVTS, inlet pipes may be set at the

permanent pool or at the base of the gravel bed.

- A Gravel WVTS designed with an organic soil layer at the surface should have vertical perforated riser pipes that deliver stormwater from the surface down to the subsurface perforated distribution lines. These risers shall have a maximum spacing of 15 feet. Oversizing of the perforated vertical risers is useful to allow a margin of safety against clogging with a minimum recommended diameter of 12” for the central riser and 6” for end risers (see Figure 5-3). The vertical risers shall not be capped, but rather covered with an inlet grate to allow for an overflow when the water level exceeds the WQ_v.

Adequate Outfall Protection

<u>Required Elements</u>

- The channel immediately below a WVTS outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance, typically by use of appropriately sized riprap placed over filter cloth.
- A stilling basin or outlet protection shall be used to reduce flow velocities from the principal spillway to non-erosive velocities (3.5 to 5.0 fps).
- A subsurface water level must be maintained in the Gravel WVTS through the design of the outlet elevation (invert just below the surface). Care should be taken to not design a siphon that would drain the WVTS: the outlet invert location must be open or vented.
- For discharges beyond 200 ft from streams (and any contiguous natural or vegetated wetlands) in cold-water fisheries, the underdrained gravel trench shall be designed to meet the following requirements:
  - Shall be sized to release the CP_v over at least 12 hours and not more than 24 hours to provide adequate cooling of stormwater runoff discharging from the WVTS;
  - Shall be four feet wide, located at least 2 feet from the WVTS permanent pool, and located at the furthest location opposite from the principal inflow location to the facility;
  - The trench shall have a length of 3 feet per 1,000 ft^3 of CP_v storage volume, have a depth of at least 3 feet, and maintain 2 feet of gravel cover over a 6-inch diameter perforated pipe outlet (Rigid Sch. 40 PVC or SDR35);
  - Shall utilize geotextile fabric placed between the gravel trench and adjacent soil; and
  - Shall utilize clean poorly-graded gravel (i.e., uniform stone size - refer to Figure 5-4).

<u>Design Guidance</u>

- Outfalls should be constructed such that they do not increase erosion or have undue influence on the downstream geomorphology of any natural watercourse by discharging at or near the stream water surface elevation or into an energy dissipating step-pool arrangement.

- If a WVTS discharges to a watercourse with dry weather flow (baseflow), care should be taken to minimize tree clearing along the downstream channel, and to re-establish a forested riparian zone in the shortest possible distance.
- The Gravel WVTS outlet structure should be based on a calculated release rate by orifice control to drain the WQ_v over 24 hrs. The practice may also have an additional orifice for draining the CP_v over 24 hours.

WVTS Liners

Required Elements

- When a WVTS is located in medium to coarse sands and above the average groundwater table, a liner shall be used to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner (soils with an infiltration rate of 0.05 in/hr or greater), acceptable options include: (a) 6 to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1×10^{-5} cm/sec), (b) a 30 mil poly-liner, (c) bentonite, or (d) use of chemical additives.

Design Guidance

- No-geotextile fabrics are necessary within a WVTS, but may be used to line walls of a Gravel WVTS.

5.2.3 Pretreatment

Sediment Forebay

Required Elements

- A sediment forebay is important for maintenance and longevity of a WVTS. Each WVTS shall have a sediment forebay or equivalent upstream pretreatment (see Chapter Six for design requirements and guidance for pretreatment BMPs). The forebay shall consist of a separate cell, formed by an acceptable barrier. Typical examples include earthen berms, concrete weirs, and gabion baskets.
- The forebay shall be sized to contain a minimum of 10% of the WQ_v, and shall be at least three feet deep. The forebay storage volume counts toward the total WQ_v requirement.
- A forebay shall be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the WVTS.
- The forebay shall be designed with non-erosive outlet conditions.
- Direct access for appropriate maintenance equipment shall be provided to the forebay.

Design Guidance

- A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.

- The bottom of the forebay may be hardened (i.e., concrete, asphalt, grouted riprap) to make sediment removal easier.

5.2.4 Treatment

Minimum Water Quality Volume (WQ_v)

Required Elements

- The surface area of a Shallow WVTS shall be at least 1.5% of the contributing drainage area; the gravel WVTS surface area shall be at least 0.35% of contributing drainage area.
- For a Shallow WVTS: A minimum of 35% of the total surface area shall have a depth of 6 inches or less, and at least 65% of the total surface area shall be shallower than 18 inches. At least 10% of the WQ_v shall be provided in a sediment forebay or other pretreatment practice, and at least 25% of the WQ_v shall be provided in "deep water zones" with a depth equal to or greater than 4 feet. The remaining 65% of the WQ_v shall be provided in some combination of shallow permanent pool (depth less than 4 feet) and the extended detention (ED) storage volume above the permanent pool, as applicable. ED storage volume shall not exceed 50% of the WQ_v and shall drain over 24 hours.
- For a Gravel WVTS: At least 10% of the WQ_v shall be provided in a sediment forebay or other pretreatment practice. The remaining 90% of the WQ_v shall be provided in some combination of one or more basins or chambers filled with a minimum 24-inch gravel layer and the open, ED storage volume above the gravel, as applicable. ED storage volume shall not exceed 50% of the WQ_v and shall drain over 24 hours.

Design Guidance

- It is generally desirable to provide water quality treatment off-line when topography, head, and space permit.
- Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and emergent vegetation).
- For Gravel WVTS, a layer of organic soil may be used as substrate for emergent vegetation, but is not necessary depending on chosen species. If an organic soil layer is used as a top layer, it should have a minimum thickness of 8", should be leveled (constructed with a surface slope of zero), and should be underlain by 3" minimum thickness of an intermediate layer of a graded aggregate filter to prevent the organic soil from moving down into the gravel sublayer. The organic soil shall meet the material specifications in Appendix F.

Minimum WVTS Geometry

Required Elements

- Flow paths from the inflow points to the outflow points of WVTS shall be maximized through the use of BMP geometry and features such as berms and islands. The minimum length to width ratio for a Shallow WVTS is 2:1 (i.e., length relative to width).

- For a Gravel WVTS: length to width ratio of 1:1 (L:W) or greater is needed for each treatment cell with a minimum flow path (L) within the gravel substrate of 15 feet.

Design Guidance

- The bed of a WVTS should be graded to create maximum internal flow path and microtopography. Microtopography (complex contours along the bottom of the WVTS, providing greater depth variation) is encouraged to enhance habitat diversity.
- For a Shallow WVTS: To the greatest extent possible, maintain a long flow path through the system, and design with irregular shapes. A more traditionally shaped (oval or rectangular) basin may be permitted when conditions such as topography, parcel size, or other site conditions warrant. Basins shall follow natural landforms to the greatest extent possible or be shaped to mimic a naturally formed depression.

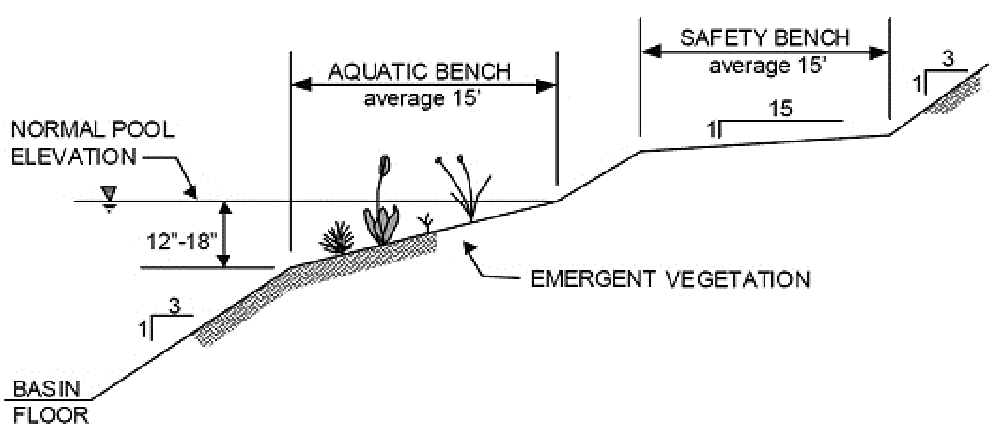
5.2.5 Vegetation

Shallow WVTS Benches

Required Elements

- The perimeter of all deep pool areas (four feet or greater in depth) shall be surrounded by two benches as follows:
  - Except when side slopes are 4:1 (h:v) or flatter, provide a safety bench that generally extends 15 ft outward (a 10ft minimum bench is allowable on sites with extreme space limitations at the discretion of the approving agency) from the normal water edge to the toe of the WVTS side slope. The maximum slope of the safety bench shall be 6%; *and*
  - Incorporate an aquatic bench that generally extends up to 15 feet inward from the normal edge of water, has an irregular configuration, and a maximum depth of 18 inches below the normal pool water surface elevation.

Figure 5-5 Typical Shallow WVTS Geometry Criteria (ARC, 2001)



Planting Plan

Required Elements

- A planting plan for a WVTS and its setback shall be prepared to indicate how aquatic and terrestrial areas will be stabilized and established with vegetation. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, plant locations, sequence for preparing WVTS bed (including soil amendments, if needed), and sources of plant material.
- Donor soils for WVTS mulch shall not be removed from natural wetlands.

Design Guidance

- The best elevations for establishing emergent plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.
- The soils of a WVTS setback are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration, and therefore, may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and backfill these with uncompacted topsoil.
- A Gravel WVTS should be planted to achieve a rigorous root mat with grasses, forbs, and shrubs with obligate and facultative wet species.
- Planting holes should be the same depth as the root ball and two to three times wider than the diameter of the root ball. In addition, the root ball of container-grown stock should be gently loosened or scored along the outside layer or roots to stimulate new root development. This practice should enable the stock to develop unconfined root systems. Avoid species that require full shade or are prone to wind damage. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds (Save the Bay, 1999).
- Structures such as fascines, coconut rolls, or carefully designed stone weirs can be used to create shallow cells in high-energy flow areas of the WVTS.

WVTS Setbacks

Required Elements

- A WVTS setback shall be provided that extends 25 feet outward from the maximum design water surface elevation of the WVTS.
- Woody vegetation shall not be planted or allowed to grow on a dam, or within 15 feet of a dam or toe of the embankment, or within 25 feet of a principal spillway outlet.

Design Guidance

- An additional setback (greater than 25 feet outward from the maximum design water surface elevation of the WVTS) may be provided to permanent structures.

- Existing trees should be preserved in the setback area during construction. It is desirable to locate forest conservation areas adjacent to a WVTS. To help encourage reforestation and discourage resident geese populations, the setback can be planted with trees, shrubs and native ground covers.
- Annual mowing of the WVTS setback is only required along maintenance rights-of-way and the embankment. The remaining setback can be managed as a meadow (mowing every other year) or forest.

5.2.6 Maintenance

Required Elements

- Maintenance responsibility for a WVTS and its setback shall be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.
- General inspections shall be conducted on an annual basis and after storm events greater than or equal to the 1-year, 24-hour Type III precipitation event.
- The principal spillway shall be equipped with a removable trash rack, and generally accessible from dry land. See the maintenance checklist in Appendix E for more detail on maintaining trash racks.
- A maintenance and operation plan must specify that sediment removal in the forebay shall occur every 5 years or after 50% of total forebay capacity has been lost, whichever occurs first.
- An operation and maintenance plan shall specify that if a minimum vegetative coverage of 50% is not achieved in the planted areas after the second growing season, a reinforcement planting is required.
- Sediment and organic build-up shall be removed from a Gravel WVTS every 2 years, as needed.
- In a Gravel WVTS, vertical cleanouts must be constructed that are connected to the distribution and collection subdrains at each end.
- For discharges beyond 200 ft from streams (and any contiguous natural or vegetated wetlands) in cold-water fisheries, the gravel trench outlet shall be inspected after every storm in the first 3 months of operation to ensure proper function. Thereafter, the trench shall be inspected at least once annually. Inspection shall consist of verifying that the WVTS is draining to the permanent pool elevation within the 24-hour design requirement and that potentially clogging material, such as accumulation of decaying leaves or debris, does not prevent the discharge through the gravel. When clogging occurs, at least the top 8 inches of gravel shall be replaced over with new material. Sediments shall be disposed of in an acceptable manner.

Design Guidance

- Areas with a permanent pool should be inspected on an annual basis. The maintenance objectives for these practices include preserving the hydraulic and removal efficiency of the WVTS and maintaining the structural integrity.

- Sediments excavated from a WVTS that do not receive runoff from designated LUHPPL are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be required prior to sediment disposal when a LUHPPL is present. Sediment removed from forebays shall be treated similarly to street sweepings as provided in Appendix G.4.1.
- Sediment removed from a WVTS should be disposed of according to an approved comprehensive operation and maintenance plan.
- The slopes of the basin or WVTS should be inspected for erosion and gullying. Reinforce existing riprap if riprap is found to be deficient, erosion is present at the outfalls of any control structures, or the existing riprap has been compromised. Re-vegetate slopes as necessary for stabilization.
- All structural components, which include, but are not limited to, trash racks, access gates, valves, pipes, weir walls, orifice structures, and spillway structures, should be inspected and any deficiencies should be reported. This includes a visual inspection of all stormwater control structures for damage and/or accumulation of sediment.
- All dead or dying vegetation within the extents of the WVTS should be removed, as well as all herbaceous vegetation rootstock when overcrowding is observed and any vegetation that has a negative impact on stormwater flowage through the facility. Any invasive vegetation encroaching upon the perimeter of the facility should be pruned or removed if it is prohibiting access, compromising sight visibility and/or compromising original design vegetation.

Maintenance Access

Required Elements

- A maintenance right of way or easement shall extend to a WVTS from a public or private road.

Design Guidance

- Maintenance access should be at least 10 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access should extend to the forebay(s), safety bench, emergency spillway, outlet control structure, and outlet and be designed to allow vehicles to turn around.
- The grass around the perimeter of the WVTS should be mowed at least 4 times annually.

Non-clogging Low-flow Orifice/Weir

Required Elements

- A low-flow orifice or weir shall be provided when a WVTS is sized for the CP_v. The low-flow orifice or weir shall be designed to ensure that no clogging shall occur.

Design Guidance

- The low-flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3") or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice of 1"). See Appendix H for sample schematics of low-flow orifice protection alternatives.
- The preferred method is a submerged reverse-slope pipe that extends downward from the outlet control structure to an inflow point one foot below the normal pool elevation (see Figure 5-1 for schematic profile).
- Alternative methods are to employ a broad-crested rectangular, V-notch, or proportional weir, protected by a half-round pipe or "hood" that extends at least 12 inches below the normal pool.
- The use of horizontally extended perforated pipe protected by geotextile fabric and gravel is not recommended. Vertical pipes may be used as an alternative where a permanent pool of sufficient depth is present.

Outlet Control Structure in Embankment

Required Elements

- The outlet control structure shall be located within the embankment for maintenance access, safety and aesthetics.

Design Guidance

- Access to the outlet control structure should be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening should be "fenced" with pipe or rebar at 8-inch intervals (for safety purposes).

WVTS Drain

Required Elements

- Except where local slopes (e.g., coastal areas) prohibit this design, each WVTS shall have a drain pipe that can completely or partially drain the practice. The drain pipe shall have an elbow or protected intake within the WVTS to prevent sediment deposition, and a diameter capable of draining the permanent pool within 24 hours.
- Access to the drain pipe shall be secured by a lockable structure to prevent vandalism and/or accidental draining of the pond, which could pose a safety hazard due to high drainage velocities.

Safety Features

Required Elements

- Proposed graded side slopes to the WVTS shall not exceed 3:1 (h:v), and shall terminate on the safety bench.
- The principal spillway opening shall not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent a hazard.
- “Token” or emergency spillways (those placed above the water elevation of the largest managed storm) are required if not already provided as part of the conveyance of the 100-year storm event and must be a minimum 8 ft wide, 1 ft deep, with 2:1 channel side slopes.

Design Guidance

- Both the safety bench and the aquatic bench may be landscaped to prevent access to the permanent pool.
- Warning signs prohibiting swimming and skating may be posted.
- Fencing is generally not encouraged, but may be required by some owners and/or agencies. A preferred method is to manage the contours of the WVTS to eliminate dropoffs or other safety hazards.

5.3 STORMWATER INFILTRATION PRACTICES

Source: Schueler File Photo

Description: Stormwater infiltration practices capture and temporarily store the WQ_v before allowing it to infiltrate into the soil over a maximum period of 48 hours. Design variants include Infiltration Basins, Infiltration Trenches, Sub-surface Chambers, and Dry Wells.

KEY CONSIDERATIONS

FEASIBILITY

- Minimum soil infiltration rate of 0.5 inches per hour.
- Soils less than 20% clay and 60% silt.
- Natural slope less than 15%.
- Cannot accept LUHPPL runoff.
- Separation from seasonal high groundwater table and bedrock of at least 3 feet except for strictly residential land uses, for which it may be reduced to 2 feet.

CONVEYANCE

- Flows exiting the practice through vegetation must be non-erosive (3.5 to 5.0 ft/sec).
- Maximum dewatering time of 48 hours.
- Design off-line if stormwater is conveyed to the practice by a storm drain pipe.

PRETREATMENT

- Pretreatment of 25% of the WQ_v at all sites.
- Exit velocities from pretreatment through vegetation must be non-erosive for the 1-year storm.

TREATMENT

- 100% water quality treatment by a separate BMP in areas with in-situ infiltration rates >8.3 inches/hour.
- Water quality volume designed to exfiltrate through the floor of the practice in soil horizons (not through bedrock).
- Construction sequence to maximize practice life.

VEGETATION

- Upstream area shall be completely stabilized before flow is directed to the practice.

STORMWATER MANAGEMENT SUITABILITY

☑ Recharge
☑ Water Quality
☑ Channel Protection*
☑ Overbank Flood Control*

* Generally applies only to infiltration basin

Accepts LUHPPL Runoff: *No*

IMPLEMENTATION CONSIDERATIONS

H Capital Cost
H Maintenance Burden

Residential/Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *Basins -10 acres max, chambers/trenches – 5 acres max, drywells – 1 acre max*

Soils: *Pervious soils required (0.5 in/hr or greater)*

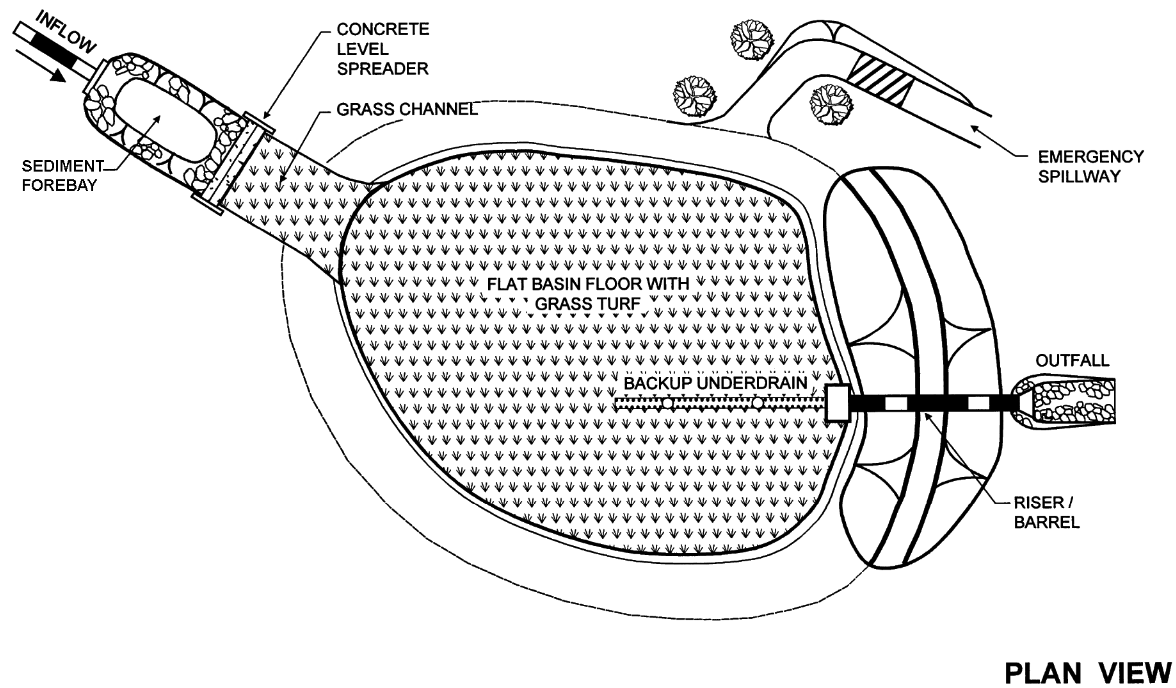
Other Considerations:

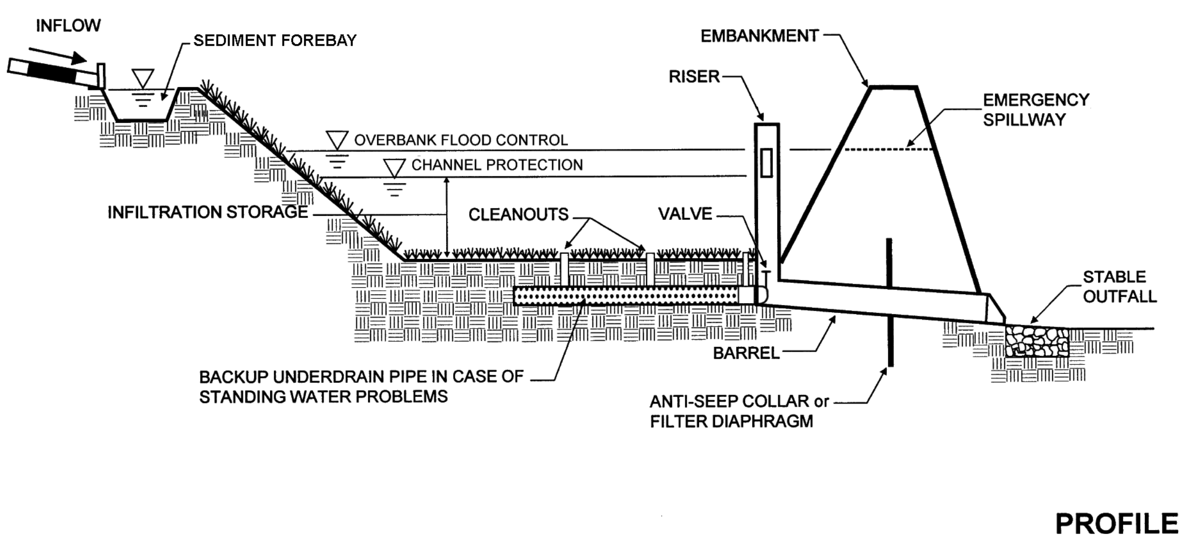
- *Ideally not placed under pavement or concrete for easy maintenance*

Key: L=Low M=Moderate H=High

MAINTENANCE REQUIREMENTS	POLLUTANT REMOVAL
• Legally binding maintenance agreement. • Never to serve as a temporary sediment control device. • Observation well shall be installed in every trench, (4-6” PVC pipe, with a lockable cap). • Provide direct maintenance access.	**POLLUTANT REMOVAL** G Phosphorus F Nitrogen G Metals **-** Cadmium, Copper, Lead, and Zinc removal G Pathogens - Coliform, *Streptococci, E. coli* removal Key: G=Good F=Fair P=Poor

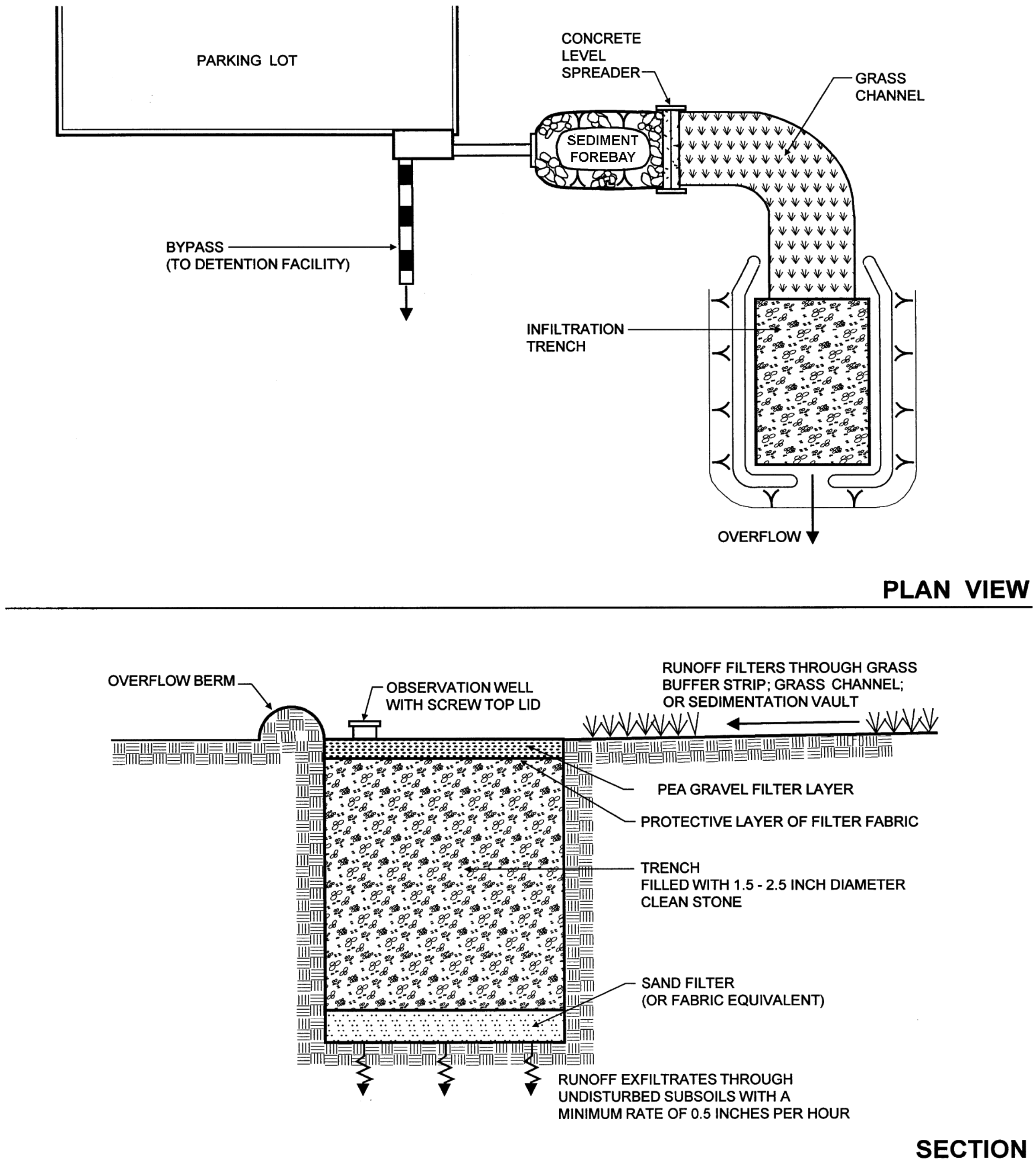
Figure 5-6 Infiltration Basin





Adapted from MDE, 2000

Figure 5-7 Infiltration Trench



Adapted from MDE, 2000

Figure 5-8 Underground Infiltration Chambers

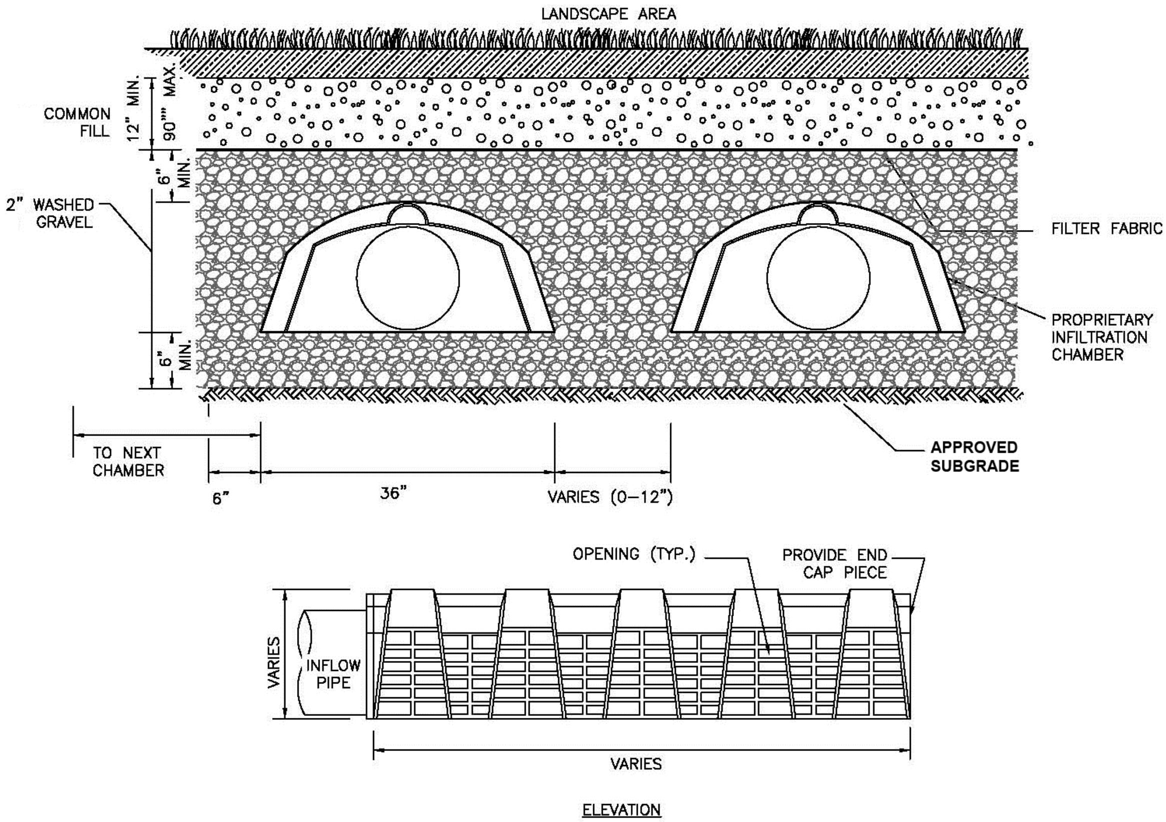
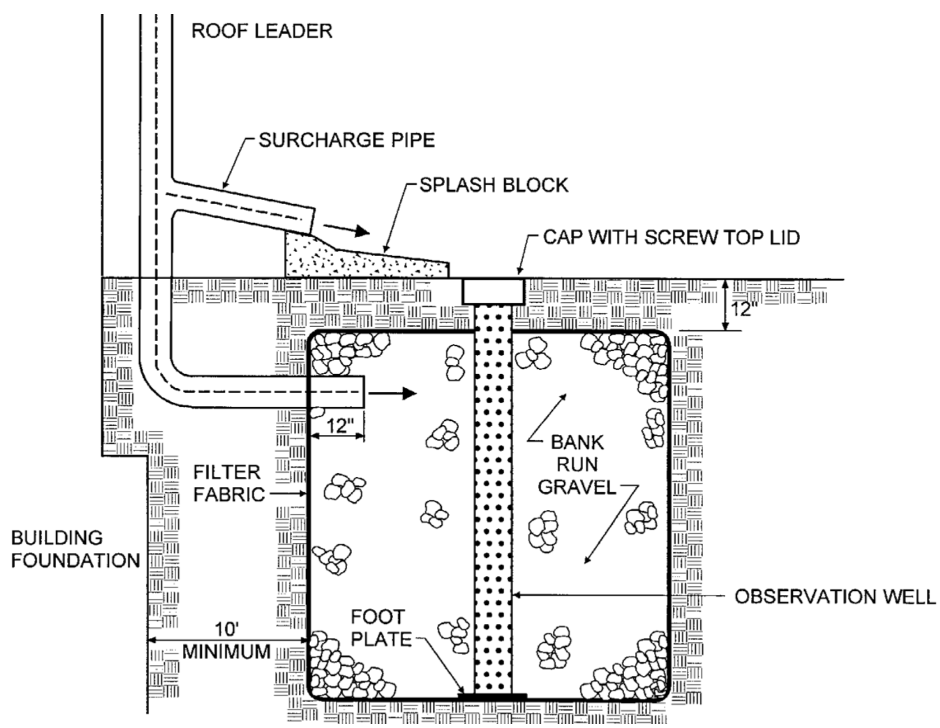


Figure 5-9 Dry Well



Source: MDE, 2000

Treatment Suitability: Infiltration practices typically cannot provide channel protection (CP_v) and/or overbank flood control (Q_p) storage, except on sites where the soil infiltration rate is high (typically greater than 8.3 in/hr). See Section 7.4 for guidance on designing infiltration practices for meeting the requirements for large storm events (i.e., CP_v and Q_p). To assure that long-term infiltration rates are achieved, extraordinary care should be taken to protect the infiltration practice during construction and followed with post-construction inspection and long-term maintenance. Roof runoff from non-LUHPPL sites can be infiltrated directly, without pretreatment, and counted toward both Re_v and WQ_v requirements.

5.3.1 Feasibility

Required Elements

- In order to meet the water quality standard, the bottom of infiltration practices must be located in the soil profile. Where a TMDL or CRMC goal requires maximum treatment of runoff, the bottom of infiltration practices shall be within the uppermost soil horizons (A or B) or another BMP is required.
- To be suitable for infiltration, underlying soils shall have an in-situ infiltration rate of at least 0.5 inches per hour, as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests (refer to Appendix H for acceptable testing procedures). The minimum geotechnical testing at the site of a proposed infiltration practice is one test hole per 5,000 ft^2, with a minimum of one boring or test pit (taken within the proposed limits of the facility). However, for residential rooftop runoff, testing requirements are reduced to 1 infiltration test and 1 test pit per 5 lots assuming consistent terrain and within the same NRCS soil series. If terrain and soil series are not consistent, then requirements increase to 1 infiltration test and 1 test pit per 1 lot.
- Soils shall also have a clay content of less than 20% and a silt content of less than 60%.
- The bottom of infiltration practices cannot be located in fill with the exception for strictly residential land uses, for which the bottom of practices may be located in up to 2 feet of fill consisting of material suitable for long-term infiltration after placement. Practices for non-residential sites that cannot be placed in natural soil may be designed as filtering systems. Such cases shall meet the media requirements of sand filters as described in Section 5-5.
- To protect groundwater from possible contamination, runoff from designated LUHPPLs or activities shall not be directed to an infiltration facility.
- The bottom of the infiltration facility shall be separated by at least 3 feet vertically from the seasonal high groundwater table (SHGT) and the bedrock layer (when treating WQ_v), as documented by on-site soil testing. The SHGT elevation in the area of each infiltration facility must be verified by a DEM-licensed Class IV soil evaluator or RI-registered PE. The distance may be reduced to 2 feet for strictly residential land uses, i.e., stormwater runoff from residential rooftops, driveways, and parking areas, but not roadways.
- Infiltration practices that are designed for the 10-year storm event or greater *and* have a separation from the bottom of the system to the seasonal high groundwater

of less than four feet shall provide a groundwater mounding analysis[1]. Infiltration practices designed for residential rooftops ≤ 1,000 ft^2 are exempt from this requirement.

- Infiltration practices cannot be placed in locations that cause water problems (such as seepage which may cause slope failure) to downgrade properties.
- Infiltration facilities must meet the setbacks in Table 5-2.

Table 5-2 Minimum Horizontal Setbacks from Infiltration Facilities

	Minimum Horizontal Setbacks	
	From small-scale facilities serving residential properties (ft)	**From all other infiltration facilities (ft)**
Public Drinking Water Supply Well – Drilled (rock), Driven, or Dug	200	200
Public Drinking Water Supply Well – Gravel Packed, Gravel Developed	400	400
Private Drinking Water Wells	50	100
Surface Water Drinking Water Supply Impoundment* with Supply Intake	100	200
Tributaries that Discharge to the Surface Drinking Water Supply Impoundment*	50	100
Coastal Features	50	50
All Other Surface Waters	50	50
Up-gradient from Natural slopes > %15	25	50
Down-gradient from Building Structures**	10	25
Up-gradient from Building Structures**	10	50
Onsite Wastewater Treatment Systems (OWTS)	15	25

*Refer to DEM Onsite Wastewater Treatment System Rules Figures 14-16 for maps of the drinking water impoundments.
**Setback applies only where basement or slab is below the ponding elevation of the infiltration facility. Note that all basements and slabs should be above the SHGT.

[1] The groundwater mounding analysis must show that the groundwater mound that forms under the infiltration system will not break out above the land or jurisdictional water. The Hantush Method (Hantush, 1967) or other equivalent method may be used.

Design Guidance

- The maximum contributing area to infiltration chambers and trenches should generally be less than 5 acres. The infiltration basin can receive runoff from larger areas up to 10 acres. Drywells should generally receive runoff from areas less than 1 acre.
- Infiltration practices should not be used where subsurface contamination is present from prior land use due to the increased threat of pollutant migration associated with increased hydraulic loading from infiltration systems, unless contaminated soil is removed and the site is remediated, or if approved by DEM on a case-by-case basis.

5.3.2 Conveyance

Required Elements

- Adequate stormwater outfalls shall be provided for the overflow associated with the 1-year design storm event (non-erosive velocities on the down-slope).
- The overland flow path of surface runoff exceeding the capacity of the infiltration system shall be evaluated to preclude erosive concentrated flow during the overbank events. If computed flow velocities exiting the system overbank exceed erosive velocities (3.5 to 5.0 fps) for the 1-year storm event, an overflow channel and/or level spreader shall be provided.
- All infiltration systems shall be designed to fully de-water the entire WQ_v within 48 hours after the storm event.
- If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice must be designed as an off-line practice, except when used exclusively to manage CP_v and Q_p (see Chapter Seven).

5.3.3 Pretreatment

Required Elements

- For infiltration basins, chambers, and trenches, a minimum pretreatment volume of at least 25% of the WQ_v must be provided to protect the long-term integrity of the infiltration rate. This must be achieved by using one of the following options (see Chapter Six for pretreatment design requirements):
  - Grass channel
  - Filter strip
  - Sediment forebay
  - Deep sump catch basin AND <u>one</u> of the following:
    - Upper sand layer (6” minimum with filter fabric at the sand/gravel interface); or
    - Washed pea gravel (1/8” to 3/8”) (see section, Figure 5-7).
  - Proprietary device
- Exit velocities from pretreatment chambers flowing over vegetated channels shall be non-erosive (3.5 to 5.0 fps) during the 1-year design storm.

Design Guidance

- The sides of infiltration chambers, trenches, and dry wells should be lined with an acceptable filter fabric that prevents soil piping.

5.3.4 Treatment

Required Elements

- If the in-situ infiltration rate for the underlying soils is greater than 8.3 inches per hour, 100% of the WQ_v shall be treated by an acceptable water quality practice prior to entry into an infiltration facility.
- Infiltration practices shall be designed to exfiltrate the entire WQ_v through the floor of each practice (i.e., sidewalls are not considered in sizing), unless the depth is greater than ½ the square root of the bottom surface area.
- The construction sequence and specifications for each infiltration practice shall be precisely followed. Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction.
- Design infiltration rates (f_c) shall be determined by using Table 5-3, or shall be determined by in-situ rates (using a factor of safety of 2 from the field-derived value) established by one of the approved methods listed in Appendix H.1.3 (rates derived from standard percolation tests are not acceptable).

Table 5-3 Design Infiltration Rates for Different Soil Textures (Rawls et al., 1982)

USDA Soil Texture	Design Infiltration Rate (f_c) (in/hr)	Design Infiltration Rate (f_c) (ft/min)
Sand	8.27	0.0115
Loamy Sand	2.41	0.0033
Sandy Loam	1.02	0.0014
Loam	0.52	0.0007
Silt Loam	0.27	0.0004

Design Guidance

- Infiltration practices are best used in conjunction with other practices, and often downstream detention is still needed to meet the CP_v and Q_p sizing criteria.
- A porosity value (V_v/V_t) of 0.33 should be used to design stone reservoirs for infiltration practices.
- The bottom of the stone reservoir should be completely flat or nearly so (i.e., 0.5% slope) in order that infiltrated runoff will be able to infiltrate through the entire bottom surface area.
- One method to calculate the surface area of infiltration trenches is to use the following equation:

$$A_p = V / (nd_t + f_c t/12)$$

Where:

A_p = surface area at the bottom of the trench (ft^2)

V = design volume (e.g., WQ_v) (ft^3)
n = porosity of gravel fill (assume 0.33)
d_t = trench depth (separated from seasonal high groundwater as required) (ft)
f_c = design infiltration rate (in/hr)
t = time to fill trench (hours) (assumed to be 2 hours for design purposes)

- One method to calculate the design volume of manufactured infiltration chambers is to use the following equation:

$$V = L\,[(wdn) - (\#A_c n) + (\#A_c) + (wf_c t/12)]$$

Where:

V = design volume (e.g., WQ_v) (ft^3)
L = length of infiltration facility (ft)
w = width of infiltration facility (ft)
d = depth of infiltration facility (separated from seasonal high groundwater as required) (ft)
$\#$ = number of rows of chambers
A_c = cross-sectional area of chamber (see manufacturer's specifications)
n = porosity (assume 0.33)
f_c = design infiltration rate (in/hr)
t = time to fill chambers (hours) (assumed to be 2 hours for design purposes)

- One method to calculate the surface area of trapezoidal infiltration basins is to use the following equation:

$$A_b = (2V - A_t d_b)/(d_b - P/6 + f_c t/6)$$

Where:

A_b = surface area at the bottom of the basin (ft^2)
V = design volume (e.g., WQ_v) (ft^3)
A_t = area at the top of the basin (ft^2)
d_b = depth of the basin (separated from seasonal high groundwater as required) (ft)
P = design rainfall depth (inches)
f_c = design infiltration rate (in/hr)
t = time to fill basin (hours) (assumed to be 2 hrs for design purposes)

5.3.5 Vegetation

Required Elements

- Upstream construction shall be completed and stabilized before connection to a downstream infiltration facility. A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.

Design Guidance

- Mow upland and adjacent areas, and seed bare areas.

5.3.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the responsible authority to ensure the following:
  - Infiltration practices shall never serve as a sediment control device during site construction phase. Great care must be taken to prevent the infiltration area from compaction by marking off the location before the start of construction at the site and constructing the infiltration practice last, connecting upstream drainage areas only after construction is complete, and the contributing area is stabilized. In addition, the ESC plan for the site shall clearly indicate how sediment will be prevented from entering the site of an infiltration facility.
  - An observation well shall be installed in every infiltration trench or chamber system, consisting of an anchored 4- to 6-inch diameter perforated PVC pipe with a lockable cap installed flush with the ground surface. The approving agency may require multiple observation wells for large underground chamber systems.
- Infiltration practices shall be inspected annually and after storms equal to or greater than the 1-year, 24-hour Type III storm event.
- If sediment or organic debris build-up has limited the infiltration capabilities (infiltration basins) to below the design rate, the top 6 inches shall be removed and the surface roto-tilled to a depth of 12 inches. The basin bottom should be restored according to original design specifications.

Design Guidance

- OSHA trench safety standards should be observed if the infiltration trench will be excavated more than five feet.
- Infiltration basin designs may include dewatering methods in the event of failure. Dewatering can be accomplished with underdrain pipe systems that accommodate drawdown as shown in Figure 5-6.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility. Any oil or grease found at the time of the inspection should be cleaned with oil absorption pads and disposed of in an approved location.
- Preferably, direct access should be provided to infiltration practices for maintenance and rehabilitation. For trenches or chambers, which are used to temporarily store runoff prior to infiltration, the practice should ideally not be completely covered by an impermeable surface unless significant design constraints exist.
- Surface infiltration practices should be mowed at least 2 times/yr. Stabilize eroded banks and repair eroded areas at inflow and outflow structures as necessary.

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5.4 PERMEABLE PAVING

Source: Roseen File Photo

Description: Permeable paving practices capture and temporarily store the WQ_v before allowing it to infiltrate into the soil or conveying it to another stormwater practice. The two major types include permeable asphalt/porous concrete and pavers.

KEY CONSIDERATIONS	STORMWATER MANAGEMENT SUITABILITY

FEASIBILITY
• Infiltrating permeable paving practices:
  • Minimum soil infiltration rate of 0.5 inches per hour.
  • Soils less than 20% clay and 60% silt.
  • Cannot accept LUHPPL runoff.
  • Separation from groundwater table and bedrock of at least 3 feet except for strictly residential land uses, for which it may be reduced to 2 feet.
• All permeable paving practices:
  • Use only in gentle slopes < 5%.
  • Not appropriate for high traffic or high speed areas.
 	
PRETREATMENT
• Not Applicable
 	
TREATMENT
• For infiltrating permeable pavements, water quality volume designed to exfiltrate through the floor of the practice in soil horizons or media bed.
 	
VEGETATION
• Upstream area shall be completely stabilized before any flow is directed to the practice.
• Pavers that are planted with grass require species with deep root systems.
	✓ Recharge
	✓ Water Quality
	✓ Channel Protection
	✓ Overbank Flood Control
	
	Accepts LUHPPL Runoff: *Only if designed with impermeable liner*
	
	IMPLEMENTATION CONSIDERATIONS
	
	M Capital Cost
	H Maintenance Burden
	
	Residential/Subdivision Use: *Yes*
	High Density/Ultra-Urban: *Maybe*
	Drainage Area: *No limit but runoff from surrounding areas should be minimized.*
	Soils: *Pervious soils required for infiltrating permeable paving practices (0.5 in/hr or greater)*
	
	Key: L=Low M=Moderate H=High

MAINTENANCE REQUIREMENTS	POLLUTANT REMOVAL
• Legally binding maintenance agreement. • Never to serve as a temporary sediment control device.	G Phosphorus G Nitrogen G Metals - Cadmium, Copper, Lead, and Zinc removal G Pathogens - Coliform, *Streptococci, E. coli* removal Key: G=Good F=Fair P=Poor

There are two major types of permeable paving:

- **Porous asphalt and pervious concrete**. Although they appear to be the same as traditional asphalt or concrete pavement, they have 10%-25% void space and are constructed over a base course that doubles as a reservoir for the stormwater before it infiltrates into the subsoil or is directed to a downstream facility. Required construction specifications for porous asphalt and pervious concrete are located in Appendix F.
- **Pavers**. Three alternative paver configurations will be acceptable to the approving agency as water quality BMPs. These are as follows:
  - **Permeable solid blocks or reinforced turf:** This type of permeable paving surface includes permeable solid blocks (where the blocks have a minimum void ratio of 15%) and contain open-cell grids filled with either ASTM No. 8 washed aggregate for (paving blocks) or sandy soil and planted with turf (for reinforced turf applications), set on a prepared base course consisting of a minimum of 1.5 inches of No. 8 washed aggregate, over a minimum of 4 inches of No. 57 washed stone. No. 2 washed stone is used as a reservoir course as necessary to manage variable storm sizes or provide other functions.
  - **Solid blocks with open-cell joints > 15% of surface:** This type of paver surface includes interlocking impermeable solid blocks or open grid cells that must contain permeable void areas (between the impermeable blocks) exceeding 15% of the surface area of the paving system. Permeable void areas are to be filled with ASTM No. 8 washed aggregate and compacted with a minimum 5,000 lb_f plate compactor. Pavers are set on prepared base course materials consisting of a minimum of 1.5 inches of No. 8 washed aggregate, over a minimum of 4 inches of No. 57 washed stone. No. 2 washed stone is used as a reservoir course as necessary to manage variable storm sizes or provide other functions.
  - **Solid blocks with open-cell joints < 15% of surface:** This type of paver surface includes interlocking impermeable solid blocks or open grid cells that must contain permeable void areas (between the impermeable blocks) less than 15% of the surface area of the paving system. Permeable void areas are to be filled with ASTM No. 8 washed aggregate and compacted with a minimum 5,000 lb_f plate compactor. In order to meet the water quality treatment requirements of Standard 3, these types of systems must be designed to provide one inch of surface storage above the permeable pavement system. Pavers are set on prepared base course materials consisting of a minimum of 1.5 inches of No. 8 washed aggregate, over a minimum of 4 inches of No. 57 washed stone. No. 2 washed stone is used as a reservoir course as necessary to manage variable storm sizes or provide other functions.

Treatment Suitability: Permeable paving practices might not be able to provide overbank flood control (Q_p) storage. Combine with other practices to handle runoff from large storm events, when required. Extraordinary care shall be taken to assure that clogging does not occur through the use of performance bonds, post-construction inspection and long-term maintenance.

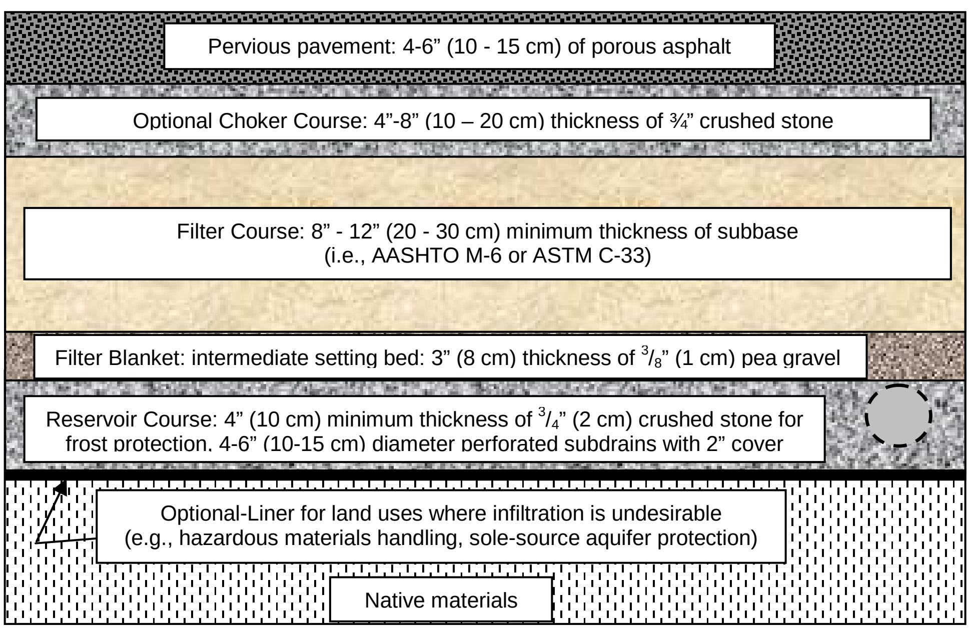
There are two categories of permeable pavement:

- Infiltration Facility. The base stores water and drains to underlying soil. There are no perforated drain pipes at bottom of base; however, they may have overflow pipes for saturated conditions and extreme storm events.
- Detention Facility. This design includes an impermeable liner at the bottom of the base aggregate, which then flows to a downstream facility for additional treatment and storage. This category is useful in sites with high groundwater, bedrock, LUHPPL, and areas with fill soils. If designed as a detention system, infiltration restrictions noted in Section 5.4.1 do not apply; refer to Chapter Seven design requirements for detention structures.

Figure 5-10 Permeable Paving Surfaces (Source: MA EOEA, 2006)

Open-celled Grid Pavers **Permeable Paving Blocks with Open Joints**

Figure 5-11 Example Cross-section of Porous Asphalt (UNHSC, 2009)



5.4.1 Feasibility

Required Elements

- In order to meet the water quality standard, the bottom of infiltrating permeable pavement practices must be located in the soil profile. Where a TMDL or CRMC goal requires maximum treatment of runoff, the bottom shall be within the uppermost soil horizons (A or B) or another BMP is required.
- To be suitable for infiltration, underlying soils shall have an in-situ infiltration rate of at least 0.5 inches per hour, as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing at the site of a proposed infiltrating practice is one test hole per 5,000 ft^2, with a minimum of one boring or test pit per infiltration facility (taken within the proposed limits of the facility).
- For infiltrating permeable paving practices, underlying soils shall also have a clay content of less than 20% and a silt content of less than 60%.
- The bottom of an infiltrating permeable pavement practice cannot be located in fill with the exception for strictly residential land uses, for which the bottom may be located in up to 2 feet of fill consisting of material suitable for long-term infiltration. Practices for non-residential sites that must be placed in fill shall meet the media requirements of sand filters as described in Section 5-5.
- To protect groundwater from possible contamination, runoff from designated LUHPPL land uses or activities must not be directed to permeable pavement unless designed as a detention facility (with an impermeable liner).
- To avoid excessive nitrogen loading to coastal embayments, permeable pavements are not permitted to receive runoff from other areas (i.e., they shall only be used to manage precipitation that falls directly on the permeable pavement area).
- The bottom of an infiltrating permeable pavement practice shall be separated by at least 3 feet vertically from the SHGT or bedrock layer (when treating WQ_v), as documented by on-site soil testing. The SHGT elevation in the area of an infiltrating permeable pavement facility must be verified by a DEM-licensed Class IV soil evaluator or RI-registered PE. The distance may be reduced to 2 feet in strictly residential areas.
- Infiltrating permeable pavement practices must meet the setbacks in Table 5-4.

Table 5-4 Minimum Horizontal Setbacks from Infiltrating Permeable Pavements

	Minimum Horizontal Setbacks	
	From small-scale facilities serving residential properties OR non-vehicle surface applications (ft)	**For all other applications (ft)**
Public Drinking Water Supply Well – Drilled (rock), Driven, or Dug	200	200

	Minimum Horizontal Setbacks	
	From small-scale facilities serving residential properties OR non-vehicle surface applications (ft)	**For all other applications (ft)**
Public Drinking Water Supply Well – Gravel Packed, Gravel Developed	400	400
Private Drinking Water Wells	25	100
Surface Water Drinking Water Supply Impoundment* with Supply Intake	100	200
Tributaries that Discharge to the Surface Drinking Water Supply Impoundment*	50	100
Coastal Features	50	50
All Other Surface Waters	50	50
Up-gradient from Natural slopes > %15	25	50
Down-gradient from Building Structures**	10	25
Up-gradient from Building Structures**	10	50
Onsite Wastewater Treatment Systems (OWTS)	15	25

*Refer to DEM Onsite Wastewater Treatment System Rules Figures 14-16 for maps of the drinking water impoundments.
**Setback does not apply where basement or slab is at or above the surface elevation of the permeable pavement.

- This practice is not appropriate for high traffic/high speed areas (≥ 1,000 vehicle trips/day) due to clogging potential.
- To avoid frost heave, design base to drain quickly (depth > 24 inches).
- Use permeable paving only on gentle slopes (less than 5%).

<u>Design Guidance</u>

- The permitting agencies may reduce the minimum horizontal setbacks for infiltrating permeable pavements on a case-by-case basis in residential and non-vehicle surface (e.g., walkways/plazas) applications.
- Permeable paving surfaces are best used in low traffic areas such as overflow parking, residential driveways, sidewalks, plazas and courtyard areas. Areas with high amounts of sediment particles and high traffic volumes may cause system failures. Should not construct adjacent to areas subject to significant wind erosion.
- In general, permeable pavements should only be used to manage precipitation that falls directly on the permeable pavement area to protect the surface from clogging.

Contributing drainage areas should be kept to a minimum (i.e., runoff from upgradient impermeable or permeable surfaces should be minimal).
- Typically, reservoirs consist of uniformly sized washed gravel, with a depth sufficient to store all of the rainfall from the design storm.
- Designers may incorporate catch basins or an "overflow edge" (a trench surrounding the edge of the pavement) connected to the stone reservoir below the surface of the pavement as a temporary emergency backup in case the surface clogs.
- Permeable paving practices generally should be designed with an impermeable liner when used where subsurface contamination is present from prior land use due to the increased threat of pollutant migration associated with increased hydraulic loading from infiltration systems, unless contaminated soil is removed and the site is remediated, or if approved by DEM on a case-by-case basis.

5.4.2 Conveyance

Required Elements

- The overland flow path of surface runoff exceeding the capacity of the permeable paving system shall be evaluated to preclude erosive concentrated flow during the overbank events. If computed flow velocities exiting the system over-bank exceed erosive velocities (3.5 to 5.0 fps), an overflow channel shall be provided to a stabilized watercourse.
- All permeable pavement systems shall be designed to fully de-water the entire WQ_v within 24 hours after the storm event.

5.4.3 Pretreatment

Design Guidance

- Pretreatment is not possible for this practice. Frequent maintenance is required to prevent clogging of the surface.

5.4.4 Treatment

Required Elements

- Permeable pavements used as infiltration practices shall be designed to exfiltrate the entire WQ_v through the floor of each practice (sides are not considered in sizing).
- Base course is a reservoir layer which shall be a minimum 6 inches, but is generally 12 to 24 inches or greater (function of storage needed and frost heave resistance). Base material must be poorly graded (uniform size material), must maintain adequate evaluate bearing capacity, depending on the use, and compaction effort must be adjusted to meet design storage requirements. Base course also includes a filter course above reservoir layer (2 to 6 inches of smaller material). See Appendix F for more information on material specifications.
- The construction sequence and specifications for permeable pavement areas shall

be precisely followed, particularly for infiltrating permeable paving practices. Experience has shown that the longevity of any infiltration practice is strongly influenced by the care taken during construction.

- For infiltrating permeable pavements, design infiltration rates (f_c) should be determined by using Table 5-3 based on the soil texture of the underlying soil. These are conservative values that take into account future clogging as the practice is used over the years.
- For permeable paving practices used for detention only, no runoff reduction is allowed, i.e., impermeable CNs shall be used in hydraulic and hydrologic models when calculating CP_v and Q_p.

Design Guidance

- Permeable paving practices are best used in conjunction with other practices, and often downstream detention may still be needed to meet the Q_p sizing criteria.
- A porosity value (V_v/V_t) of 0.33 shall be used to design stone reservoirs.
- For infiltrating permeable pavements, the bottom of the stone reservoir should be completely flat, or nearly so, in order that runoff will be able to infiltrate through the entire bottom surface area.
- One way to calculate the surface area of infiltrating permeable paving surfaces is to use the following equation:

$$A_p = V / (n8d_t + f_c t/12)$$

Where:

A_p = surface area (ft^2)
V = design volume (e.g., WQ_v) (ft^3)
n = porosity of gravel fill (assume 0.33)
d_t = depth of aggregate base (separated at least three feet from seasonal high groundwater) (ft)
f_c = design infiltration rate (in/hr)
t = time to fill (hours) (assumed to be 2 hours for design purposes)

- To account for the runoff reduction from infiltrating permeable paving materials in hydraulic and hydrologic models when calculating CP_v and Q_p, designers may use the runoff CNs listed in Table 5-5. CNs for infiltrating permeable pavements are a function of the depth of reservoir storage provided and underlying soils.

Table 5-5 Curve Numbers for Infiltrating Permeable Pavements (MDE, 2009)

Subbase (inches)	**Hydrologic Soil Group**			
	A	**B**	**C**	**D**
6	76	84	93	-
9	62	65	77	-
≥12	40	55	70	-

5.4.5 Vegetation

Required Elements

- Other adjacent construction shall be completed and site stabilized before installation of reservoir materials. A dense and vigorous vegetative cover shall be established over any contributing pervious drainage areas before runoff can be accepted into the facility.
- Pavers that are planted with grass require species with deep root systems. Follow manufacturer's guidelines on appropriate species.

Design Guidance

- Table G-3 in Appendix G includes a list of native, drought tolerant grasses that may be appropriate for grid pavers.

5.4.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the responsible authority.
- Areas where infiltrating permeable pavement practices are proposed shall not serve as a temporary sediment control device during site construction phase.
- Permeable paving surfaces require regular vacuum sweeping or hosing (minimum every three months or as recommended by manufacturer) to keep the surface from clogging. Maintenance frequency needs may be more or less depending on the traffic volume at the site.
- Minimize use of sand and salt in winter months.
- Do not repave or reseal with impermeable materials.
- The Erosion and Sediment Control (ESC) Plan shall specify at a minimum:
  - how sediment will be prevented from entering the pavement area;
  - a construction sequence;
  - drainage management; and
  - vegetative stabilization.

Design Guidance

- Keep adjacent landscape areas well maintained and stabilized (erosion gullying quickly corrected).
- Post signs identifying permeable pavement.
- Pavers planted with grass need mowing and often need reseeding of bare areas.
- Mow any upgradient contributing pervious drainage areas, and seed any bare areas.
- Monitor regularly to ensure that the paving surface drains properly after storms.
- Inspect the surface annually for deterioration or spalling.
- Attach rollers to the bottoms of snowplows to prevent them from catching on the edges of pavers.

- Avoid stockpiling snow on permeable pavement. Identify stockpile areas on design plans and in maintenance specifications and contracts to prevent unintentional stockpiling on permeable pavement.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility.
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.

5.5 FILTERING SYSTEMS

Source: HW Group File Photo

Description: Filtering systems capture and temporarily store the WQ_v and pass it through a filter media. Filtered runoff may be collected and returned to the conveyance system, or may be allowed to partially exfiltrate into the soil. Filtering systems include Sand Filters, Organic Filters, Bioretention, and Tree Filters.

KEY CONSIDERATIONS: SAND/ORGANIC FILTERS

FEASIBILITY

- Bottom of filter at or above SHGT.
- Top of filter at least 3ft above SHGT.

CONVEYANCE

- If stormwater is delivered by storm drain, design off-line. For off-line facilities, flow regulator is needed to divert WQ_v to the practice and to bypass larger flows.
- Overflow for the 1-year storm to a non-erosive point.
- Underdrain (4" min) unless designed as exfilter system.

PRETREATMENT

- Pretreatment volume of 25% (or equivalent) of WQ_v.
- Typically filter strip, grass channel, or sediment forebay.

TREATMENT

- Total system (including pretreatment) must hold 75% of the WQ_v.
- Filter media shall be ASTM C-33 sand for sand filters.
- Organic filters shall be a reed-sedge hemic peat/sand mix, or leaf compost.

VEGETATION

- Contributing area stabilized before runoff is directed to facility.

MAINTENANCE REQUIREMENTS

- Legally binding maintenance agreement.
- Sediment cleaned out of sediment forebay when it reaches more than 12" in depth.
- Vegetation limited to 18".
- Sediment chamber cleaned if drawdowns exceed 36 hours.
- Trash and debris removal.
- Silt/sediment removed from filter bed after it reaches 1".
- If water ponds on the filter bed for greater than 48 hours, remove and replace filter media.

STORMWATER MANAGEMENT SUITABILITY

- [x] Water Quality
- [x] Recharge (if designed as an exfilter system)
- [ ] Channel Protection
- [ ] Overbank Flood Control

Accepts LUHPPL Runoff: *Yes (requires impermeable liner for water quality treatment)*

IMPLEMENTATION CONSIDERATIONS (SAND/ORGANIC FILTERS)

H	Capital Cost
H	Maintenance Burden

Residential/Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *10 acres max.*

Soils: *No restrictions*

Other Considerations:

Typically needs to be combined with other controls to provide water quantity control

Key: L=Low M=Moderate H=High

KEY CONSIDERATIONS: BIORETENTION/TREE FILTERS

FEASIBILITY

- Bottom of filter at or above SHGT.
- Top of filter at least 3ft above SHGT.

CONVEYANCE

- Provide overflow for the 1-yr storm to the conveyance system.
- Conveyance to the system is typically overland flow delivered to the surface of the system, typically through curb cuts or over a concrete lip.

PRETREATMENT

- Pretreatment volume of 25% (or equivalent) of WQ_v.
- Typically grass channel or grass filter strip, a pea gravel diaphragm, and a mulch layer.

TREATMENT

- Total system (including pretreatment) must hold 75% of the WQ_v.
- Treatment area to have a 2-4ft deep planting soil bed, a surface mulch layer, and a 6"-9" ponding layer.
- Soil media as detailed in Appendix F.

VEGETATION

- Detailed planting plan required.
- Use of native plants is recommended.

MAINTENANCE REQUIREMENTS

- Legally binding maintenance agreement.
- Inspect and repair/replace treatment area components.
- Remulch annually.
- Vegetation pruning, harvesting.

IMPLEMENTATION CONSIDERATIONS (BIORETENTION/TREE FILTERS)

M	Capital Cost
M	Maintenance Burden

Residential/Subdivision Use: *Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *5 acres max.*

Soils: *Planting soils must meet specified criteria; No restrictions on surrounding soils, except the depth above water table.*

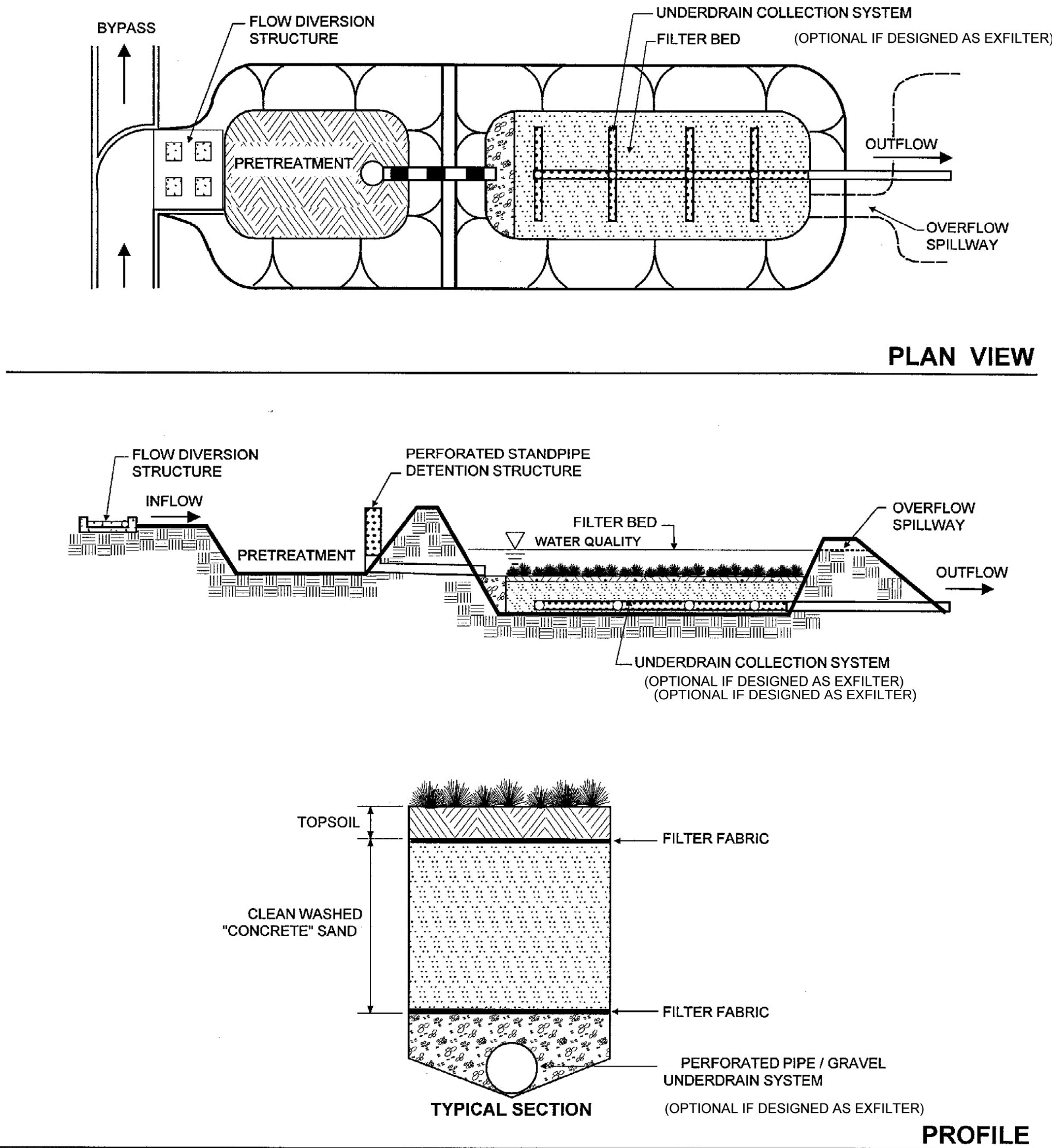
Key: L=Low M=Moderate H=High

POLLUTANT REMOVAL – ALL FILTERS

F	Phosphorus
G	Nitrogen
G	Metals - Cadmium, Copper, Lead, and Zinc removal
G	Pathogens - Coliform, *Streptococci, E. coli* removal

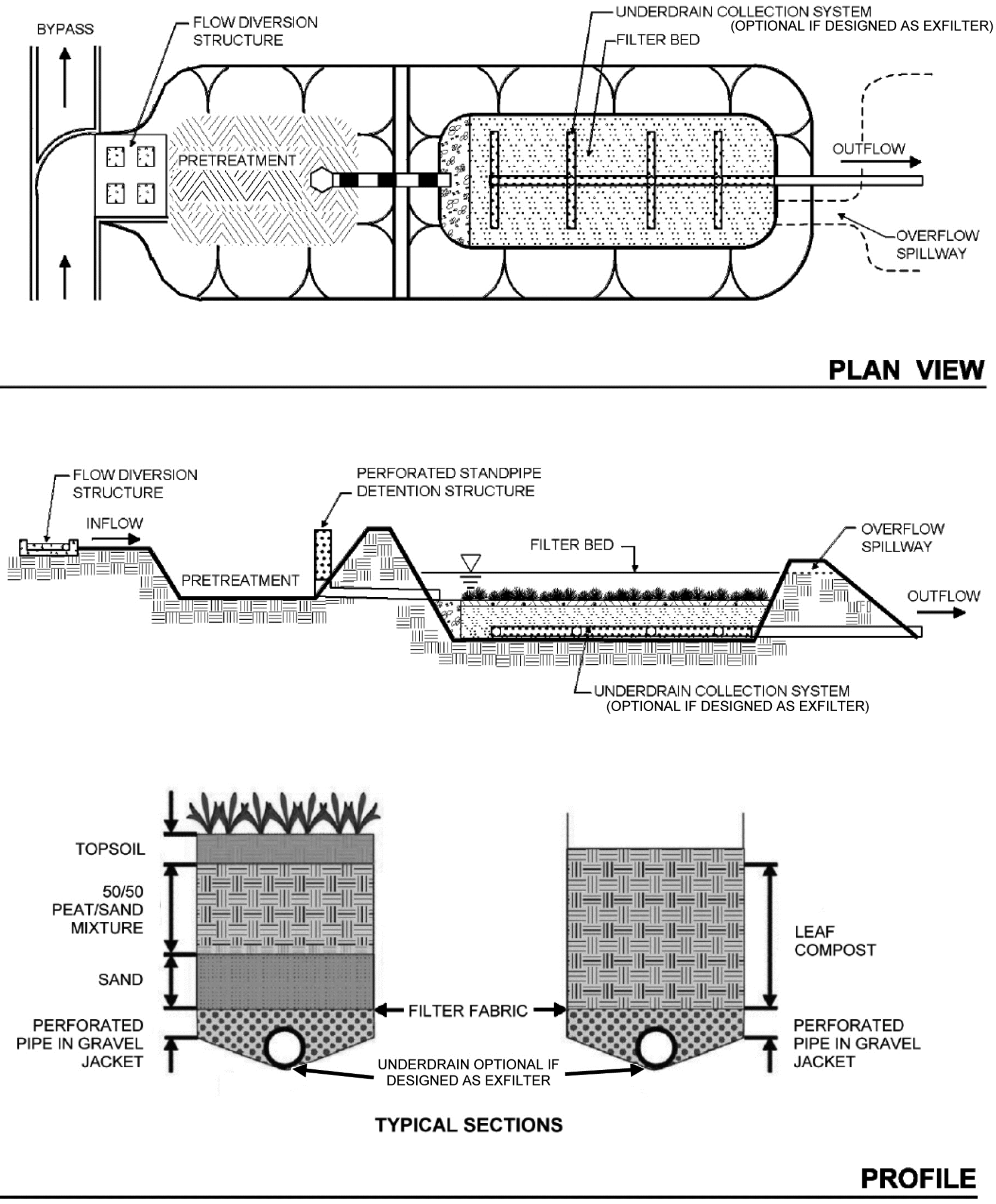
Key: G=Good F=Fair P=Poor

Figure 5-12 Sand Filter



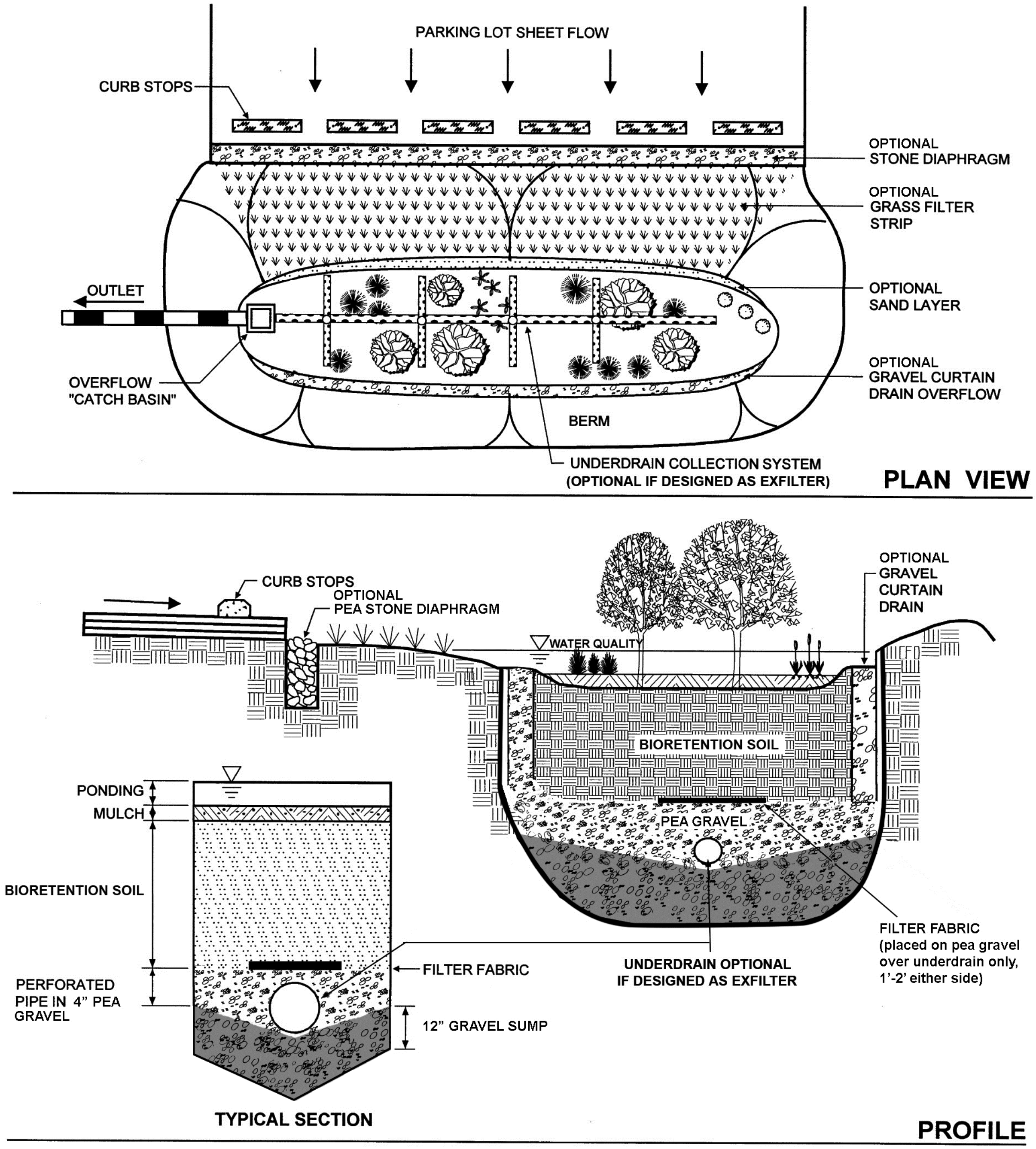
Adapted from MDE, 2000

Figure 5-13 Organic Filter



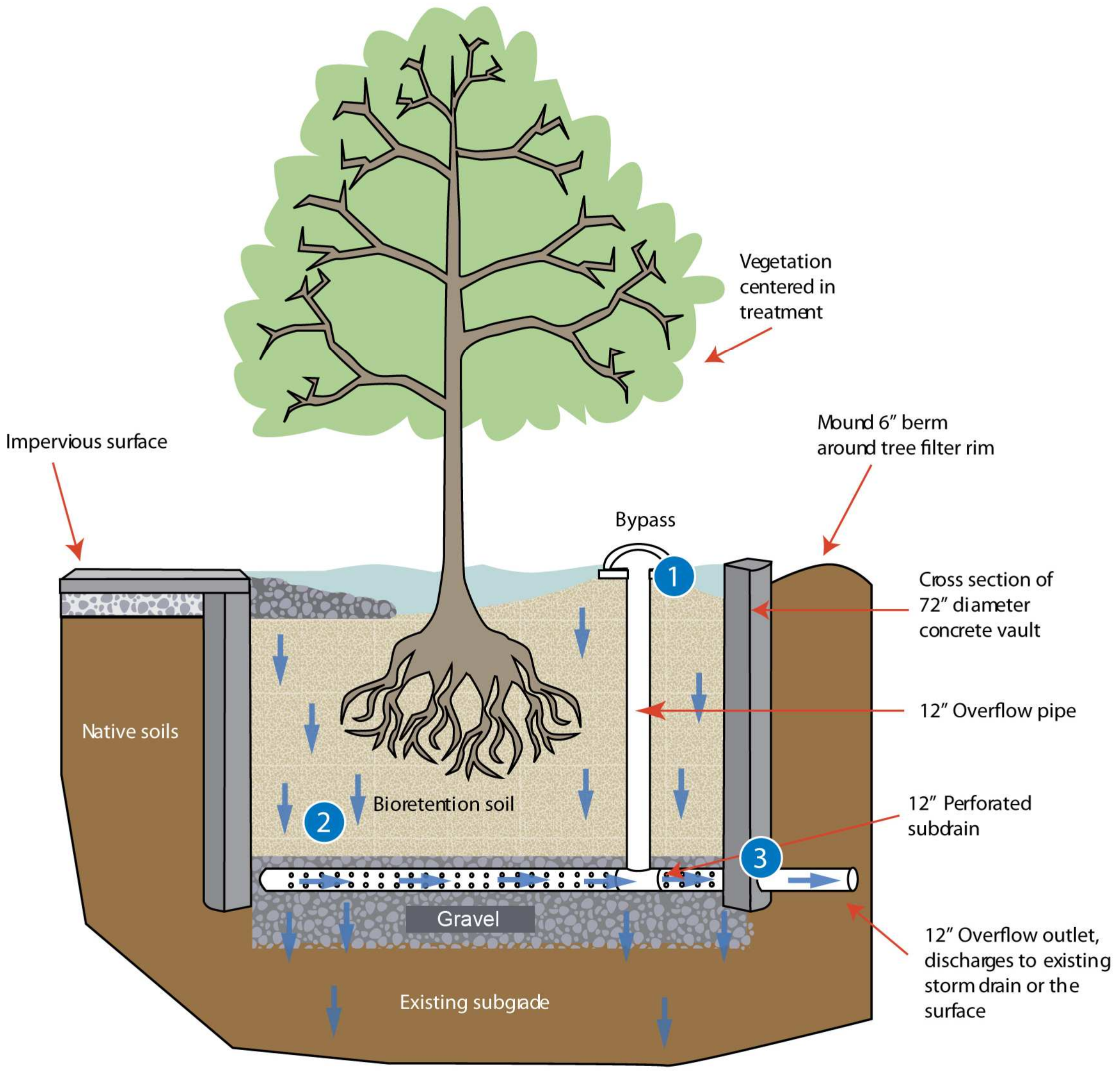
Adapted from MDE, 2000

Figure 5-14 Bioretention



Adapted from MDE, 2000

Figure 5-15 Tree Filter



Source: adapted from UNHSC, 2007

5.5.1 Feasibility

<u>Required Elements</u>

- The bottom of filtering systems shall be located at or above the seasonal high groundwater table. The top of filtering systems shall be located at least 3 feet above the seasonal high groundwater table.
- Unlined filtering systems greater than 1,000 sf in size shall not be located within 15 feet of any OWTS drainfield.

<u>Design Guidance</u>

- Filtering systems normally require between 2 and 6 feet of head, depending on site configuration and land area available and physical constraints.

- The recommended maximum contributing area to an individual bioretention system is usually less than 5 acres. In some situations, larger areas may be acceptable (e.g., design that has sufficient distance across entire surface area, multiple inflow locations, and bypass of larger storms).
- Tree filters are small bioretention practices that may be contained in a concrete vault with an underdrain connecting to the storm drain system, or may have an open base for infiltration into the underlying soils. All other design criteria and guidance for tree filters are identical to bioretention practices, excepting pretreatment[1].
- Sand and organic filtering systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with imperviousness less than 75% will require more aggressive sedimentation pretreatment techniques.

5.5.2 Conveyance

Required Elements

- If runoff is delivered by a storm drain pipe or is along the main conveyance system, the filter practice shall be designed off-line to the maximum extent practicable. In these cases, a flow regulator (or flow splitter diversion structure) shall be supplied to divert the WQ_v to the filter practice, and allow larger flows to bypass the practice.
- An overflow shall be provided for runoff greater than the WQ_v to a non-erosive outlet point (i.e., prevent downstream slope erosion).

Design Guidance

- Synthetic filter fabrics should not be used to completely separate the soil filter media from the underdrain bedding material. Experience has shown this to be a major source of failure for underdrained filters (see specifications in Appendix F for installation).
- Bioretention should be equipped with a minimum 4" perforated pipe underdrain in a pea gravel layer, and a 12" gravel drainage blanket. Filter fabric should be used only on top of the portion of the pea gravel layer that is over the underdrain, 1'-2' either side (see Figure 5-14 for schematic).
- If designing an exfiltrating system, an underdrain might not be necessary for filter practices.

5.5.3 Pretreatment

Required Elements

- Dry or wet pretreatment shall be provided prior to filter media equivalent to at least 25% of the computed WQ_v.

[1] Decreased pretreatment is warranted in severely constrained site applications and where enhanced maintenance is assured (e.g., contracted landscaper).

Design Guidance

- Pretreatment for bioretention systems should incorporate all of the following (unless a sediment forebay is provided): (a) grass filter strip below a level spreader or grass channel (using guidelines in Chapter Six), (b) pea gravel diaphragm (a small trench running along the edge of the practice), and (c) a mulch layer.
- Sediment forebays may be used as pretreatment and should be designed according to the guidance in Chapter Six.
- Deep sump catch basins may be used as pretreatment only if used along with other pretreatment BMP options listed above.

5.5.4 Treatment

Required Elements

- The entire treatment system (including pretreatment) shall be sized to temporarily hold at least 75% of the WQ_v. A porosity value (V_v/V_t) of 0.33 shall be used to account for storage within the filter media.
- The filter media for a sand filter shall consist of a medium sand (meeting ASTM C-33 concrete sand). Media used for organic filters may consist of peat/sand mix or leaf compost. Peat shall be a reed-sedge hemic peat.
- Sand and organic filter beds shall have a minimum depth of 18 inches.
- Bioretention systems shall consist of the following treatment components: A 24” to 48” deep planting soil bed (depending on requirements of proposed vegetation), a surface mulch layer, and a 6” to 9” deep surface ponding area. Soils shall consist of USDA loamy sand to sandy loam classification and meet the following graduation: sand 85-88%, silt 8-12%, clay 0-2%, and organic matter (in the form of leaf compost) 3-5%.
- The minimum filter area for sand and organic filters shall be sized based on the principles of Darcy’s Law. A coefficient of permeability (k) shall be used as follows:

Sand:	3.5 ft/day (City of Austin, 1988)
Peat:	2.0 ft/day (Galli, 1990)
Leaf compost:	8.7 ft/day (Claytor and Schueler, 1996)
Bioretention soil:	1.0 ft/day for sandy-loam soils

The minimum required filter bed area is computed using the following equation (City of Austin, 1988):

$$A_f = (WQ_v)\,(d_f) / [(k)\,(h_f + d_f)\,(t_f)]$$

Where:

A_f = Surface area of filter bed (ft^2)
d_f = Filter bed depth (ft)
k = Coefficient of permeability of filter media (ft/day)
h_f = Average height of water above surface of practice (i.e., height above the uppermost mulch/organic layer) (ft)
t_f = Design filter bed drain time (days)
(2 days is the maximum t_f for bioretention)

Design Guidance

- The depth of sand and organic filters may be reduced to 12" on a case-by-case basis as demonstrated by the designer that 18" is not feasible, such as sites with high groundwater or shallow depth to bedrock or clay soils, or in retrofit situations where pre-existing site constraints exist.
- The depth of bioretention systems may be reduced to 12" on a case-by-case basis as demonstrated by the designer that the 24" to 48" range is not feasible, such as sites with high groundwater or shallow depth to bedrock or clay soils, or in retrofit situations where pre-existing site constraints exist. In these cases, the designer should add 20% (by volume) of well-aged (6-12 months), well-aerated, leaf compost (or approved equivalent) to the planting soil mixture, and will need to demonstrate that the facility meets the required 75% WQ_v storage.
- For designers using a TR-55 hydrologic/hydraulic model for filter facility sizing, an exfiltration outlet structure should be used with a constant velocity rate of exfiltration per Table 5-3. This rate is used in hydraulic routing to reflect the design infiltration rate when using NRCS methods for a Type III, 24-hour storm where the vast majority of the runoff enters the system in just a few hours. Note that this is different from the hydraulic conductivity (e.g., for bioretention areas, k = 1 ft/day as listed above vs. 2.41 inches/hr for loamy sand from Table 5-3) used in establishing the required minimum surface area, which is reflective of the long-term acceptance rate over a range of different storm intensities and durations with a 2-day drawdown.

5.5.5 Vegetation

Required Elements

- A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.
- Vegetation is critical to the performance and function of bioretention areas; therefore, a planting plan must be provided that follows the general guidance in Appendix B. The permitting agency may require applicants to retain the services of a qualified professional with the educational background and/or experience to select appropriate plants.

Design Guidance

- Sand and organic filters can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.
- Planting recommendations for bioretention facilities are as follows:
  - Native plant species should be specified over non-native species, see Appendix B.
  - Vegetation should be selected based on a specified zone of hydric tolerance.
  - A selection of trees with an understory of shrubs and herbaceous materials should be provided.
  - Woody vegetation should not be specified at inflow locations.

- Trees should be planted primarily along the perimeter of the facility.
- A tree density of approximately one tree per 250 ft^2 (i.e., 15 ft on-center) is recommended. Shrubs and herbaceous vegetation should generally be planted at higher densities (5-10 ft on-center and 2.5 ft on center, respectively).

5.5.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the responsible authority to ensure the following:
  - Sediment shall be cleaned out of the sediment forebay when it accumulates to a depth of more than ½ the design depth. Vegetation within the sediment forebay shall be limited to a height of 18 inches. The sediment chamber outlet devices shall be cleaned/repaired when drawdown times exceed 36 hours. Trash and debris shall be removed as necessary.
  - Silt/sediment shall be removed from the filter bed when the accumulation exceeds one inch. When the filtering capacity of the filter diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), the top few inches of discolored material shall be removed and shall be replaced with fresh material. The removed sediments shall be disposed in an acceptable manner at an approved and permitted location.
- For unique installations in extremely tight sites or redevelopment/infill projects where pretreatment strips have been downsized, enhanced maintenance shall be required through more frequent inspections, more frequent sediment removal, and enhanced landscape maintenance.
- During the six months immediately after construction, filter practices shall be inspected following at least the first two precipitation events of at least 1.0 inch to ensure that the system is functioning properly. Thereafter, inspections shall be conducted on an annual basis and after storm events of greater than or equal the 1-year, 24-hour Type III precipitation event.

Design Guidance

- Organic filters or sand filters that have a grass cover should be mowed a minimum of three times per growing season to maintain maximum grass heights less than 12".
- For bioretention areas, pruning or replacement of woody vegetation should occur when dead or dying vegetation is observed. Separation of herbaceous vegetation rootstock should occur when over-crowding is observed, or approximately once every 3 years. If at least 50 percent vegetation coverage is not established after two years, a reinforcement planting should be performed. The mulch layer should be replenished (to the original design depth) every other year, as directed by inspection reports. The previous mulch layer should be removed, and properly disposed of, or roto-tilled into the soil surface.
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.
- Minor soil erosion gullies should be repaired when they occur.

5.6 Green Roofs

Description: Green rooftops are rooftop areas that have been landscaped with grasses, shrubs and, in some cases, trees. The two main types of green roofs are intensive and extensive.

KEY CONSIDERATIONS

FEASIBILITY

- Maximum 20% roof slope, unless specific measures are provided to retain the system on steeper slopes.
- Extensive: designed for maximum thermal and hydrological performance and minimum weight load and aesthetics.
- Intensive: designed with a deeper planting media, larger plants, and often incorporate public benches and walkways.

CONVEYANCE

- Safely convey runoff exceeding the capacity of the green roof system to a drainage system/BMP without causing erosion.

PRETREATMENT

- Not Applicable

TREATMENT

- Design to manage the water quality volume.

VEGETATION

- Plant species based on specific site, structural design, and hydric conditions present on the roof.
- Often contain ground cover that can thrive in very shallow soils with little to no maintenance.

STORMWATER MANAGEMENT SUITABILITY

- ☐ Recharge
- ☑ Water Quality
- ☑ Channel Protection*
- ☐ Overbank Flood Control

**Only in certain cases for intensive green roofs*

Accepts LUHPPL Runoff: *Yes*

IMPLEMENTATION CONSIDERATIONS

- H Capital Cost
- M Maintenance Burden

Residential/Subdivision Use: *Depends*

High Density/Ultra-Urban: *Yes*

Drainage Area: *No limit but generally cannot accept runoff from surrounding areas.*

Key: L=Low M=Moderate H=High

<table>
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MAINTENANCE REQUIREMENTS

- Legally binding maintenance agreement.
- Inspect for leaks, remove leaves, and litter.
- Extensive: May need to be watered during the first season and during dry periods. May need to be lightly fertilized and weeded once a year.
- Intensive: Maintain as any other landscaped area (gardening, irrigation).

</td>
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POLLUTANT REMOVAL

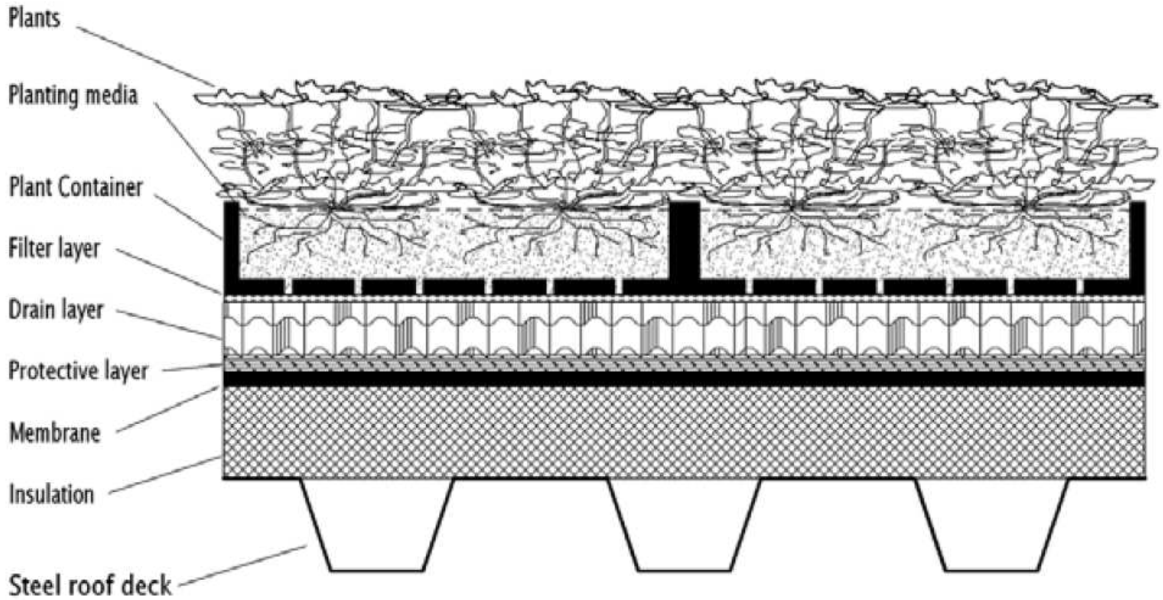
F	Phosphorus
G	Nitrogen
G	Metals - Cadmium, Copper, Lead, and Zinc removal
G	Pathogens - Coliform, *Streptococci, E. coli* removal

Key: G=Good F=Fair P=Poor

</td>
</tr>
</table>

"Intensive" rooftops are designed with pedestrian access and deep soil layers to provide for complex planting schemes. "Extensive" rooftops are designed with a more shallow soil foundation and generally do not incorporate pedestrian access. Stormwater runoff from small storms is retained until uptake can occur, while runoff from larger events is typically conveyed to downstream stormwater facilities for quantity control.

Figure 5-16 Extensive Green Roof Construction Cross Section



Source: Wark and Wark, 2003 (originally from SHADE Consulting, LLC, 2003)

5.6.2 Feasibility

<u>Required Elements</u>

- The system shall have a maximum slope of 20%, unless specific measures from the manufacturer are provided to retain the system on steeper slopes.
- Green roofs can meet water quality treatment goals only, and are not appropriate for Re_v, CP_v, or Q_p.

<u>Design Guidance</u>

- Extensive rooftops are commonly designed for maximum thermal and hydrological performance and minimum weight load while being aesthetically pleasing. Typically, only maintenance personnel have access to this type of roof. It can be installed on either a flat or pitched roof.
- Intensive rooftops are designed with a deeper planting media, larger plants (trees and shrubs), and often incorporate public walkways and benches. These are installed on flat roofs.

Vegetation
Almost any plant can be put on a roof. The only limitations are climate, structural design and maintenance budgets. Since green roofs are typically lightweight, they often contain ground cover that can thrive in very shallow soils with little to no maintenance. Sedum, a succulent ground cover, has become very popular for use on green roofs in North America. Also commonly used are a variety of hearty wildflowers and shallow-rooting grasses. At times, rooftop vegetation may go dormant and lose foliage.

Planting medium
Not to be confused with soil, the planting medium is distinguished by its mineral content, which is synthetically produced, expanded clay. The clay is considerably less dense and more absorbent than natural minerals, providing the basis for an ultra-lightweight planting medium. Perlite is a common form of expanded clay and is found in garden nursery planting mix (not planting soil). The types of expanded clays used in green roofs are also used in hydroponics.

Filter layer
Between the planting media and drain layer lays a filter, which not only allows water to flow through while retaining the planting medium, but serves as a root barrier. The filter usually comprises one or two layers of non-woven geotextile, where one of the layers may be treated with a root inhibitor (i.e., copper or a mild herbicide). Extensive green roofs usually employ plants with easy-to-control roots, whereas intensive green roofs may contain deeper rooting plants requiring multiple filter layers. Since root and media particle diameters can vary, filters should be specified for different media and plant types to ensure adequate flow rates for a given planting mix without losing too much silt or allowing excessive root penetration. See Appendix F for sample specifications for the planting media and filter layer.

Containment
In modular systems, containment refers to actual plant containers. In non-modular systems, the planting medium is supported by the drain layer and contained at the perimeter by a metal or plastic barrier, or the roof parapet.

Drain layer
Between the planting medium and roof membrane is a layer through which water can flow from anywhere on the green roof to the building’s drainage system. Some systems simply use a layer of large-diameter expanded clay, but the preferred method is to use a corrugated plastic drain mat with a structural pattern resembling an egg carton or landscape paver. The minimum drain layer thickness is usually less than 20 mm (0.8 inches), but a thicker mat can provide additional insulation and root restriction.

The critical specification for a drain layer is the maximum volumetric flow rate, which is determined based on the design precipitation of 1 inch for WQ_v. Minimum passage area should be standardized for various locations. Since the drain layer supports the planting medium and vegetation, the compression strength should be specified. Many drain mat products are segmented or baffled to get the necessary compression strength, and hence, have insulating qualities that should be considered.

Protective layer
The roof's membrane needs protection, primarily from damage during green roof installation, but also from fertilizers and possible root penetrations. The protective layer can be a slab of lightweight concrete, sheet of rigid insulation, thick plastic sheet, copper foil, or a combination of these, depending on the particular design and green roof application.

Since current standards do not recognize the insulating qualities of green roofs, a local code variance would probably be needed to install one on an under-insulated roof. Rigid insulation can certainly be used as a protective layer. Insulation may be above or below the rigid roof surface.

Waterproofing
A green roof can be installed with any kind of waterproofing system, but single-ply membranes have become very popular in recent years and are specified by nearly all green roof companies for their cost effectiveness and simplicity. As such, the waterproofing layer is typically assumed to be a membrane.

A membrane is actually protected, not degraded, by a green roof. Without one, a membrane is subjected to UV radiation, extreme heat cycling, wind, rain, pollution (especially when ponding occurs), and damage from maintenance activities. With a properly designed green roof incorporating a protective layer, the membrane is subjected to nothing more than a small amount of moisture. Since a green roof keeps the membrane surface temperature much closer to the roof deck temperature, mechanical stress within the membrane is tremendously reduced. This helps maintain joint integrity, adherence to the deck, and reduces water vapor transfer.

The design criteria of the system should include provisions in case an exceptional situation develops, such as particularly invasive roots or excessive fertilizer from a rooftop garden. Here, an appropriate protective layer must be selected. Vegetation that can root through an undamaged, watertight membrane is rarely used in green roof construction. Some companies now offer membranes incorporating a layer of copper foil for added protection against root penetration.

Existing standards and codes for membrane installation are more than sufficient for green roof applications. The only additional requirements might involve special provisions for the inspection of a membrane before and after the subsequent green roof layers are installed.

Vapor restriction
Since a green roof reduces the temperature gradients throughout the roof system, condensation is less likely to occur beneath the membrane. Situations requiring an additional vapor restricting sheet should be determined on an individual basis.

(Guidance from Wark and Wark, 2003)

5.6.3 Conveyance

Required Elements

- The runoff exceeding the capacity of the green roof system shall be safely conveyed to a drainage system or BMP without causing erosion. If an overland path is used, a stabilized channel shall be provided for erosive velocities (3.5 to 5.0 fps) for the 1-year storm event.
- The green roof system shall safely convey runoff from the 100-year storm away from the building and into a downstream drainage system.

5.6.4 Pretreatment

Required Elements

- No pretreatment is required for direct rainfall.

5.6.5 Treatment

Required Elements

- Green roofs shall be designed to manage (i.e., without bypass to overflow) the WQ_v.

Design Guidance

- To account for the runoff reduction from green roofs in hydraulic and hydrologic models, designers may use a reduced CN. Intensive green roofs should use the runoff CNs for Woods, Brush, or Grass, depending on the specific plant communities used. Extensive green roofs should use the curve numbers listed in Table 5-6 based on the thickness of the growing media.

Table 5-6 Effective Curve Numbers for Extensive Green Roofs (MDE, 2009)

Growing Media Thickness (in.)	2	3	4	6	8
Effective CN	94	92	88	85	77

- The following ASTM Standards should be used for determining the appropriate planting medium and calculating the resulting loads on the roof (Halsall, 2007).

E2396-05 Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems

This test method is used to determine the water permeability of coarse granular materials used in the drainage layer (100% of material retained on a 2.25 mm sieve) under low-head conditions typical of horizontal flow in green roofs. The method *allows for direct comparison with alternative components, such as geocomposite drain layers. Also measured in the test is the wet density of the granular medium. The resultant water permeability is used to calculate the runoff coefficient.*

E2397-05 Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems

This method is used to predict the overall weight of a green roof system, including components typically encountered (membranes, non-absorptive plastic sheets, metallic layers, fabrics, geocomposite drain layers, synthetic reinforcing layers, protection boards, insulation, growing media, granular drainage media and plants. The procedure addresses the weight under two different conditions: 1) weight under drained conditions following rainfall or irrigation (including retained and captured water) and 2) weight during active rainfall when the drainage layer is completely saturated. The first condition is considered the dead load and the difference between the two conditions, approximated by the weight of transient water in the drainage layer is considered the live load. The procedure does not account for live loads associated with architectural elements, construction activities, snow or wind.

E2398-05 Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems

This method determines the water and media retention of synthetic drain layers used in green roof systems typically consisting of cup-like receptacles on the upper surface (shaped plastic membranes and closed-cell plastic foam boards). The standard does not apply to products manufactured from water-absorptive materials. The standard involves filling the drain layer with sand and water to determine the volume. To account for the difference in water capture depending on roof slope, the tests are performed under different inclinations of the drainage layer. The resultant water retention is used to calculate the runoff coefficient.

E2399-05 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems

This test method is used to determine the maximum density of media used for dead load analysis. The method also provides a measure of the moisture content and the water permeability measured at the maximum media density. The procedure is suitable for media with less than 30% organic content. The test comprises of compressing moist media into a perforated cylinder using a Proctor hammer, immersed it in water and then determining the density and moisture content using standard gravimetric procedures. The sample is allowed to dry for 2 hours and is again measured to determine the maximum media density. The 2-hr value can be directly compared to media densities determined using the most common international procedures for establishing green roof dead load values.

5.6.6 Vegetation

Design Guidance

Landscape design should specify proper plant species based on specific site, structural design, and hydric conditions present on the roof. Plant species range from sedums, grasses, and wildflowers on extensive green roofs to trees and shrubs in intensive green roofs.

The ASTM *E2400-06 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems* covers the criteria considered for the selection, installation and maintenance of plants of a green roof system and applies to both intensive and extensive roof types. The primary considerations for plant selection are design intent, aesthetics, climate, plant characteristics including longevity, rate of establishment and pest resistance, and, media composition and depth. Also covered are installation methods including pre-cultivation (followed by transplant to the roof), direct seeding and seasonal issues (Halsall, 2007).

5.6.7 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the responsible authority to ensure the following:

  Extensive
  - Vegetation may need to be watered periodically during the first season and during exceptionally dry periods.
  - Vegetation may need to be lightly fertilized and weeded once a year.

  Intensive
  - Vegetation should be maintained as any other landscaped area, which may involve gardening and irrigation.

- Inspect green roof for leaks on a quarterly basis. Foreign matter, including leaves and litter, should be removed.

5.7 OPEN CHANNEL SYSTEMS

Source: HW Group File Photo

Description: Open channel systems are vegetated open channels that are explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means. Design variants include Dry Swales and Wet Swales.

KEY CONSIDERATIONS

FEASIBILITY

- Maximum longitudinal slope of 4%, without checkdams.

CONVEYANCE

- Non-erosive (3.5 to 5.0 fps) peak velocity for the 1-year storm.
- Safe conveyance of the 10-year storm.
- Side slopes gentler than 2:1 (3:1 preferred).
- The maximum allowable temporary ponding time of 48 hours.

PRETREATMENT

- 10% of the WQ_v in pretreatment, usually provided using check dams at culverts or driveway crossings.

TREATMENT

- Storage of WQ_v in facility (wet swale) or through properly sized filter media/bioretention soil (dry swale).
- Bottom width no greater than 8 feet, but no less than 2 feet.
- Dry Swale utilizes bioretention soil media as detailed in Appendix F.

STORMWATER MANAGEMENT SUITABILITY

- [x] Water Quality
- [x] Recharge
- [x] Channel Protection*
- [ ] Overbank Flood Control

* Generally applies only to wet swale

Accepts LUHPPL Runoff: *Yes (requires impermeable liner for water quality treatment)*

IMPLEMENTATION CONSIDERATIONS

L Capital Cost

L Maintenance Burden

Residential/Subdivision Use: *Yes*

High Density/Ultra-Urban: *No*

Drainage Area: *5 acres max. to one inlet*

Soils: *No restrictions*

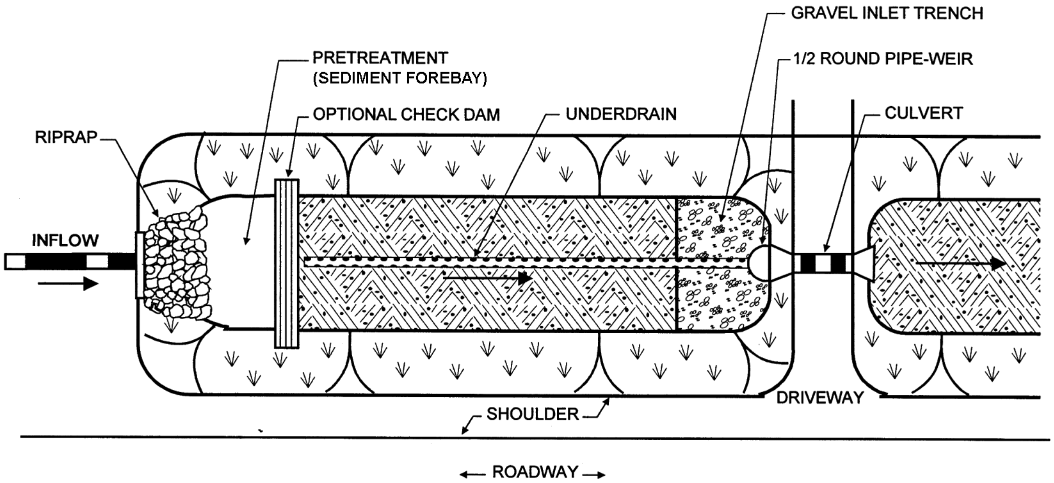
Other Considerations:

- Bioretention soil layer (Dry Swale)
- Emergent plants (Wet Swale)

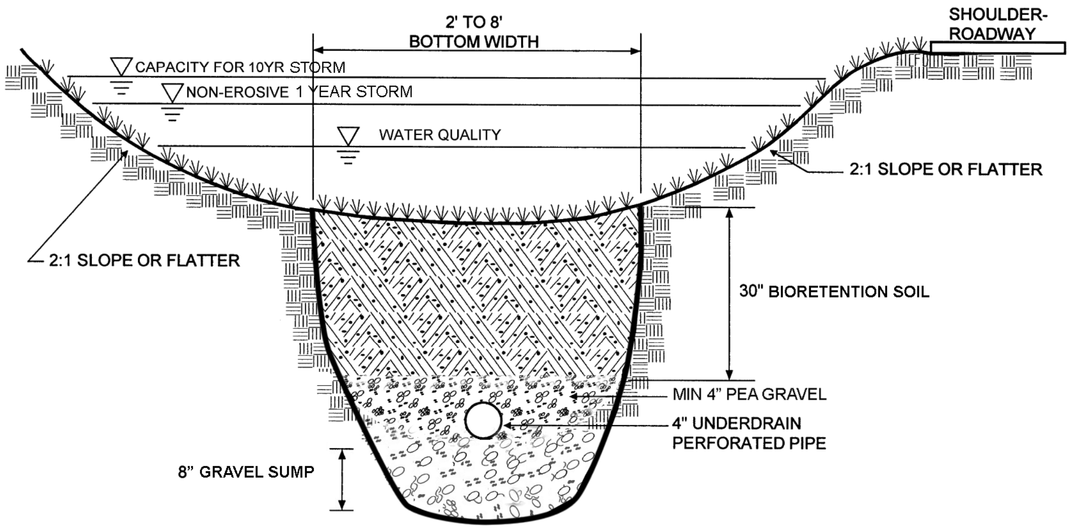
Key: L=Low M=Moderate H=High

MAINTENANCE REQUIREMENTS:	POLLUTANT REMOVAL
• Legally binding maintenance agreement. • Removal of sediment build-up within the bottom of the channel when 25% of the original WQ_v volume has been exceeded. • Maintain an average grass height of 6” in dry swales. • Correct erosion gullies and maintain healthy stand of vegetation.	G Phosphorus G Nitrogen G Metals - Cadmium, Copper, Lead, and Zinc removal F Pathogens - Coliform, Streptococci, E. coli removal Key: G=Good F=Fair P=Poor

Figure 5-17 Dry Swale



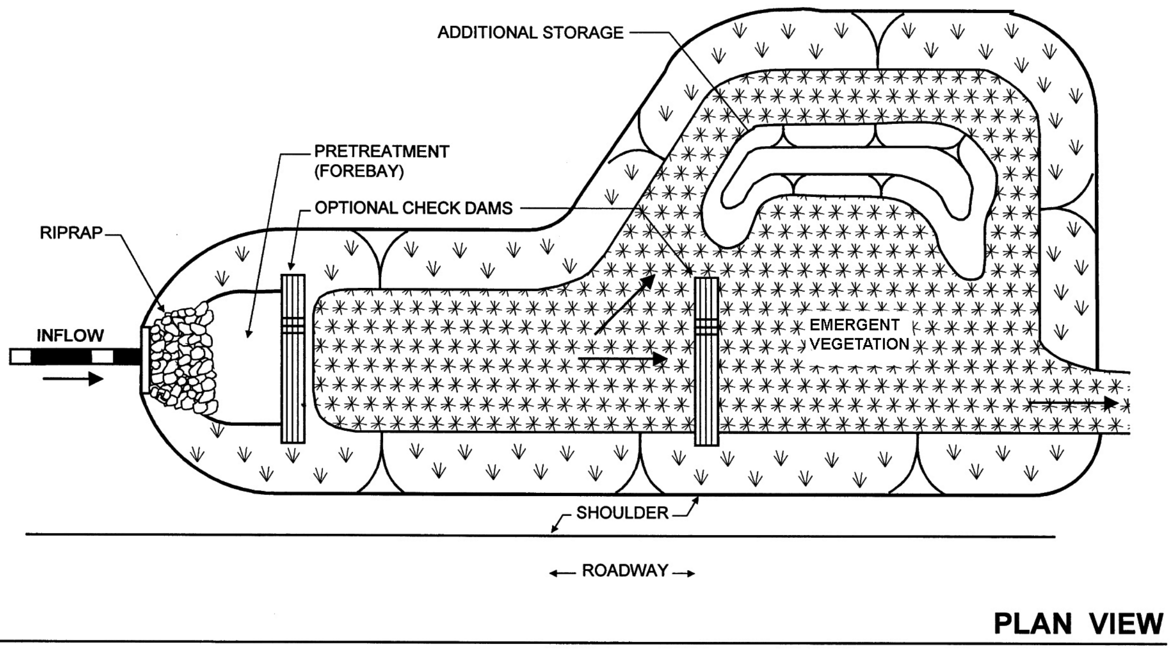
PLAN VIEW

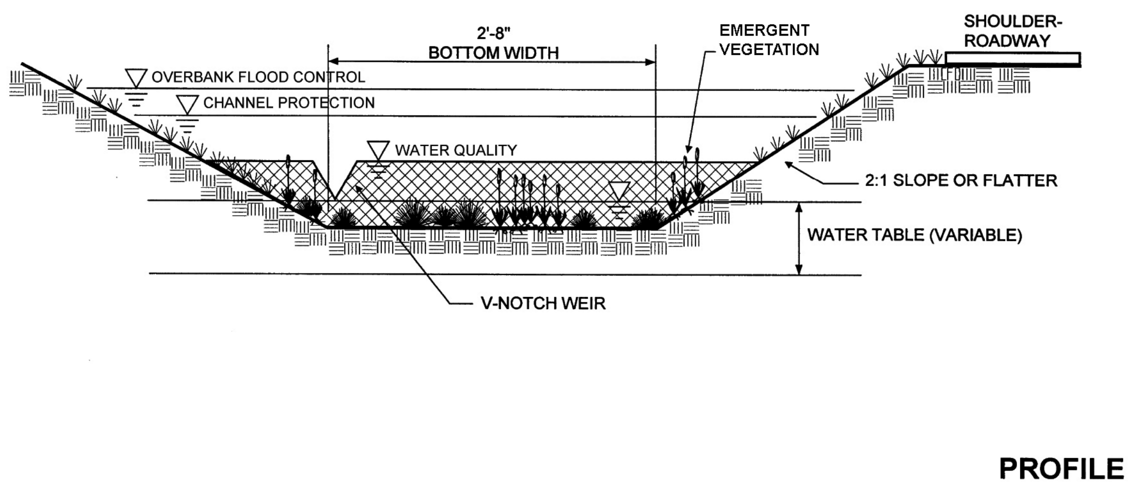


SECTION

Adapted from MDE, 2000

Figure 5-18 Wet Swale





Adapted from MDE, 2000

5.7.1 Feasibility

<u>Required Elements</u>

- Open channels shall have a maximum drainage area of 5 acres draining to any one inlet. No maximum drainage area if flow enters via sheet flow along a linear feature, such as a road.

- Open channels shall have a maximum longitudinal slope of 4%, without check dams.
- Wet Swales are constructed in groundwater. The bottom of a Dry Swale shall be located at or above the seasonal high groundwater table; the top of a Dry Swale shall be located at least 3 feet above the seasonal high groundwater table.
- Wet swales shall be placed a minimum 50 feet downgradient of any OWTS drainfield.

Design Guidance

- Dry Swales are primarily applicable for land uses such as roads, highways, residential development, and pervious areas.
- Wet Swales should be restricted in residential areas because of the potential for stagnant water and other nuisance ponding.
- Wet Swales excavated into groundwater may trigger a water budget analysis at the discretion of the permitting agency.
- In order to maintain the required permanent pool volume, Wet Swales typically need a longitudinal slope of <1%.

5.7.2 Conveyance

Required Elements

- The maximum allowable temporary ponding time within a channel shall be less than 48 hours. An underdrain system shall be used in the dry swale to ensure this ponding time, unless designed as an exfilter in which case an underdrain might not be necessary. (An exfilter is a conventional stormwater filter without an underdrain system; the filtered volume ultimately infiltrates into the underlying soils).
- The peak velocity for the 1-year storm must be non-erosive (i.e., 3.5-5.0 fps).
- Open channels shall be designed to safely convey the 10-year storm.
- Channels shall be designed with moderate side slopes (flatter than 3:1) for most conditions. Designers may utilize a 2:1 maximum side slope, where 3:1 slopes are not feasible.
- If the site slope is greater than 4%, additional measures such as check dams shall be utilized to retain the water quality volume within the swale system.

Design Guidance

- Open channel systems may be designed as off-line systems to reduce erosion during large storm events.
- Open channel systems which directly receive runoff from non-roadway impervious surfaces may have a 6” drop onto a protected shelf (pea gravel diaphragm) to minimize the clogging potential of the inlet. Runoff from roads should drain over a vegetative slope, check dam, or forebay prior to flowing into a swale.
- The underdrain system should be composed of a minimum 4” pea gravel bed, underlain a minimum 8” gravel sump.

5.7.3 Pretreatment

Required Elements

- Provide 10% of the WQ_v in pretreatment.

Design Guidance

- The pretreatment storage is usually obtained by providing forebays/checkdams at pipe inlets and/or driveway crossings.
- Road drainage entering a swale along the length of the road may pre-treat runoff using a vegetative filter strip, see Chapter Six for design guidance.
- A washed, pea gravel diaphragm and gentle side slopes may be utilized along the top of channels to provide pretreatment for lateral sheet flows.

5.7.4 Treatment

Required Elements

- Wet swale length, width, depth, and slope shall be designed to temporarily accommodate the WQ_v through surface ponding.
- Dry swales shall consist of the following treatment components: A 30” deep bioretention soil bed, a surface mulch layer, and no more than a 12” deep average surface ponding depth. Soil media shall meet the specifications outlined for bioretention areas.
- The minimum filter area for dry swales shall be sized based on the principles of Darcy’s Law. A coefficient of permeability (k) shall be used as follows:

  Dry Swale (same as for bioretention): 1.0 ft/day for sandy-loam soils

The minimum required filter area is computed using the following equation:

$$A_f = (WQ_v)\ (d_f) / [(k)\ (h_f + d_f)\ (t_f)]$$

Where:

A_f = Surface area of filter bed (ft^2)
d_f = Filter bed depth (ft)
k = Coefficient of permeability of filter media (ft/day)
h_f = Average height of water above dry swale surface (ft)
t_f = Design filter bed drain time (days)
(2 days is maximum t_f for dry swales, per first bullet in Section 5.7.2)

- Swales shall be designed with a bottom width no greater than 8 ft to avoid potential gullying and channel braiding, but no less than 2 ft.

Design Guidance

- Open channels should maintain a maximum ponding depth of one foot at the longitudinal mid-point of the channel, and a maximum depth of 18" at the end point of the channel (for head/storage of the WQ_v).

- For the wet swale, the permanent pool may be included in water quality volume calculations.
- The bioretention soil depth of dry swales may be reduced to 12" on a case-by-case basis as demonstrated by the designer that 30" is not feasible, such as sites with high groundwater or shallow depth to bedrock or clay soils, or in retrofit situations where pre-existing site constraints exist. In these cases, the designer should add 20% (by volume) of well-aged (6-12 months), well-aerated, leaf compost (or approved equivalent) to the bioretention soil mixture and will need to provide a calculation to demonstrate that an equal WQ_v is provided as with a 30" deep soil bed.

5.7.5 Vegetation

Design Guidance

- The planting plan should specify proper grass species and emergent plants based on specific site, soils, and hydric conditions present along the proposed swale (see Appendix B for guidance on species selection).

5.7.6 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the responsible authority.
- Open channel practices shall be inspected annually and after storms of greater than or equal to the 1-year, 24-hour Type III precipitation event.
- Sediment build-up within the bottom of the channel or filter strip shall be removed when 25% of the original WQ_v volume has been exceeded.
- Eroded side slopes and channel bottoms shall be stabilized as necessary.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility.
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.
- Vegetation in dry swales shall be mowed as required to maintain grass heights in the 4-6 inch range, with mandatory mowing once grass heights exceed 10 inches.
- Woody vegetation in wet swales shall be pruned where dead or dying branches are observed, and reinforcement plantings shall be planted if less than 50% of the original vegetation establishes after two years.
- If the surface of the dry swale becomes clogged to the point that standing water is observed on the surface 48 hours after precipitation events, the bottom shall be roto-tilled or cultivated to break up any hard-packed sediment, and then reseeded.

Design Guidance

- Every five years, the channel bottom of dry swales should be scraped to remove sediment and to restore original cross section and infiltration rate, and should be seeded to restore ground cover.
- During inspection, any structural components of the system, including trash racks, valves, pipes and spillway structures, should be checked for proper function. Any clogged openings should be cleaned out and repairs should be made where necessary.

5.8 Selection Criteria for Stormwater Treatment Practices

This section presents a series of matrices that can be used as a screening process for selecting the best BMP or group of BMPs for a development site. It also provides guidance for locating practices on the site. The matrices presented can be used to screen practices in a step-wise fashion. Screening factors include:

- Land Use;
- Physical Feasibility;
- Watershed;
- Stormwater Management Capability; and
- Community and Environmental Benefit.

The five matrices presented here are not exhaustive. Specific additional criteria may be incorporated depending on local design knowledge and resource protection goals. Caveats for the application of each matrix are included in the detailed description of each. These matrices are provided as guidance to help designers and planners choose the most appropriate practices for their given conditions. Specific limitations such as maximum site slope or maximum drainage area will generally not be viewed by the permitting agencies as absolute limitations.

5.8.1 Step 1 - Land Use

Which practices are best suited for the proposed land use at this site? In this step, the designer makes an initial screen to select practices that are best suited to a particular land use or to exclude those practices that are ill suited for certain land uses. For example, infiltration practices should not be utilized where runoff is expected to contain high levels of dissolved pollutants, such as metals or hydrocarbons or where prior subsurface contamination is evident. Increased hydraulic loading to contaminated soils can accelerate pollutant migration and/or leaching into underlying groundwater.

This matrix (Table 5-7) allows the designer to make an initial screen of practices most appropriate for a given land use.

Rural. This column identifies BMPs that are best suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre).

Residential. This column identifies the best treatment options in medium to high density residential developments.

Roads and Highways. This column identifies the best practices to treat runoff from major roadway and highway systems.

Commercial/High-density Development. This column identifies practices that are suitable for new commercial development.

LUHPPL. This column examines the capability of BMPs to treat runoff from designated LUHPPLs. BMPs that receive LUHPPL runoff may have design restrictions, as noted.

Ultra-urban Sites. This column identifies BMPs that work well in the ultra-urban environment, where space is limited and original soils have been disturbed. These BMPs are frequently used at redevelopment and infill sites.

Table 5-7 BMP Selection Matrix 1 – Land Use

BMP Group	BMP Design	Rural	Residential	Roads and Highways	Commercial/ High Density	LUHPPL	Ultra-urban
WVTS	Shallow WVTS	○	○	◗	◗	①	●
	Gravel WVTS	○	○	◗	◗	①	●
Infiltration	Infiltration Trench/Chambers	○	◗	○	○	●	◗
	Dry Wells	○	○	◗	◗	●	◗
	Shallow I-Basin	◗	◗	◗	◗	●	◗
	Permeable Pavement	○	○	◗	◗	②	◗
Filters	Sand Filter	◗	◗	◗	○	②	○
	Organic Filter	◗	◗	○	○	②	○
	Bioretention	○	◗	○	○	②	○
Green Roofs	Extensive	◗	◗	●	○	○	○
	Intensive	◗	◗	●	◗	○	○
Open Channels	Dry Swale	○	◗	○	◗	②	◗
	Wet Swale	○	◗	○	●	●	●

○: Yes. Good option in most cases.
◗: Depends. Suitable under certain conditions, or may be used to treat a portion of the site.
●: No. Seldom or never suitable.
①: Acceptable option, but may require a liner to reduce risk of groundwater contamination.
②: Acceptable option, if <u>not</u> designed as an exfilter. (An exfilter is a conventional stormwater filter without an underdrain system. The filtered volume ultimately infiltrates into the underlying soils.)

5.8.2 Step 2 - Physical Feasibility

Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP? In this step, the designer screens the BMP list using Matrix No. 2 (Table 5-8) to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site might limit the use of a BMP. For example, shallow WVTSs generally require a drainage area of 10 acres or more unless groundwater interception is likely, and can consume a significant land area.

This matrix allows the designer to evaluate possible options based on physical conditions at the site. More detailed testing protocols are often needed to confirm these conditions. Five primary factors are:

Soils. The key evaluation factors are based on an initial investigation of the NRCS hydrologic soil groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Water Table. This column indicates the minimum depth to the seasonal high water table from the bottom elevation, or floor, of a BMP.

Drainage Area. This column indicates the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for WVTSs should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope guidance refers to how flat the area where the practice is installed must be and/or how steep the contributing drainage area or flow length can be.

Head. This column provides an estimate of the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

Table 5-8 BMP Selection Matrix 2-Physical Feasibility

BMP Group	BMP Design	Soils	Water Table	Drainage Area (Ac)	Site Slope[1]	Head (Ft)
WVTS	Shallow/ Gravel WVTS	HSG A soils require liner	3 ft* separation if LUHPPL; OK to be in WT otherwise	10 min if not intercepting gw 5 min if not intercepting gw	No more than 8%	3 to 5 ft
Infiltration	Infiltration Trench/ Chamber	In-situ infiltration rate > 0.5 in/hr*[2]	2 ft* for strictly residential land uses; otherwise, 3 ft*	5 max	No more than 6%	1 ft
	Dry Well			<1		1ft
	Infiltration Basin			10 max		3 ft
	Permeable Pavement			NA	No more than 5%	NA
Filters	Sand Filter	OK	Bottom of filter at or above WT*	10 max **	No more than 6%	2 to 6 ft
	Organic Filter			5 max**		
	Bioretention	Made Soil				
Green Roofs	Extensive	NA	NA	NA	No more than 20%	NA
	Intensive				No more than 6%	
Open Channels	Dry Swale	Made Soil	Bottom of filter at or above WT*	5 max* to any 1 inlet, no limit if runoff enters via sheet flow	No more than 4%*, unless check dams are used	18 in - 5 ft
	Wet Swale	OK	below WT		Typically <1%, unless check dams are used	1 ft

Notes: OK= not restricted, WT= water table, NA = Not Applicable
* denotes a required limit, other elements are planning level guidance and may vary somewhat depending on site conditions.
**drainage area can be larger in some instances.

5.8.3 Step 3 – Watershed

What watershed protection goals need to be met by my project? Matrix No.3 outlines BMP goals and restrictions based on the resource being protected. This set of factors involves screening out those practices that might contradict overall watershed protection strategies, or eliminating management requirements where they are unnecessary or

[1] Refers to post-construction slope at the BMP site.
[2] Soil matrix must extend at least 3 feet below bottom of practice if being used to meet water quality criteria – if a deep soil profile does not exist, another BMP must be used prior to infiltration for treatment of WQ_v.

inappropriate. Regulatory requirements under the Clean Water Act, TMDL reduction requirements and/or interests from watershed associations may influence the type, location, and design requirements for stormwater management practices.

The design and implementation of stormwater management control measures is strongly influenced by the nature and sensitivity of the receiving waters. In some cases higher pollutant removal, more recharge or other environmental performance is warranted to fully protect the resource quality, human health and/or safety. Based on the discussions in Chapter Two, water resource areas include: *groundwater, freshwater streams and rivers, ponds, lakes, wetlands, and coastal waters.* Table 5-9 presents the key design variables and considerations that must be addressed for sites that drain to any of the above areas.

Table 5-9 BMP Selection Matrix 3-Watershed

BMP Group	**Receiving Waters**			
	Groundwater	**Freshwater Streams and Rivers**	**Other Freshwaters (Ponds/Lakes/ Wetlands)**	**Coastal Waters**
WVTS	Provide 3 ft GW elevation SD if LUHPPL or aquifer and pretreat LUHPPL at 100% of WQ_v, unless lined.	Overland erosion and channel protection necessary (CP_v). Restrictions on discharges in cold-water fisheries.	OK	Provide long ED (> 48 hrs) for maximum bacteria dieoff.
Infiltration	Must meet setbacks from water supply wells.	OK	OK, if site has appropriate soils. Highest TP removal.	OK, but TN removal is increased if placed within A or B soil horizon.
Filtering Systems	OK, ideal practice for pretreatment prior to infiltration.	Practices rarely can provide CP_v or Q_p, other detention needed.	OK, moderate to high TP removal.	OK, moderate to high bacteria and nitrogen removal.

BMP Group	Receiving Waters			
	Groundwater	**Freshwater Streams and Rivers**	**Other Freshwaters (Ponds/Lakes/ Wetlands)**	**Coastal Waters**
Open Channels	Pre-treat LUHPPL	OK, should be linked w/ basin to provide CP_v or Q_p.	OK, Wet Swale provides more TP removal than Dry Swale.	Swales provide moderate bacteria removal when installed in conjunction with aggressive pollution prevention programs. Dry Swales have higher TN removal.
Detention/Wet Basins	Does not meet WQ_v treatment requirements.	Often needed to provide CP_v or Q_p, unless discharging to a 4^{th}-order stream or larger.	Needed to provide CP_v or Q_p.	Generally not necessary for CP_v or Q_p.

SD = separation distance, ED = extended detention, GW = groundwater

5.8.4 Step 4 - Stormwater Management Capability

Can one BMP meet all design criteria, or is a combination of practices needed? In this step, designers can screen the BMP list using Matrix No. 4 (Table 5-10) to determine if a particular BMP can manage a wide range of storm frequencies. For example, the filtering practices are generally limited to water quality treatment and seldom can be utilized to meet larger stormwater management objectives. At the end of this step, the designer can screen the BMP options down to a manageable number and determine if a single BMP or a group of BMPs are needed to meet stormwater sizing criteria at the site.

This matrix examines the capability of each BMP option to meet stormwater management criteria. It shows whether a BMP can meet requirements for:

Recharge. The matrix indicates whether each practice can provide groundwater recharge, in support of recharge requirements. It may also be possible to meet this requirement using LID practices (see Chapter Four).

Water Quality. The matrix tells whether each practice can be used to provide water quality treatment effectively. For more detail, consult the pollutant removal table in Appendix H.

Channel Protection. The matrix indicates whether the BMP can typically provide channel protection storage. Finding that a particular BMP cannot meet the channel protection requirement does not necessarily imply that the BMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream stormwater detention basin).

Quantity Control. The matrix shows whether a BMP can typically meet the overbank and extreme event flooding criteria for the site. Again, if a particular BMP cannot meet these requirements does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream stormwater detention basin).

Table 5-10 BMP Selection Matrix 4-Stormwater Management Capability

BMP Group	BMP Design	Recharge?	Water Quality?	Channel Protection?	Flood Control?
WVTS	Shallow WVTS	●	○	○	○
	Gravel WVTS	●	○	○	○
Infiltration	Infiltration Trench/Chamber	○	❶	❸	❹
	Shallow I-Basin	○	❶	❸	❹
	Drywell	○	❶	❸	❹
	Permeable Pavement	○	❶	❸	❹
Filters	Sand Filter	❷	○	❸	●
	Organic Filter	❷	○	●	●
	Bioretention	❷	○	❸	●
Green Roofs	Extensive	●	○	●	●
	Intensive	●	○	❸	●
Open Channels	Dry Swale	❷	○	●	●
	Wet Swale	●	○	❸	●

○ Practice generally meets this stormwater management goal.
● Practice can almost never be used to meet this goal.
❶ Only provides water quality treatment if bottom of practice is in the soil profile and separated by at least 3 feet from the SHGT or bedrock (only 2 ft SD required for strictly residential land uses); if the in-situ infiltration rate ≥ 8.3 in/hr, a separate BMP is needed to provide treatment of 100% WQv.
❷ Provides recharge only if designed as an exfilter system.
❸ Practice may partially meet this goal, or under specific site and design conditions.
❹ Can be used to meet flood control in highly permeable soils.

5.8.5 Step 5 - Community and Environmental Benefit

Do the remaining BMPs have any important community or environmental benefits or drawbacks that might influence the selection process? In this step, a matrix is used to compare the BMP options with regard to maintenance, cost, community acceptance, safety, and habitat. Some practices can have significant secondary environmental impacts that might preclude their use in certain situations. Likewise, some practices have frequent maintenance and operation requirements that are beyond the capabilities of the owner. For example, infiltration practices are generally considered to have the highest maintenance burden because of a high failure history and consequently, a higher pretreatment maintenance burden and/or replacement burden.

This last step assesses community and environmental benefits involved in BMP selection. This matrix employs a comparative index approach. An open circle indicates that the BMP has a high benefit, and a dark circle indicates that the particular BMP has a low benefit.

Maintenance. This column assesses the relative maintenance effort needed for a practice, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging) and reported failure rates. It should be noted that all BMPs require routine inspection and maintenance.

Affordability. The BMPs are ranked according to their relative construction cost per impervious acre treated. These costs exclude design, land acquisition, and other costs.

Community Acceptance. This column assesses community acceptance, as measured by three factors: market and preference surveys, reported nuisance problems, and visual orientation (i.e., is it prominently located or is it in a discrete underground location). It should be noted that a low rank can often be improved by a better planting plan.

Safety. A comparative index that expresses the relative public safety of a BMP. An open circle indicates a reasonably safe BMP, while a darkened circle indicates deep pools may create potential public safety risks. The safety factor is included at this stage of the screening process because liability and safety are of paramount concern in many residential settings.

Habitat. BMPs are evaluated on their ability to provide wildlife habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, and vegetative cover of the BMP and the surrounding area.

Table 5-11 BMP Selection Matrix 5-Community and Environmental Benefit

BMP Group	BMP List	Ease Of Maintenance	Affordability	Community Acceptance	Safety	Habitat
WVTS	Shallow WVTS	○	◗	○	◗	○
	Gravel WVTS	◗	●	○	○	○
Infiltration	Infiltration Trench/Chambers	●	◗	○	○	●
	Drywell	○	○	○	○	●
	Shallow I-Basin	●	◗	●	○	●
	Permeable Pavement	●	◗	○	○	●
Filters	Sand Filter	●	●	◗	○	●
	Organic Filter	◗	●	○	○	◗
	Bioretention	◗	◗	◗	○	◗
Green Roofs	Extensive	◗	◗	○	○	◗
	Intensive	◗	●	○	○	○
Open Channels	Dry Swale	◗	◗	○	○	●
	Wet Swale	○	○	◗	◗	◗

○ High Benefit
◗ Medium Benefit
● Low Benefit

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6.0 PRETREATMENT PRACTICES

6.1 Design Elements for Pretreatment Practices

There are several stormwater management practices that do not meet the water quality performance Standard 3 and therefore cannot be used to treat the water quality volume, but may be useful to provide pretreatment. Pretreatment BMPs are designed to improve water quality and enhance the effective design life of practices by consolidating the maintenance to a specific location, but do not meet the pollutant removal targets on their own. Pretreatment practices must be combined with an acceptable water quality BMP from Chapter Five to meet the water quality criteria.

This section presents two types of criteria for pretreatment BMPs—required design elements and design guidelines. Required design elements are features that shall be used in all applications. If required design criteria for a particular pretreatment BMP cannot be met at a site, an alternative pretreatment BMP must be selected, or adequate justification must be provided to the approving agency why the particular criteria is not practicable. Design guidance includes features that enhance practice performance, and are therefore optional and might not be necessary for all applications. In cases where the practice is a proprietary product, specifications and design criteria can typically be obtained from vendors. The figures and photographs included in this chapter are schematic graphics only. Design plans should be consistent with the schematic figures when using the method or practice described, but must be completely detailed by the designer for site-specific conditions and construction purposes.

6.2 Grass Channel

Grass channels are similar to conventional drainage ditches, with the major differences being flatter side and longitudinal slopes, as well as a slower design velocity for small storm events. The best application of a grass channel is as pretreatment to other structural stormwater treatment practices (adapted from the CWP, 2008).

6.2.1 Feasibility

<u>Design Guidance</u>

- Grass channels can be applied in most development situations with few restrictions, and are well-suited to treat highway or residential road runoff due to their linear nature.
- LUHPPL runoff should not be directed toward grass channels (particularly for pervious soils and shallow groundwater), unless they are lined to prevent infiltration.

6.2.2 Design

<u>Required Elements</u>

- Sizing of the grass channel length is based on flow rate from the water quality storm

(WQ_f) and should be designed to ensure an average residence time of ten (10) minutes to flow from the inlet to the outlet of the channel (for linear projects with no defined primary inflow location, residence time shall be measured from the mid-point location of the channel).

Design Guidance

- Channels should generally have a trapezoidal or parabolic cross section with relatively mild side slopes (generally, flatter than 3:1). Designing the channel with mild side slopes also maximizes the wetted perimeter. The wetted perimeter is the length along the edge of the channel cross section where runoff flowing through the channel is in contact with the vegetated sides and bottom of the channel. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage filtering and infiltration. Another advantage of mild side slopes is that runoff entering the grass channel from the side receives additional pretreatment along the side slope. The bottom of the channel should be between two and eight feet wide. The minimum width ensures a minimum filtering surface for water quality treatment, and the maximum width prevents braiding, the formation of small channels within the channel bottom.
- Channels should have at least 18” separation from seasonal high groundwater.
- A small forebay should be used upstream of the channel to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river-run gravel) can also be used to pretreat runoff that enters the sides of the channel.
- Two other design features that enhance the treatment ability of grassed channels are a mild longitudinal slope (generally between 1% and 2%) and a dense vegetative cover in the channel. The mild slope helps to reduce the velocity of flow in the channel. The dense vegetation also helps reduce flow velocities, protects the channel from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel before the turf has been established, either with a temporary grass cover, or the use of natural or synthetic erosion control products.
- Typical designs allow the runoff from the 1-year storm to flow through the grass channel without causing erosion.
- Grass channels should also have the capacity to pass larger storms (typically a 10-year storm) safely.

6.2.3 Maintenance

Required Elements

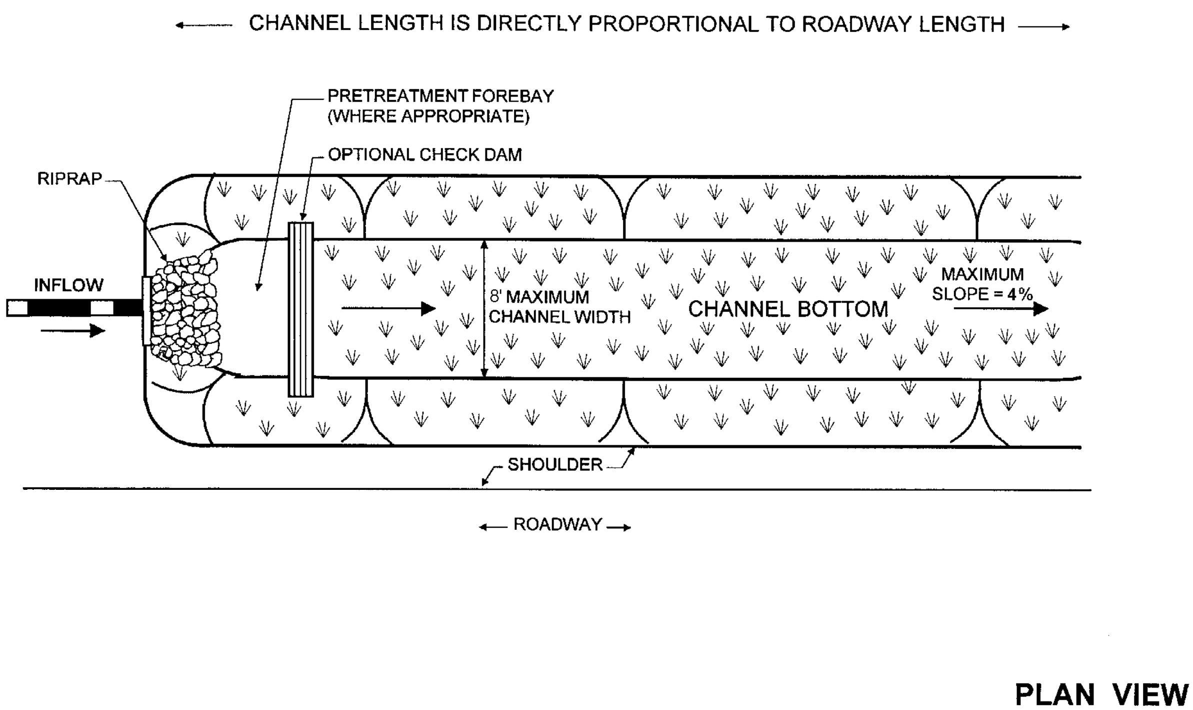
- The lifetime of grass channels is directly proportional to the maintenance frequency. The maintenance objective for this practice includes preserving or retaining the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover. The following activities shall be performed on an annual basis or more frequently as needed:
  - Sediment removal;
  - Mowing and litter and debris removal; and/or

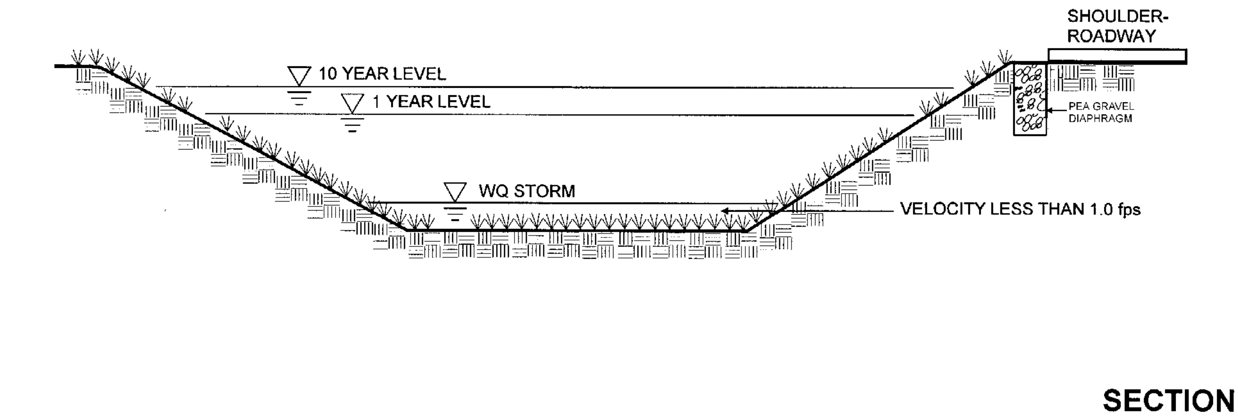
- Stabilization of eroded side slopes and bottom.

Design Guidance

- The following maintenance activities should be performed on an annual basis or more frequently as needed:
  - Nutrient and pesticide use management;
  - Dethatching swale bottom and removal of thatching; and/or
  - Discing or aeration of channel bottom.
- When sediment accumulates to a depth of approximately ¼ of the original design depth, it should be removed, and the channel should be reconfigured to its original dimensions.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility.
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.
- The grass in the channel should be mowed at least 2 times during the growing season.
- If the surface of the grass channel becomes clogged to the point that standing water is observed on the surface 48 hours after precipitation events, the bottom should be roto-tilled or cultivated to break up any hard-packed sediment, and then reseeded.
- Trash and debris should be removed and properly disposed.

Figure 6-1 Grass Channels





Adapted from MDE, 2000

6.3 FILTER STRIPS

Filter strips (i.e., vegetated filter strips, grass filter strips, and grassed filters) are vegetated areas that are intended to treat sheet flow from adjacent impervious areas. Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice, and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide effective pretreatment. One challenge associated with filter strips, however, is that it is difficult to maintain sheet flow. Consequently, urban filter strips are often "short circuited" by concentrated flows, which results in little or no treatment of stormwater runoff (adapted from the CWP, 2008).

6.3.1 Feasibility

Design Guidance

- Filter strips are restricted in some watersheds where land is not available to install them.
- Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal pretreatment to another stormwater treatment practice.
- In general, filter strips should not accept LUHPPL runoff to prevent groundwater contamination, particularly for pervious soils with shallow groundwater.

6.3.2 Design

Required Elements

- The filter strip must abut the entire length of the contributing area to ensure that runoff from all portions of the site are treated.

<u>Design Guidance</u>

- Filter strips should be designed according to Table 6-1.

Table 6-1 Guidelines for Filter Strip Pretreatment Sizing

Parameter	Impervious Parking Lots				Residential Lawns			
Maximum Inflow Approach Length (ft)	35		75		75		150	
Filter Strip Slope (%)	<2	>2	<2	>2	<2	>2	<2	>2
Filter Strip Minimum Length (ft)	10	15	20	25	10	12	15	18

- Smaller/shorter filter strips may be considered for projects with a specifically enhanced maintenance program.
- Typically, filter strips are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the filter strip treats but rather the length of flow contributing to it. As stormwater runoff flows over the ground's surface, it changes from sheet flow to concentrated flow. That is, rather than moving uniformly over the surface, it forms rivulets which are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (Claytor and Schueler, 1996).
- Filter strips should be designed on slopes between 2% and 4%. Greater slopes than this would encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff tends to pond on the surface of filter strips. Slopes flatter than 2% may result in puddling and other nuisance problems. Slopes may be between 4 and 6% but will require erosion control matting and a detailed engineering evaluation.
- Filter strips should not be used on soils with a high clay content because they require some infiltration for proper treatment. Another possible limiting factor would be very poor soils that cannot sustain a grass cover crop.
- Filter strips used at LUHPPLs should be separated from the groundwater by a minimum of three feet to prevent contamination. All other filter strips should be separated from the groundwater by 18”.
- Designers should choose a grass that can withstand relatively high velocity flows, and both wet and dry periods. See Appendix B for appropriate plantings/grasses for open channels and filter strips.
- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.
- To improve the pretreatment capabilities of a filter strip, a pea gravel diaphragm may be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it settles out sediment particles before they reach the practice. Second it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

6.3.3 Maintenance

Maintenance is very important for filter strips, particularly in terms of ensuring that flow does not short circuit the practice.

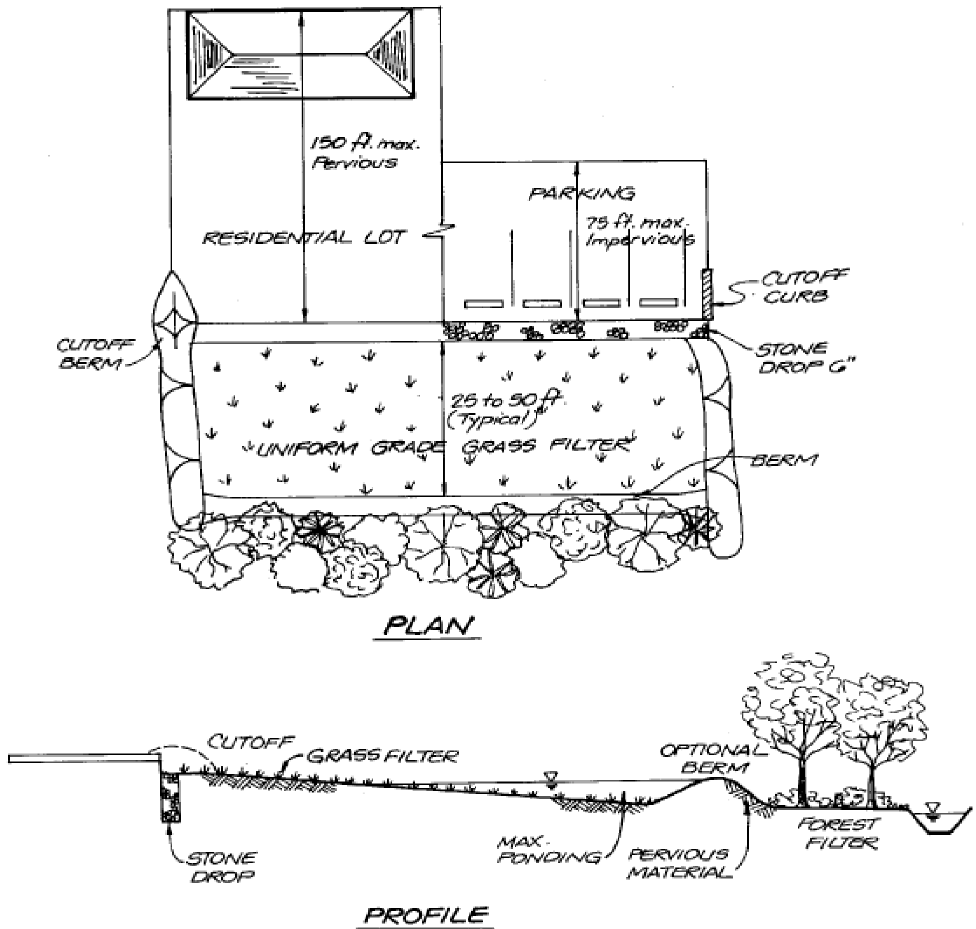
Required Elements

- Ensure that grass has established; if not, replace with an alternative species.
- Filter strips shall be inspected at least quarterly during the first year of operation and semiannually thereafter. Evidence of erosion and concentrated flows within the filter strip must be corrected immediately. Eroded spots must be reseeded and mulched to enhance a vigorous growth and prevent future erosion problems.
- The bulk of accumulated sediments will be trapped at the initial entry point of the filter strip. These deposited sediments shall be removed manually at least once per year or when accumulating sediments cause a change in the grade elevation. Reseeding may be necessary to repair areas damaged during the sediment removal process.
- Filter strips, or areas proposed as such, must be protected by proper soil erosion and sediment control techniques (e.g., hay bales and silt fences) during all phases of construction. These measures must be properly maintained until final site stabilization and subsequent removal of all trapped sediments has occurred.

Design Guidance

- Procedures for soil preparation and seeding should be done in accordance with the most recent version of the Permanent Vegetative Cover section in Chapter 4 of the *RI Soil Erosion and Sediment Control Handbook.*
- Grass filter strips should be mowed approximately 2 to 4 times a year, leaving vegetation a minimum of 4 inches in height. Mowing operations are to be conducted during the growing season, but preferably after mid-August. This management technique maintains a tall vigorous growth.
- Filter strips provide a convenient area for snow storage and treatment. If used for this purpose, vegetation in the filter strip should be salt tolerant, (e.g., creeping bentgrass), and a maintenance schedule should include the removal of sand built up at the bottom of the slope.

Figure 6-2 Filter Strip



Source: Claytor and Schueler, 1996

6.4 Sediment Forebay

A sediment forebay can be used as a pretreatment device to minimize maintenance needs for stormwater BMPs. The purpose of the forebay is to provide pretreatment by settling out sediment particles. This will enhance treatment performance, reduce maintenance, and increase the longevity of a storm water facility. A forebay is a separate cell within the facility formed by a barrier such as an earthen berm, concrete weir, or gabion baskets.

6.4.1 Design

Required Elements

- The required surface area of the sediment chamber or forebay shall be determined using the following equation that is based on Camp-Hazen.

$$A_s = -\frac{Q}{W}\ln(1-E)$$

where:
A_s = sedimentation surface area (ft^2)
Q = discharge from drainage area (ft^3/s) = %WQv[1]/86,400 sec
W = 0.0004 ft/s particle settling velocity recommended for silt
E = sediment removal efficiency (assume 0.9 or 90%)

[1]The percent of the water quality volume used for the sediment forebay design depends on which treatment BMP is being used. See Chapter Five for the required pretreatment percentage.

Therefore, for the purposes of this manual, use:

$$A_S = 5{,}750 * Q$$

- The forebay shall have a minimum length to width ratio of 1:1 and a preferred minimum length to width ratio of 2:1 or greater. Designers shall calculate scour potential and provide riprap sizing calculations (diameter required to effectively dissipate erosive velocities).
- The forebay shall be sized to contain at least 10% of the WQ_v (depending on the requirements of the treatment BMP) and be of an adequate depth to prevent resuspension of collected sediments during the design storm, often 4 to 6 ft deep. Shallower depths shall be evaluated such that flow-through velocities do not exceed 2 ft/sec for all design storms up to the 100-year storm. The goal of the forebay is to at least remove particles consistent with the size of medium sand.

<u>Design Guidance</u>

- A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the downgradient stormwater treatment practice. This barrier should be armored as necessary to prevent erosion of the embankment if it is designed to overtop. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion. If a channel is used to convey flows from the forebay to the facility, the side slopes of the channel must be armored as well.
- The outlet from the forebay should be designed in a manner to prevent erosion of the embankment and primary pool. This outlet can be configured in a number of ways, such as a culvert, weir, or spillway channel. The outlet should be designed to convey the same design flow proposed to enter the structure. The outlet invert should be elevated in a manner such that 10% of the WQ_v as well as the required sediment volume can be stored below it.
- The sediment forebay may be designed with a permanent pool.

6.4.2 Maintenance

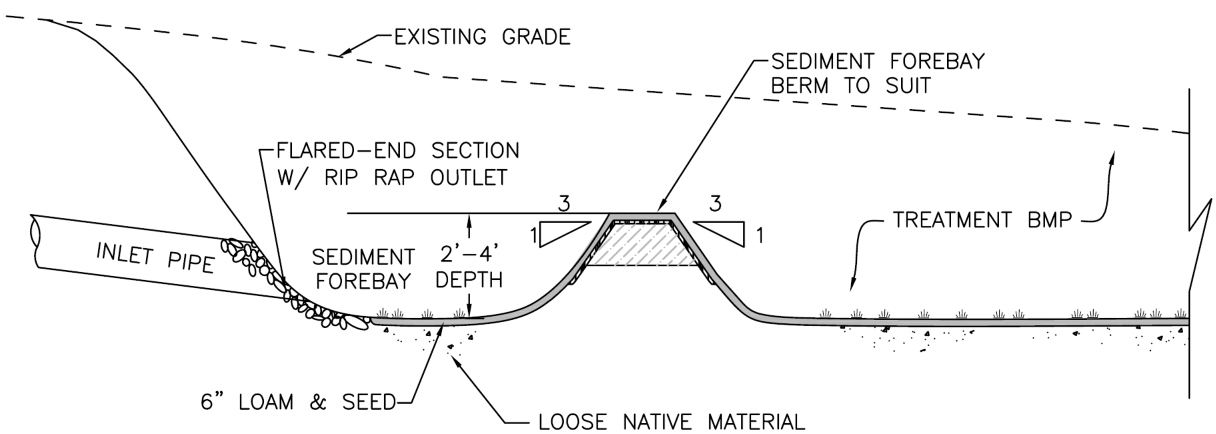
Required Elements

- Direct access for appropriate maintenance equipment needs to be provided to the forebay and may include a ramp to the bottom of the embankment if equipment cannot reach all points within the forebay from the top of the embankment. The forebay can be lined with a concrete pad to allow easy removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.

Design Guidance

- A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.
- The bottom of the forebay may be hardened (i.e., concrete, asphalt, grouted riprap) to make sediment removal easier.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility or handled similarly to contents from street sweeping activities (see Appendix G.4.1).
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.

Figure 6-3 Sediment Forebay



6.5 Deep Sump Catch Basins

Deep sump catch basins are modified inlet structures that can be installed in a piped stormwater conveyance system to remove trash, debris, and coarse sediment. They can also serve as temporary spill containment devices for floatables such as oils and greases, but shall not be used in place of an oil grit separator for LUHPPLs that have the potential to generate runoff with high concentrations of oil and grease.

6.5.1 Feasibility

Required Elements

- The deep sump catch basin must be designed in a catch basin-to-manhole configuration (NOT in a catch basin-to-catch basin configuration) to be used as pretreatment for other BMPs. Catch basin-to-catch basin or inlet-to-inlet configurations are acceptable, but they cannot be counted as a pretreatment practice.
- The contributing drainage area to each deep sump catch basin shall not exceed 0.5 acres of impervious cover.

Design Guidance

- Potential site constraints include the presence of utilities, bedrock, and high groundwater elevations.
- Inlet capacity sizing requirements on steep slopes.

6.5.2 Design

Required Elements

- The deep sump shall be a minimum 4-ft deep below the lowest pipe invert or four times the diameter of the outlet pipe, whichever value is greater.
- The inlet grate shall be sized based on the contributing drainage area to ensure that the flow rate does not exceed the capacity of the grate. The grate shall not allow flow rates greater than 3 cfs for 10-year storm event to enter the sump.
- Inlet grates designed with curb cuts must reach the back of the curb cut to prevent flow bypass.
- Hooded outlets shall be used in high litter land uses. Care shall be taken to avoid damaging and displacing hoods during cleaning.

Design Guidance

- The inlet grate should have openings not more than 4 square inches to prevent large debris from collecting in the sump.

6.5.3 Maintenance

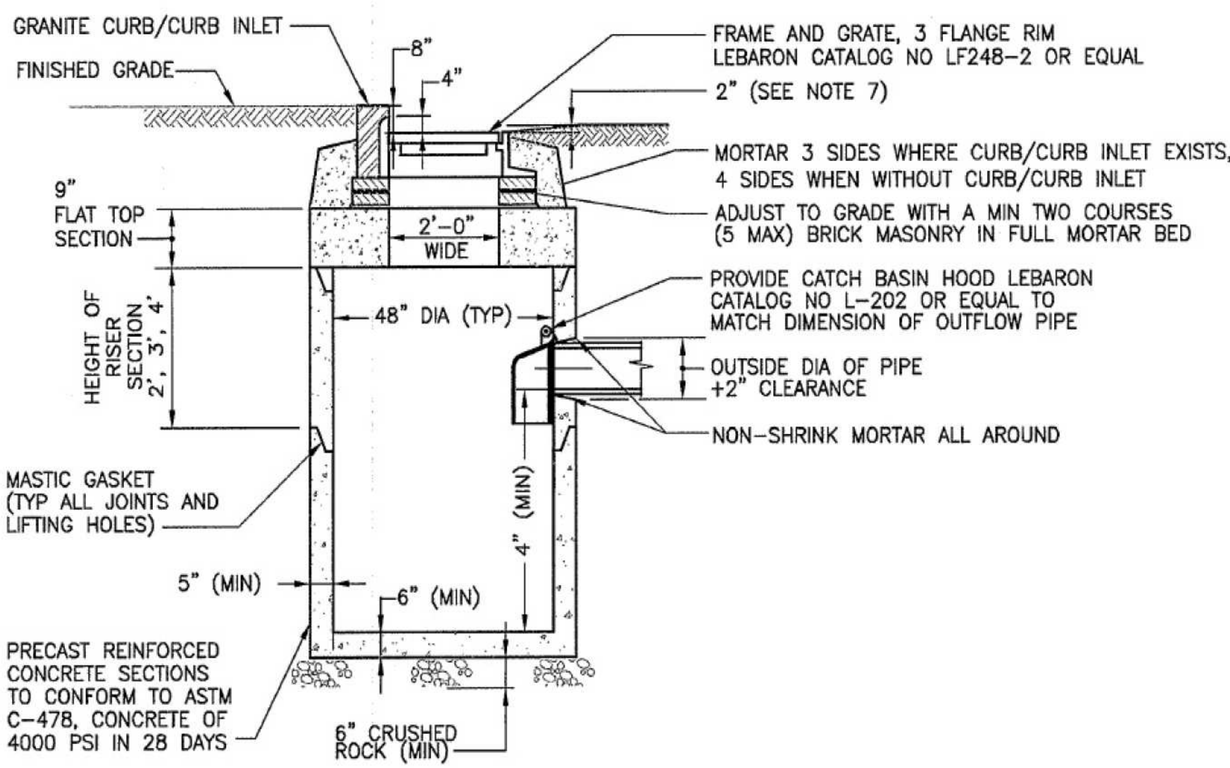
Required Elements

- Inspections shall be performed a minimum of 2 times a year (spring/fall). Units shall be cleaned annually and whenever the depth of sediment is greater than or equal to half the sump depth.
- The inlet grate shall not be welded to the frame so that the sump can be easily inspected and maintained.
- Sufficient maintenance access shall be considered when designing the geometry of deep sump catch basins.

Design Guidance

- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility.
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.

Figure 6-4 Deep Sump Catch Basin (MADEP, 2008)



6.6 PROPRIETARY DEVICES

Many proprietary devices have been developed over the years in an attempt to provide cost-effective stormwater treatment, particularly for retrofit situations, including oil/grit separators, hydrodynamic devices, and a range of media filtration devices, among others. Recent studies (Schueler, 2000; Claytor, 2000; UNHSC, 2007) have shown that these proprietary devices are not capable of achieving the required water quality performance required by Minimum Standard 3 or that there is insufficient documentation to add these practices to the list of acceptable water quality BMPs as documented in Chapter Five. However, they may provide pretreatment for stormwater before it is directed to a water quality BMP if an independent third-party monitoring group (e.g., MASTEP, ETV, TARP) verifies that it removes a minimum of 25% TSS for the WQ_v or WQ_f. Oil/grit separators are particularly useful pretreatment practices for runoff from LUHPPLs that are expected to have high pollutant loads of oils and grease. Any manufacturer who wishes to get a proprietary device approved for use as a water quality treatment device to meet Minimum Standard 3 should follow the protocol included in Appendix J.

While proprietary devices must be designed per the manufacturer's recommendations, the following design requirements and guidance apply.

6.6.1 Feasibility

Required Elements

- To qualify as an acceptable pretreatment device, proprietary devices shall remove a minimum of 25% TSS, as verified by an independent third-party monitoring group. In certain retrofit cases and other cases where higher pretreatment standards may be appropriate, higher removal efficiency for TSS may be required in order to achieve stormwater treatment goals for the project.
- Proprietary devices shall be designed per the manufacturer's recommendations.
- Proprietary devices must be designed as off-line systems or have an internal bypass to avoid large flows and resuspension of pollutants in order to be used as pretreatment for other BMPs.

Design Guidance

- The contributing drainage area to each proprietary device should generally not exceed 1 acre of impervious cover.
- Potential site constraints include the presence of utilities, bedrock, and high water tables.
- Proprietary devices such as oil/grit separators should be used at LUHPPLs that are expected to have high pollutant loads of oils and grease prior to treatment by a water quality BMP.

6.6.2 Design

Required Elements

- Flow-through proprietary devices shall be designed to treat runoff from the entire WQ_f. For these devices, a minimum detention time of 60 seconds is required for the WQ_f.
- A storage proprietary device shall be sized based on the required pretreatment volume (% WQ_v) or a designer must provide documentation that it is sized appropriately for a verified minimum removal of 25% TSS.
- For proprietary devices such as oil/grit separators, all baffles shall be tightly sealed at sidewalls and at the roof to prevent the escape of oil.

Design Guidance

- Roof drains should bypass proprietary devices.

6.6.3 Maintenance

Required Elements

- Proprietary devices shall be maintained in accordance with manufacturers' guidelines.
- Proprietary devices shall be located such that it is accessible at times for maintenance and/or emergency removal of oil or chemical spills.
- Inspections shall be performed a minimum of 2 times a year. Devices shall be cleaned when pollutant removal capacity is reduced by 50% or more, or where 50% or more of the pollutant storage capacity is filled or displaced. Hazardous debris removed shall be disposed of in accordance with State and federal regulations by a properly licensed contractor.

Figure 6-5 Oil and Grit Separator (MassHighway, 2004)

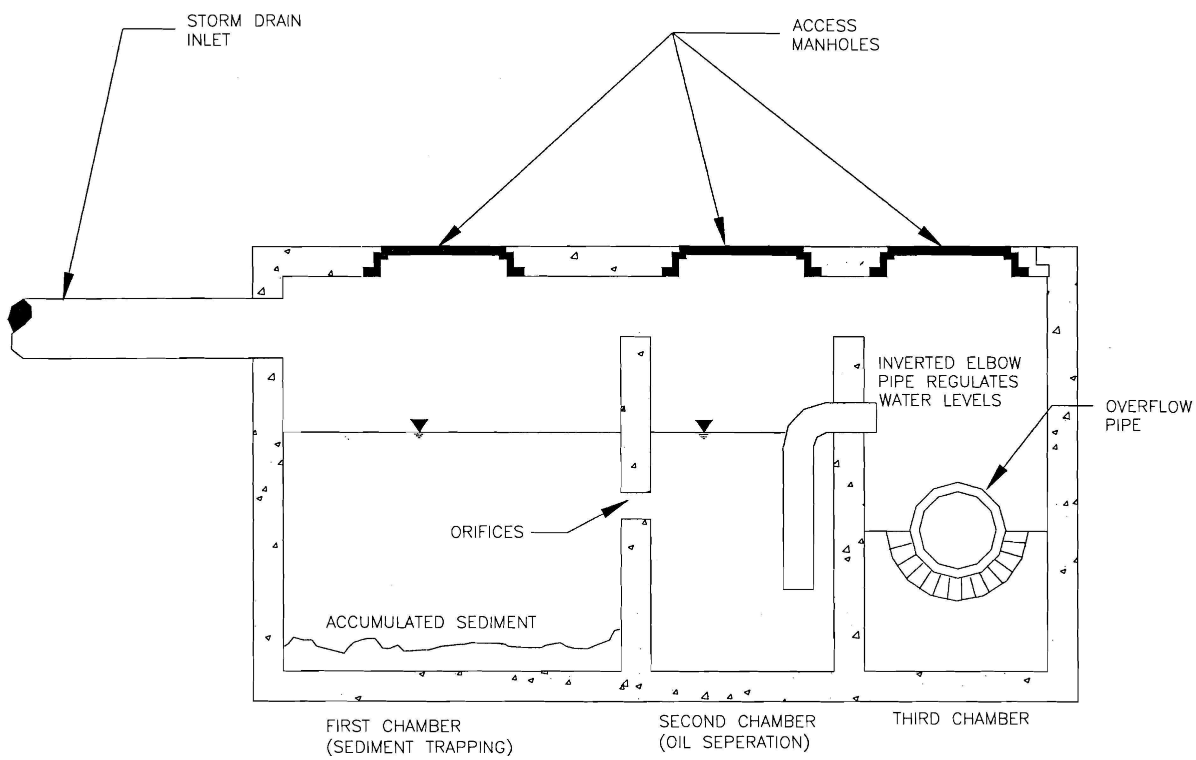
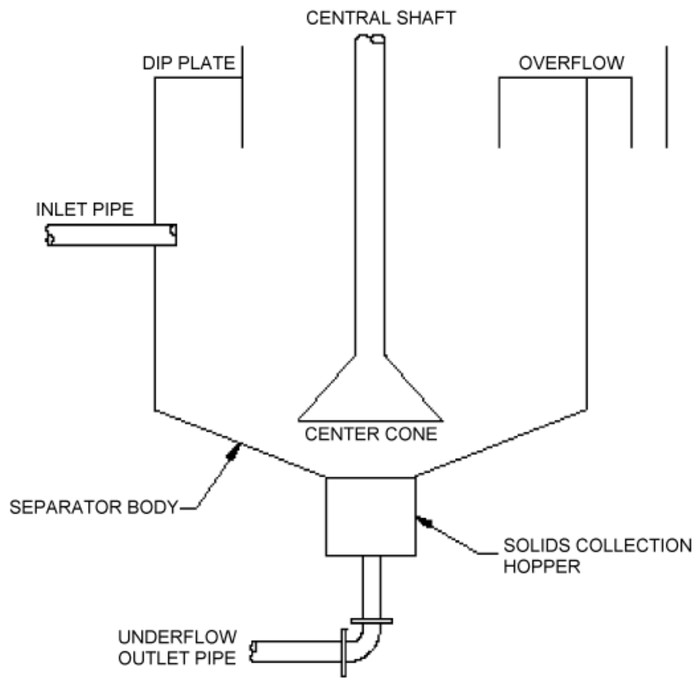


Figure 6-6 Hydrodynamic Device



Source: MDE, 2000

7.0 STORAGE PRACTICES FOR STORMWATER QUANTITY CONTROL

7.1 DESIGN ELEMENTS FOR STORAGE PRACTICES

In addition to the pretreatment practices described in Chapter Six, there are also stormwater management practices that do not meet the water quality performance Standard 3, but may be used to meet stormwater quantity control criteria (i.e., storage for CP_v and Q_p). The "storage" practices included in this chapter are explicitly designed to provide stormwater detention; these practices can be used to meet channel protection and flood protection, but must be combined with other BMPs for meeting water quality and recharge criteria.

This section presents two types of criteria for storage BMPs—required design elements and design guidelines. Required design elements are features that shall be used in all applications. If required design criteria for a particular storage BMP cannot be met at a site, an alternative storage BMP must be selected, or adequate justification must be provided to the approving agency why the particular criteria is not practicable. Design guidance includes features that enhance practice performance, and are therefore optional and might not be necessary for all applications. In cases where the practice is a proprietary product, specifications and design criteria can typically be obtained from vendors. The figures and photographs included in this chapter are schematic graphics only. Design plans should be consistent with the schematic figures when using the method or practice described, but must be completely detailed by the designer for site-specific conditions and construction purposes.

7.2 STORMWATER BASINS

All stormwater basin design variations can be used to provide channel protection volume (CP_v) as well as overbank flood attenuation (Q_p) but are not an acceptable option for meeting water quality treatment goals. However, see inset in Section 7.2.3 for information regarding using basins where additional pollutant removal may be required. Two design variants include: Dry Extended Detention Basins and Wet Extended Detention Basins. Wet basins may be located in the groundwater table; dry basins do not need a permanent pool and may be designed such that the groundwater table is at or below the bottom of the basin.

7.2.1 Feasibility

<u>Required Elements</u>

- Wet Extended Detention Basins shall have a minimum contributing drainage area of 25 acres, unless groundwater is intercepted.
- Stormwater basins shall not be located within jurisdictional waters, including wetlands, except that on already developed sites basin designs may be allowed in

jurisdictional upland buffers in areas already altered under existing conditions, if acceptable to the approving agency.

- The use of basins in watersheds draining to cold-water fisheries is restricted to prohibit discharges within 200 feet of streams and any contiguous natural or vegetated wetlands. Discharges beyond 200 feet shall be designed to discharge the CP_v through an underdrained gravel trench outlet, as depicted in Figure 5-4. Additional storage for Q_p may be discharged through traditional basin outlet structures.
- Basins receiving runoff from LUHPPLs must be lined and shall not intercept groundwater.
- Basins that do intercept groundwater (allowed as long as not receiving runoff from LUHPPLs) shall not include the volume of the permanent pool in storage calculations.

Design Guidance

- Assess the hazard classification[1] of the structure and consider alternative placement and/or design refinements to reduce or eliminate the potential for designation as a significant or high hazard dam.
- The permanent pool of wet basins should have a minimum 4-foot depth and hold a minimum 0.5"/impervious acre draining to the basin for aesthetics and ease of maintenance.

7.2.2 Conveyance

Inlet Protection

Design Guidance

- A forebay may be provided at each inlet.
- Inlet areas should be stabilized to ensure that non-erosive conditions exist for at least the 1-year frequency storm event.
- Partially submerged (i.e., ½ full) inlet pipes are acceptable and can limit erosive conditions.

Adequate Outfall Protection

Required Elements

- The channel immediately below a basin outfall shall be modified to prevent erosion

[1] "Hazard classification" is a rating for a dam that relates to the probable consequences of failure or misoperation based on an assessment of loss of human life and damages to properties or structures located downstream of an impoundment. A proposal to construct an impoundment having a dam 6 feet in height or more, or a capacity of 15 acre-feet or more, or that is a significant or high hazard dam may subject the applicant to additional requirements in accordance with the RIDEM Dam Safety Program and the State's Dam Safety Regulations.

and conform to natural dimensions in the shortest possible distance, typically by use of appropriately sized riprap placed over filter cloth.

- A stilling basin or outlet protection shall be used to reduce flow velocities from the principal spillway to non-erosive velocities (3.5 to 5.0 fps).
- Outfalls, where needed, shall be constructed such that they do not increase erosion or have undue influence on the downstream geomorphology of any natural watercourse by discharging at or near the stream water surface elevation or into an energy dissipating step-pool arrangement.
- All basins shall have an emergency outlet to accommodate the storm flow in excess of the 100-year storm event maintaining at least one foot of freeboard between the peak storage elevation and the top of the embankment crest, and to safely convey the 100-year storm without overtopping the embankment.

Design Guidance

- If a basin discharges to a watercourse 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.

Basin Liners

Design Guidance

- When a wet basin is located in medium to coarse sands or more permeable parent material, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include: (a) 6 to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1×10^{-5} cm/sec), (b) a 30 mil poly-liner (c) bentonite, or (d) use of chemical additives.

7.2.3 Treatment

Required Elements

- Stormwater basins shall not be used for meeting the water quality treatment standard (see inset on following page regarding using basins where additional pollutant removal may be required).

Design Guidance

- It is generally desirable to provide the upstream water quality treatment off-line when topography, head, and space permit.
- Additional treatment can be provided within these practices when multiple 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 shallow water).

Using Basins for Additional Pollutant Loading Reduction

In order to use the removal rates for basins as listed in Appendix H.3 (Pollutant Loading Analyses) Table H-4, the following design criteria must be met.

Pretreatment

Required Elements

- Each basin shall have a sediment forebay or equivalent upstream pretreatment. The forebay shall be sized to contain 10% of the water quality volume (WQ_v) sized per Chapter 6. The forebay storage volume counts toward the total WQ_v requirement.

Treatment

Required Elements

- The minimum detention time for the WQ_v shall be 24 hours.
- Storage for the channel protection volume (CP_v) and the WQ_v shall be computed and routed separately (i.e., the WQ_v cannot be met simply by providing CP_v storage for the one-year storm).
- Provide water quality treatment storage to capture the computed WQ_v from the contributing drainage area through a combination of permanent pool and extended detention, as outlined in Table 7-1.

Table 7-1. Minimum Required Storage Volumes for Basins Used for Enhanced Pollutant Removal

Design Variation	%WQ_v	
	Permanent Pool	Extended Detention
Dry Extended Detention Basin	20% min.	80% max.
Wet Extended Detention Basin	50% min.	50% max.

Design Guidance

- Water quality storage can 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, extended detention, and shallow water).

Minimum Basin Geometry

Required Elements

- The minimum length to width ratio for a basin shall be 1.5:1 (i.e., length relative to width).
- Provide a minimum Drainage Area: Surface Area Ratio of 75:1.
- Incorporate an aquatic bench that extends up to 15 feet inward from the normal edge of water, has an irregular configuration, and a maximum depth of 18 inches below the normal pool water surface elevation (see Figure 5-5).

Design Guidance

- To the greatest extent possible, maximize flow path through the system, and design basins with irregular shapes.

- Where a TMDL or CRMC goal requires maximum treatment, applicants may need to design wet basins for enhanced treatment through the use of increased permanent pool storage volume, complex geometry, and vegetation plantings.

7.2.4 Minimum Basin Geometry

Design Guidance

- To the greatest extent possible, should maximize flow path through the system, and design basins with irregular shapes.

7.2.5 Vegetation

Basin Benches

Required Elements

- The perimeter of all deep pool areas (four feet or greater in depth) shall be surrounded by a safety bench. Except when basin side slopes are 4:1 (h:v) or flatter, provide a safety bench that generally extends 15 feet outward (a 10' minimum bench is allowable on sites with extreme space limitations at the discretion of the approving agency) from the normal water edge to the toe of the basin side slope. The maximum slope of the safety bench shall be 6%.

Design Guidance

- Design should incorporate an aquatic bench that extends up to 15 feet inward from the normal edge of water, has an irregular configuration, and a maximum depth of 18 inches below the normal pool water surface elevation.

Planting Plan

Required Elements

- A planting plan for a stormwater basin and its setback shall be prepared to indicate how the basin perimeter will be stabilized and established with vegetation.

Design Guidance

- Wherever possible, emergent plants should be encouraged in a basin design, either along the aquatic bench, the safety bench and side slopes or within shallow areas of the pool itself.
- The best elevations for establishing emergent plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.
- The soils of a basin setback are often severely compacted during the construction process to ensure stability. The density of these compacted soils is so great that it effectively prevents root penetration, and therefore, may lead to premature mortality

or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and backfill these with uncompacted topsoil.
- Planting holes should be the same depth as the root ball and two to three times wider than the diameter of the root ball. In addition, the root ball of container-grown stock should be gently loosened or scored along the outside layer or roots to stimulate new root development. This practice should enable the stock to develop unconfined root systems. Avoid species that require full shade or are prone to wind damage. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds (Save the Bay, 1999).

7.2.6 Basin Setbacks

Required Elements

- A basin setback from structures, roads, and parking lots shall be provided that extends 25 feet outward from the maximum water surface elevation of the basin.
- Woody vegetation shall not be planted or allowed to grow on a dam, or within 15 feet of a dam or toe of the embankment, or within 25 feet of a principal spillway outlet (see footnote in Section 5.2.2 for more guidance on dam structures).

Design Guidance

- An additional setback may be provided to permanent structures.
- Existing trees should be preserved in the setback area during construction. It is desirable to locate forest conservation areas adjacent to basins. To help encourage reforestation, the setback can be planted with trees, shrubs, and native groundcover.

7.2.7 Maintenance

Required Elements

- Maintenance responsibility for a basin and its setback shall be vested with a responsible authority by means of a legally binding and enforceable maintenance agreement that is executed as a condition of plan approval.
- The principal spillway shall be equipped with a removable trash rack, and generally accessible from dry land.
- A maintenance right-of-way or easement shall extend to a basin from a public or private road.
- Sediment shall be removed from stormwater basins when the sediment volume exceeds 10% of the total basin volume and should be disposed of according to an approved comprehensive operation and maintenance plan.
- For discharges beyond 200 ft from streams (and any contiguous natural or vegetated wetlands) in cold-water fisheries, the gravel trench outlet shall be inspected after every storm in the first 3 months of operation to ensure proper function. Thereafter, the trench shall be inspected at least once every six months. Inspection shall consist of verifying that the wet basin is draining to the permanent

pool elevation within the 24-hour design requirement and that potentially clogging material, such as accumulation of decaying leaves or debris, does not prevent the discharge through the gravel. When clogging occurs, at least the top 8 inches of gravel shall be replaced over with new material. Sediments shall be disposed of in an acceptable manner.
- Annual mowing of the basin setback is only required along maintenance rights-of-way and the embankment. The remaining setback can be managed as rangeland (mowing every other year) or forest.

Design Guidance

- Sediments excavated from stormwater basins that do not receive runoff from designated LUHPPL are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be required prior to sediment disposal when a LUHPPL land use is present.
- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access should extend to the forebay, safety bench, outlet control structure, and outlet and be designed to allow vehicles to turn around.

7.2.8 Non-clogging Low-flow Orifice

Required Elements

- When CP_v is required, a low-flow orifice shall be provided, with the design of the orifice sufficient to ensure that no clogging shall occur.

Design Guidance

- The low-flow orifice should be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3”) or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice of 1”). See Appendix H for sample schematics of low-flow orifice protections.
- The preferred method for practices with a permanent pool is a submerged reverse-slope pipe that extends downward from the outlet control structure to an inflow point one foot below the normal pool elevation (see Figure 7-2 for schematic profile).
- Alternative methods are to employ a broad-crested rectangular, V-notch, or proportional weir, protected by a half-round pipe or “hood” that extends at least 12 inches below the normal pool.
- The use of horizontally extended perforated pipe protected by geotextile fabric and crushed stone is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present.

7.2.9 Outlet Control Structure

Required Elements

- The outlet control structure shall be located within the embankment for maintenance access, safety and aesthetics.
- The outlet control structure shall be sized and designed for CP_v and Q_p, as required.
- For discharges beyond 200 ft from jurisdictional waters in cold-water fisheries, the underdrained gravel trench shall be designed to meet the following requirements:
  - Shall be sized to release the CP_v over at least 12 hrs and not more than 24 hrs to provide adequate cooling of stormwater runoff discharging from the basin;
  - Shall be four feet wide, located at least 2 feet from the permanent pool, and located at the furthest location opposite from the principal inflow location to the facility;
  - The trench shall have a length of 3 feet per 1,000 ft^3 of CP_v storage volume, have a depth of at least 3 feet, and maintain 2 feet of gravel cover over a 6-inch diameter perforated pipe outlet (Rigid Sch. 40 PVC or SDR35);
  - Shall utilize geotextile fabric placed between gravel trench and adjacent soil; and
  - Shall utilize clean poorly-graded (uniform size material) gravel (refer to Figure 5-4).

Design Guidance

- Access to the outlet control structure should be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening should be "fenced" with pipe or rebar at 8-inch intervals (for safety purposes).

7.2.10 Basin Drain

Required Elements

- Except where local slopes prohibit this design, each wet basin shall have a drain pipe that can completely or partially drain the permanent pool. The drain pipe shall have an elbow or protected intake within the basin to prevent sediment deposition, and a diameter capable of draining the basin within 24 hours.
- Access to the drain pipe shall be secured by a lockable structure to prevent vandalism and/or accidental draining of the pond, which could pose a safety hazard due to high drainage velocities.

7.2.11 Safety Features

Required Elements

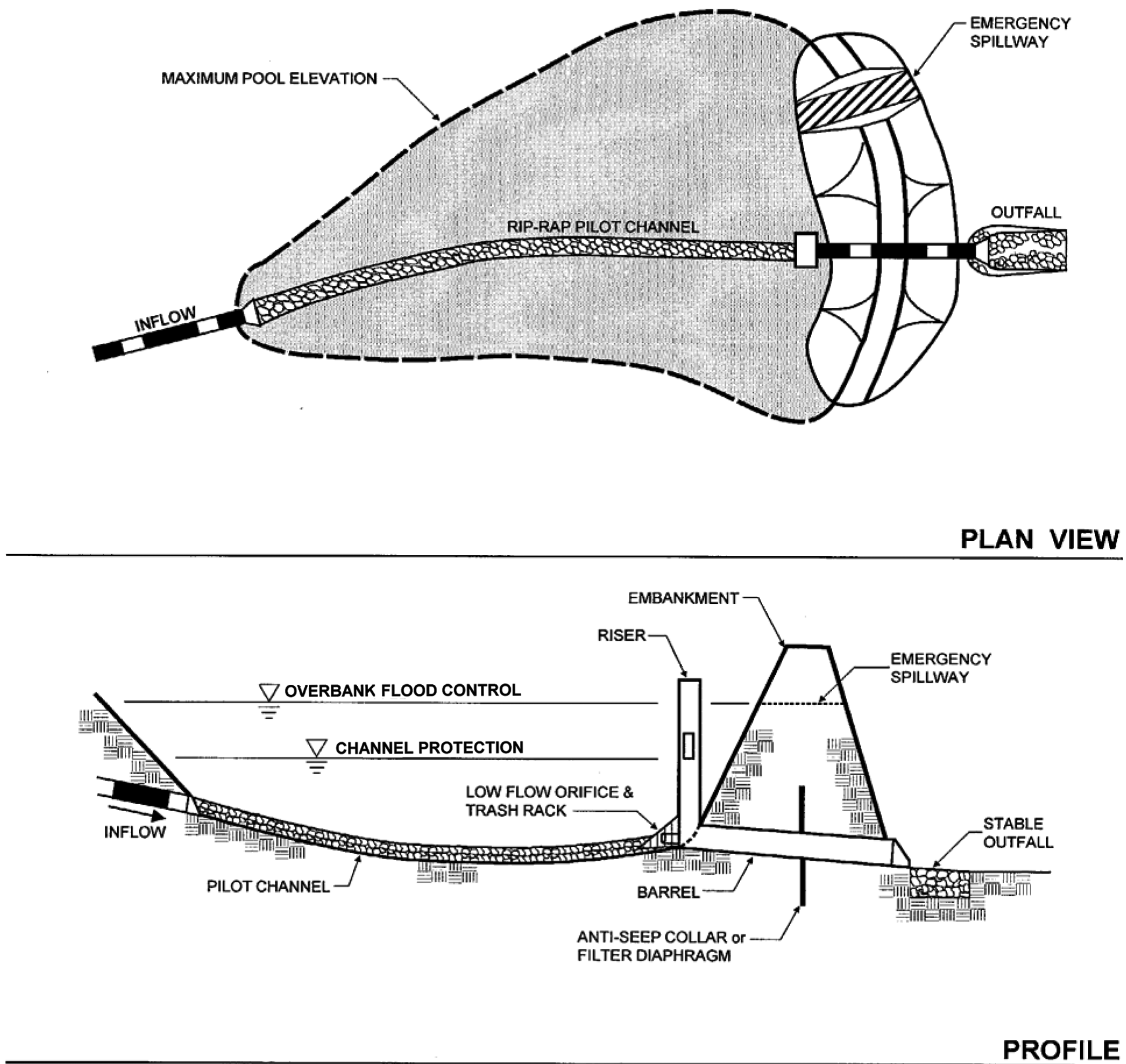
- Side slopes to the basin shall not exceed 3:1 (h:v) and, for wet basins, shall terminate on a safety bench.
- The principal spillway opening shall not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to

prevent a hazard.

Design Guidance

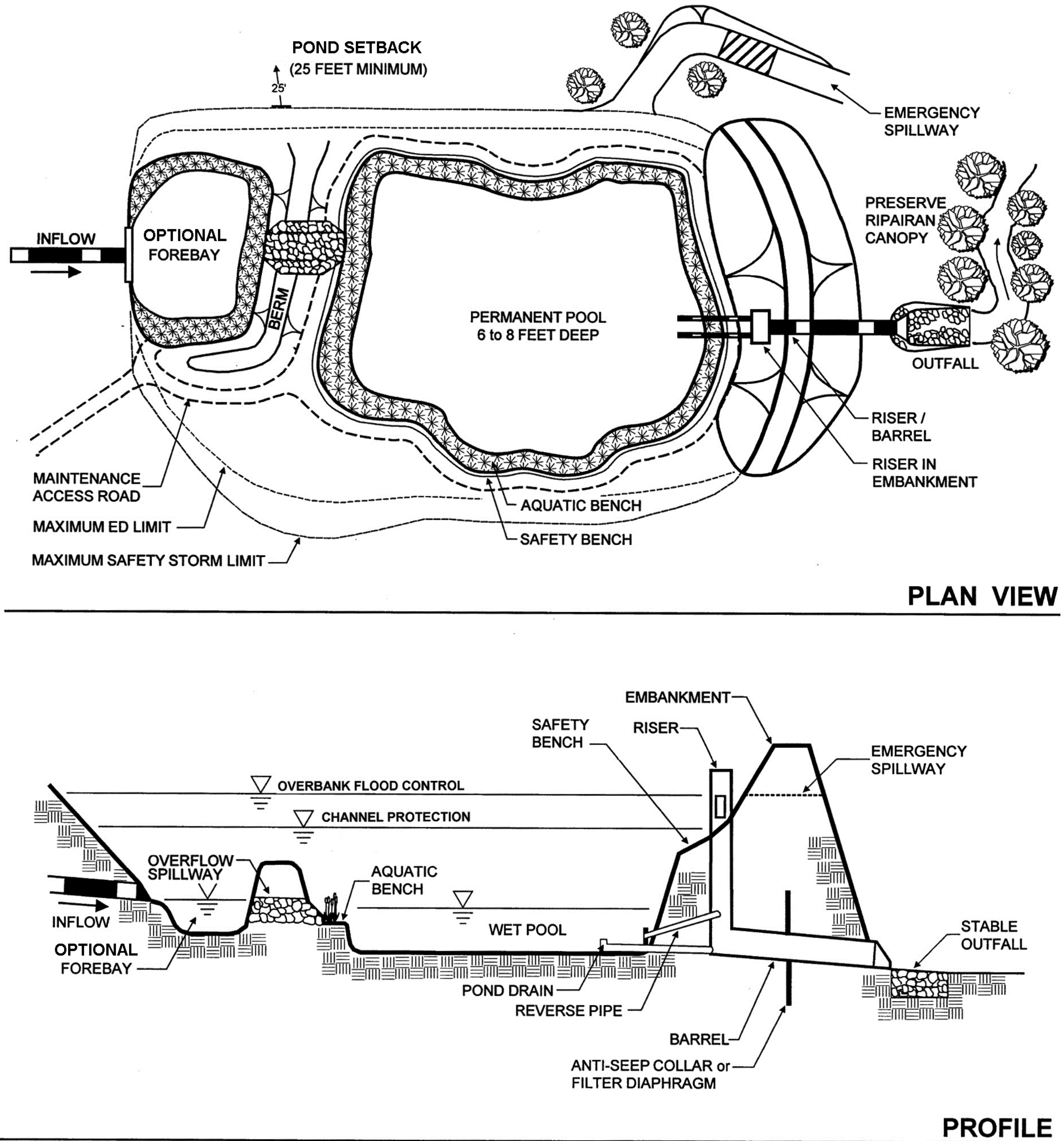
- Both the safety bench and aquatic bench may be landscaped to prevent access to the pool.
- Warning signs prohibiting swimming and ice skating may be posted.
- Basin fencing is generally not encouraged, but is often appropriate and may be required by the owner or by local ordinance in residential neighborhoods. A preferred method is to manage the contours of the basin to eliminate dropoffs or other safety hazards.

Figure 7-1 Dry Extended Detention Basin



Adapted from MDE, 2000

Figure 7-2 Wet Extended Detention Basin



Adapted from MDE, 2000

7.3 Underground Storage Devices

Underground stormwater detention practices capture and store stormwater from a site, slowly releasing it back to a natural channel or receiving waters at pre-development peak flows. These underground storage vaults provide minimal, if any, stormwater quality benefits; however, they can be used to meet channel protection and peak flow attenuation standards.

Subsurface storage structures are typically made of concrete (vaults) or large diameter, rigid pipes or arches with capped ends and made of plastic, steel or aluminum. Storage structures and appurtenances (inlet and outlet pipes, maintenance access/manholes) are constructed in a predetermined excavated area sized for the required criteria (CP_v and Q_p). The entire area is then back-filled with gravel to surrounding grades and surfaced. Due to on-going maintenance requirements and the potential need for repairs, underground storage facilities should not be built over and should be located in areas where large-sized maintenance vehicles can easily operate and excavate, if required.

Underground storage is most often used at sites where land availability, shape, and/or land costs preclude or discourage the development of surface stormwater storage. Underground storage is ideal for use under parking lots, roadways and paved areas associated with commercial, industrial and residential developments. The advantages of an underground storage facility are (1) rapid installation using prefabricated modular systems; (2) systems are durable with a long life (50 years plus for most systems); (3) increased level of public safety vs. open, deep storage basins; (4) efficient use of space in urban areas and for retrofits; and (5) ground provides insulation from freezing. Limitations of underground systems include that they often require extensive, costly excavation; material costs are high compared to surface methods; and maintenance costs are higher. In addition, routine maintenance is often overlooked because the practice is not easily inspected via casual observation.

7.3.1 Feasibility

Required Elements

- Designers shall check with local authorities regarding design requirements and necessary permits for construction of underground storage. There is great variability between localities in requirements and permissible construction materials.

Design Guidance

- Placement of underground stormwater storage is site specific. During early site inspections, special note should be made of site size, shape, and physical characteristics of the landscape. These factors will help determine basic structure of the detention system and what materials are best used in construction.
- The suggested maximum area of stormwater drainage to be collected for one underground storage system is 25 acres.
- Underground storage devices have confined entry limitations per Occupational Safety and Health Administration (OSHA) regulations.

7.3.2 Material Selection

Design Guidance

Site-specific conditions can influence which materials are selected:

- Depth and area of excavation: deeper and larger excavated areas require more fill for maintaining the integrity of plastic or metal pipe;
- Shape of space: continuous space allows for the use of concrete, while angular spaces favor the use of pipe systems. However:
  - Pipes store less water than square concrete vaults per unit of land surface.
  - Pipes require more fill than concrete structures, thus using more excavated area.
  - Use the largest pipe diameter possible. Doubling pipe diameter quadruples capacity and only doubles cost.

7.3.3 Conveyance

Required Elements

- Outfalls to the ground surface, where needed, shall be constructed such that they do not increase erosion by discharging near the stream water surface elevation or into an energy dissipating step-pool arrangement.
- An emergency overflow system shall be designed to convey flows larger than the 100-year storm or to divert water in case system fails for any reason.

Design Guidance

- If system discharges to a watercourse 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.

7.3.4 Design

Required Elements

- Capacity and discharge rate shall depend on the CP_v and Q_p requirements. Storage is a function of geometry of the structure, which shall be provided by the manufacturer.
- Sufficient maintenance access points (manholes) shall be incorporated in design to facilitate easy maintenance. Placement shall, at a minimum, occur near the intake and another at the outlet end of the system. The number of manholes depends on maintenance methods used.
- The design shall address implications of the depth to groundwater at the site. A high water table can cause structures to displace due to uplift forces if not designed correctly. Anti-floatation calculations are required when system designed below the water table.

Design Guidance

- If system outfalls to ground surface, rip-rap may be required and should be sized properly to reduce erosion.
- Pipes and floors of vaults should be designed with a maximum of two percent slope.

7.3.5 Maintenance

Required Elements

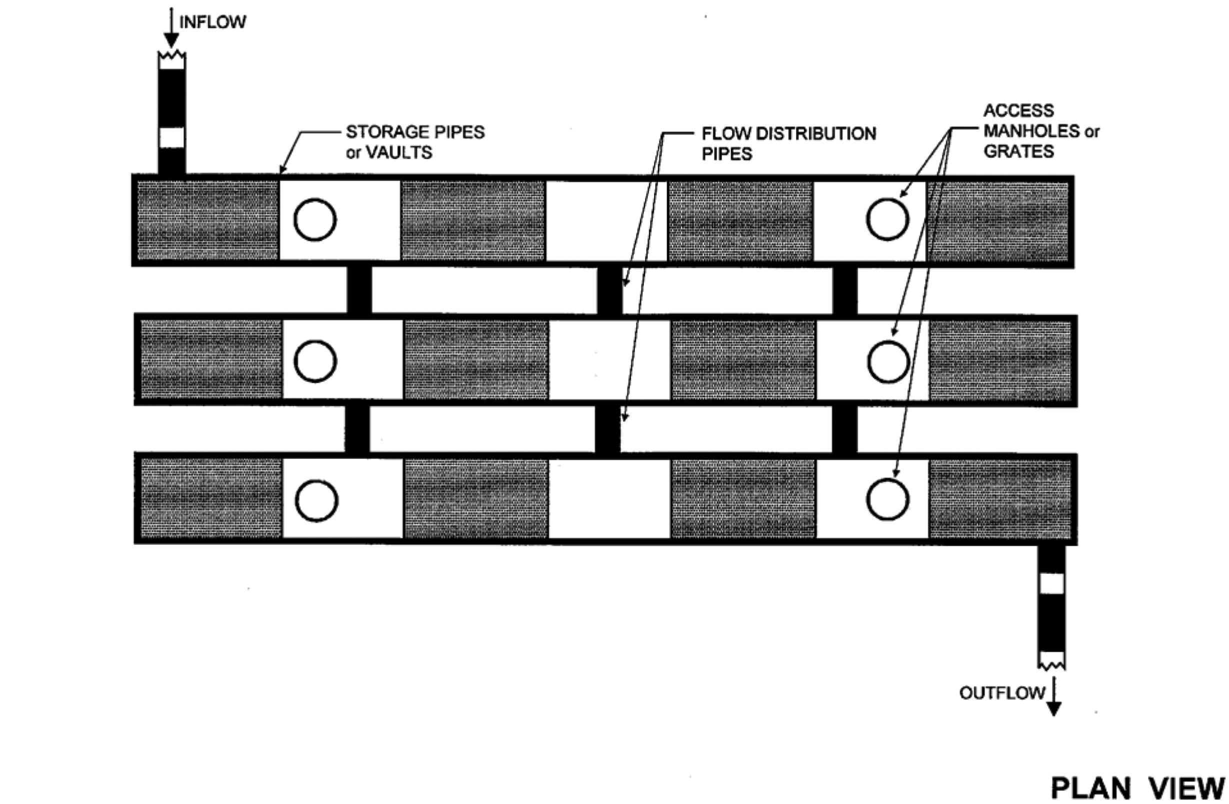
- Periodic inspections (i.e., quarterly) of the inlet and outlet areas to ascertain correct operation of system and to clean materials trapped on grates protecting catch basins and inlet area.
- Sediment shall be removed from the system when the sediment volume exceeds 10% of the total vault volume and should be disposed of according to an approved comprehensive operation and maintenance plan.

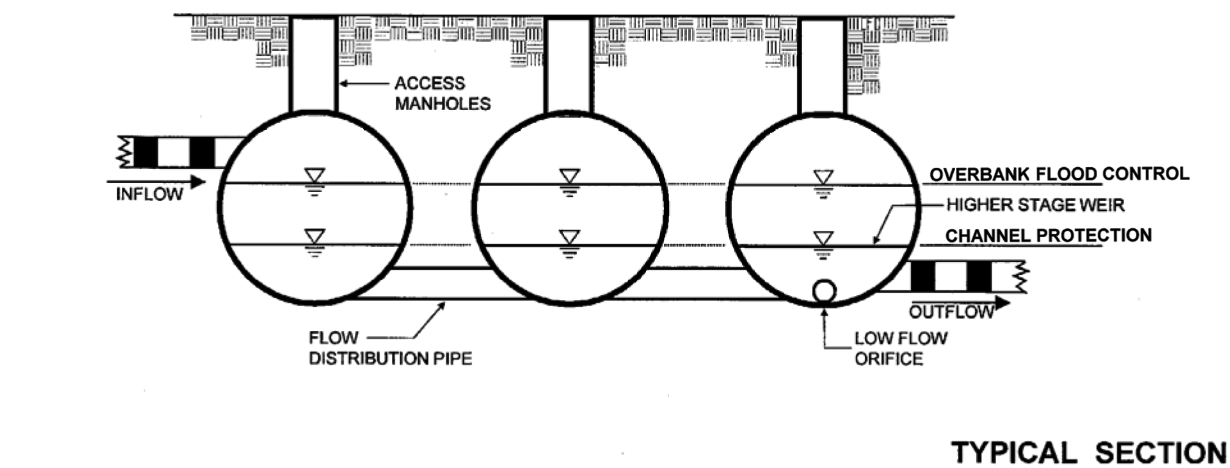
Design Guidance

- The primary maintenance concerns are removal of floatables that become trapped and removal of accumulating sediments within the system; this should be done at least on a bi-annual basis. Proprietary traps and filters associated with stormwater storage units should be maintained as recommended by the manufacturer.
  - Confined space safety procedures as required by OSHA regulations must be followed by workers entering an underground stormwater storage facility because noxious gasses may form in the system.
  - Sediments are best removed mechanically rather than flushing. If flushing is the only option, then great care must be taken not to flush sediments downstream into the receiving waters.
- Any structural repairs required to inlet and outlet areas should be addressed in a timely manner on an as-needed basis.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility.
- Sediment testing may be required prior to sediment disposal when a LUHPPL is present.

(Adapted from Lakesuperiorstreams, 2005)

Figure 7-3 Underground Storage Vault





Adapted from VTANR, 2002

7.4 STORMWATER INFILTRATION PRACTICES FOR RECHARGE/STORAGE ONLY

Infiltration within sand/gravel formations that have very high permeability rates may allow for infiltration of large volumes of stormwater. On sites where the soil infiltration rate is high (greater than 8.3 in/hr), infiltration practices cannot be used to treat the water quality volume. However, they may be used to provide recharge (Re_v), channel protection (CP_v) and/or overbank flood control (Q_p) storage (applicants must provide treatment of 100% of the WQ_v prior to direct infiltration). To assure that long-term infiltration rates are achieved, extraordinary care should be taken to protect the infiltration practice during construction and followed with post-construction inspection and long-term maintenance.

7.4.1 Feasibility

Required Elements

- To protect groundwater from possible contamination, runoff from designated LUHPPL land uses or activities should not be directed to an infiltration facility.
- The bottom of the infiltration facility shall be separated by at least 2 feet vertically from the seasonal high groundwater table (SHGT) or bedrock layer, as documented by on-site soil testing, unless a mounding analysis shows that the system will accept the stormwater without causing breakout or backup into the system with less than 2 feet vertical separation. The SHGT elevation in the area of each infiltration facility must be verified by a DEM-licensed Class IV soil evaluator or RI-registered PE.
- Infiltration practices that are designed for the 10-year storm event or greater *and* have a separation from the bottom of the system to the SHGT of less than 4 feet shall provide a groundwater mounding analysis[1].
- Infiltration practices cannot be placed in locations that cause water problems (such as seepage which may cause slope failure) to downgrade properties.
- Infiltration facilities must meet the setbacks in Table 7-2.

Table 7-2 Minimum Horizontal Setbacks from Infiltration Facilities

	Minimum Horizontal Setbacks	
	From small-scale facilities serving residential properties (ft)	**From all other infiltration facilities (ft)**
Public Drinking Water Supply Well – Drilled (rock), Driven, or Dug	200	200
Public Drinking Water Supply Well – Gravel Packed, Gravel Developed	400	400
Private Drinking Water Wells	50	100

[1] The groundwater mounding analysis must show that the groundwater mound that forms under the infiltration system will not break out above the land or jurisdictional water. The Hantush Method (Hantush, 1967) or other equivalent method may be used.

	Minimum Horizontal Setbacks	
	From small-scale facilities serving residential properties (ft)	**From all other infiltration facilities (ft)**
Surface Water Drinking Water Supply Impoundment* with Supply Intake	100	200
Tributaries that Discharge to the Surface Drinking Water Supply Impoundment*	50	100
Coastal Features	50	50
All Other Surface Waters	50	50
Up-gradient from Natural slopes > %15	25	50
Down-gradient from Building Structures**	10	25
Up-gradient from Building Structures**	10	50
Onsite Wastewater Treatment Systems (OWTS)	15	25

*Refer to DEM Onsite Wastewater Treatment System Rules Figures 14-16 for maps of the drinking water impoundments.
**Setback applies only where basement or slab is below the ponding elevation of the infiltration facility. Note that all basements and slabs should be above the SHGT.

<u>Design Guidance</u>

- Infiltration practices should not be used where subsurface contamination is present from prior land use due to the increased threat of pollutant migration associated with increased hydraulic loading from infiltration systems, unless contaminated soil is removed and the site is remediated, or if approved by DEM on a case-by-case basis.

7.4.2 Conveyance

<u>Required Elements</u>

- Adequate stormwater outfalls shall be provided for the overflow associated with the 1-year design storm event (non-erosive velocities on the down-slope).
- The overland flow path of surface runoff exceeding the capacity of the infiltration system shall be evaluated to preclude erosive concentrated flow during the overbank events. If computed flow velocities exiting the system overbank exceed erosive velocities (3.5 to 5.0 fps) for the 1-year storm event, an overflow channel and/or level spreader shall be provided.

7.4.3 Design

Required Elements

- Infiltration practices shall be designed to exfiltrate the design volume through the floor of each practice (sides are not considered in sizing), except where the depth is greater than the square root of the bottom surface area.
- The construction sequence and specifications for each infiltration practice shall be precisely followed. Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction.
- Design infiltration rates (f_c) shall be determined by using Table 5-3, or shall be determined by in-situ rates (using a factor of safety of 2 from the field-derived value) established by one of the approved methods listed in Appendix H.1.3 (rates derived from standard percolation tests are not acceptable).

7.4.4 Vegetation

Required Elements

- Upstream construction shall be completed and stabilized before connection to a downstream infiltration facility. A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility.

Design Guidance

- Mow upland and adjacent areas, and seed bare areas.

7.4.5 Maintenance

Required Elements

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the responsible authority to ensure the following:
  - Infiltration practices shall never serve as a sediment control device during site construction phase. Great care must be taken to prevent the infiltration area from compaction by marking off the location before the start of construction at the site and only constructing the infiltration practice last, connecting upstream areas only after construction is complete, and the contributing area stabilized. In addition, the Erosion and Sediment Control plan for the site shall clearly indicate how sediment will be prevented from entering the site of an infiltration facility.
  - An observation well shall be installed in every infiltration trench or chamber system, consisting of an anchored 4- to 6-inch diameter perforated PVC pipe with a lockable cap installed flush with the ground surface. The approving agency may require multiple observation wells for large underground chamber systems.

Design Guidance

- OSHA trench safety standards should be observed if the infiltration trench will be excavated more than five feet.
- Infiltration designs should include dewatering methods in the event of failure. Dewatering can be accomplished with underdrain pipe systems that accommodate drawdown.
- Preferably, direct access should be provided to infiltration practices for maintenance and rehabilitation. For trenches or chambers, which are used to temporarily store runoff prior to infiltration, the practice should ideally not be completely covered by impermeable surfaces unless significant design constraints exist.
- In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility. Any oil or grease found at the time of the inspection should be cleaned with oil absorption pads and disposed of in an approved location.

GLOSSARY OF TERMS

This section includes the definitions of various technical terms used throughout this manual and its appendices as guidance for designers and other manual users. Definitions in a specific local, State, or Federal rule or regulation may differ somewhat from those below and may have specific regulatory significance. Applicants are responsible for determining the appropriate definitions for any regulations applicable to their projects.

AGRICULTURAL RUNOFF – Runoff from land utilized for agricultural practices including growing crops and raising livestock.

AQUATIC BENCH - A ten- to fifteen-foot wide bench which is located around the inside perimeter of a permanent pool and is normally vegetated with aquatic plants; the goal is to provide pollutant removal and enhance safety in areas using stormwater ponds.

AQUIFER - A porous water-bearing formation of permeable rock, sand or gravel capable of yielding economically significant quantities of groundwater.

APPROVING AGENCY – An entity that will enforce or require compliance with the minimum standards in this manual.

AREA SUBJECT TO STORM FLOWAGE (ASSF) – a regulated wetland as defined in the Rhode Island DEM “Rules and Regulations Governing the Administration and Enforcement of the State Freshwater Wetlands Act.”

BASEFLOW - The portion of streamflow that is not due to storm runoff but is the result of groundwater discharge or discharge from lakes or similar permanent impoundments of water.

BIORETENTION - A water quality practice that utilizes vegetation and soils to treat urban stormwater runoff by collecting it in shallow depressions, before filtering through an engineered bioretention planting soil media.

BUFFER - A buffer is a special type of preserved area along a watercourse or wetland where development is restricted or prohibited. Buffers protect and physically separate a resource from development. Buffers also provide stormwater control flood storage and habitat values. Wherever possible, riparian buffers should be sized to include the 100-year floodplain as well as steep banks and freshwater wetlands.

CATCH BASIN – A structure containing a sump placed below grade to conduct water from a street or other paved surface to the storm sewer.

CATCH BASIN INSERTS – A structure, such as a tray, basket, or bag that typically contains a pollutant removal medium (i.e., filter media) and a method for suspending the structure in the catch basin. They are placed directly inside of existing catch basins where stormwater flows into the catch basin and is treated as it passes through the structure.

CHANNEL - A natural stream that conveys water; a man-made ditch or swale excavated for the flow of water.

CHANNEL PROTECTION (CP_v) - A design criteria which requires 24-hour detention of the one-year, post-developed, 24-hour Type III storm event runoff volume for the control of stream channel erosion.

CHANNEL STABILIZATION - Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, structural linings, vegetation and other measures.

CHECK DAMS - Small temporary dams constructed across a swale or drainage ditch to reduce the velocity of concentrated stormwater flows.

CISTERNS – Containers that store larger quantities of rooftop stormwater runoff and may be located above or below ground. Cisterns can also be used on residential, commercial, and industrial sites. Also see Rain Barrel.

CLAY (SOILS) - 1. A mineral soil separate consisting of particles less than 0.002 millimeter in equivalent diameter. 2. A soil texture class. 3. (Engineering) A fine-grained soil (more than 50 percent passing the No. 200 sieve) that has a high plasticity index in relation to the liquid limit. (Unified Soil Classification System)

COMBINED SEWER OVERFLOWS (CSOs) – Combined sewers collect both stormwater runoff and sanitary wastewater in a single set of sewer pipes. When combined sewers do not have enough capacity to carry all the runoff and wastewater or the receiving water pollution control plant cannot accept all the combined flow, the combined wastewater overflows from the collection system into the nearest body of water, creating a CSO.

COMPACTION (SOILS) - Any process by which the soil grains are rearranged to decrease void space and bring them in closer contact with one another, thereby increasing the weight of solid material per unit of volume, increasing the shear and bearing strength and reducing permeability.

CONTOUR - 1. An imaginary line on the surface of the earth connecting points of the same elevation. 2. A line drawn on a map connecting points of the same elevation.

CRUSHED STONE – Gravel-sized particles that pass through a 3-inch sieve and are retained on the No. 4 sieve, and are angular in shape as produced by mechanical crushing. Crushed stone must be washed in order to be used in stormwater BMPs to prevent clogging by fines.

CURVE NUMBER (CN) - A numerical representation of a given area's hydrologic soil group, plant cover, impervious cover, interception and surface storage derived in accordance with Natural Resources Conservation Service methods. This number is used to convert rainfall volume into runoff volume.

CUT - Portion of land surface or area from which earth has been removed or will be removed by excavation; the depth below original ground surface to excavated surface.

DARCY'S LAW **–** An equation stating that the rate of fluid flow through a porous medium is proportional to the potential energy gradient within the fluid. The constant of proportionality is the hydraulic conductivity, which is a property of both the porous medium and the fluid moving through the porous medium. Sizing of filtering BMPs and dry swales is based on this principle.

DEEP SUMP CATCH BASINS - Storm drain inlets that typically include a grate or curb inlet and at least a four-foot sump to capture trash, debris and some sediment and oil and grease. Also known as an oil and grease catch basin.

DEICERS - Materials applied to reduce icing on paved surfaces. These consist of salts and other formulated materials that lower the melting point of ice, including sodium chloride, calcium chloride, calcium magnesium acetate, and blended products consisting of various combinations of sodium, calcium, magnesium, and chloride, as well as other constituents.

DESIGN POINTS/POINTS OF ANALYSES – Common locations at a site where pre-development and post-development conditions can be compared.

DESIGN STORM – Precipitation event for which the capacity of a best management practice is sized and designed. Design storms are expressed in terms of Type III, 24-hour events (i.e., 1-year, 10-year, and 100-year storms).

DETENTION - The temporary storage of storm runoff in a BMP with the goals of controlling peak discharge rates.

DETENTION STRUCTURE - A structure constructed for the purpose of temporary storage of surface runoff and gradual release of stored water at controlled rates.

DISPOSAL SITE - a structure, well, pit, pond, lagoon, impoundment, ditch, landfill or other place or area, excluding ambient air or surface water, where uncontrolled oil or hazardous material has come to be located as a result of any spilling, leaking, pouring, ponding, emitting, emptying, discharging, injecting, escaping, leaching, dumping, discarding or otherwise disposing of such oil or hazardous material. Disposal sites are designated as LUHPPLs.

DISTURBED AREA - An area in which the natural vegetative soil cover has been removed or altered and, therefore, is susceptible to erosion.

DIVERSION - A channel with a supporting ridge on the lower side constructed across the slope to divert water from areas where it is in excess to sites where it can be used or disposed of safely. Diversions differ from terraces in that they are individually designed.

DOWNSTREAM ANALYSIS - Calculation of peak flows, velocities, and hydraulic effects at critical downstream locations to ensure that proposed projects do not increase post-development peak flows and velocities at these locations.

DRAINAGE - The removal of excess surface water or ground water from land by means of surface or subsurface drains.

DRAINAGE AREA (WATERSHED) - All land and water area from which runoff may run to a common (design) point.

DRY EXTENDED DETENTION POND – Stormwater basin designed to capture, temporarily hold, and gradually release a volume of stormwater runoff to attenuate and delay stormwater runoff peaks. Dry extended detention ponds provide water quantity control (peak flow control and stream channel protection) as opposed to water quality control. Also known as “dry ponds” or “detention basins”.

DRY SWALE - An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media.

DRY WELL - Small excavated pits or trenches filled with aggregate that receive clean stormwater runoff primarily from building rooftops. Dry wells function as infiltration systems to reduce the quantity of runoff from a site. The use of dry wells is applicable for small drainage areas with low sediment or pollutant loadings and where soils are sufficiently permeable to allow reasonable rates of infiltration.

EMERGENCY SPILLWAY - An open and/or closed channel designed to safely discharge stormwater flows in excess of the principal spillway capacity.

EROSION - 1. The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice or gravity. The following terms are used to describe different types of water erosion:

> Accelerated erosion - Erosion much more rapid than normal, natural or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophes that expose base surfaces, for example, fires.
>
> Gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 or 2 feet to as much as 75 to 100 feet.
>
> Rill erosion - An erosion process in which numerous small channels only several inches deep are formed.

Sheet erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not subsequently be removed by surface runoff.

EROSION AND SEDIMENT CONTROL (ESC) – A device placed, constructed on, or applied to the landscape that prevents or curbs the detachment of soil, its movement, and/or deposition.

EROSIVE VELOCITIES - Velocities of water that are high enough to wear away the land surface. Exposed soil will generally erode faster than stabilized soils. Erosive velocities will vary according to the soil type, slope, structural, or vegetative stabilization used to protect the soil.

EXFILTER - An exfilter is a conventional stormwater filter without an underdrain system. The filtered volume ultimately infiltrates into the underlying soils.

EXTENDED DETENTION (ED) - A stormwater design feature that provides for the gradual release of a volume of water over a 24- to 48-hour interval in order to increase settling of urban pollutants and protect downstream channels from frequent storm events.

FILTER STRIP - A strip of permanent vegetation above ponds, diversions and other structures to retard flow of runoff water, causing deposition of transported material, thereby reducing sediment flow.

FILTERING PRACTICES - Practices that capture and store stormwater runoff and pass it through a filtering media such as sand, organic material, or the native soil for pollutant removal. Stormwater filters are primarily water quality control devices designed to remove particulate pollutants and, to a lesser degree, bacteria and nutrients.

FLOODPLAIN - Areas adjacent to a stream or river that are subject to flooding or inundation during a storm event that occurs, on average, once every 100 years (or has a likelihood of occurrence of 1/100 in any given year).

FLOW SPLITTER - An engineered, hydraulic structure designed to divert a percentage of storm flow to a BMP located out of the primary channel, or to direct stormwater to a parallel pipe system, or to bypass a portion of baseflow around a BMP.

FOREBAY - Storage space located near a stormwater BMP inlet that serves to trap incoming coarse sediments before they accumulate in the main treatment area.

GRADE - 1. The slope of a road, channel or natural ground. 2. The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit. 3. To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.

GRASS CHANNELS - Traditional vegetated open channels, typically trapezoidal, triangular, or parabolic in shape, whose primary function is to provide non-erosive conveyance, typically up to the 10-year frequency design flow. They provide limited pollutant removal through filtration by grass or other vegetation, sedimentation, biological activity in the grass/soil media, as well as limited infiltration if underlying soils are pervious.

GRAVEL - 1. “Pea” gravel is an aggregate consisting of mixed sizes of ¼-inch to 3/4-inch particles that normally occur in or near old streambeds and have been worn smooth by the action of water. Pea gravel is often used as a filter layer in stormwater BMPs. 2. According to the Unified Soil Classification System, gravel is a soil having particle sizes that pass through a 3-inch sieve and are retained on the No. 4 sieve; may be angular in shape as produced by mechanical crushing. Also, referred to as “crushed stone.” Crushed stone can be used as a media for stormwater best management practices (e.g., infiltration trenches, gravel wet vegetated treatment practices). 3. Type of impervious surface when used for road, driveway, or parking surfaces.

GREEN ROOFS - Multilayered, constructed roof systems consisting of a vegetative layer, media, a geotextile layer, and a synthetic drain layer installed on building rooftops. Rainwater is either intercepted by vegetation and evaporated to the atmosphere or retained in the substrate before being returned to the atmosphere through transpiration and evaporation.

GROUND COVER - Plants that are low growing and provide a thick growth that protects the soil as well as providing some beautification of the area occupied.

GROUNDWATER RECHARGE – The process by which water that seeps into the ground, eventually replenishing groundwater aquifers and surface waters such as lakes, streams, and the oceans. This process helps maintain water flow in streams and wetlands and preserves water table levels that support drinking water supplies.

GROUNDWATER RECHARGE VOLUME (Re_v) - The post-development design recharge volume (i.e., on a storm event basis) required to minimize the loss of annual pre-development groundwater recharge. The Re_v is determined as a function of annual pre-development recharge for site-specific soils or surficial materials, average annual rainfall volume, and amount of impervious cover on a site.

GULLY - A channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains. The distinction between gully and rill is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lesser depth and would be smoothed by ordinary farm tillage.

HAZARD CLASSIFICATION (DAMS) - A rating for a dam that relates to the probable consequences of failure or misoperation of the dam, which is a determination made by the Director (of RIDEM) based on an assessment of loss of human life, damages to properties or structures located downstream of the reservoir, or loss of use as a drinking water supply. A higher hazard dam does not imply that it is more likely to fail or be misoperated than a lower hazard dam.

HEAD (HYDRAULICS) - 1. The height of water above any plane of reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various terms such as pressure head, velocity head, and head loss.

HEAVY METALS - Metals such as copper, zinc, barium, cadmium, lead, and mercury, which are natural constituents of the Earth's crust. Heavy metals are stable and persistent environmental contaminants since they cannot be degraded or destroyed.

HERBACEOUS PERENNIAL (PLANTS) - A plant whose stems die back to the ground each year.

HYDROCARBONS – Inorganic compounds consisting of carbon and hydrogen, including petroleum hydrocarbons derived from crude oil, natural gas, and coal.

HYDRODYNAMIC SEPARATORS – A group of stormwater treatment technologies designed to remove large particle total suspended solids and large oil droplets, consisting primarily of cylindrical-shaped devices that are designed to fit in or adjacent to existing stormwater drainage systems. The most common mechanism used in these devices is vortex-enhanced sedimentation, where stormwater enters as tangential inlet flow into the side of the cylindrical structure. As the stormwater spirals through the chamber, the swirling motion causes the sediments to settle by gravity, removing them from the stormwater.

HYDROGRAPH - A graph showing variation in stage (depth) or discharge of a stream of water over a period of time.

HYDROLOGIC CYCLE – The distribution and movement of water between the earth's atmosphere, land, and water bodies.

HYDROLOGIC SOIL GROUP (HSG) - A Natural Resource Conservation Service classification system in which soils are categorized into four runoff potential groups. The groups range from A soils, with high permeability and little runoff production, to D soils, which have low permeability rates and produce much more runoff.

HYDROLOGIC ZONES – Planting zones that reflect the degree and duration of inundation by water, consisting of a deep water pool, shallow water bench, shoreline fringe, riparian fringe, floodplain terrace, and upland slopes.

ILLICIT DISCHARGES - Unpermitted discharges to waters of the state that do not consist entirely of stormwater or uncontaminated groundwater except certain discharges identified in the RIPDES Phase II Stormwater General Permit.

IMPAIRED WATERS – Those waterbodies not meeting water quality standards. Pursuant to Section 303(d) of the federal Clean Water Act, each state prepares a list of impaired waters (known as the 303(d) list) which is presented in the state's Integrated

Water Report as Category 5 waters. Those impaired waters for which a TMDL has been approved by US EPA and is not otherwise impaired, are listed in Category 4A.

IMPERVIOUS COVER (I) - Those surfaces that cannot effectively infiltrate rainfall consisting of surfaces such as building rooftops, pavement, sidewalks, driveways, compacted gravel (e.g., driveways and parking lots).

INFILL – A development site that meets all of the following: the site is currently predominately pervious (less than 10,000 sf of existing impervious cover); it is surrounded (on at least three sides) by existing development (not including roadways); the site is served by a network of existing infrastructure and does not require the extension of utility lines or new public road construction to serve the property; and the site is one (1) acre or less where the existing land use is commercial, industrial, institutional, governmental, recreational, or multifamily residential.

INFILTRATION PRACTICES – Stormwater treatment practices designed to capture stormwater runoff and infiltrate it into the ground over a period of days.

INFILTRATION RATE (f_c) - The rate at which stormwater percolates into the subsoil measured in inches per hour.

LAND USE WITH HIGHER POTENTIAL POLLUTANT LOADS (LUHPPL) - Area where the land use has the potential to generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

LANDFILL - A facility or part of a facility established in accordance with a valid site assignment for the disposal of solid waste into or on land. Landfills are designated as LUHPPLs.

LEVEL SPREADER - A device for distributing stormwater uniformly over the ground surface as sheet flow to prevent concentrated, erosive flows and promote infiltration.

LIMIT OF DISTURBANCE – Line delineating the boundary of the area to be disturbed during a development or redevelopment project. Area outside this boundary shall not be touched.

LOW IMPACT DEVELOPMENT (LID) - Low impact development is a site planning and design strategy intended to maintain or replicate predevelopment hydrology through the use of site planning, source control, and small-scale practices integrated throughout the site to prevent, infiltrate and manage runoff as close to its source as possible.

MAXIMUM EXTENT PRACTICABLE – To show that a proposed development has met a standard to the maximum extent practicable, the applicant must demonstrate the following: (1) all reasonable efforts have been made to meet the standard in accordance with current local, state, and federal regulations, (2) a complete evaluation of all possible management measures has been performed, and (3) if full compliance cannot be achieved, the highest practicable level of management is being implemented.

“MAY” – This language is used when design guidance is recommended for consideration by the designer. Optional.

MICROPOOL - A smaller permanent pool that is incorporated into the design of larger stormwater ponds or WVTSs to avoid resuspension or settling of particles.

MULCH - A natural or artificial protective layer of suitable materials, usually of organic matter such as wood chips, leaves, straw, or peat, placed around plants that aids in soil stabilization, soil moisture conservation, prevention of freezing, and control of weeds. In addition, mulches serve as soil amendments upon decomposition (for organic mulches).

“MUST,” “SHALL,” “REQUIRED” – This language is used when a design standard or criterion is essential, not optional. A written technical justification acceptable to the approving agency must be provided if not used or achieved.

NATIVE PLANTS - Plants that are adapted to the local soil and rainfall conditions and that require minimal watering, fertilizer, and pesticide application.

NONPOINT SOURCE POLLUTION – Pollution caused by diffuse sources that are not regulated as point sources and are normally associated with precipitation and runoff from the land or percolation.

NON-STRUCTURAL CONTROLS – Pollution control techniques, such as management actions and behavior modification that do not involve the construction or installation of devices.

OFF-LINE - A stormwater management system designed to manage small storm events by diverting a percentage of stormwater flow away from the storm drainage system. Flow from large storm events will bypass this stormwater management system. See Figure H-5 for a graphic illustration “off-line.”

OIL/PARTICLE SEPARATORS - Consist of one or more chambers designed to remove trash and debris and to promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil) from stormwater runoff. Oil/particle separators are typically designed as off-line systems for pretreatment of runoff from small impervious areas, and therefore provide minimal attenuation of flow. Also called oil/grit separators, water quality inlets, and oil/water separators.

ON-LINE - A stormwater management system designed to manage stormwater in its original drainage channel or pipe network such that all stormwater flow will be directed to and through the stormwater management system. See Figure H-5 for a graphic illustration “on-line.”

OPEN CHANNELS - Also known as swales and grass channels. These systems are used for the conveyance, retention, infiltration and filtration of stormwater runoff.

OUTFALL - The point where water flows from a conduit, stream, or drain.

OUTLET - The point at which water discharges from stormwater practices such as pipes or channels.

OUTLET CONTROL STRUCTURE - A hydraulic structure placed at the outlet of a channel, spillway, pond, etc., for the purpose of dissipating energy, providing a transition to the channel or pipe downstream, while achieving the discharge rates for specified designs.

PEAK DISCHARGE RATE - The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

PEAK FLOW CONTROL - Criteria intended to address increases in the frequency and magnitude of a range of potential flood conditions resulting from development and include stream channel protection, conveyance protection, peak runoff attenuation, and emergency outlet sizing.

PERFORMANCE MONITORING – Collection of data on the effectiveness of individual stormwater treatment practices.

PERMANENT (WET) POOL – An area of a stormwater management practice that has a fixed water surface elevation due to a manipulation of the outlet structure.

PERMEABILITY - The rate of water movement through the soil column under saturated conditions

PERMEABLE PAVING MATERIALS - Materials that are alternatives to conventional pavement surfaces and are designed to increase infiltration and reduce stormwater runoff and pollutant loads. Alternative materials include porous asphalt, pervious concrete, and various pavers and open-celled grids.

pH - A number denoting the common logarithm of the reciprocal of the hydrogen ion concentration. A pH of 7.0 denotes neutrality, higher values indicate alkalinity, and lower values indicate acidity.

PIPING - Removal of soil material through subsurface flow channels or “pipes” developed by seepage water.

PLUGS - Pieces of vegetation, usually cut with a round tube, which can be used to propagate the plant by vegetative means.

POINT SOURCE - any discernible, confined and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged.

PONDSCAPING - Plantings around stormwater ponds that emphasizes native vegetative species to meet specific design intentions. Species are selected for up to six zones in the basin and its surrounding setback, based on their ability to tolerate inundation and/ or soil saturation.

PRETREATMENT - Techniques employed in stormwater BMPs to provide storage or filtering to help trap coarse materials before they enter the system.

PRINCIPAL SPILLWAY - An open and/or closed channel designed to allow a normal range of stormwater flows to discharge from an impoundment.

QUALIFYING PERVIOUS AREA – the generally flat, natural or landscaped vegetated areas that are fully stabilized and where discharge from impervious areas may be directed via sheet flow in order to obtain a Stormwater Credit. Specific criteria for qualifying pervious areas are included in Section 4.6.

RAIN BARRELS - Barrels designed to retain small volumes of runoff for reuse for gardening and landscaping. They are applicable to residential, commercial, and industrial sites and can be incorporated into a site's planting plan. The size of the rain barrel is a function of rooftop surface area and the design storm to be stored.

RATIONAL EQUATION – An empirical equation acceptable for estimating peak flow rates for small urbanized drainage areas with short times of concentration, but not for estimating runoff volume. The Rational Equation is $Q=CiA$, where Q = Peak discharge; C = Rational Method runoff coefficient; i = rainfall intensity (in/hr); and A = drainage area (acres).

REDEVELOPMENT – Any construction, alteration, or improvement that disturbs a total of 10,000 square feet or more of existing impervious area where the existing land use is commercial, industrial, institutional, governmental, recreational, or multifamily residential. Building demolition is included as an activity defined as "redevelopment", but building renovation is not. Similarly, removing of roadway materials down to the erodible soil surface is an activity defined as "redevelopment," but simply resurfacing of a roadway surface is not. Pavement excavation and patching that is incidental to the primary project purpose, such as replacement of a collapsed storm drain, is not classified as redevelopment. In general, the requirements in this manual do not apply to projects or portions of projects when the total existing impervious area disturbed is less than 10,000 square feet. However, specific regulatory programs may impose additional requirements. Any creation of new impervious area over portions of the site that are currently pervious is required to comply fully with the requirements of this manual, with the exception of infill projects.

REDOXIMORPHIC FEATURES - Features in the soil profile that are formed by the processes of reduction, translocation, and/or oxidation of iron and manganese oxides. They are an indicator of seasonal water table elevations.

RESPONSIBLE AUTHORITY – Authority responsible for long-term maintenance of stormwater BMPs.

RETENTION - The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

RIGHT-OF-WAY (ROW) - Right of passage, as over another's property. A route that is lawful to use. A strip of land acquired for transport or utility construction.

RISER - A type of outlet control structure that consists of a vertical pipe that extends from the bottom of a pond BMP and houses the control devices (weirs/orifices) to achieve the discharge rates for specified designs.

RUNOFF - the water from rain, snowmelt, or irrigation that flows over the land surface and is not absorbed into the ground, instead flowing into surface waters or land depressions.

SAFETY BENCH - A flat area above the permanent pool and surrounding a stormwater basin designed to provide a separation from the basin pool and adjacent slopes.

SAND - 1. (Agronomy) A soil particle between 0.05 and 2.0 millimeters in diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System, a soil particle larger than the No. 200 sieve (0.074mm) and passing the No. 4 sieve (approximately 1/4 inch).

SARA 312 GENERATOR - a facility that is required by the Emergency Planning and Community Right to Know Act (EPCRA), also known as Title III of the Superfund Amendments and Reauthorization Act of 1989 (SARA Title III), to submit an inventory of the location of hazardous chemicals which are located at the site. SARA 312 generators are designated as LUHPPLs.

SEASONAL HIGH GROUNDWATER TABLE – the elevation of the groundwater table during that time of the year at which it is highest as determined by direct observation or by interpretation of hydromorphic features in the soil profile.

SEDIMENT - Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

SEDIMENT CHAMBER OR FOREBAY – An underground chamber or surface impoundment (i.e., forebay) designed to remove sediment and/or floatables prior to a primary or other secondary stormwater treatment practice.

SEEPAGE - 1. Water escaping through or emerging from the ground. 2. The process by which water percolates through the soil.

SETBACKS - The minimum distance requirements for location of a structural BMP in relation to roads, wells, septic fields, other structures. Also, the area immediately surrounding a best management practice that provides a separation barrier to adjacent development and acts as filter to remove pollutants and provide infiltration of stormwater prior to reaching the BMP.

SHALLOW WVTS – A WVTS that consists of aquatic vegetation within a permanent pool ranging in depth from 6” to 18” during normal conditions.

SHEET FLOW - Water, usually storm runoff, flowing in a thin layer over the ground surface.

“SHOULD” – This language is used in design guidance for a well-accepted practice, a satisfactory and advisable option or method. Optional, but subject to review by the approving agency.

SIDE SLOPES (ENGINEERING) - The slope of the sides of a channel, dam or embankment. It is customary to name the horizontal distance first, as 1.5 to 1, or frequently, 1 ½: 1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

SILT - 1. (Agronomy) A soil separate consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter. 2. A soil textural class. 3. (Engineering) According to the Unified Soil Classification System a fine-grained soil (more than 50 percent passing the No. 200 sieve) that has a low plasticity index in relation to the liquid limit.

SITE – One or more lots, tracts, or parcels of land to be developed or redeveloped for a complex of uses, units or structures, including but not limited to commercial, residential, institutional, governmental, recreational, open space, and/or mixed uses. When calculating site size, jurisdictional wetland areas defined by DEM or CRMC regulations and undeveloped lands protected by conservation easements should be subtracted from the total site area.

SITE PLANNING AND DESIGN STRATEGIES – Techniques of planning, engineering, and landscape design that maintain predevelopment hydrologic functions and pollutant removal mechanisms to the extent practical.

SOIL TEST - Chemical analysis of soil to determine needs for fertilizers or amendments for species of plant being grown.

SOURCE CONTROLS - Practices to limit the generation of stormwater pollutants at their source.

STABILIZATION - Providing adequate measures, vegetative and/or structural that will prevent erosion from occurring.

STAGE (HYDRAULICS) - The variable water surface or the water surface elevation above any chosen datum.

STORMWATER – Water consisting of precipitation runoff or snowmelt.

STORMWATER BASIN - A land depression or impoundment created for the detention or retention of stormwater runoff.

STORMWATER FILTERING - Stormwater treatment methods that utilize an artificial media to filter out pollutants entrained in urban runoff.

STORMWATER MANAGEMENT PLAN - Plan describing the proposed methods and measures to prevent or minimize water quality and quantity impacts associated with a development project both during and after construction. It identifies selected LID source controls and treatment practices to address those potential impacts, the engineering design of the treatment practices, and maintenance requirements for proper performance of the selected practices.

STORMWATER POLLUTION PREVENTION PLAN (SWPPP) - Identifies potential sources of pollution and outlines specific management activities designed to minimize the introduction of pollutants into stormwater.

STORMWATER RETROFITS – Modifications to existing development to incorporate source controls and structural stormwater treatment practices to remedy problems associated with and improve water quality mitigation functions of older, poorly designed, or poorly maintained stormwater management systems.

STORMWATER TREATMENT TRAIN - Stormwater treatment practices, as well as site planning techniques and source controls, combined in series to enhance pollutant removal or achieve multiple stormwater objectives.

STREAM BUFFERS - Zones of variable width that are located along both sides of a stream and are designed to provide a protective natural area along a stream corridor.

STREAM ORDER – Stream order indicates the relative size of a stream based on Strahler's (1957) method. Streams with no tributaries are first-order streams, represented as the start of a solid line on a 1:24,000 USGS Quadrangle Sheet. A second-order stream is formed at the confluence of two first-order streams. However, if a first-order stream joins a second-order stream, it remains a second-order stream; it is not until a second-order stream combines with another second-order stream that it becomes a third-order stream, and so on. Peak flow controls (CP_v and Q_p) are waived for discharges to fourth-order and larger streams. Appendix I includes a description and a map of all fourth-order and larger streams in Rhode Island.

STREET SWEEPER – Equipment that removes particulate debris from roadways and parking lots. Includes mechanical broom sweepers, vacuum sweepers, regenerative air sweepers, and dry vacuum sweepers.

STRUCTURAL BMPs - Devices that are constructed to manage stormwater runoff.

SUBGRADE - The soil prepared and compacted to support a structure or a pavement system.

SUBWATERSHED - The area draining to the point of confluence between two first-order tributaries.

TECHNICAL RELEASE No. 55 (TR-55) - A watershed hydrology model developed by the Soil Conservation Service (now NRCS) used to calculate runoff volumes and provide a simplified routing for storm events through ponds.

TEMPORARY SEEDING - A seeding which is made to provide temporary cover for the soil while waiting for further construction or other activity to take place.

TIME OF CONCENTRATION - Time required for water to flow from the most remote point of a drainage area, in a hydraulic sense, to the point of analysis.

TOE (OF SLOPE) - Where the slope stops or levels out. Bottom of the slope.

TOKEN SPILLWAYS – Also known as emergency spillways, these are placed above the water elevation of the largest managed storm and are required if not already provided as part of the conveyance of the 100-year storm event.

TOPSOIL - Fertile or desirable soil material used to top dress road banks, subsoils, parent material, etc.

TOTAL MAXIMUM DAILY LOAD (TMDL) - A calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources, including a margin of safety.

TOTAL NITROGEN (TN) – The sum of total Kjeldahl nitrogen, nitrate, and nitrite. Nitrogen is typically the growth-limiting nutrient is estuarine and marine systems.

TOTAL PHOSPHORUS (TP) – Sum of orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Phosphorus is typically the growth-limiting nutrient is freshwater systems.

TOTAL SUSPENDED SOLIDS (TSS) - The total amount of soils particulate matter that is suspended in the water column.

TRASH RACK - Grill, grate, or other device at the intake of a channel, pipe, drain or spillway for the purpose of preventing oversized debris from entering the structure and clogging the outlet weir/orifice.

ULTRA-URBAN - Densely developed urban areas in which little pervious surface exists.

UNDERGROUND DETENTION FACILITIES - Vaults, pipes, tanks, and other subsurface structures designed to temporarily store stormwater runoff for water quantity control and to drain completely between runoff events. They are intended to control peak flows, limit downstream flooding, and provide some channel protection.

UNDERGROUND INFILTRATION SYSTEMS – Structures designed to capture, temporarily store, and infiltrate the water quality volume over several days, including premanufactured pipes, vaults, and modular structures. Used as alternatives to infiltration trenches and basins for space-limited sites and stormwater retrofit applications.

URBAN STORMWATER RUNOFF - Stormwater runoff from developed areas.

VELOCITY HEAD - Head due to the velocity of a moving fluid, equal to the square of the mean velocity divided by twice the acceleration due to gravity (32.16 feet per second per second).

WATER BALANCE – Equation describing the input, output, and storage of water in a watershed or other hydrologic system.

WATER QUALITY SWALES - Vegetated open channels designed to treat and attenuate the water quality volume and convey excess stormwater runoff. Dry swales are primarily designed to receive drainage from small impervious areas and rural roads. Wet swales are primarily used for highway runoff, small parking lots, rooftops, and pervious areas.

WATER QUALITY VOLUME (WQ_v) -The storage needed to capture and treat 90% of the average annual stormwater runoff volume. In Rhode Island, this equates to 1-inch of runoff from impervious surfaces.

WATERSHED INCHES - Watershed inches are used to compare stormwater volume requirements between sites of varying sizes. Required volumes in acre-feet can be converted to watershed inches by dividing by the total site area in acres and multiplying by 12 inches/feet.

WATERSHED MANAGEMENT **-** Integrated approach addressing all aspects of water quality and related natural resource management, including pollution prevention and source control.

WET SWALE - An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

WET VEGETATED TREATMENT SYSTEMS (WVTS) - Shallow, constructed pools that capture stormwater and allow for the growth of characteristic emergent vegetation.

XERISCAPING - Planting to minimize water usage (“xeri” is the Greek prefix meaning ”dry”) by using plants that are adapted to the local climate and require minimal watering, fertilizer, and pesticide application, and improving soils by adding soil amendments or using mulches to reduce the need for watering by increasing the moisture retained in the soil.

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APPENDIX A: STORMWATER MANAGEMENT CHECKLIST

(THE MOST RECENT VERSION OF THE CHECKLIST IS PUBLISHED ON THE RIDEM WEBSITE)

APPENDIX B: VEGETATION GUIDELINES AND PLANTING LIST

Vegetation can often be an important factor in the performance and community acceptance of many stormwater BMPs. This Guide provides general background on how to determine the appropriate plant species for use in Rhode Island. This guide also includes tips on how to establish more functional landscapes within stormwater BMPs. General guidance for all BMPs is discussed, as well as specific guidance for each of the BMP groups, focusing on native, non-invasive species. For coastal-specific areas, designers should also refer to the *Coastal Buffer Zone Planting Guide* (CRMC, 2008) and the *University of Rhode Island Sustainable Coastal Plant List* (URI Cooperative Extension, 2007).

B.1 Vegetation for LID Practices

Choosing appropriate vegetation is a critical element to improve both the function and appearance of stormwater best management practices (BMPs). The first section outlines general guidance that should be considered when planting any stormwater practice. In addition, specific guidelines are presented for bioretention areas. In the second section, key factors in selecting plant material for stormwater practices are reviewed, including hardiness zones, physiographic regions, hydrologic zones, and cultural factors.

B.2 Native Species

This manual encourages the use of native plants in LID practices. Native plants are defined as those species which evolved naturally to live in this region of the world. Practically speaking, this refers to those species which grew in Rhode Island before recent human settlement. Many introduced species were weeds brought in by accident; others were intentionally introduced and cultivated for use as food, medicinal herbs, spices, dyes, fiber plants, and ornamentals.

Some introduced species are invasive, have few predators, and can take over naturally occurring species at an alarming rate. As such, they can often escape cultivation and begin reproducing in the wild. This is significant ecologically because many introduced species out-compete indigenous species and begin to replace them in the wild. By planting native species in stormwater management facilities, we can help protect the natural heritage of Rhode Island and provide a legacy for future generations.

Native species also have distinct genetic advantages over non-native species for planting in Rhode Island. Because they have evolved to live here naturally, indigenous plants are best suited for the local climate. This translates into greater survival rates when planted and less replacement and maintenance during the life of a stormwater management facility. Both of these attributes provide cost savings for the facility owner.

Finally, people often plant exotic species for their ornamental value. While it is important to have aesthetic stormwater management facilities for public acceptance and the maintenance of property value, it is not necessary to introduce foreign species for this purpose. Many native species are aesthetically pleasing and can be used as ornamentals. When selecting ornamentals for LID practices, planting preference should be given to native ornamentals.

B.3 General Planting Guidance for LID Practices

- Do not plant trees and shrubs within 15 feet of the toe of slope of a dam;
- Do not plant trees or shrubs known to have long tap roots within the vicinity of the earth dam or subsurface drainage facilities;
- Do not plant trees and shrubs within 15 feet of perforated pipes;
- Do not plant trees and shrubs within 25 feet of a hydraulic outlet control structure;
- Provide 15-foot clearance from a non-clogging, low-flow orifice;
- Herbaceous embankment plantings should be limited to 10 inches in height, to allow visibility for the inspector who is looking for burrowing rodents that may compromise the integrity of the embankment;
- Provide slope stabilization methods for slopes steeper than 2:1, such as planted erosion control mats. Also, use seed mixes with quick germination rates in this area. Augment temporary seeding measures with container crowns or root mats of more permanent plant material;
- Utilize erosion control mats and fabrics to protect channels and slopes that may be subject to frequent wash outs;
- Stabilize all water overflows with plant material that can withstand strong current flows. Root material should be fibrous and substantial but lacking a tap root;
- Sod drainage channels subjected to high velocities that are not stabilized by erosion control mats;
- Divert flows temporarily from seeded areas until stabilized;
- Check water tolerances of existing plant materials prior to inundation of area;
- Check salt tolerances for applications accepting roadside drainage/areas of higher salt usage;
- Stabilize aquatic and safety benches with emergent plants and wet seed mixes;
- Do not block maintenance access to structures with trees or shrubs;
- Avoid plantings that will require routine or intensive chemical applications (i.e. turf area);
- Have soil tested to determine if there is a need for amendments;
- Select plants that can thrive with on-site soil with no additional amendments or a minimum of amendments;

- Decrease the areas where turf is used. Use low-maintenance ground cover to absorb run-off;
- Plant stream and edge of water buffers with trees, shrubs, ornamental grasses, and herbaceous materials where possible, to stabilize banks and provide shade;
- Maintain and frame desirable views. Be careful not to block views at entrances, exits, or difficult road curves. Screen or buffer unattractive views into the site;
- Use plants to prohibit pedestrian access to pools or steeper slopes that may be unsafe;
- The designer should carefully consider the long-term vegetation management strategy for the BMP, keeping in mind the “maintenance” legacy for the future owners. Keep maintenance area open to allow future access for maintenance. Provide a planting surface that can withstand the compaction of vehicles using maintenance access roads. Make sure the facility maintenance agreement includes a maintenance requirement of designed plant material;
- Provide Signage for:
    - Stormwater Management Areas to help educate the public when possible
    - Wildflower/native grass areas, when possible, to designate limits of mowing
- Avoid the overuse of any plant materials; and
- Preserve existing natural vegetation when possible.

It is often necessary to test the soil in which you are about to plant in order to determine the following:

- pH - whether acid, neutral, or alkali;
- major soil nutrients - Nitrogen, Phosphorus, Potassium; and
- minerals - such as chelated iron, lime.

Have soil samples analyzed by experienced and qualified individuals, such as those at the University of Massachusetts Soil Testing Laboratory (http://www.uri.edu/ce/factsheets/sheets/soiltest.html), who will explain in writing the results, what they mean, as well as what soil amendments would be required. Certain soil conditions, such as marine clays, can present serious constraints to the growth of plant materials and may require the involvement of qualified professionals. When poor soils can’t be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

Areas that have recently been involved in construction can become compacted so that plant roots cannot penetrate the soil. Seeds lie on the surface of compacted soils, allowing seeds to be washed away or be eaten by birds. Soils should be loosened to a minimum depth of two inches, preferably to a four-inch depth. Hard soils may require tilling to a deeper depth. The soil should be loosened regardless of the ground cover. This will improve seed contact with the soil, providing greater germination rates, allowing the roots to penetrate into the soil. If the area is to be sodded, tilling will allow the roots to penetrate into the soil. Weak or patchy crops can be prevented by providing good growing conditions.

Whenever possible, topsoil should be spread to a depth of four inches (two-inch minimum) over the entire area to be planted. This provides organic matter and important nutrients for the plant material. This also allows the stabilizing materials to become established faster, while the roots are able to penetrate deeper and stabilize the soil, making it less likely that the plants will wash out during a heavy storm.

If topsoil has been stockpiled in deep mounds for a long period of time, it is desirable to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, it is necessary to inoculate the soil after application.

Remember that newly installed plant material requires water in order to recover from the shock of being transplanted. Be sure that some source of water is provided, should dry periods occur after the initial planting. This will reduce plant loss and provide the new plant materials with a chance to establish root growth. An appropriate watering schedule should be instituted for all plant material based upon plant species requirements and should be followed until plants are fully established.

B.4 Basins and WVTS

For areas that are to be planted within a stormwater management facility, it is necessary to determine what type of hydrologic zones will be created within the facility. The following six zones describe the different conditions encountered in stormwater management facilities. Every facility does not necessarily incorporate all of these zones. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation by water.

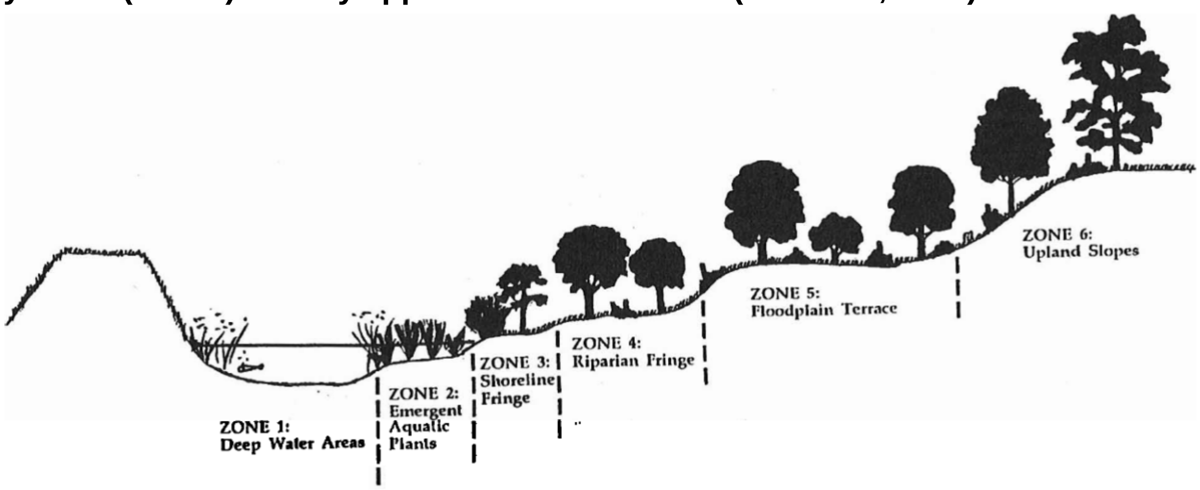
Each zone has its own set of plant selection criteria based on the hydrology of the zone, the stormwater functions required of the plant, and the desired effect. The hydrologic zones are described in Table B-1 and illustrated in Figure B-1.

Table B-1 Hydrologic Zones

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep Water Pool	1-6 feet deep Permanent Pool
Zone 2	Shallow Water Bench	6 inches to 1 foot deep

Zone #	Zone Description	Hydrologic Conditions
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Figure B-1 Planting Zones for Stormwater Basins and Wet Vegetated Treatment Systems (WVTS) as they appear in cross-section (Schueler, 1992).



<u>**Zone 1: Deep Water Area *(1 - 6 Feet)***</u>

Basins and WVTSs both have deep pool areas that comprise Zone 1. These pools range from one to six feet in depth, and are best colonized by submergent plants, if at all.

This pondscaping zone has not been routinely planted for several reasons. First, the availability of plant materials that can survive and grow in this zone is limited, and it is also feared that plants could clog the stormwater facility outlet structure. In many cases, these plants will gradually become established through natural recolonization (e.g., transport of plant fragments from other basins or natural ponds via the feet and legs of waterfowl). If submerged plant material becomes more commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

- Plant material must be able to withstand constant inundation of water of one foot or greater in depth.
- Plants may be submerged partially or entirely.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects, and other aquatic life.

Zone 2: Shallow Water Bench (*Normal Pool to 1 Foot*)

Zone 2 includes all areas that are inundated below the normal pool to a depth of one foot, and is the primary area where emergent plants will grow in WVTSs. Zone 2 also coincides with the aquatic bench found in stormwater basins. This zone offers ideal conditions for the growth of many emergent species. These areas may be located at the edge of the basin or on low mounds of earth located below the surface of the water within the basin. When planted, Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. This food chain includes predators, allowing a natural regulation of mosquito populations, thereby reducing the need for insecticidal applications.

- Plant material must be able to withstand constant inundation of water to depths between six inches and one foot deep.
- Plants will be partially submerged.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, desirable insects and other aquatic life.

Plants will stabilize the bottom of the basin, as well as the edge of the basin, absorbing wave impacts and reducing erosion, when water level fluctuates. Plants also slow water velocities and increase sediment deposition rates. Plants can reduce resuspension of sediments caused by the wind. Plants can also soften the engineered contours of the basin, and can conceal drawdowns during dry weather.

Zone 3: Shoreline Fringe (*Regularly Inundated*)

Zone 3 encompasses the shoreline of a basin or WVTS, and extends vertically about one foot in elevation from the normal pool. This zone includes the safety bench of a basin, and may also be periodically inundated if storm events are subject to extended detention. This zone can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. In order to stabilize the soil in this zone, Zone 3 must have a vigorous cover.

- Plants should stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- Plant material must be able to withstand occasional inundation of water. Plants will be partially submerged partially at this time.

- Plant material should, whenever possible, shade the shoreline, providing cover for wildlife.
- Plants should be able to enhance pollutant uptake.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife. Plants could also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- Plants should have very low maintenance requirements, since they may be difficult or impossible to reach.
- Plants should be resistant to disease and other problems which require chemical applications (since chemical application is not advised in stormwater basins or WVTSs).

Zone 4: Riparian Fringe (Periodically Inundated)

Zone 4 extends from one to four feet in elevation above the normal pool. Plants in this zone are subject to periodic inundation after storms, and may experience saturated or partly saturated soil inundation. Nearly all of the temporary extended detention area is included within this zone.

- Plants must be able to withstand periodic inundation of water after storms, as well as occasional drought during the dry season.
- Plants should stabilize the ground from erosion caused by uphill run-off.
- Plants should shade the low-flow channel.
- Plants should be able to enhance pollutant uptake.
- Plant material should have very low maintenance, since they may be difficult or impossible to access.
- Plants may provide food and cover for waterfowl, songbirds and wildlife. Plants may also be selected and located to control overpopulation of waterfowl.
- Plants should be located to reduce pedestrian access to the deeper pools.

Zone 5: Floodplain Terrace (*Infrequently Inundated*)

Zone 5 is periodically inundated by flood waters that quickly recede in a day or less. Operationally, Zone 5 extends from the maximum one year or CP_v water surface elevation (WSE) up to the 100-year maximum WSE. Key planting objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone and to establish a low maintenance, natural vegetation area.

- Plant material should be able to withstand occasional but brief inundation during storms, although typical moisture conditions may be moist, slightly wet, or even swing entirely to drought conditions during the dry season.
- Plants should stabilize the basin slopes from uphill erosion.

- Ground cover should be very low maintenance, since they may be difficult to access on steep slopes or if frequency of mowing is limited. A dense tree cover may help reduce maintenance and discourage nuisance wildlife.
- Plants may provide food and cover for waterfowl, songbirds, and wildlife.
- Placement of plant material in Zone 5 is often critical, as it often creates a visual focal point and provides structure and shade for a greater variety of plants.

Zone 6: Upland Slopes (Seldom or Never Inundated)

The last zone extends above the maximum 100-year WSE, and often includes the setback of a basin or WVTS. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe.

- Plant material is capable of surviving the particular conditions of the site. Thus, it is not necessary to select plant material that will tolerate any inundation. Rather, plant selections should be made based on soil condition, light, and function within the BMP.
- Groundcovers should emphasize infrequent mowing to reduce the cost of maintaining this BMP.
- Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, serve as a buffer, or provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

B.5 Infiltration and Sand Filters

Properly planted, infiltration practices and sand filter systems blend into natural surroundings. If unplanted or improperly planted, they can become eyesores and liabilities.

Design Constraints:

- Do not plant trees or provide shade within 15 ft of infiltration or filtering area or where leaf litter will collect and clog infiltration area.
- Have the soil tested in the filtering bed to determine if there is a need for soil amendments.
- Determine depth of water table to determine standing water conditions and depth to constant soil moisture.
- Planting turf over sand filters is allowed with prior approval of the approving agency, on a case-by-case basis.
- Do not locate plants to block maintenance access to structures.
- Divert flows temporarily from seeded areas until stabilized.

- Planting of peat filters or any filter requiring a filter fabric should include material selected with care to insure that no tap roots will penetrate the filter fabric.

B.6 Open Channels

Consult Table B-2 for grass species that perform well in the stressful environment of an open channel or grass filter strip. These practices experience fluctuating water levels and may also experience stormwater flows with high velocities. It is important to choose an appropriate grass species that will thrive given specific site conditions. If open channels are planted with an unsuitable grass species, the grass may become patchy or die back, reducing the overall treatment efficiency of the practice. Wet swales may also be planted with other aquatic species from Table B-6.

Table B-2 Common Grass Species Adapted to Open Channel Practices (Virginia ESC Handbook, 1992)

Common Name	Scientific Name	Slope Range	Permissible Velocity (fps)		Notes
			Erosion Resistant Soils	Easily Eroded Soils	
Kentucky Bluegrass	*Poa pratensis*	0-5	6	3.5	Cool. Not for wet swales
Smooth Brome	*Bromus inermis*	5-10	5	2.5	
Buffalo Grass	*Buchloe dactyloides*	Over 10	5	2.5	
Tall Fescue	*Festuca arundinacea*				
Creeping Bentgrass	*Agrostis palustris*	0-5*	6	2.5	Cool
Redtop	*Agrostis alba*				Cool
Red Fescue	*Festuca rubra*				Cool. Not for Wet swale

Note 1: These grasses are sod-forming and can withstand frequent inundation, and are thus ideal for the swale or grass channel environment. Most are salt-tolerant, as well. Cool refers to cool season grasses.

Note 2: Where possible, one or more of these grasses should be in the seed mixes.

* Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

Once grass has been established (seed or sod) their physical characteristics become indistinguishable (sod will have better erosion resistance initially, but once the seeds develop, the differences are minimal).

B.7 Bioretention Practices

B.7.1 Bioretention Soil Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location, size, and treatment volume. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

The bioretention soil should be a sandy loam, loamy sand, loam (USDA), or a loam/sand mix (should contain 85-88% sand, by volume). The clay content for these soils should by less than 2% by volume. A permeability of at least 2.0 feet per day (1.0 in/hr) is required. The soil should be free of stones, stumps, roots, other woody material over 1inch in diameter, or brush/seeds from noxious weeds. Placement of the planting soil should be in lifts of 12 to 18 inches, loosely compacted (tamped lightly with a dozer or backhoe bucket). The specific characteristics are presented in the table below.

Table B-3 Planting Soil Characteristics

Parameter	Value
Organic matter	3 to 5%
Clay*	0 to 2%
Silt*	0 to 12%
Sand*	85-88%

*Soil characteristics. Augment soils with aged leaf compost and acceptable topsoil.

Mulch Layer

The mulch layer plays an important role in the performance of the bioretention system. The mulch layer helps maintain soil moisture and avoids surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. Mulch also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment.

The mulch layer should be shredded hardwood mulch that is well aged (stockpiled or stored for at least six (6) months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Planting Plan Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat stormwater runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility. The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions.

The layout of plant material should be flexible, but should follow the general principals described in Table B-4. Tree density of approximately one tree per 250 square feet (i.e., 15 feet on center) is recommended. Shrubs and herbaceous vegetation should generally be planted at higher densities (5-10 feet on center and 2.5 feet on center, respectively). The objective is to have a system which resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth.

Figure B-2 Planting Zones for Bioretention Facilities

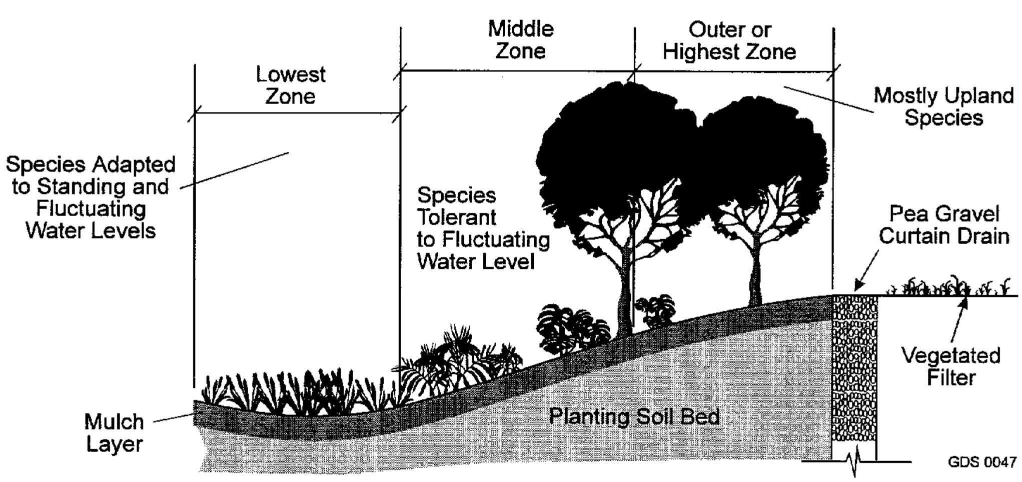


Table B-4 Planting Plan Design Considerations

• Native plant species should be specified over exotic or foreign species.
• Appropriate vegetation should be selected based on the zone of hydric tolerance
• Species layout should generally be random and natural.
• A canopy should be established with an understory of shrubs and herbaceous materials.
• Woody vegetation should not be specified in the vicinity of inflow locations.
• Trees should be planted primarily along the perimeter of the bioretention area.
• Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be considered when laying out the planting plan.
• Noxious weeds should not be specified.
• Aesthetics and visual characteristics should be a prime consideration.
• Traffic and safety issues must be considered.
• Existing and proposed utilities must be identified and considered.

<u>Plant Material Guidance</u>

Plant materials should conform to the American Standard Nursery Stock, published by the American Association of Nurserymen, and should be selected from certified, reputable nurseries. Planting specifications should be prepared by the designer and should include a sequence of construction, a description of the contractor's responsibilities, a planting schedule, installation specifications, initial maintenance, a warranty period, and expectations of plant survival. The table below presents some typical elements for planting specifications.

Table B-5 Planting Specification Elements for Bioretention Areas

Specification Element	**Description**
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation through site clean-up.
Contractor's Responsibilities	Specify the contractor’s responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency (annual mulching is most common); removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair/replacement of staking and wires.
Warranty	Specify warranty period, required survival rate, and expected condition of plant species at end of warranty period.

B.8 Other Considerations in LID Practice Planting

Use or Function

In selecting plants, consider their desired function in the landscape. Is the plant needed as ground cover, soil stabilizer, or a source of shade? Will the plant be placed to frame a view, create focus, or provide an accent? Does the adjacent use provide conflicts or potential problems and require a barrier, screen, or buffer? Nearly every plant and plant location should be selected to serve some function in addition to any aesthetic appeal.

Plant Characteristics

Certain plant characteristics are so obvious that they may actually be overlooked in the plant selection. These are:

- Size
- Shape

For example, tree limbs, after several years, can grow into power lines. A wide-growing shrub may block an important line of sight to oncoming vehicular traffic. A small tree could strategically block the view from a second-story window. Consider how these characteristics can work for you or against you, today and in the future.

Other plant characteristics must be considered to determine whether the plant will fit with the landscape today and through the years to come. Some of these characteristics are:

- Color
- Texture
- Aesthetic Interest, i.e.- Flowers, Fruit, Leaves, Stems/Bark
- Growth rate

In urban or suburban settings, residents living next to an LID practice may desire that the facility be appealing or interesting. Aesthetics is an important factor to consider in the design of these systems. Failure to consider the aesthetic appeal of a facility to the surrounding residents may result in reduced value to nearby lots. Careful attention to the design and planting of a facility can result in maintained or increased values of a property.

Availability and Cost

Often overlooked in plant selection is the availability from wholesalers and the cost of the plant material. There are many plants listed in landscape books that are not readily available from the nurseries. Without knowledge of what is available, time spent researching and finding the one plant that meets all the needs will be wasted, if it is not available from the growers. It may require shipping, therefore, making it more costly than the budget may allow. Some planting requirements may require a special effort to find the specific plant that fulfills the needs of the site and will function in the landscape as desired. Refer to the CRMC Coastal Plant Suppliers by Species list for guidance (www.crmc.ri.gov/pubs/pdfs/CoastalPlant_Suppliers.pdf).

B.9 Rhode Island LID Practices – Acceptable Plant List

The following is a list of acceptable plants for a variety of uses in Rhode Island. For a more complete and interactive listing, refer to the CRMC/URI Rhode Island Interactive Plant Guide (www.edc.uri.edu/personal/erik/coastalplants/coastalplantguide.htm).

B.9.1 Salt-Tolerant Plants

These plant species are suitable for planting within 80 feet of a roadside that is subject to de-icing and anti-icing application of salts.

B.9.1.1 Trees

Botanical Name	Common Name
Crataegus spp.	Hawthorns
Fraxinus pennsylvanica	Green Ash
Picea pungens	Blue Spruce
Pinus strobus	Eastern White Pine
Pinus rigida	Pitch Pine
Populus deltoides	Eastern Cottonwood
Quercus alba	White Oak
Quercus rubra	Red Oak

B.9.1.2 Shrubs

Botanical Name	Common Name
Forsythia x intermedia	Forsythia
Gleditsia triacanthos	Honeylocust

B.9.1.3 Grasses

Botanical Name	Common Name
Festuca arundinacea	Tall Fescue
Lolium perenne	Perennial ryegrass
Medicago sativa	Alfalfa
Panicum virgatum	Switchgrass
Typha domingensis	Cattails

B.9.2 Native Plants/Xeriscaping

These plant species are native or adapted to Southern New England. Information on these species and others that may be suitable for xeriscaping may be found in the references at the end of this appendix.

B.9.2.1 Trees

Botanical Name	Common Name
Carya spp.	Hickories
Celtis occidentalis	Hackberry
Chamaecyparis thyoides	Atlantic White Cedar
Cornus florida	Flowering Dogwood
Crataegus spp.	Hawthorns
Juglans spp.	Walnuts

Juniperus virginiana	Eastern Red Cedar
Morus rubra	Red Mulberry
Picea mariana	Black Spruce
Pinus strobus	White Pine
Prunus serotina	Black Cherry
Prunus virginiana	Choke Cherry
Quercus spp.	Oaks
Thuja occidentalis	Northern White Cedar
Tsuga canadensis	Eastern Hemlock

B.9.2.2 Shrubs

For Dry, Sunny Areas

Botanical Name	Common Name
Ceanothus americanus	Jersey Tea
Comptonia peregrina	Sweet Fern
Juniperus communis	Ground Juniper
Myrica pensylvanica	Bayberry
Vaccinium augustifolium	Lowbush Blueberry

For Shaded Areas

Botanical Name	Common Name
Corylus americana, C. cornuta	Hazelnuts
Kalmia latifolia	Mountain Laurel
Rhododendron viscosum	Swamp Azalea
Viburnum spp.	Viburnums

For Moist Sites

Botanical Name	Common Name
Amelanchier canadensis	Shadbush Serviceberry
Clethra alnifolia	Sweet Pepperbush
Cornus spp.	Dogwoods
Ilex glabra	Inkberry
Ilex verticillata	Winterberry
Hamamelis virginiana	Witch Hazel
Morus rubra	Red Mulberry
Rhododendron viscosum	Swamp Azalea
Salix discolor	Pussy Willow

Sambucus canadensis	Elderberry
Spiraea latifolia	Spiraea
Vaccinium corymbosum	Highbush Blueberry
Viburnum spp.	Viburnums

B.9.2.3 Perennials

Botanical Name	**Common Name**
Aquilegia canadensis	Wild Red Columbine
Arctostaphylos uva-ursi	Bearberry, Kinnickinick
Asarum canadense	Wild Ginger
Asclepias tuberosa	Butterfly Weed
Aster divaricatus	White Wood Aster
Aster novae-angliae	New England Aster
Caltha palustris	Marsh Marigold
Geranium maculatum	Wild Geranium
Lobelia cardinalis	Cardinal Flower
Maianthemum racemosum, syn. Smilacina racemosa	Solomon's Plume
Mitchella repens	Partridgeberry
Phlox divaricata	Wild Blue Phlox
Sanguinaria canadensis	Bloodroot
Tiarella cordifolia	Foamflower
Waldsteinia fragariodes	Barren Strawberry

B.9.2.4 Grasses

Botanical Name	**Common Name**
Andropogon gerardii	Big Bluestem
Panicum virgatum	Switchgrass
Schizachyrium scoparium, syn. Andropogon scoparius	Little Bluestem

B.9.3 Bioretention Plants

B.9.3.1 Deciduous Trees

Botanical Name	**Common Name**
Amelanchier canadensis	Shadblow Juneberry
Amelanchier Laevis	Allegheny Serviceberry
Betula nigra	River Birch
Carpinus caroliniana	American Hornbeam

Celtis occidentalis	Common Hackberry
Cercis canadensis	Eastern Red Bud
Fraxinus pennsylvanica	Green Ash
Liquidambar styracaflua	Sweet Gum Tree
Liriodendron tulipifera	Tulip Tree
Magnolia virginiana	Magnolia Virginiana
Nyssa sylvatica	Tupelo
Quercus bicolor	Swamp White Oak
Quercus palustris	Pin Oak

B.9.3.2 Evergreen Trees

Botanical Name	Common Name
Chamaecyparis thyoides	Atlantic White Cedar
Ilex opaca	American Holly
Juniperus virginiana	Eastern Red Cedar
Thuja occidentalis var	Eastern Arborvitae

B.9.3.3 Shrubs

Botanical Name	Common Name
Aronia arbutifolia	Red Choke Cherry
Aronia melanocarpa	Black Chokeberry
Baccharis halimifolia	Groundsel
Calicarpa dichotoma	Purple Beautyberry
Cephalotaxus harringtonia	Plum Yew
Cephalanthus occidentalis	Buttonbush
Clethra alnifolia	White Summer Sweet
Comptonia peregrina	Sweet Fern
Cornus racemosa	Gray Dogwood
Cornus sericea	Bailey's Red Twig Dogwood
Hamamelis virginiana	Common Witch Hazel
Hydrangea arborescens	Wild Hydrangea
Hypericum kalmianum	St. John's Wort
Hypericum patulum	St. John's Wort
Ilex glabra	Inkberry
Ilex glabra compacta	Compact Inkberry
Ilex verticillata	Winterberry
Itea virginica	Henry's Garnet
Kalmia latifolia	Mountain Laurel
Leucothoe fontanesiana	Drooping Leucothoe

Botanical Name	Common Name
Lindera benzoin	Spice Bush
Myrica pennsylvanica	Northern Bayberry
Rhododendron viscosum	Swamp Azalea
Rhus aromatica canadensis	Fragrant Sumac
Rhus aromatica gro-lo	Gro-Lo Fragrant Sumac
Rhus copallina	Shining Sumac
Rhus glabra	Sumac
Rhus typhina	Staghorn Sumac
Sambucus canadensis	American Elderberry
Vaccinium angustifolia	Low Bush Blueberry
Vaccinum corymbosum	Highbush Blueberry
Viburnum cassinoides	Wild Raisin
Viburnum dentatum	Arrowwood Viburnum
Viburnum dilatatum	Linden Viburnum
Viburnum trilobum	Highbush Cranberry

B.9.3.4 Ground Cover/Grasses/Perennials

Botanical Name	Common Name
Andropogon gerardii	Big Blue Stem
Arctostaphylos uva-ursi	Bearberry
Asclepias tuberosa	Butterfly Weed
Aster novae-angliae	New England Aster
Carex stricta	Tussock Sedge
Coreopsis species	Coreopsis
Coreopsis verticillata	Moonbeam Coreopsis
Dennstaedtia punctilobula	Hay Scented Fern
Eragrostis spectabilis	Purple Lovegrass
Eupatorium maculatum	Joe-Pye Weed
Hemerocallis spp.	Daylilies
Hibiscus moscheutus	Swamp Rose Mallow
Iris versicolor	Blue Flag
Juncus effusus	Soft Rush
Oclemena acuminata	Wood Aster
Oenothera biennis	Evening Primrose
Panicum virgatum	Switch Grass
Pennisetum alopecuroides	Fountain Grass
Penstomon Prarie Dusk	Prairie Dusk Beards Tongue
Phlox stolonifera	Phlox White

Botanical Name	Common Name
Phlox stolonifera	Phlox Purple
Polystichum arcostinchoides	Christmas Dagger Fern
Rudbeckia hirta	Black Eyed Susan
Schizachyrium scoparium	Bluestem
Solidago sempervirens	Seaside Goldenrod
Solidago virgaurea	Goldenrod

B.9.4 Open Channel Grasses

Botanical Name	Common Name
Agrostis alba	Redtop
Agrostis palustris	Creeping Bentgrass
Bromus inermis	Smooth Brome
Buchloe dactyloides	Buffalo Grass
Cynodon dactylon	Bermuda Grass
Festuca arundinacea	Tall Fescue
Festuca rubra	Red Fescue
Poa pratensis	Kentucky Bluegrass

B.9.5 Stormwater Basins and WVTS Plant List

This section contains planting guidance for stormwater basins and WVTS. The following lists emphasize the use of plants native to southern New England and are intended as general guidance for planning purposes.

Plantings for stormwater basins and WVTS should be selected to be compatible with the various hydrologic zones (NYDEC, 2001) within these treatment practices. The hydrologic zones reflect the degree and duration of inundation by water. Plants recommended for a particular zone can generally tolerate the hydrologic conditions that typically exist within that zone. Table B-6 summarizes recommended plantings (trees/shrubs and herbaceous plants) within each hydrologic zone. This list is not intended to be exhaustive, but includes a number of recommended native species that are generally available from commercial nurseries. Other plant species may be acceptable if they can be shown to be appropriate for the intended hydrologic zone.

Table B-6 Plant List for Stormwater Basins and WVTS

Hydrologic Zone	Zone Description	Plant Name and Form	
Zone 1 **Deep Water Pool**	• 1 to 6 feet deep, permanent pool • Submergent plants (if any at all) • Not routinely planted due to limited availability of plants that can survive in this zone and potential clogging of outlet structure • Plants reduce resuspension of sediments and improve oxidation/aquatic habitat	**Trees and Shrubs** Not recommended **Herbaceous Plants** Coontail (Ceratophyllum demersum) Duckweed (*Lemma sp.*) Pond Weed, Sago *(Potamogeton Pectinatus)* Waterweed (*Elodea canadensis*) Wild Celery (*Valisneria Americana)*	 Submergent Submergent/Emergent Submergent Submergent Submergent
Zone 2 **Shallow Water Bench**	• 1 foot below the normal pool (aquatic bench in stormwater basins) • Plants partially submerged • Emergent aquatic plants • Plants reduce resuspension of sediments, enhance pollutant removal, and provide aquatic and nonaquatic habitat	**Trees and Shrubs** Buttonbush *(Cephalanthus occidentalis)* **Herbaceous Plants** Arrow arum *(Peltandra virginica*) Arrowhead, Duck Potato *(Saggitaria latifolia)* Blue Flag Iris *(Iris versicolor)* Blue Joint (*Calamagrotis canadensis*) Broomsedge *(Andropogon virginicus)* Bushy Beardgrass *(Andropogon glomeratus)* Cattail *(Typha sp.)* Common Three-Square *(Scirpus pungens)* Duckweed *(Lemma sp.)* Hardstem Bulrush *(Scirpus acutus)* Giant Burreed *(Sparganium eurycarpum)* Lizard.s Tail *(Saururus cernuus)*	 Deciduous shrub Emergent Emergent Emergent Emergent Perimeter Emergent Emergent Emergent Submergent/Emergent Emergent Emergent Emergent

Hydrologic Zone	Zone Description	Plant Name and Form	
		Long-leaved Pond Weed *(Potamogeton nodosus)*	Rooted Submerged Aquatic
		Marsh Hibiscus *(Hibiscus moscheutos)*	Emergent
		Pickerelweed *(Pontederia cordata)*	Emergent
		Rice Cutgrass *(Leersia oryzoides)*	Emergent
		Sedges *(Carex spp.)*	Emergent
		Soft-stem Bulrush *(Scirpus validus)*	Emergent
		Soft Rush *(Juncus effusus)*	Emergent
		Spatterdock *(Nuphar luteum)*	Emergent
		Switchgrass *(Panicum virgatum)*	Perimeter
		Sweet Flag *(Acorus calamus)*	Herbaceous
		Wild Rice *(Zizania aquatica)*	Emergent
		Wool Grass *(Scirpus cyperinus)*	Emergent
Zone 3 **Shoreline Fringe**	• 1 foot above the normal pool (includes safety bench of stormwater basin) • Frequently inundated if storm events are subject to extended detention • Plants must be able to withstand inundation during storms and occasional drought • Plants provide shoreline stabilization, shade the shoreline, enhance pollutant removal, and provide wildlife habitat (or selected to control overpopulation of waterfowl)	**Trees and Shrubs**	
		Arrowwood Viburnum *(Viburnum dentatum)*	Deciduous shrub
		Bald Cypress *(Taxodium distichum)*	Deciduous tree
		Black Ash *(Fraxinus nigra)*	Deciduous tree
		Black Willow *(Salix nigra)*	Deciduous tree
		Blackgum *(Nyssa sylvatica)*	Deciduous tree
		Buttonbush *(Cephalanthus occidentalis)*	Deciduous shrub
		Common Spice Bush *(Lindera benzoin)*	Deciduous shrub
		Elderberry *(Sambucus canadensis)*	Deciduous shrub
		Larch, Tamarack *(Larix latricina)*	Coniferous tree
		Pin Oak *(Quercus palustris)*	Deciduous tree
		Red Choke Berry *(Pyrus arbutifolia)*	Deciduous shrub
		Red Maple *(Acer rubrum)*	Deciduous tree
		River Birch *(Betula nigra)*	Deciduous tree
		Silky Dogwood *(Cornus amomium)*	Deciduous shrub
		Slippery Elm *(Ulnus rubra)*	Deciduous tree
		Smooth Alder *(Alnus serrulata)*	Deciduous tree
		Speckled Alder *(Alnus rugosa)*	Deciduous shrub
		Swamp White Oak *(Quercus bicolor)*	Deciduous tree
		Swamp Rose *(Rosa Palustrus)*	Deciduous shrub
		Winterberry *(Ilex verticillata)*	Deciduous shrub

Hydrologic Zone	Zone Description	Plant Name and Form	
		Herbaceous Plants	
		Arrow arum *(Peltandra virginica)*	Emergent
		Arrowhead, Duck Potato *(Saggitaria latifolia)*	Emergent
		Blue Flag Iris *(Iris versicolor)*	Emergent
		Blue Joint (*Calamagrotis canadensis*)	Emergent
		Blue Vervain (*Verbena hastata*)	Emergent
		Boneset (*Eupatorium perfoliatum*)	Emergent
		Broomsedge *(Andropogon virginicus)*	Perimeter
		Bushy Beardgrass *(Andropogon glomeratus)*	Emergent
		Cattail *(Typha sp.)*	Emergent
		Chufa (*Cyperus esculentus*)	Emergent
		Creeping Bentgrass (*Agrostis stolonifera*)	Emergent
		Creeping Red Fescue (*Festuca rubra*)	Emergent
		Flat-top Aster (*Aster umbellatus*)	Emergent
		Fowl Bluegrass (*Poa palustris*)	Emergent
		Giant Burreed *(Sparganium eurycarpum)*	Emergent
		Green Bulrush (*Scirpus atrovirens*)	Emergent
		Marsh Hibiscus (*Hibiscus moscheutos*)	Emergent
		Pickerelweed *(Pontederia cordata)*	Emergent
		Redtop (*Agrostis alba*)	Perimeter
		Rice Cutgrass *(Leersia oryzoides)*	Emergent
		Sedges *(Carex spp)*	Emergent
		Tufted Hairgrass (*Deschampsia caespitosa*)	Perimeter
		Soft-stem Bulrush *(Scirpus validus)*	Emergent
		Soft Rush *(Juncus effusus)*	Emergent
		Spotted Joe-pye weed (*Eupatorium maculatum*)	Emergent
		Swamp Aster (*Aster puniceus*)	Emergent
		Switchgrass *(Panicum virgatum)*	Perimeter
		Sweet Flag *(Acorus calamus)*	Herbaceous
		Water Plantain (*Alisma plantago-aquatica*)	Emergent
		Wild-rye (*Elymus spp*.)	Emergent
		Wool Grass *(Scirpus cyperinus)*	Emergent
Zone 4 **Riparian Fringe**	• 1 to 4 feet above the normal pool • Includes nearly all of temporary extended		

<table>
<tr><th>Hydrologic Zone</th><th>Zone Description</th><th colspan="2">Plant Name and Form</th></tr>
<tr><td></td><td>detention volume
Periodically inundated after storms
Plants must be able to withstand inundation during storms and occasional drought
Plants provide shoreline stabilization, shade the shoreline, enhance pollutant removal, and provide wildlife habitat (or selected to control overpopulation of waterfowl)</td><td>Trees and Shrubs

American Elm (Ulmus americana)
Arrowwood Viburnum (Viburnum dentatum)
Bald Cypress (Taxodium distichum)
Bayberry (Myrica pensylvanica)
Black Ash (Fraxinus nigra)
Blackgum (Nyssa sylvatica)
Black Willow (Salix nigra)
Buttonbush (Cephalanthus occidentalis)
Common Spice Bush (Lindera benzoin)
Eastern Cottonwood (Populus deltoides)
Eastern Red Cedar (Juniperus virginiana)
Elderberry (Sambucus canadensis)
Green Ash, Red Ash (Fraxinus pennsylvania)
Larch, Tamarack (Larix latricina)
Pin Oak (Quercus palustris)
Red Choke Berry (Pyrus arbutifolia)
Red Maple (Acer rubrum)
River Birch (Betula nigra)
Shadowbush, Serviceberry (Amelanchier canadensis)
Silky Dogwood (Cornus amomium)
Slippery Elm (Ulnus rubra)
Smooth Alder (Alnus serrulata)
Speckled Alder (Alnus rugosa)
Swamp White Oak (Quercus bicolor)
Swamp Rose (Rosa palustrus)
Sweetgum (Liquidambar styraciflua)
Sycamore (Platanus occidentalis)
Tulip Tree (Liriodendron tulipifera)
Winterberry (Ilex verticillata)
Witch Hazel (Hamamelis virginiana)</td><td>

Deciduous tree
Deciduous shrub
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Hydrologic Zone	Zone Description	Plant Name and Form	
		Herbaceous Plants	
		Big Bluestem (*Andropogon gerardi)*	Perimeter
		Birdfoot deervetch (*Lotus corniculatus*)	Perimeter
		Blue Vervain (*Verbena hastata*)	Emergent
		Boneset (*Eupatorium perfoliatum*)	Emergent
		Blue Joint (*Calamagrotis canadensis*)	Emergent
		Cardinal flower (*Lobelia cardinalis*)	Perimeter
		Fowl Bluegrass (*Poa palustris*)	Emergent
		Fowl mannagrass (*Glyceria striata*)	Perimeter
		Green Bulrush (*Scirpus atrovirens*)	Emergent
		Redtop (*Agrostis alba*)	Perimeter
		Tufted Hairgrass (*Deschampsia caespitosa*)	Perimeter
		Sedges *(Carex spp)*	Emergent
		Soft Rush *(Juncus effusus)*	Emergent
		Spotted Joe-pye weed (*Eupatorium maculatum*)	Emergent
		Swamp Aster (*Aster puniceus*)	Emergent
		Switchgrass *(Panicum virgatum)*	Perimeter
		Water Plantain (*Alisma plantago-aquatica*)	Emergent
		Wild-rye (*Elymus spp*.)	Emergent
Zone 5 Floodplain Terrace	• Extends from the maximum channel protection water surface elevation to the 100-year water surface elevation • Infrequently inundated • Plants must be able to withstand occasional, brief inundation and occasional drought conditions • Plants provide slope stabilization, shade, and wildlife habitat	**Trees and Shrubs**	
		American Elm *(Ulmus americana)*	Deciduous tree
		Bayberry *(Myrica pensylvanica)*	Deciduous shrub
		Black Ash *(Fraxinus nigra)*	Deciduous tree
		Black Cherry *(Prunus serotina)*	Deciduous tree
		Blackgum *(Nyssa sylvatica)*	Deciduous tree
		Black Willow *(Salix nigra)*	Deciduous tree
		Buttonbush *(Cephalanthus occidentalis)*	Deciduous shrub
		Common Spicebush *(Lindera benzoin)*	Deciduous shrub
		Eastern Cottonwood *(Populus deltoides)*	Deciduous tree
		Eastern Hemlock *(Tsuga canadensis)*	Coniferous tree
		Eastern Red Cedar *(Juniperus virginiana*)	Coniferous tree
		Elderberry *(Sambucus canadensis)*	Deciduous shrub
		Green Ash, Red Ash *(Fraxinus pennsylvania)*	Deciduous tree

Hydrologic Zone	Zone Description	Plant Name and Form	
		Hackberry *(Celtis occidentalis)* Pin Oak *(Quercus palustris)* Red Choke Berry *(Pyrus arbutifolia)* Red Maple *(Acer rubrum)* River Birch *(Betula nigra)* Shadowbush, Serviceberry *(Amelanchier canadensis)* Silky Dogwood *(Cornus amomum)* Slippery Elm *(Ulnus rubra)* Smooth Alder *(Alnus serrulata)* Swamp White Oak (*Quercus bicolor*) Sweetgum *(Liquidambar styraciflua)* Sycamore (*Platanus occidentalis*) Tulip Tree *(Liriodendron tulipifera)* White Ash *(Fraxinus americana)* Winterberry *(Ilex verticillata)* Witch Hazel *(Hamamelis virginiana)* **Herbaceous Plants** Annual Ryegrass (*Lolium multiflorum*) Big Bluestem (*Andropogon gerardi*) Cardinal flower (*Lobelia cardinalis*) Creeping Red Fescue (*Festuca rubra*) Fowl mannagrass (*Glyceria striata*) Redtop (*Agrostis alba*) Timothy (*Phleum pratense*) Tufted Hairgrass (*Deschampsia caespitosa*) White Clover (*Trifolium repens*) Switchgrass *(Panicum virgatum)*	Deciduous tree Deciduous tree Deciduous shrub Deciduous tree Deciduous tree Deciduous shrub Deciduous shrub Deciduous tree Deciduous tree Deciduous tree Deciduous tree Deciduous tree Deciduous tree Deciduous tree Deciduous shrub Deciduous shrub Perimeter Perimeter Perimeter Perimeter Perimeter Perimeter Perimeter Perimeter Perimeter Perimeter
Zone 6 **Upland Slopes**	• Above the maximum 100-year water surface elev. • Typically includes setback of basin or WVTS • Plants should be selected based on soil condition, light, and function (not inundation since almost never inundated)	**Trees and Shrubs** American Elm *(Ulmus americana)* Bayberry (*Myrica pensylvanica*) Black Cherry (*Prunus serotina*)	 Deciduous tree Deciduous shrub Deciduous tree

Hydrologic Zone	Zone Description	Plant Name and Form	
		Blackgum *(Nyssa sylvatica)*	Deciduous tree
		Eastern Hemlock *(Tsuga Canadensis)*	Coniferous tree
		Eastern Red Cedar (*Juniperus virginiana*)	Coniferous tree
		Elderberry *(Sambucus canadensis)*	Deciduous shrub
		Hackenberry *(Celtis occidentalis)*	Deciduous tree
		Pin Oak *(Quercus palustris)*	Deciduous tree
		Red Maple *(Acer rubrum)*	Deciduous tree
		Shadowbush, Serviceberry *(Amelanchier canadensis)*	Deciduous shrub
		Sweetgum *(Liquidambar styraciflua)*	Deciduous tree
		Sycamore *(Platanus occidentalis)*	Deciduous tree
		Tulip Tree *(Liriodendron tulipifera)*	Deciduous tree
		White Ash (*Fraxinus Americana*)	Deciduous tree
		Herbaceous Plants	
		Cardinal flower (*Lobelia cardinalis*)	Perimeter
		Switchgrass *(Panicum virgatum)*	Perimeter

Source: Adapted from NYDEC, 2001; New England Wetland Plants, Inc

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APPENDIX C: GUIDANCE FOR RETROFITTING EXISTING DEVELOPMENT FOR STORMWATER MANAGEMENT

This appendix presents a broad overview of guidance on retrofitting existing development to provide stormwater management for a range of development and watershed scales. This guidance is adapted from the Center for Watershed Protection's Urban Stormwater Retrofit Manual (2007). The guidance and information presented will most likely be useful for applicants for redevelopment, or where retrofitting is required to meet watershed-specific goals, such as a TMDL. In general, this guidance should not be viewed as a regulatory mandate and should not relieve readers from practicing sound engineering judgment in the selection and design of appropriate BMPs. In reviewing stormwater retrofit designs to improve water quality, as compared to existing conditions, the approving agencies may approve designs that do not meet the minimum standards or performance criteria herein due to existing site constraints.

C.1 INTRODUCTION

Ideally, as land is developed, structural controls are implemented to control present and future stormwater runoff impacts. However, controlling stormwater from new development alone will not solve existing problems. Retrofitting by definition is the process by which structural controls are constructed to serve and reduce the water quantity and quality impacts from *existing* developed areas; the retrofits described in this appendix can also be helpful for meeting Minimum Standard 6 for existing sites that are redeveloped, particularly for sites with more than 40% impervious cover and where off-site BMPs are needed. The objective of stormwater retrofitting is to remedy problems associated with, and to improve water quality mitigation functions of, older poorly designed, or poorly maintained, stormwater management systems. In Rhode Island, prior to the 1970s, site drainage design did not require stormwater detention for controlling post-development peak flows. As a result, drainage, flooding, and erosion problems are common in many older developed areas of the State. Furthermore, a majority of the stormwater detention facilities throughout the State have been designed to control peak flows, without regard for water quality mitigation. Therefore, many existing stormwater detention basins provide only minimal water quality benefit.

Due to the fact that they are intended to serve existing problem areas, retrofits are typically the responsibility of the local government who must mitigate property flooding, reduce streambank erosion, or comply with TMDL or other water quality regulatory requirements. This can be accomplished through reduction in unnecessary impervious cover, incorporation of small-scale LID management practices, and construction of new or improved structural stormwater treatment practices. One of the primary benefits of stormwater retrofits is the opportunity to combine stormwater quantity and quality controls. Stormwater retrofits can also remedy local nuisance conditions and maintenance problems in older areas and improve the appearance of existing facilities through landscape amenities and additional vegetation.

Retrofits must be integrated with existing and often diverse urban development, and they assume a wider range of forms than structural controls installed during new development. Space constraints, construction costs, acquisition of easements, safety precautions, economic vitality, and property rights all compete with the need to reduce pollutant loadings in the urban environment.

C.2 Stormwater Retrofitting Process

Stormwater retrofitting is ideally performed as a part of an overall watershed planning and implementation effort. When applied along with other available water restoration strategies such as pollutant reduction, habitat restoration, and morphologic stabilization, retrofitting can be most effective. The following eight steps detail a "how-to" approach to retrofitting.

Step 1: Watershed Retrofit Inventory

The first step to putting a retrofit in place is locating and identifying where it is feasible and appropriate to put a proposed facility. This involves a process of identifying as many potential sites as possible. The best retrofit sites fit easily into the existing landscape, are located at or near major drainage or stormwater control facilities, and are easily accessible. Usually the first step is completed in the office using available topographic mapping, low altitude aerial photographs (where available), storm drain master plans, utility maps, and land use maps (zoning or tax maps are generally acceptable).

Before venturing into the field, there are two tasks that should be performed. First, the drainage areas should be delineated, and second, the potential surface area of the facility measured. The drainage area is used to compute a capture ratio. This is the percentage of the overall watershed that is being managed by the retrofit project(s). The surface area is used to compute a preliminary storage volume of the proposed facility. This information can be used as a quick screening tool. In general, an effective retrofitting strategy must capture at least 50% of the watershed, and the minimum target storage volume for each retrofit is approximately 0.5 inch per impervious acre. However for impaired receiving waters and/or those where watershed plans including Special Area Management Plans (SAMPs) or Total Maximum Daily Load (TMDLs) have been completed, capture of a higher percentage of the watershed and/or treatment of the water quality volume (1") may be necessary to achieve the specified pollutant reduction targets.

For the city/town-owned roadways within the catchment area or entire catchment area including privately owned parcels, map and characterize existing conditions including:

- Elevations and contours (scale to be specified by city/town), including severe slopes;
- Existing drainage patterns;
- Existing stormwater structures (e.g., catch basin type, pipe size and material type); and
- Interconnections with private or other publicly owned stormwater systems

Utilizing readily available information and preliminary screening-level field investigations, map and analyze environmental features and siting constraints including:

- Soil types (including Hydrologic group);
- Infiltration rates;
- Depth to groundwater (based on soils data and other readily available information);
- Surface waters;
- Wetlands or other sensitive resources;
- Rock outcroppings or shallow bedrock;
- Buried utilities;
- Public wells within 400 ft of proposed BMP site(s);
- Private wells within 100 ft of the proposed BMP site(s);
- On-site septic systems within 100 ft of proposed BMP site(s);
- Associated rights of way, easements and adjacent publicly owned and other potentially available undeveloped properties in vicinity of existing stormwater infrastructure;
- Description of downstream reach (channel and riparian area) impacted by stormwater outfall(s), including the condition of receiving waters; and
- Construction and maintenance access opportunities.

Step 2: Field Verification of Candidate Sites

Candidate retrofit sites from Step 1 are field investigated to verify that they are indeed feasible candidate sites. This field investigation involves a careful assessment of site specific information such as:

- Presence of sensitive environmental features
- Location of existing utilities (including public wells, private wells, and OWTSs within any critical setback distances established in these standards or other applicable regulation)
- Type of adjacent land uses
- Condition of receiving waters
- Construction and maintenance access opportunities, and most importantly,
- Evaluation of retrofit suitability

Usually a conceptual sketch is prepared and photographs are taken. During field verification, utilities should be located and an assessment made as to potential conflicts. Avoidance should be stressed due to cost considerations. It may also be necessary to contact the appropriate utility to verify field observations and to discuss the potential facility. This may alleviate potential conflicts later.

Existing natural resources such as wetlands, streams, and forests should be evaluated as to their sensitivity. Generally, placement of stormwater retention and detention facilities within wetlands and streams is prohibited and must be avoided. While placement of such structures in upland buffers may be acceptable, avoidance and/or minimization of impacts to these resources should be considered where feasible. Finally, identify, review, and assess adjacent land uses for consideration of structural controls that are compatible with nearby properties.

Step 3: Prioritize Sites for Implementation

Once sites have been located and determined to be feasible and practical, the next step is to set up a plan for future implementation. It is prudent to have an implementation strategy based on a predetermined set of objectives. For example, in some watersheds, implementation may be based on a strategy of reducing pollutant loads to receiving waters where the priority of retrofitting might be to go after the highest polluting land uses first. Whereas if the strategy is oriented more towards restoring stream channel morphology, priority retrofits are targeted to capture the largest drainage areas and provide the most storage. Whatever the restoration focus, it is useful to provide a scoring system that can be used to rank each retrofit site based on a uniform criteria. A typical scoring system might include a score for the following items:

- Pollutant removal capability;
- Stream channel protection capability;
- Flood protection control capability;
- Cost of facility (design, construction and maintenance costs);
- Ability to implement the project (land ownership, construction access, permits); and
- Potential for public benefit (education, location within a priority watershed, visible amenity, supports other public involvement initiatives).

Step 4: Public Involvement Process

This aspect of the process is critical if a project is to be constructed. A successful project must involve the immediate neighbors who will be affected by the changed conditions. Nearly all retrofits require modifications to the existing environment. A dry detention pond may be a very desirable area for some residents in the community. It is a community space and only rarely is there any water in the pond. A stormwater pond or WVTS retrofit, on the other hand, may have large expanses of water and may have highly variable water fluctuations. Adjacent owners may resist these changes. In order to gain citizen acceptance of retrofits, they must be involved in the process from the start and throughout the planning, design and implementation process. Citizens who are informed about the need for, and benefits of, retrofitting are more likely to accept projects.

Still, some citizens and citizen organizations will never support a particular project. This is why it is mandatory that there be an overall planning process which identifies projects early in the selection process and allows citizen input before costly field surveys and engineering designs are performed. Project sites and retrofit techniques that simply cannot satisfy citizen concerns may need to be dropped from further consideration.

A good retrofit program must also incorporate a good public relations plan. Slide shows or field trips to existing projects can be powerful persuasions to skeptical citizens. Every site that goes forward to final design and permitting should be presented at least once to the public through a public hearing or “town hall” type meeting.

Step 5: Retrofit Design

In the design process, the concept is converted to an engineering design and construction plan. Design of retrofit projects should incorporate the same elements as any other structural control design including, but not limited to:

- Adequate hydrologic and hydraulic modeling;
- Detailed topographic mapping;
- Property line establishment;
- Site grading;
- Structural design;
- Geotechnical investigations;
- Erosion and sediment control design; and
- Construction phasing and staging.

Normal structural control design usually follows prescribed design criteria (i.e., control of the 100-year storm or sizing for the water quality volume). Retrofit designers must work backwards from a set of existing site constraints to arrive at an obtainable, yet acceptable, stormwater control. This process may yield facilities that are too small or ineffective, and therefore not practical for further consideration. Designers should look for opportunities to combine projects, such as stream stabilization or habitat restoration with the retrofit in a complementary manner.

The key to successful retrofit design is the ability to balance the desire to maximize pollutant removal, channel erosion protection and flood control while limiting the impacts to adjacent infrastructure, residents or other properties. Designers must consider issues like avoiding relocations of existing utilities, minimizing existing wetland and forest impacts, maintaining existing floodplain elevations, complying with dam safety and dam hazard classification criteria, avoiding maintenance nuisance situations, and providing adequate construction and maintenance access to the site.

Retrofits can vary widely as to cost from a few thousand dollars to several hundred thousand dollars. A preliminary cost estimate should be a part of the design phase.

Step 6: Permitting

Perhaps the most difficult permitting issues for retrofit projects involve impacts to wetlands, forests, and floodplain alterations. Many of these impacts are either unavoidable or necessary to achieve reasonable storage targets. The primary goal that permitting agencies strive for is to have structural BMPs located outside regulated wetlands and buffers. Lacking alternative locations, placement of such structures in the upland buffer areas (e.g., perimeter or riverbank wetland under DEM regulations) may be acceptable provided associated impacts are reduced to the maximum extent practicable. Placement of structural BMPs within streams, rivers, or biological wetland areas is not appropriate in most instances. Permitting agencies will need a thorough explanation of the alternatives considered that could otherwise reduce impacts, why they are not feasible, and a clear demonstration that the project will result in significant improvement in water quality without significant adverse impact to floodplain, wetland habitat, and recreational environment. In some instances, mitigation may also be required in order to satisfy permitting. If so, additional costs may be involved.

Step 7: Construction and Inspections

Like any design project, proper construction, inspection, and administration are integral to a successful facility. Retrofitting often involves construction of unique or unusual elements, such as flow splitters, underground sand filters, or stream diversions. Many of these practices may be unfamiliar to many contractors. Most publicly funded projects are awarded to the low bidder who may be qualified to do the work, but may never have constructed projects of this nature. Therefore, it is almost a necessity to retain the retrofit designer of record or other qualified professional to answer contractor questions, approve shop drawings, conduct regular inspections, hold regular progress meetings, conduct construction testing, and maintain construction records. As-built drawings should also be a part of the construction process. These drawings are used for maintenance purposes.

Step 8: Maintenance Plan

Always the last element and often the least practiced component of a stormwater management program, maintenance is doubly important in retrofit situations. The reasons are simple: most retrofits are undersized when compared to their new development counterparts, and space is at a premium in urban areas where many maintenance provisions such as access roads, stockpiling, or staging areas are either absent or woefully undersized. Maintenance is vital to ensure that a retrofit functions properly for as long as possible. Appendix E offers more guidance on developing maintenance plans.

C.3 Types of Retrofitting Techniques

Retrofitting techniques can be applied to many different situations depending on the end result required and space available. Retrofitting techniques include:

- Source Retrofit – Use of techniques that attenuate runoff and/or pollutant generation before it enters a storm drain system, i.e., reducing impervious areas, using pollution prevention practices, etc. These are used in areas where build-out prevents the establishment of a significant number of new facilities, and where redevelopment will not have a significant impact on water quality.

- Redevelopment – Redevelopment will result in retrofit by means of new structural control facilities required by the stormwater management standards in Chapter Three. Projected redevelopment trends, while not within the direct control of local government, are useful in predicting areas of existing development that may be mitigated in the future.

- Existing Structural Control Retrofit – The retrofit of an existing structural control to improve its pollutant removal efficiency or storage capacity, or both.

- Installation of Additional Stormwater Controls – Additional stormwater controls can be added for existing development or redevelopment. Consideration should be given to regional controls, rather than site-specific applications.

- Conversion of Existing Stormwater Facilities to Water Quality Functions – Existing flood control facilities built to serve previous development may be modified to act as a water quality structural control on a regional or site-specific basis.

- Open Channel Retrofit – Open channel retrofits are constructed within an open channel below a storm drain outfall.

- Off-line Retrofit – Involves the use of a flow-splitter to divert the first flush of runoff to a lower open area for treatment in areas where land constraints are not present.

- In-line Retrofit – Used where space constraints do not allow the use of diversions to treatment areas.

C.4 When is Retrofitting Appropriate?

Site constraints commonly encountered in existing, developed areas can limit the type of stormwater retrofits that are possible for a site and their overall effectiveness. Retrofit of an existing stormwater management facility according to the minimum standards contained in Chapter Three of this manual may not be possible due to site-specific factors such as the location of existing utilities, buildings, wetlands, maintenance access, and adjacent land uses. Table C-1 lists site-specific factors to consider in determining the appropriateness of stormwater retrofits for a particular site.

Table C-1 Site Considerations for Determining the Appropriateness of Stormwater Retrofits

Factor	**Consideration**
Retrofit Purpose	What are the primary and secondary (if any) purposes of the retrofit project? Are the retrofits designed primarily for stormwater quantity control, quality control, or a combination of both?
Construction/ Maintenance Access	Does the site have adequate construction and maintenance access and sufficient construction staging area? Are maintenance responsibilities for the retrofits clearly defined?
Subsurface Conditions	Are the subsurface conditions at the site (soil permeability and depth to groundwater/bedrock) consistent with the proposed retrofit regarding subsurface infiltration capacity and constructability?
Utilities	Do the locations of existing utilities present conflicts with the proposed retrofits or require relocation or design modifications?
Conflicting Land Uses	Are the retrofits compatible with adjacent land uses of nearby properties?
Wetlands, Sensitive Water Bodies, and Vegetation	How do the retrofits affect adjacent or downgradient wetlands, sensitive receiving waters, and vegetation? Do the retrofits minimize or mitigate impacts where possible?
Complementary Restoration Projects	Are there opportunities to combine stormwater retrofits with complementary projects such as stream stabilization, habitat restoration, or wetland restoration/mitigation?
Permits and Approvals	Which local, state, and federal regulatory agencies have jurisdiction over the proposed retrofit project, and can regulatory approvals be obtained for the retrofits?
Public Safety	Does the retrofit increase the risk to public health and safety?
Cost	What are the capital and long-term maintenance costs associated with the stormwater retrofits? Are the retrofits cost-effective in terms of anticipated benefits?

Source: Adapted from Claytor, Center for Watershed Protection, 2000.

Retrofitted facilities may not be as effective in reducing pollutant loads as newly designed and installed facilities. However, in most cases, some improvements in stormwater quantity and quality control are possible, especially if a new use is planned for an existing development, or an existing storm drainage system is upgraded or expanded. Incorporation of a number of small-scale LID management practices or a treatment train approach may be necessary to achieve the desired level of effectiveness. It should also be recognized that stormwater quantity frequently creates the most severe impacts to receiving waters and wetlands as a result of channel erosion (Claytor, Center for Watershed Protection, 2000). Therefore, stormwater quantity control functions that existing stormwater management facilities provide should not be significantly compromised in exchange for pollutant removal effectiveness.

C.5 Stormwater Retrofit Options

Stormwater retrofit options include many of the source control and stormwater treatment practices for new developments that are described in other chapters of this manual. Common stormwater retrofit applications for existing development and redevelopment projects fall into one of two categories: subwatershed and on-site retrofits.

Subwatershed Retrofits

- Stormwater management facility retrofits (add storage to existing ponds);
- New stormwater controls at storm drain outfalls[1];
- New stormwater controls for road culverts and rights-of-way;
- Parking lots; and
- Practices in existing conveyance channels.

On-site Retrofits

- LUHPPL operations;
- Small parking lot retrofits;
- Individual rooftops;
- Individual streets;
- Little retrofits – Medians and Under-utilized Landscape Areas (i.e., MULes);
- Hardscapes/Plazas; and
- Underground.

Examples of these stormwater retrofits are described in the following sections.

[1] DEM prefers that retrofits to existing storm drainage systems be located in the upland area rights-of-way or vacant parcels as opposed to end-of-pipe. In doing so, it is possible to minimize disturbance of jurisdictional wetland areas, stormwater is treated closer to the source, and rather than siting one large BMP, multiple smaller BMPs are constructed. However, in some cases, the only retrofit options available are at the existing storm drain outfalls. In these cases, end-of-pipe retrofits should be limited to areas that are regulated as upland, upland buffer (perimeter or riverbank wetland under DEM regulations), area subject to storm flowage, and/or floodplain. Generally, placement of stormwater retention and detention facilities within wetlands and streams is prohibited and must be avoided.

C.6 Subwatershed Retrofits

C.6.1 Existing Stormwater Management Facilities

Existing stormwater management facilities originally designed for flood control can be modified or reconfigured for water quality mitigation purposes or increased hydrologic benefit. Older detention facilities offer the greatest opportunity for this type of retrofit. Traditional dry detention basins can be modified to become extended detention basins, wet ponds, or WVTSs for enhanced pollutant removal. This is one of the most common and easily implemented retrofits since it typically requires little or no additional land area, utilizes an existing facility for which there is already some resident acceptance of stormwater management, and involves minimal impacts to environmental resources (Claytor, Center for Watershed Protection, 2000).

Specific modifications to existing detention basins for improved water quality mitigation are summarized in Table C-2. Stormwater detention basin retrofits should include an evaluation of the hydraulic characteristics and storage capacity of the basin to determine whether available storage exists for additional water quality treatment. A typical retrofit of an existing detention basin is shown in Figure C-1.

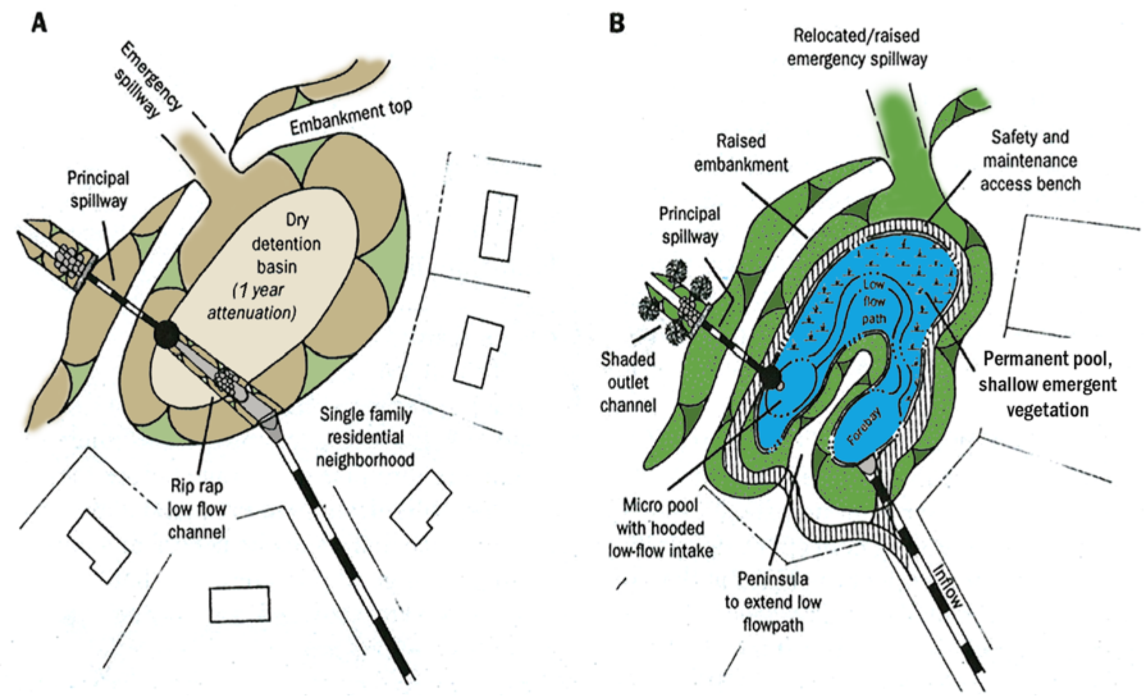
Table C-2 Detention Basin Retrofits for Improved Water Quality Mitigation

Retrofit	Retrofit
Excavate the basin bottom to create more permanent pool storage	Eliminate low-flow bypasses
Raise the basin embankment to obtain additional storage for extended detention	Incorporate stilling basins at inlets and outlets and sediment forebays at basin inlets
Modify the outfall structure to create a two-stage release to better control small storms while not significantly compromising flood control detention for large storms	Regrade the basin bottom to create a wet area near the basin outlet or revegetate parts of the basin bottom with emergent vegetation to enhance pollutant removal, reduce mowing, and improve aesthetics
Increase the flow path from inflow to outflow and eliminate short-circuiting by using baffles, earthen berms, or micro-pond topography to increase residence time of water in the pond and improve settling of solids	Create a shelf along the perimeter of a wet basin to improve shoreline stabilization, enhance pollutant filtering, and enhance aesthetic and habitat functions
Replace paved low-flow channels with meandering vegetated swales.	Create a low-maintenance “no-mow” wildflower ecosystem in the drier portions of the basin

Retrofit	Retrofit
Provide a high flow bypass to avoid resuspension of captured sediment/pollutants during high flows	

Source: Adapted from Claytor, Center for Watershed Protection, 2000; Pennsylvania Association of Conservation Districts et al., 1998; and NJDEP, 2000.

Figure C-1 Retrofit of an Existing Detention Basin (A) to a Shallow WVTS (B) (Adapted from CWP, 2007)

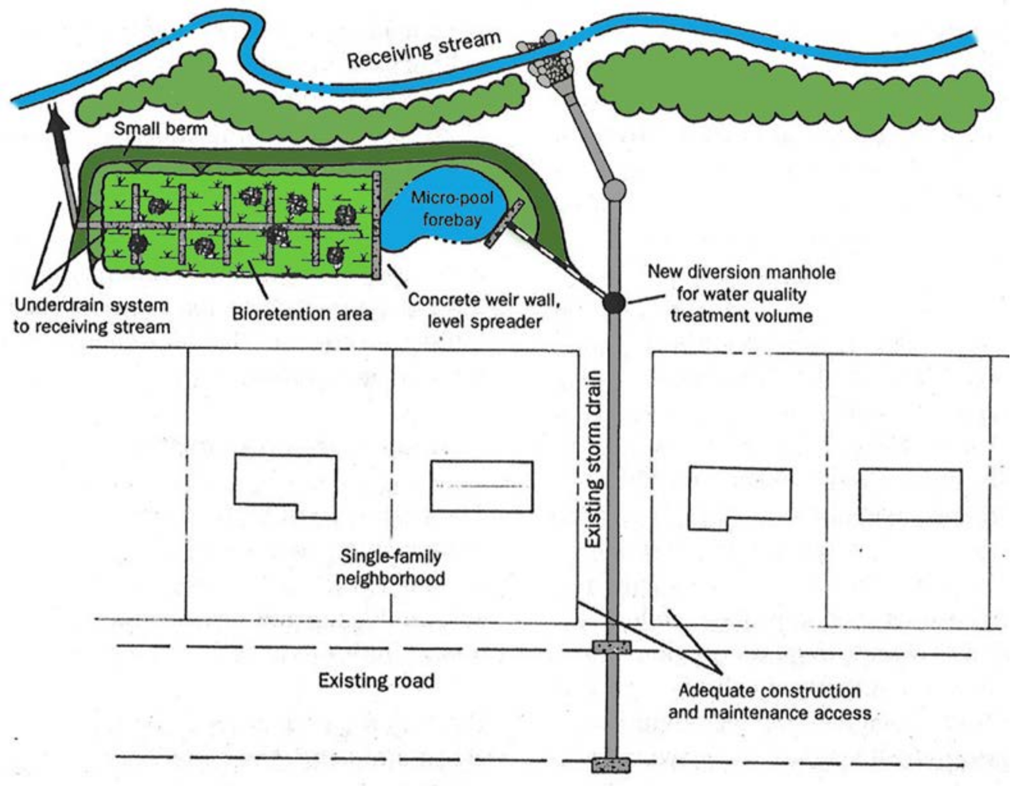


C.6.2 Storm Drain Outfalls

The permitting agencies prefer that retrofits to existing storm drainage systems be located in the upland area rights-of-way or vacant parcels as opposed to end-of-pipe. In doing so, it is possible to minimize disturbance of jurisdictional wetland areas, stormwater is treated closer to the source, and rather than siting one large BMP, multiple smaller BMPs are constructed. However, in some cases, the only retrofit options available are at the existing storm drain outfalls. In these cases, end-of-pipe retrofits should be limited to areas that are regulated as upland, upland buffer (perimeter or riverbank wetland under DEM regulations), area subject to storm flowage, and/or floodplain. Generally, placement of stormwater retention and detention facilities within wetlands and streams is prohibited and must be avoided.

The retrofit stormwater treatment practices at storm drain outfalls are commonly designed as off-line devices to treat the water quality volume and bypass larger storms. Water quality swales, bioretention, sand filters, WVTSs, and wet ponds are commonly used for this type of retrofit, although most stormwater treatment practices can be used given enough space for construction and maintenance. Figure C-2 shows a schematic of an existing outfall retrofitted with an off-line bioretention area. Manufactured, underground infiltration chambers such as those described in Chapter Five are also commonly installed as off-line retrofits at or upgradient of stormwater outfalls. Velocity dissipation devices such as plunge pools and level spreaders can also be incorporated into the retrofit design.

Figure C-2 Schematic of Existing Outfall Retrofit (Adapted from CWP, 2007)



C.6.3 Highway Rights-of-Way

Open spaces associated with highway rights-of-way such as medians, shoulders, and cloverleaf areas also present opportunities to incorporate new stormwater treatment practices. Common treatment practices used in these types of retrofits include vegetated swales, bioretention, WVTSs, and extended detention ponds. Traffic, safety, and maintenance access are important considerations for determining appropriate locations for highway right-of-way retrofits.

C.6.4 Parking Lots

Parking lots can be ideal candidates for a wide range of stormwater retrofits. Potentially applicable retrofits include site-planning techniques and small-scale management measures to reduce impervious coverage and promote increased infiltration (Chapter Four), as well as a variety of larger, end-of-pipe treatment practices.

Redevelopment of older commercial properties, which were often designed with oversized parking lots and almost 100 percent impervious coverage, is one of the most common and environmentally beneficial opportunities for parking lot stormwater retrofits.

Figure C-3 Wet Swale Used to Treat Highway Runoff

Source: DNREC Photo

Alternative site design and LID management practices are well-suited to existing developed areas because most of these practices use a small amount of land and are easily integrated into existing parking areas. Examples of these parking lot stormwater retrofits include:

<u>Incorporating Bioretention Into Parking Lot Islands and Landscaping</u>

Parking lot islands, landscaped areas, and tree planter boxes can be converted into functional bioretention areas to reduce and treat stormwater runoff.

<u>Removing Curbing and Adding Slotted Curb Stops</u>

Curbs along the edge of parking lots can sometimes be removed or slotted to re-route runoff to vegetated areas, buffer strips, or bioretention facilities. The capacity of existing swales may need to be evaluated and expanded, where necessary, as part of this retrofit option.

<u>Infiltrating Clean Roof Runoff from Buildings</u>

In some instances, building roof drains connected to the stormwater drainage system can be disconnected and re-directed to vegetated areas, buffer strips, bioretention facilities, or infiltration structures (dry wells or infiltration trenches).

Figure C-4 Example of a parking lot retrofit where curbs were removed, allowing runoff to sheet flow into a bioretention area. This site is also a LUHPPL, so the bioretention area had to be lined.

Source: LID Center Photos

<u>Incorporating New Treatment Practices at the Edge of Parking Lots</u>

New stormwater treatment practices such as bioretention, sand filters, and WVTSs can often be incorporated at the edge of large parking lots.

<u>Use of Permeable Paving Materials</u>

Existing impermeable pavement in overflow parking or other low-traffic areas can sometimes be replaced with alternative, permeable materials such as porous asphalt, porous concrete, modular concrete paving blocks, modular concrete or plastic lattice, or cast-in-place concrete grids (see Section 5.4 for more information on permeable pavements). Site-specific factors including traffic volumes, soil permeability, maintenance, sediment loads, and land use must be carefully considered for the successful application of permeable paving materials for new development or retrofit applications.

Utilizing Proprietary Devices

Many proprietary devices have been developed recently that utilize various pollutant removal techniques ranging from swirl concentrators to filters. Due to their typically compact size and/or ability to be placed in existing catch basins and manholes, these devices can be ideal for retrofit purposes. Maintenance frequency can be an issue for some of these devices to keep them working effectively; maintenance capacity of the municipality and/or homeowner's association should be carefully considered for successful application of proprietary devices for retrofit applications.

C.6.5 Practices in Existing Conveyance Channels

Existing (man-made) channels and other drainage conveyances classified as areas subject to storm flow (ASSFs – regulated wetland, work in these areas will require a permit) such as grass channels, can be modified to reduce flow velocities and enhance pollutant removal. Weir walls or riprap check dams placed across a channel create opportunities for ponding, infiltration, and establishment of vegetation upstream of the retrofit (Claytor, Center for Watershed Protection, 2000). Channel retrofit practices include bank stabilization of eroded areas and placement of flow deflectors, boulders, and low-flow channels. Channel retrofits may require evaluation of potential flooding and floodplain impacts resulting from altered channel conveyance.

C.7 On-site Retrofits

C.7.1 LUHPPL Operations

LUHPPLs are challenging sites for stormwater management. However, there are a few BMPs that are ideal for retrofitting these contaminated locations. Filters and bioretention areas can be installed in these areas, as long as they are lined to prevent infiltration to the underlying soils and groundwater.

C.7.2 Small Parking Lots

Small parking lots (less than 5 acres) can be modified to provide treatment in practices installed within islands or along the perimeter. In many cases, the parking lot is delineated in a series of smaller subwatersheds draining to several BMPs. The example shown in Figure C-4 illustrates how lined bioretention areas were used to retrofit parking lot islands.

C.7.3 Individual Rooftops

As described in Chapter Four of this manual, rooftops can be disconnected from impervious areas and from existing storm sewer connections to pervious areas nearby. This will help to attenuate and treat stormwater flows from generally clean surfaces (rooftops). Rainbarrels or cisterns are also great examples of retrofits for an individual roof.

C.7.4 Individual Streets

Similar to the opportunities for highways, open spaces associated with individual streets such as medians, shoulders, and cul-de-sac areas present opportunities to incorporate new stormwater treatment practices. Traffic calming devices can be used to direct stormwater into a retrofit practice. Common treatment practices used in these types of retrofits include vegetated swales and bioretention areas.

Figure C-5 Use of a vegetated swale along a residential street (Source: CTNEMO)

C.7.5 Little Retrofits

"Little retrofits" refers to converting or disconnecting isolated areas of impervious cover, such as medians and walkways, to drain towards existing landscaping or other pervious areas.

C.7.6 Hardscapes/Plazas

The drainage network in existing urban landscapes can be reconfigured to treat the stormwater runoff with landscaping and other urban design features. High visibility spaces offer an opportunity to celebrate stormwater as a resource and provide public education.

C.7.7 Underground

Underground practices are perfect retrofit practices for sites in urban areas or with very limited land. These practices can be used for infiltration or just stormwater storage and detention.

APPENDIX D: SITE SPECIFIC DESIGN EXAMPLES

Three step-by-step Rhode Island design examples are provided to help designers and plan reviewers better understand the new criteria in this Manual. The examples demonstrate how the site planning and stormwater criteria are applied, as well as some of the procedures and performance criteria that should be considered when siting and designing a stormwater best management practice. A stormwater design for a typical single-lot/small-scale house is also included.

D.1 Design Example #1: Low-Density Residential Site

The **hypothetical** low-density residential subdivision, Reaper Brook Estates, is located near the Village of Greenville in the Town of Smithfield, RI.[1] This step-by-step example illustrates how a designer would meet the LID requirements of Minimum Standard No. 1, size a representative bioretention basin to meet recharge (Re_v) and water quality (WQ_v) requirements, size a dry swale to meet WQ_v requirements, and size a detention basin to meet channel protection (CP_v) and overbank protection volume (Q_p) requirements.

Reaper Brook Estates is located within the Reaper Brook watershed (a warm water fishery) and a 1st-order tributary to the Stillwater River. The underlying zoning of the project site requires a 2.75 acre minimum lot area for conventional single family lots, but applicants may also utilize conservation design subdivision (CDS) provisions that allow minimum lot areas to be reduced to a minimum of 1 acre. The project parcel is approximately 80.5 acres in size and is divided by Reaper Brook that runs through the center of the project (see Figure D-1). Public water and sewer is not available in the immediate vicinity of the project. The Reaper Brook stream valley includes a major wetland complex exceeding 3 acres in size with a 50-foot perimeter wetland, and the stream exceeds 10 feet in width and thus is afforded a 200-foot riverbank wetland buffer. Other wetland areas on-site are isolated and are less than 3 acres in size.

Listed below are the lot area and setback requirements of a conventional subdivision versus conservation design for this site.

Table D-1 Zoning Dimensional Requirements

Lot Parameter	Conventional Subdivision	Conservation Subdivision
Minimum Lot Area	2.75 acres	1.0 acres
Minimum Lot Frontage	60 feet	50 feet
Minimum Lot Width at Front Setback	150 feet	75 feet
Minimum Front Setback	50 feet	25 feet
Minimum Side Yard	35 feet	12 feet
Minimum Rear Yard	60 feet	30 feet

[1]This is a hypothetical project and not related to a real project in the Town of Smithfield, nor are the zoning provisions and/or subdivision requirements presented here intended to reflect those of the Town of Smithfield. The development scenario is intended to be representative of typical zoning requirements that have been or could be adopted by Rhode Island municipalities.

As part of the conservation development process, applicants must prepare a plan that illustrates an allowable development yield in conformance with the conventional zoning. In this case, the project proponent was able to prepare a plan for 19 lots meeting the dimensional requirements of Table D-1, and served by onsite wastewater treatment systems (OWTS), private wells, and a series of conventional extended detention ponds (see Figure D-1).

Figure D-1 Reaper Brook Estates Site Yield Plan

The Yield Plan results in the following:

- 19 single-family lots of at least 2.75 acres and average lot size of 3.32 acres;
- 28.0 acres of disturbed area;
- 15.38 acres of open space (outside of lot areas);
- 3,200 linear feet of street; and
- 5.51 acres of impervious cover (roads, houses, and driveways).

The conservation design subdivision also results in a yield of 19 lots meeting the dimensional requirements of Table D-1 and served by individual OWTSs and private wells. The CDS plan, however, clusters the 19 lots on one side of the project, completely preserving the west side of Reaper Brook as undisturbed open space (see Figure D-2). The second access road and entire construction project to the west of Reaper Brook are not necessary. Lots exceeding 1 acre are sufficient in size to support the same size houses as the conventional design, thus retaining comparable market value.

Figure D-2 Reaper Brook Estates Conservation Design Subdivision Plan

Two outfall locations are proposed, designated as Outfall A and Outfall B.

At Outfall A: Stormwater structural controls measures include **3 bioretention facilities** and **dry swales** to meet recharge and water quality requirements. These facilities then drain to a **dry extended detention pond** to meet channel protection and overbank controls (See Figures D-3 and D-4).

At Outfall B: Stormwater structural control measures include **dry swales** to meet recharge and water quality requirements, which then drain to an infiltration facility to meet channel protection and overbank peak flow attenuation requirements.

The CDS Plan results in the following:

- 19 single family lots of at least 1.1 acres and average lot size of:1.37 acres;
- 20.3 acres of disturbed area;
- 51.7 acres of open space (outside of lot areas);
- 2,500 linear feet of street; and
- 3.83 acres of impervious cover (road, houses, driveways, and community parking lot).

Table D-2 Base Data for Reaper Brook Estates

Location: Smithfield, RI, discharging to Reaper Brook (1st-order stream) near the Stillwater River, a Warm Water fishery.
Total parcel site area, (A) = 80.5 acres; two study points at two outfalls[1]. Outfall A has a post-development drainage area of 20.83 acres, Outfall B has a post-development drainage area of 2.33 acres.
Measured Impervious Area, I = 3.83 acres (3.36 acres at Outfall A; 0.47 acres at Outfall B).
Site Soils Type: 100% "B"; Recharge Factor, F = 0.35. Loamy-sand soils with average depth to groundwater ~ 10.0 feet.

Summary of Hydrologic Data[2]		
Rainfall Depths		
1-year, 24-hour, Type III	=	3.1 inches
10-year, 24-hour, Type III	=	5.0 inches
100-year, 24-hour, Type III	=	8.9 inches
Post-development Conditions:		
Drainage Area:	=	20.83 acres[1]
1-year, 24-hour peak discharge	=	10.3 cfs
1-year, 24-hour runoff volume	=	0.68" = 1.173 ac-ft = 51,096 ft^3
10-year, 24-hour peak discharge	=	39.4 cfs
100-year, 24-hour peak discharge	=	105.4 cfs
Pre-development Conditions:		
Drainage Area	=	15.3 acres[3]
10-year, 24-hour peak discharge	=	11.1 cfs
100-year, 24-hour peak discharge	=	44.9 cfs

[1] Note: Project discharges to two locations; this design example is for only one discharge location; for an actual project, applicants would need to meet criteria at both outfall locations.
[2] See computer-generated hydrologic data and pond routings developed using HydroCAD Stormwater Modeling System, Version 9.00 (note, applicants are not required to use a proprietary software system; public domain versions of NRCS TR-55/TR-20 are available).
[3] Note: Pre-development drainage area to Outfall A based on natural topography to this location. For simplicity, separate drainage area map is not shown. See Appendix K for detailed guidance for hydrology/hydraulic modeling. The post-development drainage area is larger than the pre-development drainage area due to proposed changes in grading at the site. However, the post-development drainage area boundary does not cross a major subwatershed boundary and thus, no water transfers are occurring.

Figure D-3 Reaper Brook Estates Stormwater Management Controls – Plan View

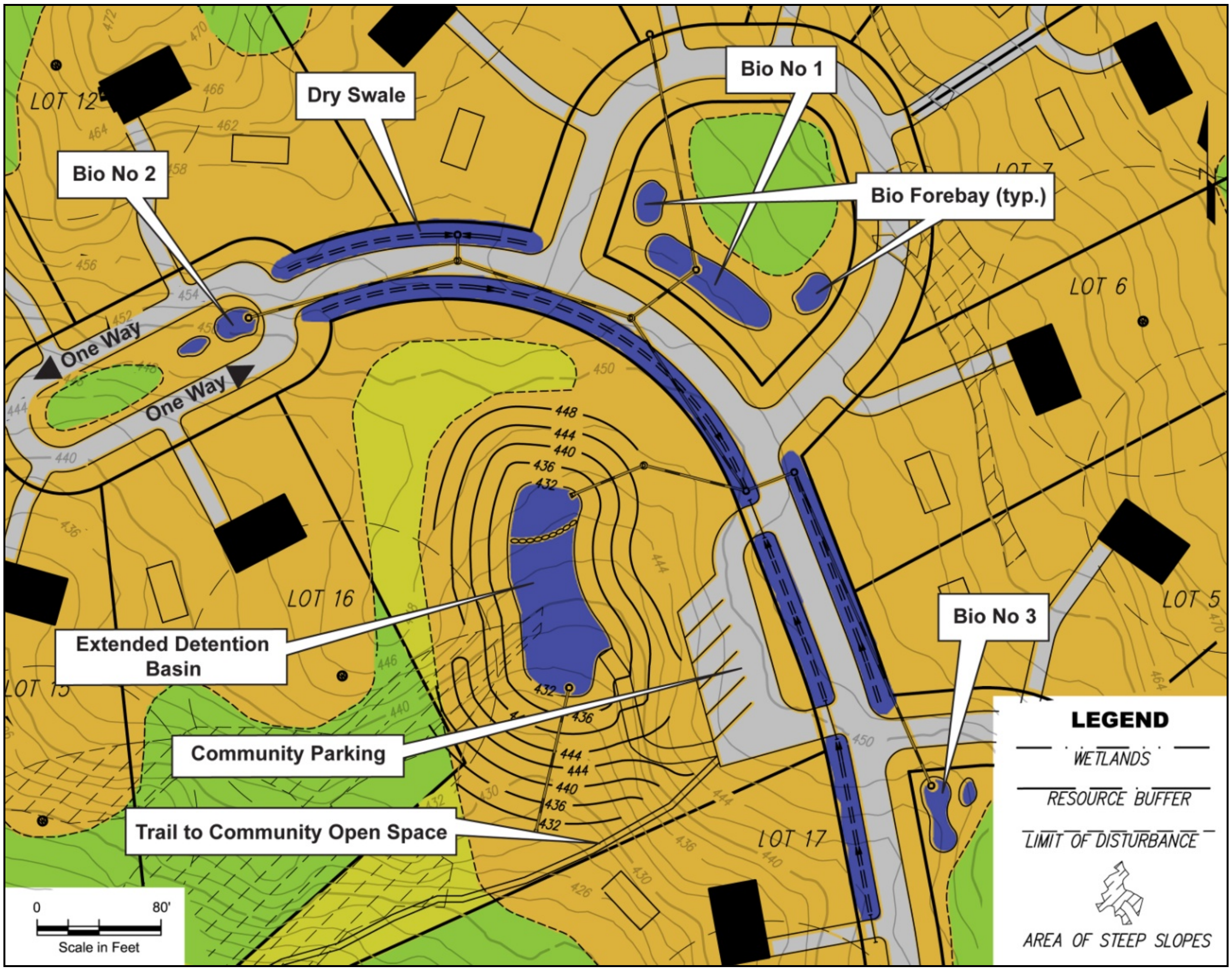
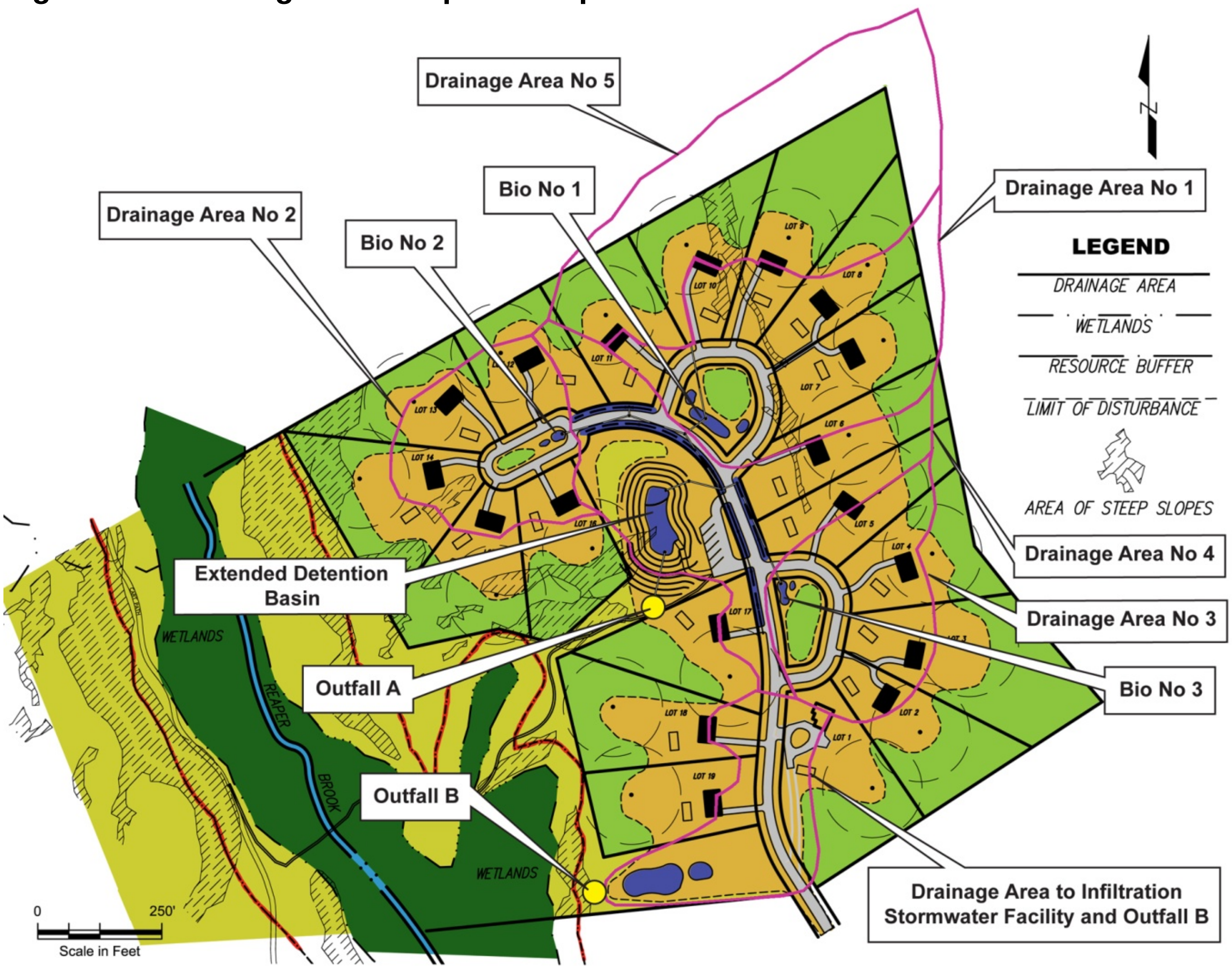


Figure D-4 Drainage Area Map for Reaper Brook Estates



Step 1:	**Document Site Planning Process in Accordance with Standard 1.**

LID site planning and design measures are incorporated at this new development site to the maximum extent practicable. For example, impervious surfaces are reduced by decreasing street width and length. Clustering the 19 lots on one side of the project reduces street length by 700 feet and impervious cover by nearly 1.7 acres; steep slopes are avoided and natural terrain is preserved where possible. Stormwater structural controls are used near the source using bioretention and dry swales. Refer to completed Table D-4 for compliance with the Checklist in Appendix A.

Step 2:	**Determine Required Design Criteria (i.e., Re_v, WQ_v, CP_v, Q_p)**

For Outfall A, 20.83 acres drain to the proposed detention pond located down-gradient from 3 bioretention facilities and a dry swale conveyance system. A storm drainage pipe system collects overflow from the bioretention facilities and swale system to discharge into the detention pond. In addition, since the bioretention facilities have been designed as exfilters, they will meet both recharge and water quality requirements as well as reduce the runoff volume for the channel protection volume, and to a lesser extent, overbank controls.

- Re_v = (1")(F)(I)/12: Recharge is required at the site based on land use and soils. Use exfiltrating bioretention to meet this requirement.
- WQ_v = (1")(I)/12: The WQ_v requirement will be managed by bioretention and dry swales.
- CP_v = 24-hour ED of post-development runoff from 1-year, 24-hour Type III storm: The CP_v is required because the site drains to a 1^{st}-order stream (< 4^{th}-order tributary), the site impervious area is greater than 1 acre, and the post-development runoff from the 1-year, 24-hour Type III storm is 10.3 cfs, which is > than 2.0 cfs.
- Q_p = Peak flow attenuation of the 10-year and 100-year, 24-hour Type III storm: The Q_p is required because the site drains to a 1^{st}-order stream (< 4^{th}-order tributary).
- A downstream analysis is not required because the project's disturbed area does not meet the thresholds in Table 3-7 in terms of area of disturbance and impervious percentage (20.3 acres and < 50% impervious).

Step 3:	**Compute Required Storage Volumes**

Given Base Data in Table D-1 (for Outfall A):

The Recharge Volume (Re_v) is calculated using the equation from Section 3.3.2: For HSG B soils, F = 0.35 and I = 3.36 ac:

- Re_v = (1")(F)(I)/12 = (1")(0.35)(3.36 ac)/12 = **.098 ac-ft (= 4,269 ft^3)**

The Water Quality Volume (WQ_v) is calculated using the equation from Section 3.3.3: For I = 3.36 ac:

- WQ_v = (1.0")(I)/12 = 1.0" (3.36 ac)/12 = **0.28 ac-ft (12,197 ft^3)**

Check WQ_v > minimum req'd 0.2" for disturbed area (14.4 acres) draining to Outfall A:

- WQ_v min = 0.2"(14.4 ac)/12 = 0.24 ac-ft; which is less than the computed value, so use 0.28 ac-ft

The Channel Protection Volume (CP_v) is calculated using the "short-cut" routing equation from Section 3.3.4: The 1-year runoff from project (after some infiltration and attenuation by the 3 up-gradient bioretention facilities) = 0.889 ac-ft = 38,725 ft^3**.**

Note, without these up-gradient facilities, the runoff volume from the 1-year storm would be substantially larger as shown in table D-2 (1.173 ac-ft = 51,096 ft^3), illustrating the substantial runoff reduction benefits of these facilities.

- $V_s = CP_v = 0.65 * V_r$ = 0.65 (38,725 ft^3) = **25,171 ft^3**

The Overbank Flood Protection (Q_p) requirement states that the post-development peak discharge rates for the 10- and 100-year, 24 hour Type III storms be reduced to the pre-development levels. For Outfall A, the pre-development 10 and 100-year rates are 11.1 cfs and 44.9 cfs, respectively. The dry detention basin must be sized to provide adequate storage to attenuate the post-development flow to these levels. See Step 8 below.

Step 4: Size Bioretention Facilities to Meet Re_v and WQ_v Requirements.

Bioretention facilities are sized in accordance with the treatment requirements in Section 5.5.4 according to the following equation:

$$A_f = (WQ_v)\ (d_f)\ /\ [(k)\ (h_f + d_f)\ (t_f)]$$

Where:

A_f = Surface area of filter bed (ft^2)
d_f = Filter bed depth (ft)
k = Coefficient of permeability of filter media (ft/day)
h_f = Average height of water above filter bed (ft)
t_f = Design filter bed drain time (days)
(2 days is the maximum t_f for bioretention)

Using Bioretention Area No. 2 (Bio 2) as an example, where the Drainage Area = 2.42 acres, and the impervious area = 0.51 acres:

Compute WQv = (1") 0.51 ac/12"/ft = 0.0425 ac-ft = 1,851.1 ft^3

For a filter bed depth of 2.5 feet, a k of 1 ft/day, and maximum head of 9" (average head of 4.5") and a 2-day drain time:

A_f = 1,851.1 ft^3(2.5 ft)/[(1.0 ft/day)(0.375 ft + 2.5 ft)(2 days)] = **805 ft^2**

Set overflow inlet elevation 0.75 ft above bioretention bottom elevation, round-up surface area to **850 ft^2**.

Size Pretreatment Forebay: The sediment forebay shall have a minimum volume equal to 25% of the WQ_v and a minimum surface sized in accordance with Section 6.4.1.

Min volume = 0.25 (1,851.1 ft^3) = 462.8 ft^3; Minimum Surface Area (A_s) = 5,750 (Q)

Where:

Q = %WQ_v/86,400 = 462.8/86,400 = .0054 cfs.
A_s = 5,750 (.0054) = 30.8 ft^2

Use A_s = 462.8/3.0 ft depth = 154 ft^2 or approx. 15 ft x 10 ft x 3 ft deep.

Using HydroCAD (or other generally accepted TR-55/TR-20 hydrologic/hydraulic software), designers can model these systems, with the following adjustments:

The method of computing the water quality flow (Section 3.3.3.2) must be followed to adjust the CN to generate runoff equivalent to the WQ_v for the 1.2 inch precipitation event, using the following equation:
$CN = 1000 / [10 + 5P + 10Q - 10(Q^2 + 1.25\ QP)^{1/2}]$

Where:
P = rainfall, in inches (use 1.2 inches for the Water Quality Storm that produces 1 inch of runoff from impervious surfaces)
Q = runoff volume, in watershed inches (equal to $WQ_v \div$ total watershed area)

Calculate the watershed runoff volume in inches as follows:
Q = (0.0425 ac-ft/2.42 ac)(12"/ft) = 0.211 inches

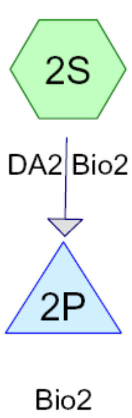
$CN = 1000 / [10 + 5(1.2) + 10(.211) – 10((.211)^2 + 1.25(.211)(1.2))^{1/2}] = 83.06$
use CN = 83

Then, run the model using the exfiltration outlet structure with constant velocity rate of exfiltration = 2.41"/hour. This is the recommended rate for loamy-sand soils, which is the texture of the required bioretention soil described in Chapter Five and Appendix F, per Table 5-3 "Design Infiltration Rates for Different Soil Texture Classes." This rate is used in hydraulic routing to reflect the design infiltration rate when using NRCS methods for a Type III, 24-hour storm where the vast majority of the runoff enters the system in just a few hours. Note, this is different from the hydraulic conductivity (k = 1 ft/day rate) used in establishing the minimum surface area, which is reflective of the long-term acceptance rate over a range of different storm intensities and durations with a 2-day drawdown.

The Bioretention No. 2 must have a minimum surface area of 850 ft^2 and a volume equal to at least ¾ of the WQ_V, including the forebay volume (per requirements in Chapter Five). For Bio2, WQ_v = 1851.1 ft^3, min Vol = 0.75(1,851.1 ft^3) = 1,388.3 ft^3

With a 9" ponding depth and 2.5 media depth, calculate available storage above and within the facility: surface ponding Vol @ depth = 850 ft^2 (0.75 ft) = 638 ft^3. Volume of voids within media = 850 ft^2 (2.5 ft) (0.33) = 701 ft^3. Sediment forebay volume = 462.8 ft^3. Total volume = 638 + 701 + 462.8 = 1,801 ft^3 > 1,388.3 ft^3. OK.

Figure D-5 Routing Diagram and Runoff Summary for Bioretention No. 2 Sizing



Reaper Brook_WQv *Type III 24-hr WQv Rainfall=1.20"*
Prepared by Horsley Witten Group, Inc. Printed 1/23/2010
HydroCAD® 9.00 s/n 02800 © 2009 HydroCAD Software Solutions LLC Page 6

Summary for Subcatchment 2S: DA2 Bio2

Runoff = 0.50 cfs @ 12.10 hrs, Volume= 0.044 af, Depth= 0.22"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 0.00-30.00 hrs, dt= 0.03 hrs
Type III 24-hr WQv Rainfall=1.20"

	Area (ac)	CN	Description
*	2.420	83	Modified CN
	2.420		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Figure D-6 HydroCAD Routing Results of Bioretention No. 2 for WQ_v

Reaper Brook_WQv *Type III 24-hr WQv Rainfall=1.20"*
Prepared by Horsley Witten Group, Inc. Printed 1/23/2010
HydroCAD® 9.00 s/n 02800 © 2009 HydroCAD Software Solutions LLC Page 5

Summary for Pond 2P: Bio2

```
Inflow Area =     2.420 ac,  0.00% Impervious,  Inflow Depth =  0.22"   for  WQv event
Inflow      =     0.50 cfs @  12.10 hrs,  Volume=        0.044 af
Outflow     =     0.06 cfs @  13.83 hrs,  Volume=        0.044 af,  Atten= 88%,  Lag= 103.9 min
Discarded   =     0.06 cfs @  13.83 hrs,  Volume=        0.044 af
Primary     =     0.00 cfs @   0.00 hrs,  Volume=        0.000 af
```

Routing by Stor-Ind method, Time Span= 0.00-30.00 hrs, dt= 0.03 hrs
Peak Elev= 447.63' @ 13.83 hrs Surf.Area= 1,090 sf Storage= 612 cf

Plug-Flow detention time= 105.0 min calculated for 0.044 af (100% of inflow)
Center-of-Mass det. time= 104.9 min (1,000.8 - 895.9)

Volume	Invert	Avail.Storage	Storage Description
#1	447.00'	2,516 cf	**Custom Stage Data (Prismatic)**Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
447.00	850	0	0
447.75	1,135	744	744
449.00	1,700	1,772	2,516

Device	Routing	Invert	Outlet Devices
#1	Discarded	447.00'	**2.410 in/hr Exfiltration over Surface area**
#2	Device 3	447.75'	**24.0" x 24.0" Horiz. Orifice/Grate** C= 0.600 Limited to weir flow at low heads
#3	Primary	443.00'	**18.0" Round Culvert** L= 260.0' RCP, square edge headwall, Ke= 0.500 Outlet Invert= 439.00' S= 0.0154 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior

Discarded OutFlow Max=0.06 cfs @ 13.83 hrs HW=447.63' (Free Discharge)
└─**1=Exfiltration** (Exfiltration Controls 0.06 cfs)

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=447.00' (Free Discharge)
└─**3=Culvert** (Passes 0.00 cfs of 14.46 cfs potential flow)
  └─**2=Orifice/Grate** (Controls 0.00 cfs)

Step 5: Size Dry Swale System to Meet WQ_v Requirement.

The dry swale drains an area of 5.14 acres (DA 4, see Figure D-4), with total impervious area = 1.1 acres. Size the Dry Swale in accordance with the treatment requirements in Section 5.7.4 (Same equation as for Bioretention).

Compute WQ_v = (1")(1.1 ac)/12"/ft = 0.093 ac-ft = **3,993 ft^3**

For a filter bed depth of 2.5 feet, a k of 1 ft/day, and maximum head of 6" (average head of 3") and a 2-day drain time.

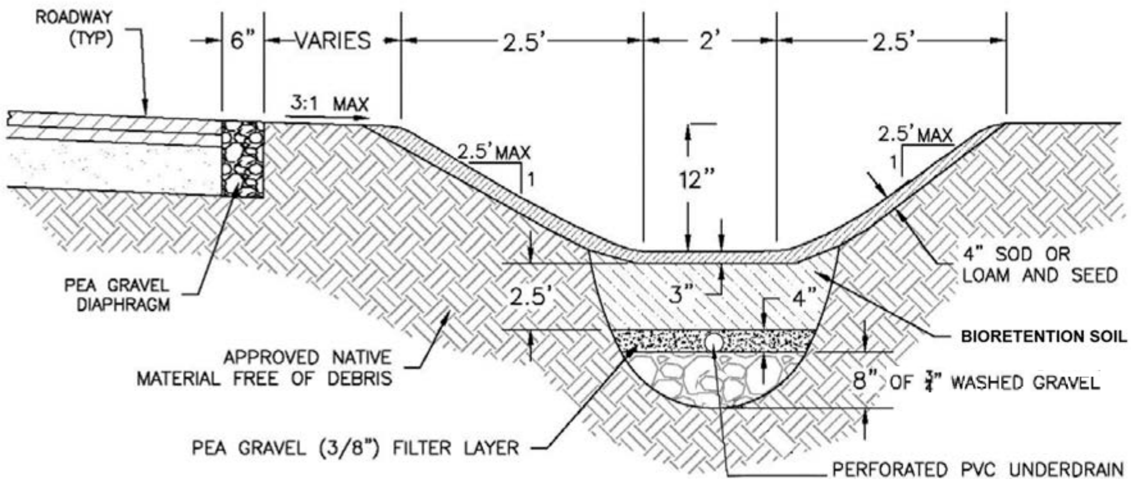
A_f = 3,993.0 ft^3(2.5 ft)/[(1.0 ft/day)(0.25 ft + 2.5 ft)(2 days)] = **1,815 ft^2**

Swales will have bottom width of 2 feet, so the minimum length of swale required to treat DA 4 = 1,815 ft^2/ 2.0 ft = **907.5 ft**

950 feet of swale are available within DA 4. Set minimum slope = 1.0%. Set all drainage inlets at an overflow elevation 6 inches above the swale bottom elevation.

Note, dry swale is designed with an underdrain system; and thus, does not meet the recharge criteria.

Figure D-7 Cross-section of Proposed Dry Swale



Step 6:	**Check the velocity of the 1-year storm and the hydraulic capacity of the 10-year storm.**

Note: For this design example, the 1-year storm is used to check the channel geometry for non-erosive conditions, and the 10-year storm is used to check the conveyance capacity of the channel.

The hydraulic calculations are performed for the drainage area level for DA 4, including the pavement and lawn that drains to the swales (See Figure D-4, Drainage Area Map). Note also, the resulting design geometry for the dry swale is conservative because it is sized based on the flows at the downstream end of the drainage area; thus, the depth of the dry swale in the upstream areas could be reduced.

<u>Check to ensure non-erosive velocity for 1-year storm:</u>
Roadway slope = 1.0%, check velocity and depth for the following parameters:

- $Q_{1\text{-year}}$ = 5.3 cfs (generated from HydroCAD model)
- Bottom width = 2.0 ft
- Side slopes = 2.5:1
- Longitudinal slope = 1.0%
- Manning's roughness coefficient (n) = 0.03

Using Manning's equation for a trapezoid channel:

$$Q = (a)\ (v) = (a)[1.49/n\ (R)^{2/3}\ (S)^{1/2}]; \quad a = b*d + z*d*d; \quad R = a\ /\ (b+2*d(z^2+1)^{1/2})$$

Where:

v = velocity (ft/s)
n = Manning's roughness coefficient,
R = hydraulic radius (ft)
a = cross sectional area (ft^2)
S = channel longitudinal slope
b = bottom width (ft)
d = depth of water (ft)
z = side slope (z:1)

Solve for depth and velocity.

Results:

$a = (2.0 * d) + 2.5(d * d) = 2.0d + 2.5d^2$
$R = (2.0d + 2.5d^2) / (2.0 + 2*d(7.25)^{1/2}) = (2.0d + 2.5d^2) / (2.0 + 5.39d)$
$Q = (2.0d + 2.5d^2) [1.49/.03 * ((2.0d + 2.5d^2) / (2.0 + 5.39d))^{2/3} * 0.01^{1/2}]$

<u>Depth</u>

Due to complexity of equation, solve for d by trial and error. First, choose a depth that seems reasonable and solve for Q. Repeat until the solution for Q is equal to $Q_{1\text{-year}}$ (5.3 cfs). Spreadsheets can be set up to help streamline this process, or an open channel flow model can be used.

Trial 1. Try a depth of 0.3 ft.

$a = 2.0(0.3) + 2.5(0.3)^2 = 0.83\ ft^2$
$R = 0.83\ ft^2 / (2.0 + 5.39(0.3)) = 0.23\ ft$
$Q = 0.83\ ft^2 [1.49/.03 * (0.23\ ft)^{2/3} * 0.01^{1/2}] = 1.5\ cfs < Q_{1\text{-year}}$.

Trial 2. Try a depth of 0.5 ft.

$a = 2.0(0.5) + 2.5(0.5)^2 = 1.63\ ft^2$
$R = 1.63\ ft^2 / (2.0 + 5.39(0.5)) = .348\ ft$
$Q = 1.63\ ft^2 [1.49/.03 * (.348\ ft)^{2/3} * 0.01^{1/2}] = 4.0\ cfs < Q_{1\text{-year}}$.

Trial 3. Try a depth of 0.6 ft.

$a = 2.0(0.6) + 2.5(0.6)^2 = 2.1\ ft^2$
$R = 2.1\ ft^2 / (2.0 + 5.39(0.6)) = .4\ ft$
$Q = 2.1\ ft^2 [1.49/.03 * (.4\ ft)^{2/3} * 0.01^{1/2}] = 5.7\ cfs > Q_{1\text{-year}}$, so OK.
Thus, depth = 0.6 ft.

Velocity

$v = Q/a$

$v = 5.7$ cfs / 2.1 ft^2 = 2.7 ft/s (v is less than 4.0 ft/s, OK)

Check to ensure adequate capacity for 10-year storm:

From hydrology information, the 10-year peak flow is 13.7 cfs. Compute depth to carry the 10-year flow.

Roadway slope = 1.0%, depth for the following parameters:

- $Q_{10\text{-year}}$ = 13.7 cfs
- Bottom width = 2.0
- Side slopes = 2.5:1
- Longitudinal slope = 1.0%
- Manning's Coeff. = 0.03

Solve for depth using Manning's equation and trial and error method shown above.

Try a depth of 1.0 ft:

$a = 2.0(1.0) + 2.5(1.0)^2 = 4.5\ ft^2$

$R = 4.5\ ft^2 / (2.0 + 5.39(1.0)) = 0.61\ ft$

$Q = 4.5\ ft^2\ [1.49/.03 * (0.61\ ft)^{2/3} * 0.01^{1/2}] = 16.1$ cfs > $Q_{10\text{-year}}$, so OK.

Step 7: Confirm Re_v has been met with the three bioretention facilities.

As computed above, Re_v = 0.098 ac-ft (= 4,269 ft^3). There are two ways to confirm compliance with the Recharge Criteria:

One method would be to confirm that the total volume exfiltrated by the three bioretention facilities prior to overflow exceeds the required Re_v. The HydroCAD model is the easiest way to confirm this, using the modified CN model run. This also assumes that the runoff filtered through the bioretention media (which is loamy sand as required in Chapter Five and Appendix F) also infiltrates into the underlying soils. Since the site soils are also loamy sands with a design infiltration rate = 2.41"/hr, this assumption is justified.

For Bio 1: Exfiltration Volume = 0.082 ac-ft (3,572 ft^3)
For Bio 2: Exfiltration Volume = 0.044 ac-ft (1,917 ft^3)
For Bio 3: Exfiltration Volume = 0.053 ac-ft (2,309 ft^3)

Total Recharge Volume = 0.179 ac-ft (7,798 ft^3) > 0.098 ac-ft (= 4,269 ft^3). OK

The second method is by the Percent Area Method (refer to Section 4.6.1.2). where,

$Re_a = (F)\ (I)$

Re_a = Required impervious area to be directed to a QPA (acres) or an approved infiltrating stormwater control measure (see Table 3-5)
F = Recharge factor based on Hydrologic Soil Group (HSG) (dimensionless)

I = Impervious area (acres)

For the Reaper Brook Site, with 100% B soils; Re_a = (0.35)(3.83 ac) = 1.34 acres.

For DA 1: I = 0.85 ac;
For DA 2: I = 0.51 ac; and
For DA 3: I = 0.6 ac.

Thus, the total DA draining to an approved infiltrating practice = 1.96 acres > 1.34 acres. OK.

Step 8:	**Size the dry extended detention basin to provide CP_v.**

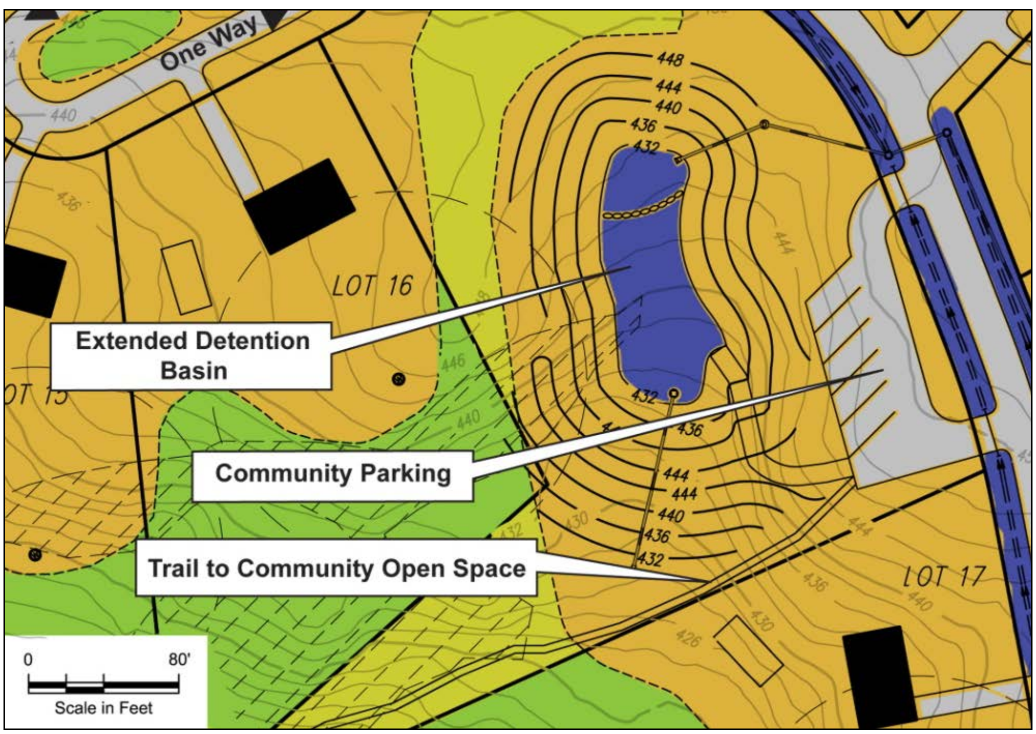
As computed in Step 3 above, $CP_v = 0.65 * V_r = 0.65\ (38{,}725\ ft^3) = 25{,}171\ ft^3$

In accordance with Section 3.3.4, size the outlet orifice to release the 1-year <u>inflow volume</u> (V_r) at roughly a uniform rate over 24 hours:

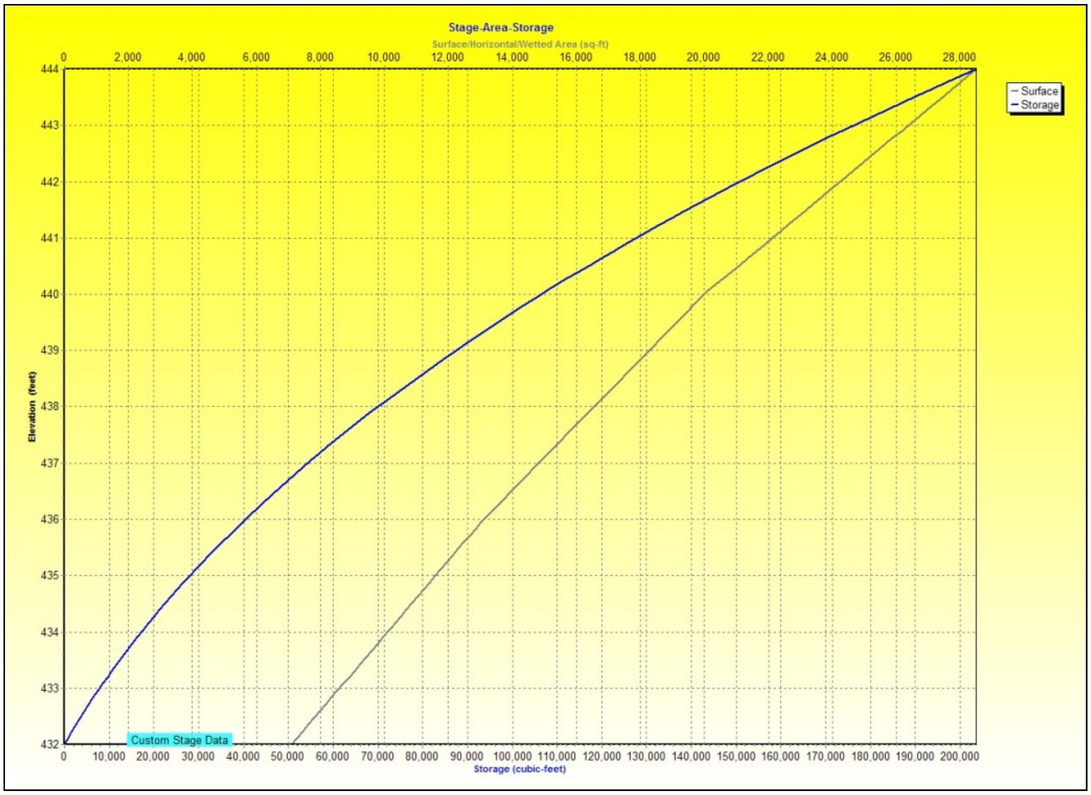
Thus, $Q_{CPv} = 38{,}725\ ft^3$ / (24 hours (3,600 seconds/hour)) = 0.45 cfs.

The Dry Extended Detention Basin has been graded to provide adequate storage volume to meet both the CP_v as well as Q_p requirements. (See Figure D-8 Extended Detention Plan View, and Figure D-9, Stage-Storage Curve).

Figure D-8 Dry Extended Detention Basin Plan View



D-9 Stage-Storage Curve for Dry Extended Detention Basin



Read Elevation (for 25,171 ft^3) ~ 434.8, with basin bottom at elevation 432. Size orifice based on approx. average head: (434.8 - 432.0) / 2 = 1.4 ft.

Using the orifice equation: $Q_{CPv} = C(A)(2f{*}h_{avg})^{1/2}$, solve for A, then calculate orifice diameter (D):

$0.45 \text{ cfs} = 0.6\ (A)\ (64.4{*}1.4)^{1/2}$:

$A = 0.08 \text{ ft}^2 = \pi D^2/4$: $D = 0.32 \text{ ft}(12''/\text{ft}) = 3.84$ inches

Use D = 3.0 inches (will provide conservative detention time). See HydroCAD results (Figure D-11).

Figure D-10 HydroCAD Routing Model for Dry Extended Detention Basin

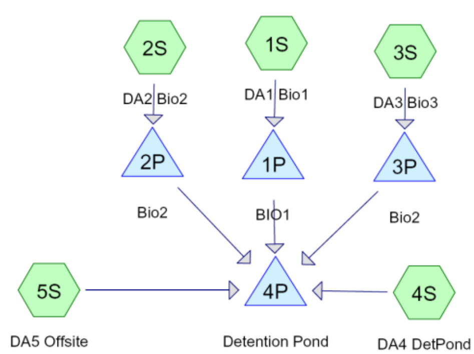


Figure D-11 HydroCAD Pond Routing for Extended Detention Pond for CP_v

100326_Reaper Brook_CDS *Type III 24-hr 1YR Rainfall=3.10"*
Prepared by Horsley Witten Group Printed 3/26/2010
HydroCAD® 9.00 s/n 02800 © 2009 HydroCAD Software Solutions LLC Page 12

Summary for Pond 4P: Detention Pond

Inflow Area = 20.830 ac, 19.18% Impervious, Inflow Depth = 0.51" for 1YR event
Inflow = 9.51 cfs @ 12.16 hrs, Volume= 0.889 af
Outflow = 0.39 cfs @ 17.39 hrs, Volume= 0.534 af, Atten= 96%, Lag= 313.8 min
Primary = 0.39 cfs @ 17.39 hrs, Volume= 0.534 af

Routing by Stor-Ind method, Time Span= 0.00-30.00 hrs, dt= 0.03 hrs
Peak Elev= 434.86' @ 17.39 hrs Surf.Area= 11,396 sf Storage= 26,486 cf

Plug-Flow detention time= 503.2 min calculated for 0.534 af (60% of inflow)
Center-of-Mass det. time= 396.9 min (1,254.6 - 857.7)

Volume	Invert	Avail.Storage	Storage Description
#1	432.00'	203,600 cf	**Custom Stage Data (Prismatic)**Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
432.00	7,100	0	0
436.00	13,100	40,400	40,400
440.00	20,000	66,200	106,600
444.00	28,500	97,000	203,600

Device	Routing	Invert	Outlet Devices
#1	Device 4	432.00'	**3.0" Vert. Orifice/Grate** C= 0.600
#2	Device 4	434.90'	**24.0" W x 12.0" H Vert. Orifice/Grate** C= 0.600
#3	Device 4	437.00'	**36.0" W x 12.0" H Vert. Orifice/Grate** C= 0.600
#4	Primary	428.00'	**21.0" Round Culvert** L= 110.0' RCP, square edge headwall, Ke= 0.500 Outlet Invert= 426.00' S= 0.0182 '/' Cc= 0.900 n= 0.013 Concrete pipe, straight & clean

Primary OutFlow Max=0.39 cfs @ 17.39 hrs HW=434.86' (Free Discharge)
└─**4=Culvert** (Passes 0.39 cfs of 28.34 cfs potential flow)
  ├─**1=Orifice/Grate** (Orifice Controls 0.39 cfs @ 7.97 fps)
  ├─**2=Orifice/Grate** (Controls 0.00 cfs)
  └─**3=Orifice/Grate** (Controls 0.00 cfs)

Note, elevation of CP_v is approximately 434.9 ft, reflecting the fact that a 3-inch orifice was used, resulting in a conservative release rate. Also, note that a sediment forebay has been provided, though it is not explicitly required for an extended detention basin.

Step 9: Size dry extended detention basin to provide Q_p controls (for 10- & 100-year storm)

As presented above, the 10- and 100-year pre-development rates from the drainage area discharging to Outfall A are 11.1 cfs and 44.9 cfs, respectively.

Calculate the 10-year release rate and required storage.

$Q_{10\text{-}out}$ = 11.1 cfs - 0.5 cfs (value of 3" CP_v orifice at estimated 10-year water surface elevation) = 10.6 cfs.

Initial estimated 10-year elevation = 436.5 (using NRCS TR-55 Short Cut Routing Method as a starting point – refer to Figure H-10).

Size outlet orifice:

$Q_{10\text{-}out} = C\,(A)\,(2g(h))^{1/2}$, where h = 436.5 - (434.9 + 0.5) = 1.1 ft (assumes 12" high slot)

10.6 cfs = 0.6 (A) $(64.4(1.1))^{1/2}$: A = 2.1 ft^2. For 12"high slot, L = 2.1 ft = 25.2" <u>use 24"</u>

Use 24" x 12" vertical slot, invert elevation 434.9 ft. See HydroCAD output Figure D-12.

Figure D-12 HydroCAD Output for 10-Year, 24-hour Type III Storm

100326_Reaper Brook_CDS *Type III 24-hr 10YR Rainfall=5.00"*
Prepared by Horsley Witten Group Printed 3/26/2010
HydroCAD® 9.00 s/n 02800 © 2009 HydroCAD Software Solutions LLC Page 12

Summary for Pond 4P: Detention Pond

Inflow Area = 20.830 ac, 19.18% Impervious, Inflow Depth = 1.67" for 10YR event
Inflow = 39.44 cfs @ 12.10 hrs, Volume= 2.906 af
Outflow = 10.74 cfs @ 12.55 hrs, Volume= 2.457 af, Atten= 73%, Lag= 27.0 min
Primary = 10.74 cfs @ 12.55 hrs, Volume= 2.457 af

Routing by Stor-Ind method, Time Span= 0.00-30.00 hrs, dt= 0.03 hrs
Peak Elev= 436.55' @ 12.55 hrs Surf.Area= 14,050 sf Storage= 47,876 cf

Plug-Flow detention time= 179.1 min calculated for 2.455 af (84% of inflow)
Center-of-Mass det. time= 116.9 min (957.7 - 840.7)

Volume	Invert	Avail.Storage	Storage Description
#1	432.00'	203,600 cf	**Custom Stage Data (Prismatic)**Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
432.00	7,100	0	0
436.00	13,100	40,400	40,400
440.00	20,000	66,200	106,600
444.00	28,500	97,000	203,600

Device	Routing	Invert	Outlet Devices
#1	Device 4	432.00'	**3.0" Vert. Orifice/Grate** C= 0.600
#2	Device 4	434.90'	**24.0" W x 12.0" H Vert. Orifice/Grate** C= 0.600
#3	Device 4	437.00'	**36.0" W x 12.0" H Vert. Orifice/Grate** C= 0.600
#4	Primary	428.00'	**21.0" Round Culvert** L= 110.0' RCP, square edge headwall, Ke= 0.500 Outlet Invert= 426.00' S= 0.0182 '/' Cc= 0.900 n= 0.013 Concrete pipe, straight & clean

Primary OutFlow Max=10.74 cfs @ 12.55 hrs HW=436.55' (Free Discharge)
└4=**Culvert** (Passes 10.74 cfs of 32.08 cfs potential flow)
  ├1=**Orifice/Grate** (Orifice Controls 0.50 cfs @ 10.13 fps)
  ├2=**Orifice/Grate** (Orifice Controls 10.24 cfs @ 5.12 fps)
  └3=**Orifice/Grate** (Controls 0.00 cfs)

Calculate the 100-year release rate and required storage.

$Q_{100\text{-out}}$ = 44.9 cfs – (18.5 cfs + 0.7) cfs (values 24" x 12" slot and 3" CP_v orifice at estimated 100-year water surface elevation) = 25.7 cfs.

Initial estimated 100-year elevation = 440.5 ft (using NRCS TR-55 Short Cut Routing Method as a starting point – refer to Figure H-10).

Size Outlet Pipe (Barrel) to control total outlet flow by elevation 440.5 ft (can use culvert charts, culvert software, hydraulic software, such as HydroCAD to estimate pipe capacity).

Use 21" RCP, upstream invert = 428.0 ft, downsteam invert = 426.0 ft (See HydroCAD output Figure D-13).

Figure D-13 HydroCAD Output for 100-Year 24-hour Type III Storm

100326_Reaper Brook_CDS *Type III 24-hr 100YR Rainfall=8.90"*
Prepared by Horsley Witten Group Printed 3/26/2010
HydroCAD® 9.00 s/n 02800 © 2009 HydroCAD Software Solutions LLC Page 12

Summary for Pond 4P: Detention Pond

Inflow Area = 20.830 ac, 19.18% Impervious, Inflow Depth = 4.75" for 100YR event
Inflow = 105.40 cfs @ 12.11 hrs, Volume= 8.240 af
Outflow = 38.96 cfs @ 12.44 hrs, Volume= 7.766 af, Atten= 63%, Lag= 20.3 min
Primary = 38.96 cfs @ 12.44 hrs, Volume= 7.766 af

Routing by Stor-Ind method, Time Span= 0.00-30.00 hrs, dt= 0.03 hrs
Peak Elev= 440.53' @ 12.44 hrs Surf.Area= 21,134 sf Storage= 117,575 cf

Plug-Flow detention time= 91.8 min calculated for 7.759 af (94% of inflow)
Center-of-Mass det. time= 61.9 min (884.2 - 822.3)

Volume	Invert	Avail.Storage	Storage Description
#1	432.00'	203,600 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
432.00	7,100	0	0
436.00	13,100	40,400	40,400
440.00	20,000	66,200	106,600
444.00	28,500	97,000	203,600

Device	Routing	Invert	Outlet Devices
#1	Device 4	432.00'	**3.0" Vert. Orifice/Grate** C= 0.600
#2	Device 4	434.90'	**24.0" W x 12.0" H Vert. Orifice/Grate** C= 0.600
#3	Device 4	437.00'	**36.0" W x 12.0" H Vert. Orifice/Grate** C= 0.600
#4	Primary	428.00'	**21.0" Round Culvert** L= 110.0' RCP, square edge headwall, Ke= 0.500 Outlet Invert= 426.00' S= 0.0182 '/' Cc= 0.900 n= 0.013 Concrete pipe, straight & clean

Primary OutFlow Max=38.96 cfs @ 12.44 hrs HW=440.53' (Free Discharge)
- **4=Culvert** (Barrel Controls 38.96 cfs @ 16.20 fps)
  - **1=Orifice/Grate** (Passes < 0.69 cfs potential flow)
  - **2=Orifice/Grate** (Passes < 21.81 cfs potential flow)
  - **3=Orifice/Grate** (Passes < 25.12 cfs potential flow)

The calculated 100-year water surface elevation = 440.5 ft. Set emergency spillway elevation in native ground at elevation 440.6 ft and top of embankment elevation at 444.0 ft. Note, embankment exceeds 6 feet in height. Thus, if an immediate downstream hazard were present (e.g., road crossing or building in floodplain), a dam breach analysis would be required. See Table D-3 for a summary of results.

Table D-3 Design Example Summary of Results

Criteria	Required	Provided	Practice Notes
Recharge Volume (Re_v)	0.098 ac-ft	0.178 ac-ft	3 exfiltrating bioretention facilities
Water Quality Volume (WQ_v)	0.28 ac-ft	> 0.28 ac-ft[1]	3 bioretention facilities and dry swale system
Channel Protection volume (CP_v)	0.58 ac-ft	0.61 ac-ft peak release rate= 0.4 cfs	Dry extended detention basin peak elev. = 434.9 ft
Overbank Protection (Q_p)	Pre-development peak: Q_{p-10}= 11.1 cfs Q_{p-100} = 44.9 cfs	Post-development basin peak release rate: Q_{p-10}= 10.7 cfs Q_{p-100} = 39.0 cfs	Detention storage 10-yr peak elev.= 436.6 ft 100-yr peak elev.= 440.5 ft

[1] Because bioretention is a flow-through device the storage volume of these facilities must be at least ¾ of the computed WQ_v, yet total volume of infiltration plus dry swale volume exceeds 0.28 ac-ft.

Table D-4 Completed LID Site Planning and Design Checklist for Reaper Brook Estates

1. Strategies to Avoid the Impacts

A. Preservation of Undisturbed Areas

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ Limits of disturbance clearly marked on all construction plans.
- ☒ Mapped soils by Hydrologic Soil Group (HSG).
- ☒ Building envelopes avoid steep slopes, forest stands, riparian corridors, HSG D soils, and floodplains.
- ☒ New lots, to the extent practicable, have been kept out of freshwater and coastal wetland jurisdictional areas.
- ☒ Important natural areas (i.e., undisturbed forest, riparian corridors, and wetlands) identified and protected with permanent conservation easement.
- ☒ Percent of natural open space calculation is provided.
- ☒ Other (describe):

Explain constraints when a strategy is applied and/or proposed alternatives in space below:

Design completely preserves one whole side of the project. Open space is accessed by a community trail system, steep slopes are avoided except in a few isolated locations, natural vegetation is preserved in cul-de-sac and eyebrow islands.

B. Preservation of Buffers and Floodplains

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following:

- ☒ Applicable vegetated buffers of coastal and freshwater wetlands and perennial and intermittent streams have been preserved, where possible.
- ☒ Limits of disturbance included on all construction plans that protect applicable buffers
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

All lots are located out of wetland and riverbank buffers; limits of disturbance are clearly marked on all plans.

C. Minimized Clearing and Grading

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☐ Site fingerprinting to extent needed for building footprints, construction access and safety (i.e., clearing and grading limited to 15 feet beyond building pad or 5 feet beyond road bed/shoulder).
- ☒ Other (describe):

Explain constraints and/or proposed alternatives in space below:

Clearing extends beyond houses to construct OWTS, wells, and grade a minimum yard area for each lot.

D. Locating Sites in Less Sensitive Areas

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ A site design process, such as conservation development, used to avoid or minimize impacts to sensitive resources such as floodplains, steep slopes, erodible soils, wetlands, hydric soils, surface waters, and their riparian buffers.
- ☐ Development located in areas with least hydrologic value (e.g., soil groups A and B)
- ☐ Development on steep slopes, grading and flattening of ridges has been avoided to the maximum extent practicable.
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

The project was developed as a CDS. Sensitive areas have been avoided to the maximum extent practicable. Site soils are uniformly HSG B, thus hydrologic value is not a specific factor. Site itself consists of very steep slopes, and thus, will require significant grading, but the steepest slopes have been avoided.

E. Compact Development

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ A site design technique (e.g., conservation development) used to concentrate development to preserve as much undisturbed open space as practicable and reduce impervious cover.
- ☒ Reduced setbacks, frontages, and right- of- way widths have been used where practicable.
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

See response to item D, above. Setbacks all reduced. R/W remains at 50 feet per town requirements.

F. Work with the Natural Landscape Conditions, Hydrology, and Soils

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ Stormwater management system mimics pre-development hydrology to retain and attenuate runoff in upland areas (e.g., cuts and fills limited and BMPs distributed throughout site; trees used for interception and uptake).
- ☒ The post-development time of concentration (t_c) should approximate pre-development t_c.
- ☒ Flow velocity in graded areas as low as practicable to avoid soil erosion (i.e., slope grade and/or length minimized). Velocities shall not exceed velocities in Appendix B, Table B-2.
- ☐ Plans show measures to prevent soil compaction in areas designated for Qualified Pervious Areas (QPAs) for better infiltration.
- ☐ Site designed to locate buildings, roadways and parking to minimize grading (cut and fill quantities)
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

For the most part, the site has been designed to retain natural features. Flow velocities are as low as possible for graded swales, and t_c as long as possible by draining through bioretention facilities and dry swales. QPAs for disconnected rooftop runoff undisturbed were possible in rear yards. Building and driveways located to avoid steep slopes, and street designed to minimize cuts and fills.

2. Strategies to Reduce the Impacts

A. Reduce Impervious Cover

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ Reduced roadway widths
- ☐ Reduce driveway areas
- ☐ Reduced building footprint
- ☐ Reduced sidewalk area
- ☒ Reduced cul-de-sacs
- ☐ Reduced parking lot area
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

Roads designed with 20 foot paving width; 3-foot shoulders; and swales with 2 foot bottom width, 2.5:1 side slopes and 1 foot depth. Cul-de-sacs are looping lanes or eyebrows with open islands, sidewalks are not proposed, but pedestrian wood-chip trail connects project to undisturbed community open space.

3. Strategies to Manage the Impacts

A. Disconnecting Impervious Area

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☐ Impervious surfaces have been disconnected to QPAs to the extent possible.
- ☒ Other (describe):

Explain constraints and/or proposed alternatives in space below:

Rooftops from several lots will drain to QPAs but no specific credit has been calculated.

B. Mitigation of Runoff at the point of generation

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ Roof runoff has been directed to a QPA, such as a yard or vegetated area.
- ☒ Roof runoff has been directed to a lower impact practice such as a rain barrel or cistern.
- ☐ A green roof has been designed to reduce runoff.
- ☒ Small-scale BMPs applied at source.
- ☒ Other (describe):

Explain constraints and/or proposed alternatives in space below:

Open section road provided instead of closed section with dry swale.

C. Stream/Wetland Restoration

☒ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☐ Historic drainage patterns have been restored by removing closed drainage systems and/or restoring degraded stream channels and/or wetlands.
- ☐ Removal of invasive species.
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

Stream is currently in stable condition, and wetlands are pristine.

D. Reforestation

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ Low maintenance landscaping and native vegetation has been proposed.
- ☒ Trees are proposed to be planted or conserved to reduce runoff volume, increase nutrient uptake, and provide shading and habitat.
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

E. Source Control

☐ Not Applied or N/A. *Use space below to explain why:*

Select from the following list:

- ☒ Source control techniques such as street sweeping or pet waste management have been proposed.
- ☐ Other (describe):

Explain constraints and/or proposed alternatives in space below:

Aggressive pet waste management will be implemented, and enforced in neighborhood association rules to increase effectiveness of stormwater treatment system.

D.2 Design Example #2: Commercial Site

The Ocean Breeze Marina is a hypothetical marina located in Newport, Rhode Island. The site is approximately 2 acres in size and is immediately adjacent to Rhode Island Sound. The project consists of new development of parking areas (used for boat storage and maintenance in the off-season), boat yard, and an access road. The immediate drainage area consists of an access road, parking lot, and marina buildings. In addition, drainage from the adjacent area equaling an area of approximately 2.5 acres is conveyed through the site via storm drain.

The project site contains a number physical constraints that impact the design options, including:

- Existing fill within the project site area;
- High groundwater elevation and little available head due to adjacent tidal fluctuations;
- Extremely flat terrain across the site from the existing access drive and parking lot;
- Elevations of the existing drainage system; and
- Poor draining soils across the field.

As a marina, this site is considered a LUHPPL. As such, lined bioretention areas are chosen to treat runoff from the parking lots, as well as the adjacent road. The parking lot runoff enters several on-line bioretention areas via sheet flow over grass filter areas. In addition, one off-line bioretention area accepts both boat yard runoff and the runoff from the adjacent road, which is collected in drainage pipes and conveyed through a proprietary pretreatment device before entering the bioretention through a distribution manifold. A downstream tide gate was incorporated to prevent extreme tides from backing up into the bioretention facilities. This example steps through the design process for the off-line bioretention area, which has a total drainage area of 3.0 acres, with 2.5 impervious acres.

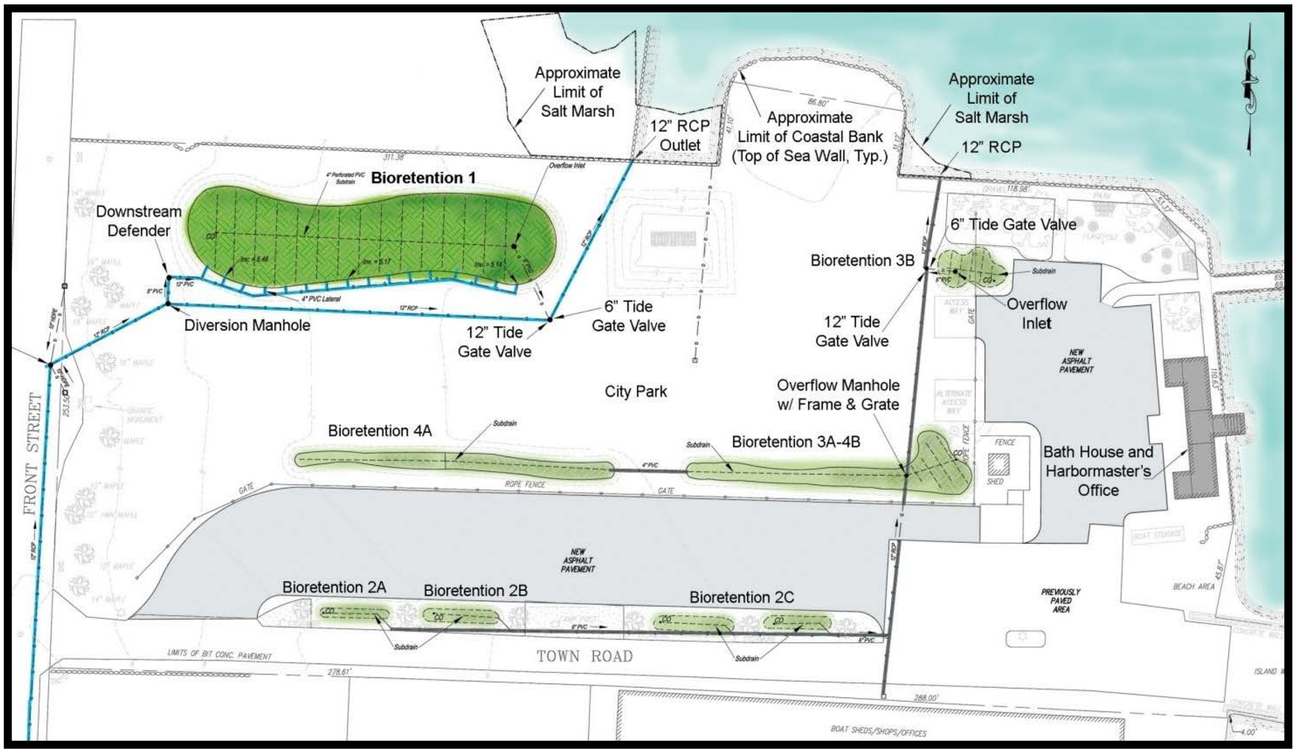
Table D-5 Base Data for Ocean Breeze Marina

Location: Newport, RI
  Drainage Area to Off-line Bioretention
  Site Area: 3.0 acres
  Impervious Area: 2.5 acres
  Time of Concentration: 6 minutes
Soils Type: Urban Land

Step 1:	**Document Site Planning Process in Accordance with Standard 1.**

LID measures were incorporated at this new development site to the maximum extent practicable. For example, impervious surfaces were reduced by decreasing the size of parking spaces, as well as the access road. Rooftop runoff was disconnected to flow into vegetated areas instead of the storm drain system.

Figure D-14 Plan View of the Site (not to scale)



Step 2:	**Determine Required Design Criteria (i.e., Re_v, WQ_v, CP_v, Q_p)**

- Re_v: The whole site is considered a LUHPPL since the parking area is used for boat storage and maintenance, so stormwater cannot be infiltrated.
- WQ_v: The WQ_v will be treated with bioretention areas.
- CP_v: The CP_v does not need to be managed because the site discharges to a tidally influenced waterbody.
- Q_p: The Q_p does not need to be managed because the site discharges to a tidally influenced waterbody.
- A downstream analysis is not required because the disturbed area is smaller than 5 acres.

Step 3:	**Compute Required Design Volumes (WQ_v)**

$$WQ_v = [(1.0") (I)] / 12$$
$$= [(1.0 \text{ in}) (2.5 \text{ ac}) (1\text{ft}/12\text{in})]$$
$$= \underline{0.208 \text{ ac-ft}}$$

Bioretention will be designed with an impermeable liner to protect groundwater from the stormwater pollutants at this LUHPPL. Total WQ_v to be treated by the bioretention facility is: <u>WQ_v = 0.208 ac-ft = 9,075 ft^3</u>.

Step 4:	**Determine if the development site and conditions are appropriate for the use of a bioretention area.**

Site Specific Data:

Existing ground elevation at practice location is 6.25 ft, mean sea level. Soil boring observations reveal that the seasonally high water table is at elevation 0.5 ft and underlying soil is urban fill. A 3-ft separation distance from the seasonally high water table is not required for this site since the bioretention is not designed to infiltrate to the underlying soils. Thus, bioretention is an acceptable BMP for this site.

Step 5:	**Confirm local design criteria and applicability.**

There are no additional local criteria that must be met for this design.

Step 6:	**Determine size of bioretention filter area.**

Use sizing equation and values provided in Section 5.5.4:

$$A_{f\,=}\ (WQ_v)\ (d_f)\ /\ [(k)\ (h_f + d_f)\ (t_f)]$$

Where:
- A_f = surface area of filter bed (ft^2)
- d_f = filter bed depth (ft) (use 2 ft given physical constraints at the site)
- k = coefficient of permeability of filter media (ft/day)
- h_f = average height of water above filter bed (ft) (max 9 in allowed, so ave = 0.375ft)
- t_f = design filter bed drain time (days) (2 days is recommended)

A_f = (9,075 ft^3) (2 ft) / [(1 ft /day) (0.375ft + 2 ft) (2 days)] (With d_f = 2 ft, k = 1.0 ft /day, h_f = 0.25ft, t_f = 2 days)

A_f = <u>3,821 ft^2</u>

The Bioretention facility must have a minimum surface area of 3,821 ft^2 and a volume equal to at least ¾ of the WQ_v, including the forebay volume (per requirements in Chapter Five). WQ_v = 9,075 ft^3, min Vol = 0.75(9,075 ft^3) = 6,806.3 ft^3

With a 9” ponding depth and 2.0 media depth, calculate available storage above and within the facility: surface ponding Vol @ depth of 0.75 ft = 3,152 ft^3. Vol of voids within media = 3,821 ft^2 (2.0 ft) (0.33) = 2,522 ft^3. Total volume = 3,152 + 2,522 = 5,674 ft^3 <

6,806 ft^3. (too small - due to the shallow depth associated with the groundwater constraint).

Increase minimum surface area to 4,500 ft^2 and maintain maximum ponding depth of 0.75 ft. Available surface storage at ponding depth of 0.75 ft = 3,881 ft^3. Volume of voids within media = 4,500 ft^2 (2.0 ft) (0.33) = 2,970 ft^3. Total volume = 3,881 + 2,970 = 6,851 ft^3 > 6,806 ft^3. OK.

Step 7: Set design elevations and dimensions.

Given a filter area requirement of 4,500 ft^2 and the dimensions of available area, <u>say facility is roughly 25 ft by 180 ft</u>. Set top of the bioretention surface at elev. 5.0 ft, with the top of berm at elevation 6.25 ft.

Step 8: Design conveyance to facility.

Stormwater treatment practices can be either on or off-line. On-line facilities are generally sized to receive, but not necessarily treat, larger storms. Off-line facilities are designed to receive a more or less exact flow rate through a weir, channel, manhole "flow splitter", etc. When flow is directed via a pipe system, as is the case here, it must be designed as off-line (see Section 5.5.2). The facility in this example is situated to receive only the WQ_v via a flow splitter in the existing storm drain network.

To design a flow splitter for this offline bioretention area, refer to Section 3.3.3.2 for guidance on Water Quality Peak Flow Calculation.

Using the water quality volume (WQ_v), a corresponding Curve Number (CN) is computed utilizing the following equation:

$$CN = 1000 / [10 + 5P + 10Q - 10(Q^2 + 1.25\, Q*P)^{½}]$$

Where P = rainfall, in inches (use 1.2 inches)

Q = runoff volume, in inches (equal to WQ_v ÷ area)

Q = (0.21 ac-ft) (12 inches/ft) / (3.0 acres) = 0.84 inches

$$CN = 1000 / [10 + 5(1.2\text{ in}) + 10\,(0.84\text{ in}) - 10((0.84\text{ in})^2 + 1.25\,(0.84\text{ in})(1.2\text{ in}))^{½}]$$

$$CN = 1000 / [10 + 6.0 + 8.4 – 14.02] = 96.3$$

The time of concentration (t_c) is 6 min (0.1 hr).

Read initial abstraction (Ia) from TR-55 Table 4-1 or calculate Ia = 200/CN - 2 = 0.077

Compute Ia/P = 0.077 / 1.2 in = 0.064

Approximate the unit peak discharge (q_u) from TR-55 Exhibit 4-III for appropriate t_c.

q_u = 660 csm/in

Using the water quality volume (WQ_v), compute the peak discharge (Q_{peak})

$$Q_{peak} = q_u * A * WQ_v$$

where
Q_{peak} = the peak discharge, in cfs
q_u = the unit peak discharge, in cfs/mi²/inch (670 csm/in)
A = drainage area, in square miles (0.0047 sq miles)
WQ_v = Water Quality Volume, in watershed inches (0.84 inches)

Q_{peak} = 660 * 0.0047 * 0.84 = 2.61 cfs

Use the orifice equation to size pipe to bioretention area. $Q_{peak} = CA(2gh)^{1/2}$

where:
C = discharge coefficient (0.6)
A = cross-section area of orifice ($D^2/4*\pi$)
g = acceleration due to gravity (32.2 ft/s^2)
h = head, height above center of the orifice (assume 2 ft)

$A = Q_{peak} / [C * (2gh)^{1/2}]$ = 2.61 cfs / [0.6 * (2*32.2 ft/s^2 * 2 ft) $^{1/2}$] = 0.38 ft^2
Diameter = [(0.38 ft^2) * 4 / π] $^{1/2}$ = 0.7 ft (12 in/ft) = 8.4 in. Use 10 in pipe.
(Note, could provide an orifice plate within the structure with an 8.4-inch diameter opening, but a 10-inch pipe will carry more flow than the design, so it is conservative)

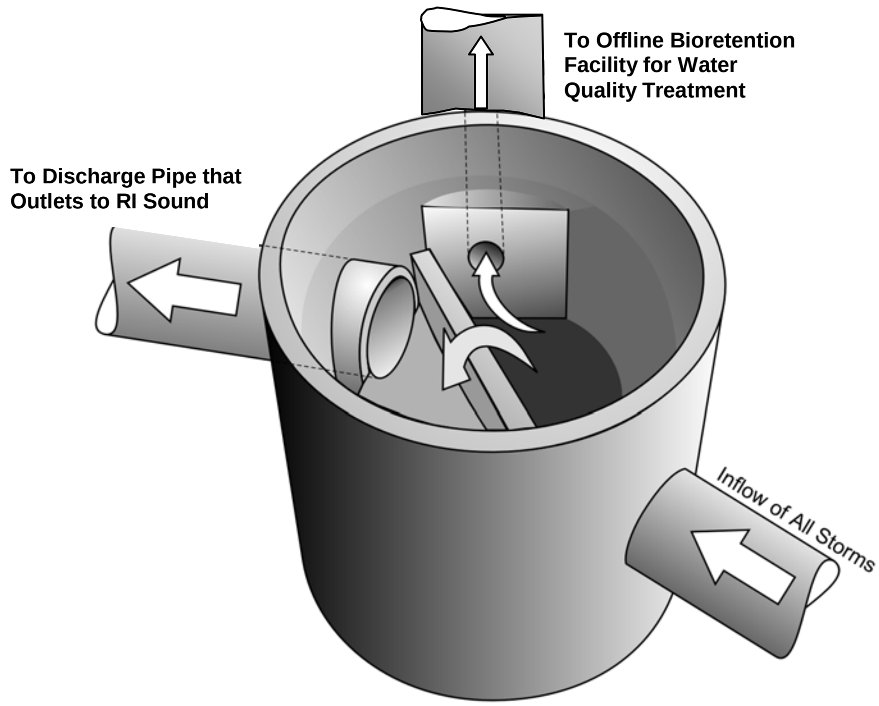
Step 9:	**Design pretreatment.**

Pretreatment provided with proprietary swirl-concentrator according to manufacturer's instructions. Flow is then distributed along the length of the bioretention area with a PVC manifold to prevent erosion at one inlet location and to ensure equal distribution of stormwater to reach all areas of the bioretention.

Step 10:	**Overflow design.**

Since the bioretention is designed as an off-line practice sized to treat only the WQ_v, it theoretically should not overflow (see Figure D-15). However, should filtering rates become reduced due to facility age or poor maintenance, an overflow weir should be provided to prevent inadvertent overflows. The overflow weir elevation is set so that a maximum of 9 inches of ponding occurs above the bottom of the bioretention area. In this case, the overflow weir is set at 5.75 ft.

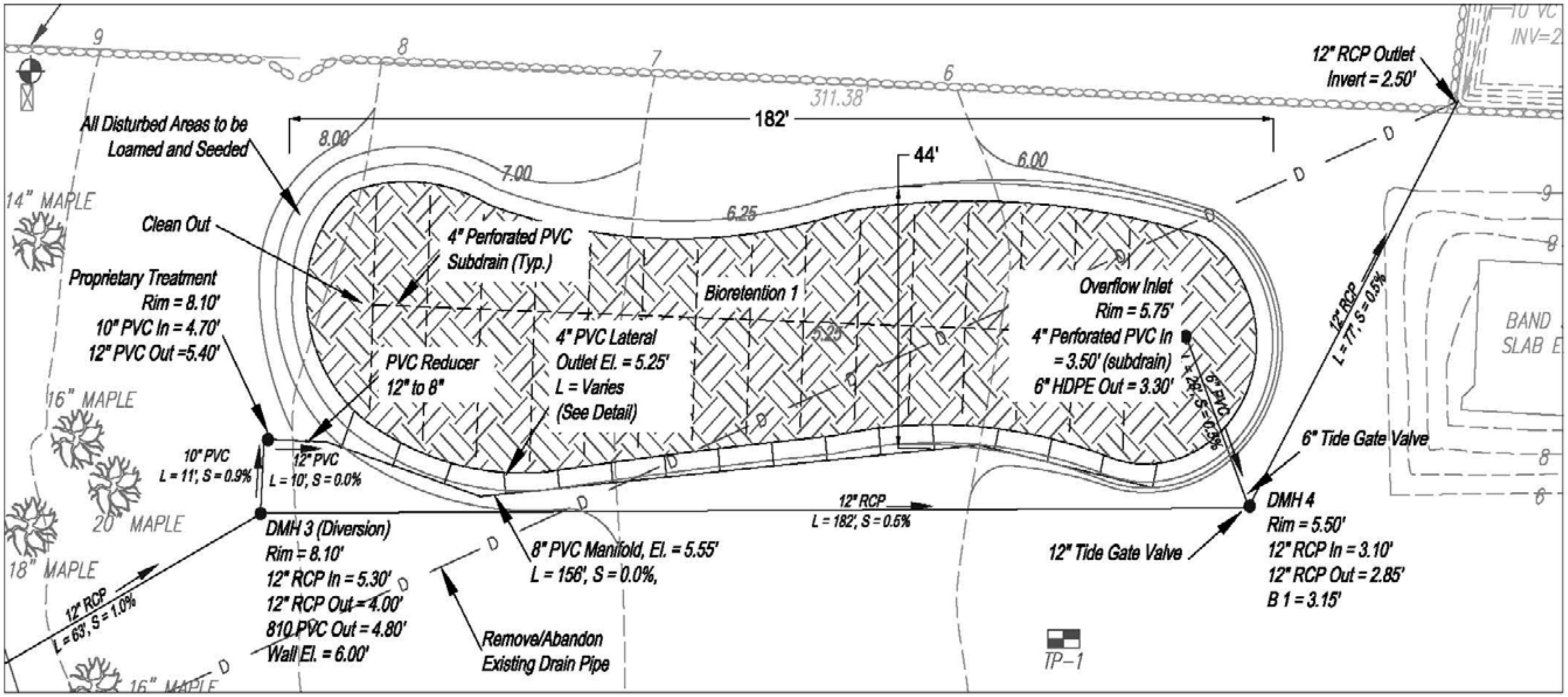
Figure D-15 Flow Splitter Design



Step 11: Choose plants for planting area.

Choose plants based on factors such as whether native or not, tolerance to salt spray and wind, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on-center planting distances) so species will not "shade out" one another. Do not plant trees and shrubs with extensive root systems near pipe work. Planting guidelines for this practice are presented in Appendix B.

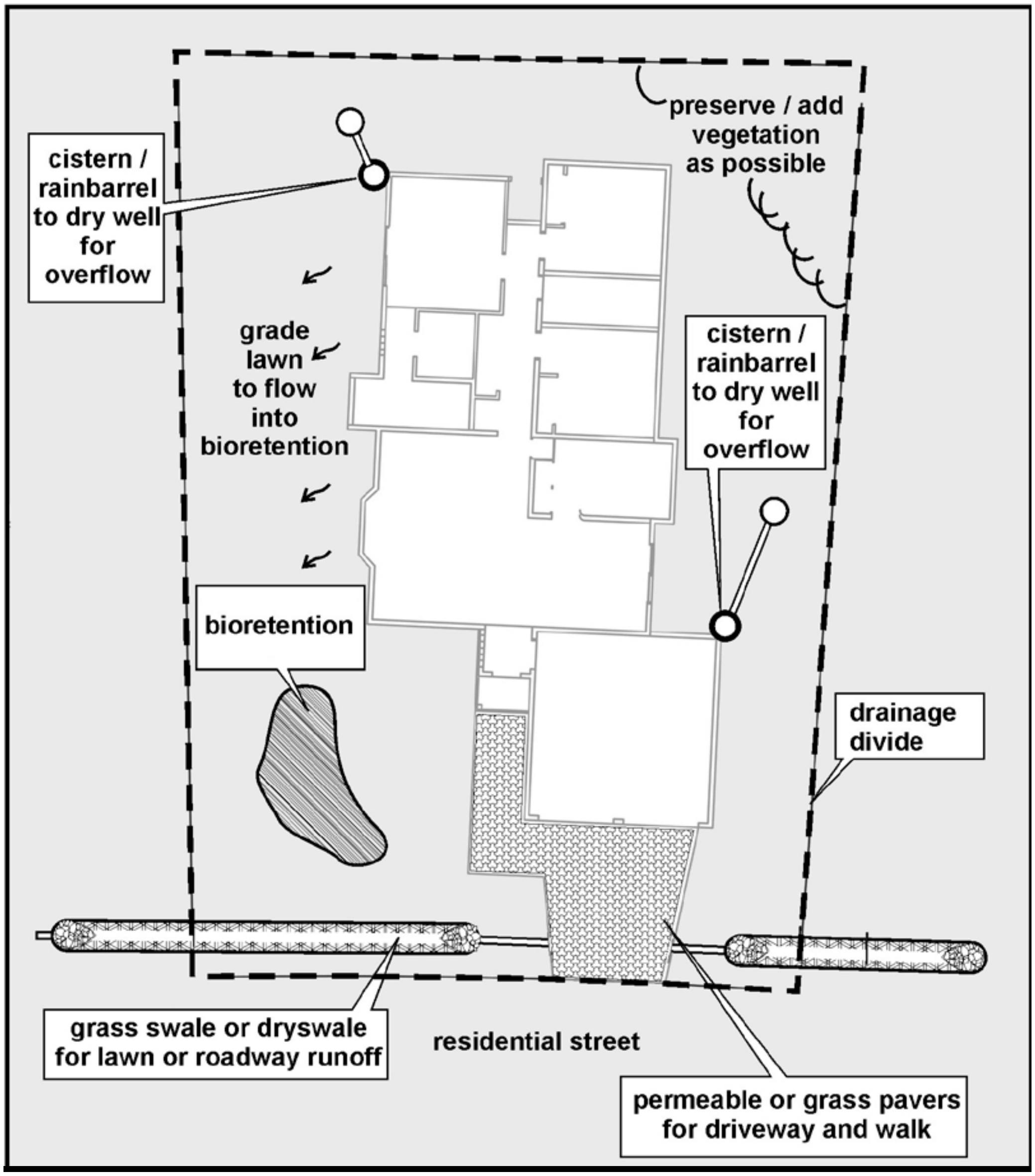
Figure D-16 Plan View of Off-line Bioretention Facility



D.3 Design Example #3: Single-Family Residential Site

The final example demonstrates how a single-family home site can be designed to manage stormwater. The BMPs covered in this example include a cistern, bioretention area, permeable pavers, and a dry swale. For further guidance on small site stormwater BMPs, designers are encouraged to consult the State of Vermont, Department of Environmental Conservation "Small Sites Guide for Stormwater Management" at http://www.vtwaterquality.org/stormwater.htm.

Figure D-17 Various Options for Managing Stormwater from a Single-family Home

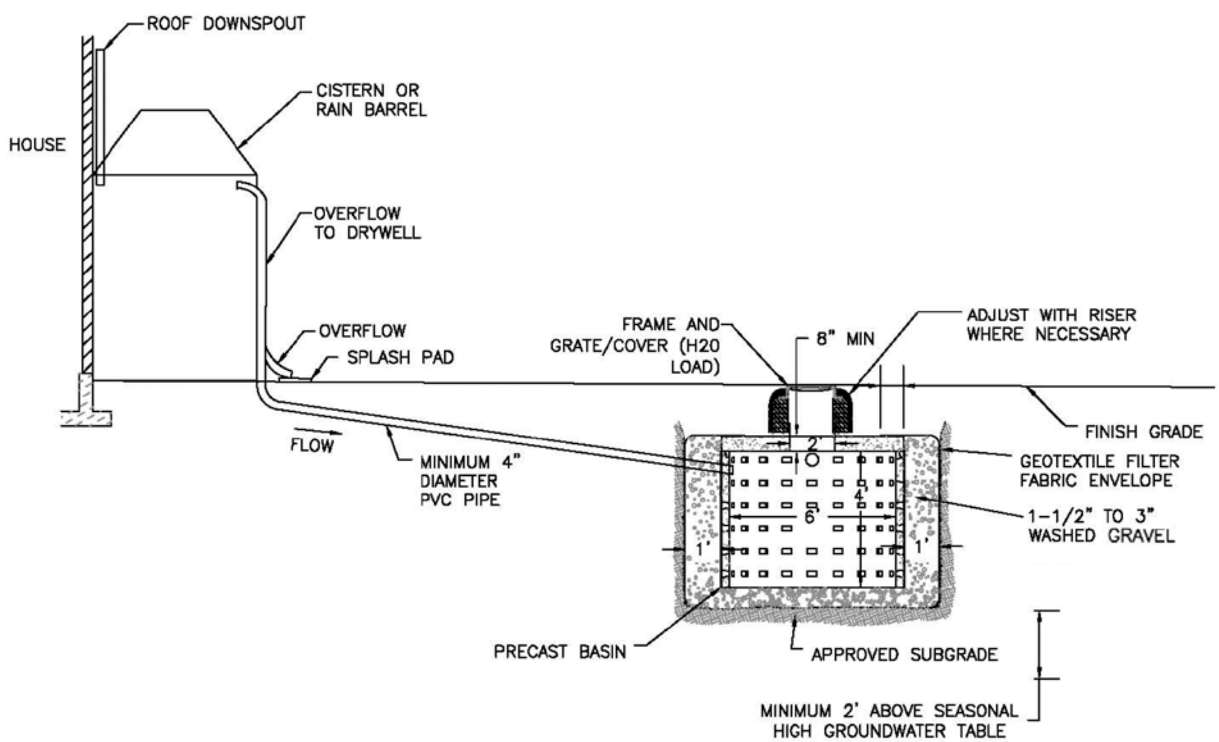


Site Area: 0.25 acres
Impervious Area: 0.08 acres
Soils Type: HSG "B"

D.3.1 Cistern and Drywell

The first part of this example focuses on the design of a cistern and a drywell to intercept rooftop runoff for a single family home. This example shows how the recharge requirements for this portion of the site will be met by cisterns that overflow to drywells. In general, the primary function of cisterns is to capture and store rooftop runoff that can be used at a later time. A drywell is a single infiltration chamber; in this case, it is intended to accept overflow from the cistern in larger rain events, or when the cistern is already full from a previous storm event. Both the cistern and the drywell help to reduce peak flows leaving the site, thus helping to meet channel protection and peak control requirements. Cisterns are only optional – since rooftop runoff does not need to be treated, it can discharge directly into the ground via drywells, with the volume counting towards both recharge and water quality requirements.

Figure D-18 Detail of Cistern and Drywell



Step 1:	**Compute the Recharge Volume (Re_v) and Water Quality Volume (WQ_v)**

Recharge, Re_v

The site is located HSG "B" soils.

Re_v = [(1") (F) (I)] / 12

= [(1.0 in) (0.35) (0.08 ac)] * (1 ft /12 in)

= <u>0.002 ac-ft = 102 ft^3</u>

Water Quality Volume, WQ_v

$$WQ_v = [(1.0\text{ in})\,(I)] / 12$$
$$= [(1.0\text{ in})\,(0.08\text{ ac})] * (1\text{ ft} / 12\text{ in})$$
$$= \underline{0.007\text{ ac-ft} = 290\text{ ft}^3}$$

The cistern should be sized for the larger volume to meet both requirements.

Step 2: Size the cistern and drywell.

Cisterns are only optional, but for this example, they will be used as a supplemental water source for the house. For this example, two cisterns (see Figure D-17) will be sized to handle the water quality volume from the house roof using the following equation recommended by the Low Impact Development Center, Inc. (http://www.lid-stormwater.net):

$$Vol = A * P * 0.90 * 7.5\text{ gals/ ft}^3$$

Where:
- Vol = Volume of rain barrel or cistern (gallons)
- A = Impervious surface area draining into cistern (ft^2)
- P = Precipitation (ft)
- 0.90 = fraction of total volume used by system (unitless)
- 7.5 = conversion factor (gallons per ft^3)

The total roof area draining to the cisterns is 2,300 ft^2; thus, Vol = (2,300 ft^2) (0.083 ft) (0.9) (7.5) = 1,289 gallons required. Divide by 2 since flow will be diverted to two cisterns = 644 gallons. Thus, use two (2) 1,000-gallon tanks with an overflow to a drywell for recharge.

The drywell can be sized by following the infiltration trench sizing approach in Section 5.3.4.

Step 3: Select additional BMPs to treat runoff from the site.

There are many structural and non-structural ways that a single-family home can meet stormwater requirements. Additional structural BMPs that could be utilized for this site are shown in Figure D-17 and described below.

D.3.2 Bioretention

The step-by-step example in Sections D.1 and D.2 show how bioretention areas can be designed to provide water quality treatment, recharge, and in some instances peak flow controls. In this particular example, the bioretention area is treating runoff from the yard and paved areas, although they can also be designed to capture rooftop runoff.

D.3.3 Permeable Pavers

Permeable pavers (as described in Section 5.4) can be used in the driveway and walkway areas associated with the single family home. In general, permeable pavers are designed to promote recharge and decrease peak flows. For more information on specifications and installation, visit the Interlocking Concrete Pavement Institute at http://www.icpi.org/.

D.3.4 Swale

A dry swale can be used along the road to collect the overflow from the bioretention area, driveway, and walkways. Dry swales can help meet recharge, water quality, and water quantity requirements for the site. See Section D.1 for a detailed design example.

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APPENDIX E: GUIDANCE FOR DEVELOPING OPERATION AND MAINTENANCE PLANS

An essential component of a successful stormwater system is the ongoing operation and maintenance of the various components of the stormwater drainage, control, and conveyance systems. Failure to provide effective maintenance can reduce the hydraulic capacity and the pollutant removal efficiency of stormwater practices.

Many people expect that stormwater facilities will continue to function correctly as designed forever. However, it is inevitable that deterioration of the stormwater infrastructure will occur once it becomes operational. The question is not whether stormwater management system maintenance is necessary but how often. Ideally, a program should address operation and maintenance concerns proactively instead of reacting to problems that occur such as flooding or water quality degradation associated with erosion, clogging, or outright failure of one or more practices. Thus, on-going maintenance is a vital part of ensuring the operational success of stormwater management facilities and is critical to achieving an extended service life of continuous operation as designed.

There are two key components to adequately maintaining a stormwater management infrastructure:

- Periodic and scheduled inspections, and
- Maintenance scheduling and performance.

This appendix offers <u>guidance</u> for developing operation and maintenance plans for a development site to help an applicant meet Standard 11. In addition, sample checklists are provided that can be used during maintenance inspections to ensure that all aspects of a constructed BMP are inspected. For specific maintenance requirements for each BMP, designers should refer to the applicable sections in Chapters Five, Six, and Seven.

Inspections

It is clear that an inspection program is necessary to ensure a stormwater facility remains operational. Inspections should be performed on a regular basis and scheduled based on the stormwater control type and characteristics. In addition, inspections should occur after major rainfall events for those components deemed to be critically affected by the resulting runoff. Not all inspections can be conducted by direct human observation. For subsurface systems, video equipment may be required. There may be cases where other specialized equipment is necessary. The inspection program should be tailored to address the operational characteristics of the system.

It is not mandatory that all inspectors be trained engineers, but they should have some knowledge or experience with stormwater systems. In general, trained stormwater engineers should, however, direct them. Inspections by registered engineers should be performed where routine inspection has revealed a question of structural or hydraulic integrity affecting public safety.

The inspection process should document observations made in the field and should cover structural conditions, hydraulic operational conditions, evidence of vandalism, condition of vegetation, occurrence of obstructions, unsafe conditions, and build-up of trash, sediments and pollutants. This is also an efficient way to take water quality measurements required for monitoring programs and to incorporate them into the inspection history.

Maintenance Scheduling and Performance

Maintenance activities can be divided into two types: scheduled and corrective. Scheduled maintenance tasks are those that are typically accomplished on a regular basis and can generally be scheduled without referencing inspection reports. These items consist of such things as vegetation maintenance (such as mowing) and trash and debris removal. These tasks are required at well-defined time intervals and should be considered a requirement for most, if not all, stormwater structural facilities. A maintenance crew is typically given a fixed scope of responsibility to address these items.

Corrective tasks consist of items such as sediment removal, stream bank stabilization, and outlet structure repairs that are done on an as-needed basis. These tasks are typically scheduled based on inspection results or in response to complaints. Corrective maintenance sometimes calls for more specialized expertise and equipment than scheduled tasks. For example, a task such as sediment removal from a stormwater basin requires specialized equipment for which not every jurisdiction is willing to invest. Therefore, some maintenance tasks might be effectively handled on a contract basis with an outside entity specializing in that field. In addition, some corrective maintenance may also require a formal design and bid process to accomplish the work.

The following section describes appropriate maintenance and inspection activities for the acceptable best management practices.

E.1 Maintenance Descriptions and Guidance

A stormwater control system should be regularly inspected to ensure proper performance and to prevent deficiencies in the effectiveness of the systems due to sediment build-up, damage, or deterioration. The following operation and maintenance provisions should be provided:

E.1.1 Stormwater Basins and WVTSs

General inspections should be conducted on an annual basis and after storm events greater than or equal to the 1-year, 24-hour Type III precipitation event. Areas with a permanent pool should be inspected on a semi-annual basis. The maintenance objectives for these practices include preserving the hydraulic and removal efficiency of the basin or WVTS and maintaining the structural integrity.

The slopes of the basin or WVTS should be inspected for erosion and gullying. Reinforce existing riprap if riprap is found to be deficient, erosion is present at the outfalls of any control structures, or the existing riprap has been compromised. All structural components, which include, but are not limited to, trash racks, access gates, valves, pipes, weir walls, orifice structures, and spillway structures, should be inspected and any deficiencies should be reported. This includes a visual inspection of all stormwater control structures for damage and/or accumulation of sediment. Sediment should be removed from the forebay when design depth has been reduced by 50%. All material, including any trash and/or debris from all areas within the extents of the basin or WVTS area including trash rack and flow control structures, should be disposed of in accordance with all federal and local regulations.

Any areas within the extents of the stormwater facility that are subject to erosion or gullying should be replenished with the original design material and re-vegetated according to design drawings. Slope protection material should be placed in areas prone to erosion. Embankment stability should be inspected for seepage and burrowing animals.

Mow the grass around the perimeter of the basin or WVTS at least 4 times annually. Vegetation along the maintenance access roads should be mowed annually. Prune all dead or dying vegetation within the extents of the basin or WVTS, remove all herbaceous vegetation root stock when overcrowding the maintenance access to the facility, remove any vegetation that has a negative impact on stormwater flowage through the facility, and trim any overgrown vegetation within the basin. Any invasive vegetation encroaching upon the perimeter of the facility should be pruned or removed if it is prohibiting access to the facility, compromising sight visibility and/or compromising original design vegetation. Replace any/all original vegetation that has died off or has not fully established, as determined at the time of the inspection. WVTS vegetation should be reinforced to its original design standards if less than 50% of the original vegetation is established after two years.

E.1.2 Infiltration

Infiltration facilities should be inspected annually to ensure that design infiltration rates are being met. If sediment or organic debris build-up has limited the infiltration capabilities (infiltration basins) to below the design rate, the top 6 inches should be removed and the surface roto-tilled to a depth of 12 inches. The basin bottom should be restored according to original design specifications. Any oil or grease found at the time of the inspection should be cleaned with oil absorption pads and disposed of in an approved location.

Inspect facility for signs of wetness or damage to structures and note any eroded areas. If dead or dying grass on the bottom is observed, check to ensure that water percolates 2-3 days following storms. Mow and remove litter and debris. Stabilize eroded banks and repair undercut and eroded areas at inflow and outflow structures. Vegetation along the maintenance access roads should be mowed annually.

E.1.3 Permeable Pavement

Permeable pavements performing as infiltration practices require regular vacuum sweeping or hosing (minimum every three months or as recommended by manufacturer) to keep the surface from clogging. Maintenance frequency needs may be more or less depending on the traffic volume at the site. The site should be inspected regularly to ensure that the paving surface drains properly after storms. Inspect the surface annually for deterioration or spalling. If surface needs to be repaired, ensure that it is not repaved or resealed with impermeable materials.

Maintenance activities include the following: minimize use of sand and salt in winter months, keep adjacent landscape areas well maintained and stabilized (erosion gullying quickly corrected), post signs identifying permeable pavement, mow and reseed grass pavers as needed, and add joint material (e.g., sand) periodically to replace material that has been transported from paving stones/bricks. Attach rollers to the bottoms of snowplows to prevent them from catching on the edges of grass pavers and some paving stones.

E.1.4 Filters

Sand Filters

Sand filters should be inspected annually and after storm events greater than or equal to the 1-year, 24-hour Type III precipitation event. Open the access covers of the underground sand filters and make a visual inspection to determine the extents of maintenance necessary to rehabilitate the sand filter to its original design standards.

Proceed with the following if half of the entire sediment chamber depth is found to be full of sediment at the time of the inspection. All oil, sludge, sediment, solids, trash, debris and floatable material should be removed from all chambers of the sand filter. All stormwater within an underground sand filter should be pumped out of the facility by means of a vactor truck. All remaining oil and grit should be removed from the face of the exposed concrete within the perimeter sand filter, including but not limited to the wet storage chamber, sand filter chamber and overflow chamber.

Materials deposited on the surface of the sand filter (e.g., trash and litter) should be removed manually. Clean-out should be accomplished via catch vac or vactor truck. After cleaning, the cover and grate are to be reset and all resulting waste including oil, sludge, sediment, and water should be disposed of in accordance with all applicable federal and local regulations.

If standing water is observed more than 48 hours after a storm event, then the top 6 inches of sand should be removed and replaced with new materials. If discolored or contaminated material is found below this removed surface then that material should also be removed and replaced until all contaminated sand has been removed from the filter chamber. The sand should be disposed of in accordance with all applicable federal and local regulations.

All structural components, which include the outlet structure, valves, pipes, frame and grate, cover, underdrain system, and structural concrete, should be inspected and any deficiencies should be reported.

Bioretention

Inspections are an integral part of system maintenance. During the six months immediately after construction, bioretention facilities should be inspected at least twice or more following precipitation events of at least 1.0 inch to ensure that the system is functioning properly. Thereafter, inspections should be conducted on an annual basis and after storm events of greater than or equal the 1-year, 24-hour Type III precipitation event.

Minor soil erosion gullies should be repaired when they occur. Pruning or replacement of woody vegetation should occur when dead or dying vegetation is observed. Separation of herbaceous vegetation rootstock should occur when over-crowding is observed, or approximately once every 3 years. The mulch layer should also be replenished (to the original design depth) every other year, as directed by inspection reports. The previous mulch layer should be removed, and properly disposed of, or roto-tilled into the soil surface. If at least 50 percent vegetation coverage is not established after two years, a reinforcement planting should be performed. If the surface of the bioretention system becomes clogged to the point that standing water is observed on the surface 48 hours after precipitation events, the surface should be roto-tilled or cultivated to breakup any hard-packed sediment and then re-vegetated. Vegetation along the maintenance access roads should be mowed annually.

E.1.5 Open channels

The maintenance objective for this practice includes preserving the hydraulic and removal efficiency of the channel and maintaining a dense, healthy vegetative cover. The following activities are recommended on an annual basis or as needed:

- Mowing and litter and debris removal;
- Stabilization of eroded side slopes and bottom;
- Nutrient and pesticide use management;
- De-thatching swale bottom and removal of thatching; and
- Discing or aeration of swale bottom.

Every five years, scraping of the channel bottom and removal of sediment to restore original cross section and infiltration rate, and seeding to restore ground cover is recommended.

Dry swales should be inspected on an annual basis and after storms of greater than or equal to the 1-year, 24-hour Type III precipitation event. Both the structural and vegetative components should be inspected and repaired. When sediment accumulates to a depth of approximately 3 inches, it should be removed, and the swale should be reconfigured to its original dimensions. The vegetation in the dry swale should be mowed as required to maintain heights in the 4-6 inch range, with mandatory mowing once heights exceed 10 inches. If the surface of the dry swale becomes clogged to the point that standing water is observed on the surface 48 hours after precipitation events, the bottom should be roto-tilled or cultivated to break up any hard-packed sediment, and then reseeded. Trash and debris should be removed and properly disposed of.

Wet swales should be inspected annually and after storms of greater than or equal to the 1-year precipitation event. During inspection, the structural components of the system, including trash racks, valves, pipes and spillway structures, should be checked for proper function. Any clogged openings should be cleaned out and repairs should be made where necessary. Embankments should be checked for stability, and any burrowing animals should be removed according to State or local Animal Control requirements. Vegetation along the maintenance access roads should be mowed annually. Woody vegetation along those surfaces should be pruned where dead or dying branches are observed, and reinforcement plantings should be planted if less than 50 percent of the original vegetation establishes after two years. Sediment should be removed from the bottom of the swale.

E.2 Best Management Practices Operation, Maintenance, and Inspection Checklists

This section includes sample checklists that can be used during maintenance inspections to ensure that all aspects of a constructed BMP are inspected. These checklists should be modified for a specific BMP that may or may not need all of the maintenance items shown here.

Stormwater Basin/WVTS Operation,
Maintenance, and Management Inspection Checklist

Project

Location:

Site Status:

Date:

Time:

Inspector:

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
1. Embankment and emergency spillway (Annual, After Major Storms)		
1. Vegetation and ground cover adequate		
2. Embankment erosion		
3. Animal burrows		
4. Unauthorized planting		
5. Cracking, bulging, or sliding of dam		
a. Upstream face		
b. Downstream face		

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
c. At or beyond toe		
downstream		
upstream		
d. Emergency spillway		
6. Basin, toe & chimney drains clear and functioning		
7. Seeps/leaks on downstream face		
8. Slope protection or riprap failure		
9. Vertical/horizontal alignment of top of dam "As-Built"		
10. Emergency spillway clear of obstructions and debris		
2. Riser and principal spillway	(Annual, After Major Storms)	
Type: Reinforced concrete _______ Corrugated pipe _______ Masonry _______ 1. Low-flow orifice obstructed		
2. Low-flow trash rack. a. Debris removal necessary		
b. Corrosion control		
3. Weir trash rack maintenance a. Debris removal necessary		
b. corrosion control		
4. Excessive sediment accumulation inside riser		

Maintenance Item	**Satisfactory/ Unsatisfactory**	**Comments**
5. Concrete/masonry condition riser and barrels a. cracks or displacement		
b. Minor spalling (<1")		
c. Major spalling (rebars exposed)		
d. Joint failures		
e. Water tightness		
6. Metal pipe condition		
7. Control valve a. Operational/exercised		
b. Chained and locked		
8. Basin drain valve a. Operational/exercised		
b. Chained and locked		
9. Outfall channels functioning		
3. Permanent Pool (WVTS/Wet Basins)	(Semi-annually)	
1. Undesirable vegetative growth		
2. Floating or floatable debris removal required		
3. Visible pollution		
4. Shoreline problem		
5. Other (specify)		
4. Sediment Forebays	(Semi-annually)	

Maintenance Item	**Satisfactory/ Unsatisfactory**	**Comments**
1. Sedimentation noted		
2. Sediment cleanout when depth < 50% design depth		
5. Dry Basin Areas (Annual, After Major Storms)		
1. Vegetation adequate		
2. Undesirable vegetative growth		
3. Undesirable woody vegetation		
4. Low-flow channels clear of obstructions		
5. Standing water or wet spots		
6. Sediment and/or trash accumulation		
6. Condition of Outfalls (Annual , After Major Storms)		
1. Riprap failures		
2. Slope erosion		
3. Storm drain pipes		
4.Endwalls / Headwalls		
5. Other (specify)		
7. Other (Semi-annually)		
1. Encroachment on basin, WVTS or easement area		
2. Complaints from residents		

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
3. Aesthetics a. Grass growing required		
b. Graffiti removal needed		
c. Other (specify)		
4. Conditions of maintenance access routes		
5. Signs of hydrocarbon build-up		
6. Any public hazards (specify)		
8. Emergent Vegetation	(Annual)	
1. Vegetation healthy and growing WVTS maintaining 50% surface area coverage of emergent plants after the second growing season. (If unsatisfactory, reinforcement plantings needed)		
2. Dominant emergent plants: Survival of desired emergent plant species Distribution according to planting plan?		
3. Evidence of invasive species		
4. Maintenance of adequate water depths for desired emergent plant species		
5. Harvesting of emergent plantings needed		

Maintenance Item	**Satisfactory/ Unsatisfactory**	**Comments**
6. Have sediment accumulations reduced pool volume significantly or are plants "choked" with sediment		
7. Eutrophication level of the WVTS		

Comments:

Actions to be Taken:

Infiltration System Operation, Maintenance, and Management Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Annual)		
Trench/chamber or basin surface clear of debris		
Inflow pipes clear of debris		
Overflow spillway clear of debris		
Inlet area clear of debris		
2. Sediment Traps or Forebays (Annual)		
Obviously trapping sediment		
Greater than 50% of storage volume remaining		
3. Dewatering (Annual)		
Trench/chamber or basin dewaters between storms		
4. Sediment Cleanout of Trench/Chamber or Basin (Annual)		

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
No evidence of sedimentation in trench/chamber or basin		
Sediment accumulation doesn't yet require cleanout		
5. Inlets (Annual)		
Good condition		
No evidence of erosion		
6. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repair		
No evidence of erosion		
7. Aggregate Repairs (Annual)		
Surface of aggregate clean		
Top layer of stone does not need replacement		
Trench/Chamber or basin does not need rehabilitation		

Comments:

Actions to be Taken:

Permeable Pavement Operation, Maintenance, and Management Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Sediment and Debris Cleanout (3 Months or Manufacturer's Recommendation)		
Contributing area free of sediment and debris		
Contributing area stabilized and mown, with grass clippings removed		
Surface free of sediment and debris (e.g., mulch, leaves, trash, etc.)		
No signs of clogging (e.g., standing water)		
Surface does not require vacuuming		
2. Dewatering (Monthly)		
Permeable pavement dewaters between storms		
3. Underdrain Outfall, if present (Annual)		
No evidence of erosion		

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Surface Repairs (Annual)		
Surface has not been sealed		
No evidence of surface deterioration or spalling		
Surface (top and base course) does not need to be replaced		

Comments:

Actions to be Taken:

Sand/Organic Filter Operation, Maintenance, and Management Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Annual, After Major Storms)		
Contributing areas clean of debris		
Filtration facility clean of debris		
Inlet and outlets clear of debris		
2. Oil and Grease (Annual, After Major Storms)		
No evidence of filter surface clogging		
Activities in drainage area minimize oil and grease entry		
3. Vegetation (Semi-annually)		
Contributing drainage area stabilized		
No evidence of erosion		
Area mowed and clipping removed		

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
4. Water Retention Where Required (Annual, After Major Storms)		
Water holding chambers at normal pool		
No evidence of leakage		
5. Sediment Deposition (Annual. After Major Storms)		
Filter chamber free of sediments		
Sedimentation chamber not more than half full of sediments		
6. Structural Components (Annual, After Major Storms)		
No evidence of structural deterioration		
Any grates are in good condition		
No evidence of spalling or cracking of structural parts		
7. Outlet/Overflow Spillway (Annual, After Major Storms)		
Good condition, no need for repairs		
No evidence of erosion (if draining into natural channel)		
8. Overall Function of Facility (Annual, After Major Storms)		
Evidence of flow bypassing facility		
No noticeable odors		

Comments:

Actions to be Taken:

Bioretention Operation, Maintenance, and Management Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Annual, After Major Storms)		
Bioretention and contributing areas clean of debris		
No dumping of yard wastes into practice		
Litter (branches, etc.) have been removed		
2. Vegetation (Annual, After Major Storms)		
Plant height not less than design water depth		
Fertilized per specifications		
Plant composition according to approved plans		
No placement of inappropriate plants		
Grass height not greater than 10 inches		

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
No evidence of erosion		
3. Check Dams/Energy Dissipaters/Sumps (Annual, After Major Storms)		
No evidence of sediment buildup		
Sumps should not be more than 50% full of sediment		
No evidence of erosion at downstream toe of drop structure		
4. Dewatering (Semi-annually)		
Dewaters between storms		
No evidence of standing water		
5. Sediment Deposition (Annual, after Major Storms)		
Swale clean of sediments		
Sediments should not be > 20% of swale design depth		
6. Outlet/Overflow Spillway (Annual, After Major Storms)		
Good condition, no need for repair		
No evidence of erosion		
No evidence of any blockages		
7. Integrity of Filter Bed (Annual, After Major Storms)		
Filter bed has not been blocked or filled inappropriately		

Comments:

Actions to be Taken:

Open Channel Operation, Maintenance, and Management Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

MAINTENANCE ITEM	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Annual, After Major Storms)		
Contributing areas clean of debris		
2. Check Dams or Energy Dissipators (Annual, After Major Storms)		
No evidence of flow going around structures		
No evidence of erosion at downstream toe		
Soil permeability		
Groundwater / bedrock		
3. Vegetation (Annual, After Major Storms)		
Mowing done when needed		
Minimum mowing depth not exceeded		
No evidence of erosion		
Fertilized per specification		

MAINTENANCE ITEM	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Dewatering (Annual, After Major Storms)		
Dewaters between storms		
5. Sediment deposition (Annual, After Major Storms)		
Clean of sediment		
6. Outlet/Overflow Spillway (Annual, After Major Storms)		
Good condition, no need for repairs		
No evidence of erosion		

Comments:

Actions to be Taken:

E.2 Maintenance Agreements

A major contributor to unmaintained stormwater facilities is a lack of clear ownership and responsibility definition. In order for an inspection and maintenance program to be effective, the roles for each responsibility must be clearly defined prior to construction of a system. This can be accomplished with a maintenance agreement between the site owners and the responsible authority.

Some key aspects of these maintenance agreements are the clear delineation of responsibilities, such as:

- Identification of who will perform inspection duties and how often.
- Listed duties that are to be performed by the owner, such as mowing, debris removal, and replanting of vegetation.
- Defined roles for the responsible authority, such as inspection, and/or modifications to the system such as resizing an orifice.
- Determination of a course of action to be taken if the owner does not fulfill their obligations (i.e. repayment to the responsible authority for activities that the owner did not perform).
- Development of a pollution prevention plan by the owner.
- Requirement of a report, possibly annually, that would serve to keep the owner involved and aware of their responsibilities.

A sample maintenance agreement is included below.

Sample Stormwater Facility Maintenance Agreement

THIS AGREEMENT, made and entered into this ___ day of _________, 20___, by and between (Insert Full Name of Owner) ____ hereinafter called the "Landowner", and the [Local Jurisdiction], hereinafter called the "[Town/City]". WITNESSETH, that WHEREAS, the Landowner is the owner of certain real property described as (Tax Map/Parcel Identification Number) ___________________________ as recorded by deed in the land records of [Local Jurisdiction] Deed Book __________ Page __________, hereinafter called the "Property".

WHEREAS, the Landowner is proceeding to build on and develop the property; and WHEREAS, the Site Plan/Subdivision Plan known as _________________________________, (Name of Plan/Development) hereinafter called the "Plan", which is expressly made a part hereof, as approved or to be approved by the [Town/City], provides for detention of stormwater within the confines of the property; and

WHEREAS, the [Town/City] and the Landowner, its successors and assigns, including any homeowners association, agree that the health, safety, and welfare of the residents of [Local Jurisdiction] require that on-site stormwater management facilities be constructed and maintained on the Property; and

WHEREAS, the [Town/City] requires that on-site stormwater management facilities as shown on the Plan be constructed and adequately maintained by the Landowner, its successors and assigns, including any homeowners association.

NOW, THEREFORE, in consideration of the foregoing premises, the mutual covenants contained herein, and the following terms and conditions, the parties hereto agree as follows:

1. The on-site stormwater management facilities shall be constructed by the Landowner, its successors and assigns, in accordance with the plans and specifications identified in the Plan.
2. The Landowner, its successors and assigns, including any homeowners association, shall adequately maintain the stormwater management facilities in accordance with the required Operation and Maintenance Plan. This includes all pipes, channels or other conveyances built to convey stormwater to the facility, as well as all structures, improvements, and vegetation provided to control the quantity and quality of the stormwater. Adequate maintenance is herein defined as good working condition so that these facilities are performing their design functions. The Stormwater Best Management Practices Operation, Maintenance and Management Checklists are to be used to establish what good working condition is acceptable to the [Town/City].

3. The Landowner, its successors and assigns, shall inspect the stormwater management facility and submit an inspection report annually. The purpose of the inspection is to assure safe and proper functioning of the facilities. The inspection shall cover the entire facilities, berms, outlet structure, basin areas, access roads, etc. Deficiencies shall be noted in the inspection report.
4. The Landowner, its successors and assigns, hereby grant permission to the [Town/City], its authorized agents and employees, to enter upon the Property and to inspect the stormwater management facilities whenever the [Town/City] deems necessary. The purpose of inspection is to follow-up on reported deficiencies and/or to respond to citizen complaints. The [Town/City] shall provide the Landowner, its successors and assigns, copies of the inspection findings and a directive to commence with the repairs if necessary.
5. In the event the Landowner, its successors and assigns, fails to maintain the stormwater management facilities in good working condition acceptable to the [Town/City], the [Town/City] may enter upon the Property and take <u>whatever steps necessary</u> to correct deficiencies identified in the inspection report and to charge the costs of such repairs to the Landowner, its successors and assigns. This provision shall not be construed to allow the [Town/City] to erect any structure of permanent nature on the land of the Landowner outside of the easement for the stormwater management facilities. It is expressly understood and agreed that the [Town/City] is under no obligation to routinely maintain or repair said facilities, and in no event shall this Agreement be construed to impose any such obligation on the [Town/City].
6. The Landowner, its successors and assigns, will perform the work necessary to keep these facilities in good working order as appropriate. In the event a maintenance schedule for the stormwater management facilities (including sediment removal) is outlined on the approved plans, the schedule will be followed.
7. In the event the [Town/City] pursuant to this Agreement, performs work of any nature, or expends any funds in performance of said work for labor, use of equipment, supplies, materials, and the like, the Landowner, its successors and assigns, shall reimburse the [Town/City] upon demand, within thirty (30) days of receipt thereof for all actual costs incurred by the [Town/City] hereunder.
8. This Agreement imposes no liability of any kind whatsoever on the [Town/City] and the Landowner agrees to hold the [Town/City] harmless from any liability in the event the stormwater management facilities fail to operate properly.
9. This Agreement shall be recorded among the land records of [Local Jurisdiction] and shall constitute a covenant running with the land, and shall be binding on the Landowner, its administrators, executors, assigns, heirs and any other successors in interests, including any homeowners association.

WITNESS the following signatures and seals:

____

Company/Corporation/Partnership Name (Seal)

By: ____

____
(Type Name and Title)

The foregoing Agreement was acknowledged before me this ____ day of
____________, 20___, by
____
___.

____
NOTARY PUBLIC
My Commission Expires: ____________

By: ____
____
(Type Name and Title)

The foregoing Agreement was acknowledged before me this ____ day of
____________, 20___, by
____
___.

____
NOTARY PUBLIC
My Commission Expires: ____________

Approved as to Form:
___________________________ __________
[Town/City] Attorney Date

APPENDIX F: GUIDANCE ON BMP CONSTRUCTION SPECIFICATIONS

The following sections provide guidance on the standards and specifications for the design and construction of the stormwater treatment practices described in Chapters Five and Seven. In addition, a sample construction checklist is provided with each specification. These checklists should be modified for a specific BMP that may or may not need all of the items listed. The information provided in this appendix does not relieve an engineer's responsibility for the safety and function of the BMPs constructed at a site. This specification is intended solely for use by professional personnel who are competent to evaluate the significance and limitations of the information provided and who will accept responsibility for the application of this information. The authors, DEM, and CRMC disclaim any and all responsibility and liability for the accuracy and the application of the information contained in this appendix. While this appendix serves as guidance, it is expected that these specifications will be used when reference is made to the technical specifications related to BMP performance, or if no other specifications are provided by an applicant. If an applicant does not use the specifications herein, an explanation must be provided.

F.1 Construction Standards/Specifications for Shallow WVTSs and Stormwater Basins

These specifications are generally appropriate to earthen basins. Practitioners proposing to construct an impoundment having a dam 6 feet in height or more, or a capacity of 15 ac-ft or more, should consult the State of Rhode Island DEM Office of Compliance and Inspection Dam Safety regulations for the latest version of dam construction specifications.

All references to ASTM and AASHTO specifications apply to the most recent version.

F.1.1 Site Preparation

Site preparation should be in accordance with RIDOT specification section 201 - Site Preparation and the following provisions, as applicable.

Areas designated for borrow areas, embankment, and structural works shall be cleared, grubbed and stripped of topsoil. All trees, vegetation, roots and other objectionable material shall be removed. Channel banks and sharp breaks shall be sloped to no steeper than 1:1. All trees shall be cleared and grubbed within 15 feet of the toe of the embankment, and within 25 feet of the principal spillway outlet.

Areas to be covered by the impoundment will be cleared of all trees, brush, logs, fences, rubbish and other objectionable material unless otherwise designated on the plans. Trees, brush, and stumps shall be cut approximately level with the ground surface.

All cleared and grubbed material shall be disposed of outside and below the limits of the dam and reservoir as directed by the owner or his representative. When specified, a sufficient quantity of topsoil will be stockpiled in a suitable location for use on the embankment and other designated areas.

F.1.2 Earth Fill

Earth fill should be in accordance with RIDOT specification no. 202 – Earthwork and Erosion Control and the following provisions, as applicable.

Material - The fill material shall be taken from approved designated borrow areas. It shall be free of roots, stumps, wood, rubbish, stones greater than 6 inches, frozen or other objectionable materials. Fill material for the center of the embankment, and cut off trench shall conform to Unified Soil Classification GC, SC, CH, or CL and must have at least 30% passing the #200 sieve. Consideration may be given to the use of other materials in the embankment if designed by a geotechnical engineer. Such special designs must have construction supervised by a geotechnical engineer. Materials used in the outer shell of the embankment must have the capability to support vegetation of the quality required to prevent erosion of the embankment.

Placement - Areas on which fill is to be placed shall be scarified prior to placement of fill. Fill materials shall be placed in maximum 8-inch thick (before compaction) layers which are to be continuous over the entire length of the fill. The most permeable borrow material shall be placed in the downstream portions of the embankment. The principal spillway must be installed concurrently with fill placement and not excavated into the embankment.

Compaction - The movement of the hauling and spreading equipment over the fill shall be controlled so that the entire surface of each lift shall be traversed by not less than one tread track of heavy equipment or compaction shall be achieved by a minimum of four complete passes of a sheepsfoot, rubber tired or vibratory roller. Fill material shall contain sufficient moisture such that the required degree of compaction will be obtained with the equipment used. The fill material shall contain sufficient moisture so that if formed into a ball it will not crumble, yet not be so wet that water can be squeezed out.

When required by the approving agency the minimum required density shall not be less than 95% of maximum dry density with a moisture content within 2% of the optimum. Each layer of fill shall be compacted as necessary to obtain that density, and is to be certified by the Engineer at the time of construction. All compaction is to be determined by AASHTO Method T-99 (Standard Proctor).

Cut-off Trench - The cut-off trench shall be excavated into low hydraulic conductivity material to the depth specified along or parallel to the centerline of the embankment as shown on the plans. The bottom width of the trench shall be governed by the equipment used for excavation, with the minimum width being four feet. The depth shall be at least four feet below existing grade or as shown on the plans. The side slopes of the trench shall be 1:1 or flatter. The backfill shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability.

Embankment Core - The core shall be parallel to the centerline of the embankment as shown on the plans. The top width of the core shall be a minimum of four feet. The height shall extend up to at least the 100-year water elevation or as shown on the plans. The side slopes shall be 1:1 or flatter. The core shall be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability. In addition, the core shall be placed concurrently with the outer shell of the embankment.

F.1.3 Structure Backfill

Backfilling should be performed in accordance with RIDOT specification No. 203.03.5 - Backfilling and the following provisions, as applicable.

Backfill adjacent to pipes or structures shall be of the type and quality conforming to that specified for the adjoining fill material. The fill shall be placed in horizontal layers not to exceed four inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material needs to fill completely all spaces under and adjacent to the pipe. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet, measured horizontally, to any part of a structure. Under no circumstances shall equipment be driven over any part of a concrete structure or pipe, unless there is a compacted fill of 24 inches or greater over the structure or pipe.

Structure backfill may be flowable fill meeting the requirements of the Federal Highway Administration standards. The mixture shall have a 100-200 psi; 28-day unconfined compressive strength. The flowable fill shall have a minimum pH of 4.0 and a minimum resistivity of 2,000 ohm-cm. Material shall be placed such that a minimum of 6 inches (measured perpendicular to the outside of the pipe) of flowable fill shall be under (bedding), over and, on the sides of the pipe. It only needs to extend up to the spring line for rigid conduits. Average slump of the fill shall be 7 inches to assure flowability of the material. Adequate measures shall be taken (sand bags, etc.) to prevent floating the pipe. When using flowable fill, all metal pipe shall be bituminous coated. Any adjoining soil fill shall be placed in horizontal layers not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material shall completely fill all voids adjacent to the flowable fill zone. At no time during the backfilling operation shall driven equipment be allowed to operate closer than four feet, measured horizontally, to any part of a structure. Under no circumstances shall equipment be driven over any part of a structure or pipe unless there is a compacted fill of 24 inches or greater over the structure or pipe. Backfill material outside the structural backfill (flowable fill) zone shall be of the type and quality conforming to that specified for the core of the embankment or other embankment materials.

F.1.4 Pipe Conduits

All pipes shall be circular in cross section.

F.1.4.1 Corrugated Metal Pipe

Corrugated metal pipe should be in accordance with RIDOT specification section M.04.02 - Drainage and the following provisions, as applicable.

All of the following criteria shall apply for corrugated metal pipe:

- Materials - (Polymer-coated steel pipe) - Steel pipes with polymeric coatings shall have a minimum coating thickness of 0.01 inch (10 mil) on both sides of the pipe. This pipe and its appurtenances shall conform to the requirements of AASHTO Specifications M-245 & M-246 with watertight coupling bands or flanges.
- Materials - (Aluminum-coated Steel Pipe) - This pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-274 with watertight coupling bands or flanges. Aluminum Coated Steel Pipe, when used with flowable fill or when soil and/or water conditions warrant the need for increased durability, shall be fully bituminous coated per requirements of AASHTO Specification M-190 Type A. Any aluminum coating damaged or otherwise removed shall be replaced with cold applied bituminous coating compound. Aluminum surfaces that are to be in contact with concrete shall be painted with one coat of zinc chromate primer or two coats of asphalt.
- Materials - (Aluminum Pipe) - This pipe and its appurtenances shall conform to the requirements of AASHTO Specification M-196 or M-211 with watertight coupling bands or flanges. Aluminum Pipe, when used with flowable fill or when soil and/or water conditions warrant for increased durability, shall be fully bituminous coated per requirements of AASHTO Specification M-190 Type A. Aluminum surfaces that are to be in contact with concrete shall be painted with one coat of zinc chromate primer or two coats of asphalt. Hot dip galvanized bolts may be used for connections. The pH of the surrounding soils shall be between 4 and 9.
- Coupling bands, anti-seep collars, end sections, etc., must be composed of the same material and coatings as the pipe. Metals must be insulated from dissimilar materials with use of rubber or plastic insulating materials at least 24 mils in thickness.
- Connections - All connections with pipes must be completely watertight. The drain pipe or barrel connection to the riser shall be welded all around when the pipe and riser are metal. Anti-seep collars shall be connected to the pipe in such a manner as to be completely watertight. Dimple bands are not considered to be watertight.

  All connections shall use a rubber or neoprene gasket when joining pipe sections. The end of each pipe shall be re-rolled an adequate number of corrugations to accommodate the bandwidth. The following type connections are acceptable for pipes less than 24 inches in diameter: flanges on both ends of the pipe with a circular 3/8 inch closed cell neoprene gasket, pre-punched to the flange bolt circle, sandwiched between adjacent flanges; a 12-inch wide standard lap type band with 12-inch wide by 3/8-inch thick closed cell circular neoprene gasket; and a 12-inch wide hugger type band with o-ring gaskets having a minimum diameter of 1/2 inch greater than the corrugation depth. Pipes 24 inches in diameter and larger shall be connected by a 24-inch long annular corrugated band using a minimum of 4 (four) rods and lugs, 2 on each connecting pipe end. A 24-inch wide by 3/8-inch thick closed cell circular neoprene gasket will be installed with 12 inches on the end of each pipe. Flanged joints with 3/8-inch closed cell gaskets the full width of the flange is also acceptable.

Helically corrugated pipe shall have either continuously welded seams or have lock seams with internal caulking or a neoprene bead.

- Bedding - The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.
- Backfilling shall conform to "Structure Backfill."
- Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

F.1.4.2 Reinforced Concrete Pipe

Reinforced concrete pipe should be in accordance with RIDOT specification section M.04.01 - Drainage and the following provisions, as applicable.

All of the following criteria shall apply for reinforced concrete pipe:

- Materials - Reinforced concrete pipe shall have bell and spigot joints with rubber gaskets and shall equal or exceed ASTM C-361.
- Bedding - Reinforced concrete pipe conduits shall be laid in a concrete bedding / cradle for their entire length. This bedding / cradle shall consist of high slump concrete placed under the pipe and up the sides of the pipe at least 50% of its outside diameter with a minimum thickness of 6 inches. Where a concrete cradle is not needed for structural reasons, flowable fill may be used as described in the "Structure Backfill" section of this standard. Gravel bedding is not permitted.
- Laying pipe - Bell and spigot pipe shall be placed with the bell end upstream. Joints shall be made in accordance with recommendations of the manufacturer of the material. After the joints are sealed for the entire line, the bedding shall be placed so that all spaces under the pipe are filled. Care shall be exercised to prevent any deviation from the original line and grade of the pipe. The first joint must be located within 4 feet from the riser.
- Backfilling shall conform to "Structure Backfill".
- Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

F.1.4.3 Plastic Pipe

Plastic pipe should be in accordance with RIDOT specification No. 701.02.1 - Non-Metallic Pipe and the following provisions, as applicable.

The following criteria shall apply for plastic pipe:
- Materials - PVC pipe shall be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241. Corrugated High Density Polyethylene (HDPE) pipe, couplings and fittings shall conform to the following: 4 – 10 inch pipe shall meet the requirements of AASHTO M252 Type S, and 12 inch through 24 inch shall meet the requirements of AASHTO M294 Type S.
- Joints and connections to anti-seep collars shall be completely watertight.
- Bedding -The pipe shall be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material shall be removed and replaced with suitable earth compacted to provide adequate support.
- Backfilling shall conform to "Structure Backfill."
- Other details (anti-seep collars, valves, etc.) shall be as shown on the drawings.

Drainage Diaphragms

When a drainage diaphragm is used, a RI-licensed PE or qualified designee will supervise the design and construction inspection.

Concrete

Concrete should meet the requirements of the RIDOT specification section 600 - Concrete.

Rock Riprap

Rock riprap should be in accordance with RIDOT specification section 920 - Riprap and the following provisions, as applicable.

Filter fabric placed beneath the riprap shall meet federal department of transportation requirements for a Class "C" filter fabric. Some acceptable filter fabrics that meet the Class "C" criteria include:
- Mirafi 180-N
- Amoco 4552
- Webtec N07
- Geolon N70
- Carthage FX-70S

This is only a partial listing of available filter fabrics. It is the responsibility of the engineer to verify the adequacy of the material, as there are changes in the manufacturing process and the type of fabric used, which may affect the continued acceptance.

Care of Water during Construction

All work on permanent structures shall be carried out in areas free from water. The Contractor shall construct and maintain all temporary dikes, levees, cofferdams, drainage channels, and stream diversions necessary to protect the areas to be occupied by the permanent works. The contractor shall also furnish, install, operate, and maintain all necessary pumping and other equipment required for removal of water from various parts of the work and for maintaining the excavations, foundation, and other parts of the work free from water as required or directed by the engineer for constructing each part of the work. After having served their purpose, all temporary protective works shall be removed or leveled and graded to the extent required to prevent obstruction in any degree whatsoever of the flow of water to the spillway or outlet works and so as not to interfere in any way with the operation or maintenance of the structure. Stream diversions shall be maintained until the full flow can be passed through the permanent works. The removal of water from the required excavation and the foundation shall be accomplished in a manner and to the extent that will maintain stability of the excavated slopes and bottom required excavations and will allow satisfactory performance of all construction operations. During the placing and compacting of material in required excavations, the water level at the locations being refilled shall be maintained below the bottom of the excavation at such locations which may require draining the water sumps from which the water shall be pumped.

F.1.5 Stabilization

All borrow areas shall be graded to provide proper drainage and left in a sightly condition. All exposed surfaces of the embankment, spillway, spoil and borrow areas, and berms shall be stabilized by seeding, liming, fertilizing and mulching in accordance with local Natural Resources Conservation Service Standards and Specifications.

F.1.6 Erosion and Sediment Control

Erosion and sediment control should be in accordance with RIDOT specification section 200 - Earthwork and Erosion Control and the following provisions, as applicable.

Construction operations will be carried out in such a manner that erosion will be controlled, and water and air pollution minimized. State laws concerning pollution abatement will be followed. Construction plans shall detail erosion and sediment control measures.

F.1.7 Operation and Maintenance

An operation and maintenance plan in accordance with the State of Rhode Island Dam Safety Rules and Regulations will be prepared for all WVTS facilities and basins with embankments that meet the dam criteria. As a minimum, a dam inspection checklist shall be included as part of the operation and maintenance plan and performed at least annually.

Supplemental Stormwater Basin and Shallow WVTS Specifications

1. It is preferred to use the same material in the embankment as is being installed for the core trench. If this is not possible because the appropriate material is not available, a dam core with a shell may be used. The cross-section of the stormwater facility should show the limits of the dam core (up to the 100-year water surface elevation) as well as the acceptable materials for the shell. The shape of the dam core and the material to be used in the shell should be provided by the design engineer.

2. If the compaction tests for the remainder of the site improvements are using Modified Proctor (AASHTO T-180), then to maintain consistency on-site, modified proctor may be used in lieu of standard proctor (AASHTO T-99). The minimum required density using the modified proctor test method shall be at least 92% of maximum dry density with a moisture content of ±2% of the optimum.

3. For all WVTS facilities and basins with dam embankments, a RI-licensed PE (civil) or qualified designee must be present to verify compaction in accordance with the selected test method. This information needs to be provided in a report to the design engineer, so that certification of the construction of the facility can be made.

4. A 4-inch layer of topsoil shall be placed on all disturbed areas of the dam embankment. Seeding, liming, fertilizing, mulching, etc. shall be in accordance with NRCS Soil Standards and Specifications and with RIDOT specification section L.01 - Topsoiling and Seeding. The purpose of the topsoil is to establish a good growth of grass which is not always possible with some of the materials that may be placed for the embankment fill.

5. Fill placement shall not exceed a maximum of 8 inches. Each lift shall be continuous for the entire length of the embankment.

Table F-1 Stormwater Basin/Shallow WVTS Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction/Materials and Equipment		
Pre-construction meeting		
Pipe and appurtenances on-site prior to construction and dimensions checked		
1. Material (including protective coating, if specified)		
2. Diameter		
3. Dimensions of metal riser or pre-cast concrete outlet structure		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope		
6. Number and dimensions of prefabricated anti-seep collars		

CONSTRUCTION SEQUENCE	**SATISFACTORY/ UNSATISFACTORY**	**COMMENTS**
7. Watertight connectors and gaskets		
8. Outlet drain valve		
Project benchmark near basin site		
Equipment for temporary de-watering		
2. Subgrade Preparation		
Area beneath embankment stripped of all vegetation, topsoil, and organic matter		
3. Pipe Installation		
Method of installation detailed on plans		
A. Bed preparation		
Basin/WVTS excavated with specified side slopes		
Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have defined steps before proceeding with installation)		
Invert at proper elevation and grade		
B. Pipe placement		
Metal/plastic pipe		
1. Watertight connectors and gaskets properly installed		
2. Anti-seep collars properly spaced and having watertight connections to pipe		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
3. Backfill placed and tamped by hand under "haunches" of pipe		
4. Remaining backfill placed in max. 8 inch lifts using small power tamping equipment until 2 ft cover over pipe is reached		
Concrete pipe		
1. Pipe set on blocks or concrete slab for pouring of low cradle		
2. Pipe installed with rubber gasket joints with no spalling in gasket interface area		
3. Excavation for lower half of anti-seep collar(s) with reinforcing steel set		
4. Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other approved waterproof sealant		
5. Low cradle and bottom half of anti-seep collar installed as monolithic pour and of an approved mix		
6. Upper half of anti-seep collar(s) formed with reinforcing steel set		
7. Concrete for collar of an approved mix and vibrated into place		
8. Forms stripped and collar inspected for honeycomb prior to backfilling. Parge if necessary.		
C. Backfilling		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Fill placed in maximum 8-in lifts		
Backfill taken minimum 2 ft above top of anti-seep collar elevation before traversing with heavy equipment		
4. Riser / Outlet Structure Installation		
Riser located within embankment		
A. Metal riser		
Riser base excavated or formed on stable subgrade to design dimensions		
Set on blocks to design elevations and plumbed		
Reinforcing bars placed at right angles and projecting into sides of riser		
Concrete poured so as to fill inside of riser to invert of barrel		
B. Pre-cast concrete structure		
Dry and stable subgrade		
Riser base set to design elevation		
If more than one section, no spalling in gasket interface area; gasket or approved caulking material placed securely		
Watertight and structurally sound collar or gasket joint where structure connects to pipe spillway		
C. Poured concrete structure		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set		
Structure formed to design dimensions, with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place		
Forms stripped & inspected for "honeycomb" prior to backfilling; parge if necessary		
5. Embankment Construction		
Fill material		
Compaction		
Embankment		
1. Fill placed in specified lifts and compacted with appropriate equipment		
2. Constructed to design cross-section, side slopes and top width		
3. Constructed to design elevation plus allowance for settlement		
6. Impounded Area Construction		
Excavated / graded to design contours and side slopes		
Inlet pipes have adequate outfall protection		
Forebay(s)		
Basin benches		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
7. Earth Emergency Spillway Construction		
Spillway located in cut or structurally stabilized with riprap, gabions, concrete, etc.		
Excavated to proper cross-section, side slopes and bottom width		
Entrance channel, crest, and exit channel constructed to design grades and elevations		
8. Outlet Protection		
A. End section		
Securely in place and properly backfilled		
B. Endwall		
Footing excavated or formed on stable subgrade, to design dimensions and reinforcing steel set, if specified		
Endwall formed to design dimensions with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place		
Forms stripped and structure inspected for “honeycomb” prior to backfilling; parge if necessary		
C. Riprap apron / channel		
Apron / channel excavated to design cross-section with proper transition to existing ground		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Filter fabric in place		
Stone sized as per plan and uniformly place at the thickness specified		
9. Vegetative Stabilization		
Approved seed mixture		
Proper surface preparation and required soil amendments		
Excelsior mat or other stabilization, as per plan		
10. Miscellaneous		
Drain for basins having a permanent pool		
Trash rack / anti-vortex device secured to outlet structure		
Trash protection for low flow pipes, orifices, etc.		
Fencing (when required)		
Access road		
Set aside for clean-out maintenance		
11. Shallow WVTSs		
Adequate water balance		
Variety of depth zones present		
Approved pondscaping plan in place and budget for additional plantings		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Plants and materials ordered 6 months prior to construction		
Construction planned to allow for adequate planting and establishment of plant community		
Shallow WVTS setback area preserved to maximum extent possible		

Comments:

Actions to be Taken:

F.2 Construction Standards/Specifications for Gravel WVTS

The specifications listed here were adapted from UNHSC (2009).

F.2.1 SPECIFICATIONS SUMMARY

- No-geotextile or geofabric layers are used within this system, but may be used to line walls;
- If a native low hydraulic conductivity soil is not present below the desired location of the gravel WVTS, a low permeability liner or soil (hydraulic conductivity less than 10^{-5} cm/s = 0.03 ft/day) below the gravel layer should be used to minimize infiltration, preserve horizontal flow in the gravel, and maintain the emergent plants;
- 8 in. thickness of an organic soil as optional top layer. This layer is leveled (constructed with a surface slope of zero);
- 3 in. minimum thickness of an intermediate layer of a graded aggregate filter is needed to prevent the organic soil from moving down into the gravel sublayer;
- 24 in. minimum thickness of ¾-inch gravel sublayer.
- Where applicable, the primary outlet invert shall be located 4 inches below the elevation of the organic soil surface to control water elevation. Care should be taken to not design a siphon that would drain the WVTS: the primary outlet invert location must be open or vented;
- The minimum spacing between the subsurface perforated distribution line and the subsurface perforated collection drain (see Figure 5-3) at either end of the gravel in each treatment cell should be 15 ft: there should be a minimum horizontal travel distance of 15 ft within the gravel layer in each cell;
- Vertical perforated or slotted riser pipes deliver water from the surface down to the subsurface, perforated or slotted distribution lines. These risers should have a maximum spacing of 15 feet (Figure 5-3) (between each other). Oversizing of the perforated vertical risers is useful to allow a margin of safety against clogging with a minimum recommended diameter of 12 in. for the central riser and 6 in. for end risers. The vertical risers shall not be capped, but rather covered with an inlet grate to allow for an overflow when the water level exceeds the WQ_v;
- Vertical cleanouts connected to the distribution and collection subdrains, at each end, shall be perforated or slotted only within the gravel layer, and solid within the organic soil and storage area above. This is important to prevent short-circuiting and soil piping; and
- Berms and weirs separating the forebay and treatment cells should be constructed with clay, or non-conductive soils, and/or a fine geotextile, or some combination thereof to avoid water seepage and soil piping through these earthen dividers.

F.2.2 SURFACE INFILTRATION RATES AND HYDROGEOLOGIC MATERIALS

F.2.2.1 Organic Soil (Optional)

The surface infiltration rates of the gravel WVTS soil should be similar to a low hydraulic conductivity organic soil (0.1-0.01 ft/day). This soil can be manufactured using compost, sand, and some fine soils to blend to a high % organic matter content soil (>15% organic matter). Avoid using clay contents in excess of 15% because of potential migration of fines into subsurface gravel layer. Do not use geotextiles between the horizontal layers of this system as they will clog due to fines and may restrict root growth.

An intermediate layer of a graded aggregate filter (i.e., pea gravel) is needed to prevent the organic soil from migrating down into the gravel sublayer. This is to prevent migration of the finer setting bed (organic soil) into the coarse sublayer. Material compatibility should be evaluated using FHWA criteria (see Ferguson, 2005):

Criteria 1: $D_{15,\ COARSE\ \ SUBLAYER} \leq 5\ D_{85,SETTING\ \ BED}$

Criteria 2: $D_{50,\ COARSE\ \ SUBLAYER} \leq 25\ D_{50,\ \ SETTING\ \ BED}$

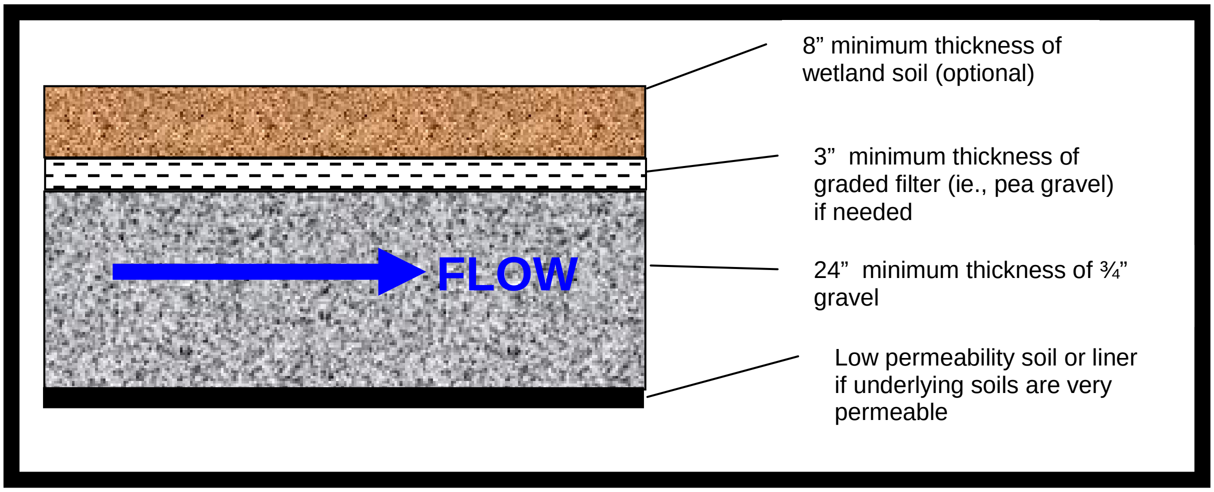
F.2.2.2 Gravel Layer

Below the organic soil and pea gravel is a gravel sublayer with a 24 in. minimum thickness. Angular gravel is needed with a minimum size ~3/4–in (2-cm). Large particle, angular coarse to very coarse gravel is needed to maintain system longevity.

F.2.2.3 Native Materials and Liner

If native a low hydraulic conductivity native soil is not present below the gravel layer, a low permeability liner or soil should be used to: minimize infiltration, preserve horizontal flow in the gravel, and maintain the emergent plants. If geotechnical tests confirm the need for a liner, acceptable options include: (a) 6 to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1 x 10^{-5} cm/sec), (b) a 30 ml HDPE liner, (c) bentonite, (d) use of chemical additives (see NRCS Agricultural Handbook No. 386, dated 1961, or Engineering Field Manual), or (e) a design prepared by a RI-licensed PE.

Figure F-1 Gravel WVTS Materials Cross-Section



F.2.3 Gravel WVTS Testing Specifications

Gravel WVTSs that are designed with concrete chambers are to be tested for watertightness prior to placement of gravel. The systems should be tested for watertightness using the US EPA test procedures as described below and included in the Onsite Wastewater Treatment Systems Manual (USEPA, 2002). Hydrostatic or vacuum tests, and manway risers and inspection ports should be included in the test. The professional association representing the materials industry of the type of tank construction (e.g., the National Pre-cast Concrete Association) should be contacted to establish the appropriate testing criteria and procedures. Test criteria for precast concrete are presented below in Table F-2.

Table F-2 Watertightness Testing Procedure/Criteria for Precast Concrete Tanks (USEPA, 2002)

Standard	Hydrostatic test		Vacuum test	
	Preparation	Pass/fail criterion	Preparation	Pass/fail criterion
C 1227, ASTM (1993)	Seal tank, fill with water, and let stand for 24 hours. Refill tank.	Approved if water level is held for 1 hour	Seal tank and apply a vacuum of 2 in. Hg.	Approved if 90% of vacuum is held for 2 minutes.
NPCA (1998)	Seal tank, fill with water, and let stand for 8 to 10 hours. Refill tank and let stand for another 8 to 10 hours.	Approved if no further measurable water level drop occurs	Seal tank and apply a vacuum of 4 in. Hg. Hold vacuum for 5 minutes. Bring vacuum back to 4 in. Hg.	Approved if vacuum can be held for 5 minutes without a loss of vacuum.

Table F-3 Gravel WVTS Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction/Materials and Equipment		
Pre-construction meeting		
Pipe and appurtenances on-site prior to construction and dimensions checked		
1. Material (including protective coating, if specified)		
2. Diameter		
3. Dimensions of outlet structure		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope		
6. Number and dimensions of prefabricated anti-seep collars		
7. Watertight connectors and gaskets		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
8. Outlet drain valve		
Project benchmark near site		
Equipment for temporary de-watering		
2. Subgrade Preparation		
Area beneath practice stripped of all vegetation, topsoil, and organic matter		
3. Pipe Installation		
Method of installation detailed on plans		
A. Bed preparation		
Installation trench excavated with specified side slopes		
Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have defined steps before proceeding with installation)		
Invert at proper elevation and grade		
B. Pipe placement		
Metal/plastic pipe		
1. Watertight connectors and gaskets properly installed		
2. Anti-seep collars properly spaced and having watertight connections to pipe		
3. Backfill placed and tamped by hand under “haunches” of pipe		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
4. Remaining backfill placed in max. 8 inch lifts using small power tamping equipment until 2 ft cover over pipe is reached		
Concrete pipe		
1. Pipe set on blocks or concrete slab for pouring of low cradle		
2. Pipe installed with rubber gasket joints with no spalling in gasket interface area		
3. Excavation for lower half of anti-seep collar(s) with reinforcing steel set		
4. Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other approved waterproof sealant		
5. Low cradle and bottom half of anti-seep collar installed as monolithic pour and of an approved mix		
6. Upper half of anti-seep collar(s) formed with reinforcing steel set		
7. Concrete for collar of an approved mix and vibrated into place		
8. Forms stripped and collar inspected for honeycomb prior to backfilling. Parge if necessary.		
C. Backfilling		
Fill placed in maximum 8-in lifts		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Backfill taken minimum 2 ft above top of anti-seep collar elevation before traversing with heavy equipment		
4. Outlet Structure Installation		
Outlet Structure located within embankment or at end of chamber		
A. Metal riser		
Riser base excavated or formed on stable subgrade to design dimensions		
Set on blocks to design elevations and plumbed		
Reinforcing bars placed at right angles and projecting into sides of riser		
Concrete poured so as to fill inside of riser to invert of barrel		
B. Pre-cast concrete structure		
Dry and stable subgrade		
Riser base set to design elevation		
If more than one section, no spalling in gasket interface area; gasket or approved caulking material placed securely		
Watertight and structurally sound collar or gasket joint where structure connects to pipe spillway		
C. Poured concrete structure		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set		
Structure formed to design dimensions, with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place		
Forms stripped & inspected for "honeycomb" prior to backfilling; parge if necessary		
5. Embankment Construction, if applicable		
Fill material		
Compaction		
Embankment		
1. Fill placed in specified lifts and compacted with appropriate equipment		
2. Constructed to design cross-section, side slopes and top width		
3. Constructed to design elevation plus allowance for settlement		
6. Impounded Area Construction		
Excavated / graded to design contours and side slopes, if applicable		
Inlet pipes have adequate outfall protection		
Forebay(s)		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Pour-in-place concrete chambers, if applicable		
7. Earth Emergency Spillway Construction, if applicable		
Spillway located in cut or structurally stabilized with riprap, gabions, concrete, etc.		
Excavated to proper cross-section, side slopes and bottom width		
Entrance channel, crest, and exit channel constructed to design grades and elev.		
8. Outlet Protection		
A. End section		
Securely in place and properly backfilled		
B. Endwall		
Footing excavated or formed on stable subgrade, to design dimensions and reinforcing steel set, if specified		
Endwall formed to design dimensions with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place		
Forms stripped and structure inspected for “honeycomb” prior to backfilling; parge if necessary		
C. Riprap apron / channel		

CONSTRUCTION SEQUENCE	**SATISFACTORY/ UNSATISFACTORY**	**COMMENTS**
Apron/channel excavated to design cross-section with proper transition to existing ground		
Filter fabric in place		
Stone sized as per plan and uniformly place at the thickness specified		
9. Vegetative Stabilization		
Approved seed mixture		
Proper surface preparation and required soil amendments, if applicable		
Excelsior mat or other stabilization, as per plan		
10. Miscellaneous		
Drain for permanent pool maintenance		
Trash rack/anti-vortex device secured to outlet structure		
Trash protection for low flow pipes, orifices, etc.		
Fencing (when required)		
Access road		
Set aside for clean-out maintenance		
11. Emergent Vegetation		
Approved pondscaping plan in place and budget for additional plantings		

CONSTRUCTION SEQUENCE	**SATISFACTORY/ UNSATISFACTORY**	**COMMENTS**
Plants and materials ordered 6 months prior to construction		
Construction planned to allow for adequate planting and establishment of plant community		

Comments:

Actions to be Taken:

F.3 Construction Standards/Specifications for Infiltration BMPs

F.3.1 Infiltration Trench/Chamber General Notes and Specifications

Infiltration trench or chamber systems may not receive run-off until the entire contributing drainage area to the infiltration system has received final stabilization.

1. Construction equipment and traffic shall be restricted from traveling over the infiltration trench or chamber areas to minimize compaction of the soil.

2. Excavate the infiltration trench/chamber to the design dimensions. Excavated materials shall be placed away from the trench/chamber sides to enhance trench wall stability. Large tree roots must be trimmed flush with the trench sides in order to prevent fabric puncturing or tearing of the filter fabric during subsequent installation procedures. The side walls of the trench/chamber shall be roughened where sheared and sealed by heavy equipment.

3. A Class “C” geotextile or better shall interface between the trench/chamber side walls and between the stone reservoir and gravel filter layers. A partial list of non-woven filter fabrics that meet the Class “C” criteria is contained below..

   Mirafi 180-N
   Amoco 4552
   WEBTEC N70
   GEOLON N70
   Carthage FX-80S

   The width of the geotextile must include sufficient material to conform to trench/chamber perimeter irregularities and for a 6-inch minimum top overlap. The filter fabric shall be tucked under the sand layer on the bottom of the infiltration trench/chamber for a distance of 6 to 12 inches. Stones or other anchoring objects should be placed on the fabric at the edge of the trench/chamber to keep the trench open during windy periods. When overlaps are required between rolls, the uphill roll should lap a minimum of 2 feet over the downhill roll in order to provide a shingled effect.

4. A 6-inch sand filter layer may be placed on the bottom of the infiltration trench/chamber in lieu of filter fabric, and shall be compacted using plate compactors. The sand for the infiltration trench shall be washed and meet AASHTO Std. M-43, Size No. 9 or No. 10.

5. The stone aggregate should be placed in lifts and compacted using plate compactors. A maximum loose lift thickness of 12 inches is recommended. The gravel (rounded “bank run” gravel is preferred) for the infiltration trench/chamber

shall be washed and meet one of the following AASHTO Std. M-43; Size No. 2 or No. 3.

6. Infiltration chambers should consist of high molecular weight high density polyethylene (HDPE) and meet AASHTO H10 and H20 standards. Chambers should have repeating endwalls for internal support. Infiltration chambers must be constructed in accordance with manufacturer's specifications.

7. Following the stone aggregate placement, the filter fabric shall be folded over the stone aggregate to form a 6-in minimum longitudinal lap. The desired fill soil or stone aggregate shall be placed over the lap at sufficient intervals to maintain the lap during subsequent backfilling.

8. Care shall be exercised to prevent natural or fill soils from intermixing with the stone aggregate. All contaminated stone aggregate shall be removed and replaced with uncontaminated stone aggregate.

9. Voids can be created between the fabric and the excavation sides and shall be avoided. Removing boulders or other obstacles from the trench walls is one source of such voids; therefore, natural soils should be placed in these voids at the most convenient time during construction to ensure fabric conformity to the excavation sides.

10. Vertically excavated walls may be difficult to maintain in areas where soil moisture is high or where soft cohesive or cohesionless soils are predominate. These conditions may require laying back of the side slopes to maintain stability.

11. PVC should be in accordance with RIDOT specification section M.04 Drainage and the following provisions, as applicable. PVC distribution pipes shall be Schedule 40 and meet ASTM Std. D 1784. All fittings and perforations (1/2 inch in diameter) shall meet ASTM Std. D 2729. A perforated pipe shall be provided only within the infiltration trench/chamber and shall terminate 1 ft short of the infiltration trench wall. The end of the PVC pipe shall be capped.

12. Corrugated metal pipes should be in accordance with RIDOT specification section M.04 Drainage and the following provisions, as applicable. The corrugated metal distribution pipes shall conform to AASHTO Std. M-36 and shall be aluminized in accordance with AASHTO Std. M-274. Coat aluminized pipe in contact with concrete with an inert compound capable of effecting isolation of the deleterious effect of the aluminum on the concrete. Perforated distribution pipe shall be provided only within the infiltration trench/chamber and shall terminate 1 ft short of the infiltration trench wall. An aluminized metal plate shall be welded to the end of the pipe.

13. Corrugated High Density Polyethylene (HDPE) pipe should be in accordance with RIDOT specification no. 701.02.1 – Non-Metallic Pipe and the following provisions,

as applicable. HDPE pipe, couplings and fittings shall conform to the following: 4-10-in pipe shall meet the requirements of AASHTO M252 Type S, and 12in through 24in shall meet the requirements of AASHTO M294 Type S. Perforated distribution pipe shall be provided only within the infiltration trench/chamber and shall terminate 1 ft short of the infiltration trench wall. The end of the pipe shall be capped.

14. The observation well is to consist of 4- to 6-inch diameter PVC Schedule 40 pipe (ASTM Std. D 1784) with a cap set 6 inches above ground level and is to be located near the longitudinal center of the infiltration trench or chamber. Preferably the observation well will not be located in vehicular traffic areas. The pipe shall have a plastic collar with ribs to prevent rotation when removing cap. The screw top lid shall be a “Panella” type cleanout or equivalent with a locking mechanism or special bolt to discourage vandalism.

15. Distribution structures should be in accordance with RIDOT specification section 700 – Drainage and Selected Utility Accessories and the following provisions, as applicable. If a distribution structure with a wet well is used, a 4-inch PVC drain pipe shall be provided at opposite ends of the infiltration trench/chamber distribution structure. Two (2) cubic feet of porous backfill meeting AASHTO Std. M-43 Size No. 57 shall be provided at each drain.

16. If a distribution structure is used, the manhole cover shall be bolted to the frame.

NOTE: PVC pipe with a wall thickness classification of SDR-35 meeting ASTM standard D3034 is an acceptable substitution for PVC Schedule 40 pipe.

Table F-4 Infiltration Trench/Chamber Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock sufficient at depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Filter Fabric Placement		
Fabric specifications		
Placed on bottom, sides, and top		

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
4. Aggregate Material		
Size as specified		
Clean / washed material		
Placed properly		
5. Observation Well		
Pipe size		
Removable cap / footplate		
Initial depth =______feet		
6. Final Inspection		
Pretreatment facility in place		
Contributing watershed stabilized prior to flow diversion		
Outlet		

Comments:

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Actions to be Taken:

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F.3.2 Infiltration Basins Notes and Specifications

1. The sequence of various phases of basin construction shall be coordinated with the overall project construction schedule. A program should schedule rough excavation of the basin with the rough grading phase of the project to permit use of the material as fill in earthwork areas. The partially excavated basin, however, cannot serve as a sedimentation basin.

   Specifications for basin construction should state: (1) the earliest point in progress when storm drainage may be directed to the basin, and (2) the means by which this delay in use is to be accomplished. Due to the wide variety of conditions encountered among projects, each should be separately evaluated in order to postpone use as long as is reasonably possible.

2. Initial basin excavation should be carried to within 1 foot of the final elevation of the basin floor. Final excavation to the finished grade should be deferred until all disturbed areas on the watershed have been stabilized or protected. The final phase excavation should remove all accumulated sediment. Relatively light-tracked equipment is recommended for this operation to avoid compaction of the basin floor. After the final grading is completed, the basin provides a well-aerated, highly porous surface texture.

3. Infiltration basins may be lined with a 6- to 12-inch layer of filter material such as coarse sand (AASHTO Std. M-43, Sizes 9 or 10) to help prevent the buildup of impervious deposits on the soil surface. The filter layer can be replaced or cleaned when it becomes clogged. When a 6-inch layer of coarse organic material is specified for discing (such as hulls, leaves, stems, etc.) or spading into the basin floor to increase the permeability of the soils, the basin floor should be soaked or inundated for a brief period, then allowed to dry subsequent to this operation. This induces the organic material to decay rapidly, loosening the upper soil layer.

4. Establishing dense vegetation on the basin side slopes and floor is recommended. A dense vegetative stand will not only prevent erosion and sloughing, but will also provide a natural means of maintaining relatively high infiltration rates. Erosion protection of inflow points to the basin shall also be provided.

5. Selection of suitable vegetative materials for the side slope and all other areas to be stabilized with vegetation and application of required lime, fertilizer, etc. shall be done in accordance with the RIDOT specification section L.01.

6. Grasses of the fescue family are recommended for seeding primarily due to their adaptability to dry sandy soils, drought resistance, hardiness, and ability to withstand brief inundations. The use of fescues will also permit long intervals between mowings. This is important due to the relatively steep slopes that make mowing difficult. Mowing 2 times a year, once in June and September, is generally satisfactory. Re-fertilization with 10-6-4 ratio fertilizer at a rate of 500 lb per acre (11 lb per 1000 sq ft) may be required the second year after seeding.

Table F-5 Infiltration Basin Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Runoff diverted		
Soil permeability tested		
Groundwater / bedrock depth		
2. Excavation		
Size and location		
Side slopes stable		
Excavation does not compact subsoils		
3. Embankment		
Barrel		
Anti-seep collar or Filter diaphragm		
Fill material		
4. Final Excavation		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Drainage area stabilized		
Sediment removed from facility		
Basin floor tilled		
Facility stabilized		
5. Final Inspection		
Pretreatment facility in place		
Inlets / outlets		
Contributing watershed stabilized before flow is routed to the facility		

Comments:

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Actions to be Taken:

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F.4 CONSTRUCTION STANDARDS/SPECIFICATIONS FOR ALTERNATIVE PAVING SURFACES

F.4.1 Porous Asphalt Notes and Specifications

The specifications listed herein were developed by the UNHSC (2009) for UNHSC-related projects and represent the author's best professional judgment. No assurances are given for projects other than the intended application. These design specifications are not a substitute for licensed, qualified engineering oversight and should be reviewed, and adapted as necessary.

PART 1 GENERAL

1.1 DESCRIPTION

A. This specification is intended to be used for porous asphalt pavement in parking lot applications. Stormwater management functions of porous asphalt installations include water quality treatment, peak flow reduction, storm volume reduction via groundwater recharge, and increased hydrograph time lag. This specification is intended for a cold climate application based upon the field experience at the UNHSC porous asphalt parking lot located in Durham, New Hampshire, however the specification can be adapted to projects elsewhere provided that selection of materials and system design reflects local conditions, constraints, and objectives.

B. The work of this Section includes subgrade preparation, installation of the underlying porous media beds, and porous asphalt mix (mix) design, production, and installation. Porous media beds refer to the material layers underlying the porous asphalt pavement. Porous asphalt pavement refers to the compacted mix of modified asphalt, aggregate, and additives.

C. The porous asphalt pavement specified herein is modified after the National Asphalt Pavement Association (NAPA) specification outlined in *Design, Construction, and Maintenance Guide for Porous Asphalt Pavements, Information Series 131* (2003) and *Design, Construction, and Maintenance of Open-Graded Friction Courses, Information Series 115* (2002).

D. Alternative specifications for mix, such as Open Graded Friction Courses (OGFC) from Federal Agencies or Rhode Island Department of Transportation (RIDOT), may be used if approved by the Engineer. The primary requirements for the specifications of the mix are performance grade (PG) asphalt binder, binder content, binder draindown, aggregate gradation, air void content, retained tensile strength (TSR).

1.2 SUBMITTALS

A. Submit a list of materials proposed for work under this Section including the name and address of the materials producers and the locations from which the materials are to be obtained.

B. Submit certificates, signed by the materials producers and the relevant subcontractors, stating that materials meet or exceed the specified requirements, for review and approval by the Engineer.

C. Submit samples of materials for review and approval by the Engineer. For mix materials, samples may be submitted only to the QA inspector with the Engineer's approval.

D. Submittal requirements for samples and certificates are summarized in 1.3 QC/QA.

1.3 QC/QA

A. Use adequate numbers of skilled workers who are thoroughly trained and experienced in the necessary crafts and who are completely familiar with the specified requirements and the methods needed for proper performance of the work in this section.

B. Codes and Standards - All materials, methods of construction and workmanship shall conform to applicable requirements of AASHTO ASTM Standards, RIDOT Standard Specifications for Road and Bridge Construction, latest revised (including supplements and updates), or other standards as specified.

C. QC/QA requirements for production of mix are discussed in the Materials section, and for construction of the porous media beds and paving in the Execution section.

Table F-6 Submittal requirements.

Material or Pavement Course*	Properties to be reported on Certificate**
choker course, reservoir course	gradation, max. wash loss, min. durability index, max. abrasion loss, air voids (reservoir course)
filter course	gradation, permeability/ sat. hydraulic conductivity
filter blanket	gradation
geotextile filter fabric	manufacturer's certification, AOS/EOS, tensile strength
striping paint	certificate
binder	PGAB certification

Material or Pavement Course*	Properties to be reported on Certificate**
coarse aggregate	gradation, wear, fracture faces (fractured and elongated)
fine aggregate	gradation
silicone	manufacturer's certification
Fibers (optional)	manufacturer's certification
mineral filler (optional)	manufacturer's certification
fatty amines (optional anti-strip)	manufacturer's certification
hydrated lime (optional anti-strip)	manufacturer's certification

* Samples of each material shall be submitted to the Engineer (or QA inspector for mix). These samples must be in sufficient volume to perform the standardized tests for each material.
** At a minimum, more material properties may be required (refer to Materials Section).

1.4 PROJECT CONDITIONS

A. Site Assessment should be performed per the steps outlined in IS 131 (NAPA, 2003).

B. Construction Phasing should be performed as outlined in IS 131 (NAPA, 2003).

C. Protection of Existing Improvements
   1. Protect adjacent work from the unintended dispersal/splashing of pavement materials. Remove all stains from exposed surfaces of pavement, structures, and grounds. Remove all waste and spillage. If necessary, limit access to adjacent work/structures with appropriate signage and/or barriers.
   2. Proper erosion and sediment control practices shall be provided in accordance with existing regulations. Do not damage or disturb existing improvements or vegetation. Provide suitable protection where required before starting work and maintain protection throughout the course of the work. This includes the regular, appropriate inspection and maintenance of the erosion and sediment control measures.
   3. Restore damaged areas, including existing pavement on or adjacent to the site that has been damaged as a result of construction work, to their original condition or repair as directed to the satisfaction of the Engineer at no additional cost.

D. Safety and Traffic Control
   1. Notify and cooperate with local authorities and other organizations having jurisdiction when construction work will interfere with existing roads and traffic.
   2. Provide temporary barriers, signs, warning lights, flaggers, and other protections as required to assure the safety of persons and vehicles around and within the construction area and to organize the smooth flow of traffic.

E. Weather Limitations
   1. Porous asphalt, Open graded friction course, or dense-mixed asphalt shall not be placed between November 15 and March 15, or when the ambient

air temperature at the pavement site in the shade away from artificial heat is below 16 °C (60 °F) or when the actual ground temperature is below 10 °C (50 °F). Only the Engineer may adjust the air temperature requirement or extend the dates of the pavement season.

2. The Contractor shall not pave on days when rain is forecast for the day, unless a change in the weather results in favorable conditions as determined by the Engineer.

1.5 REFERENCES

A. *General Porous Asphalt Bituminous Paving and Groundwater Infiltration Beds,* specification by UNH Stormwater Center, February, 2005.
B. *Design, Construction, and Maintenance Guide for Porous Asphalt Pavements, Information Series 131*, National Asphalt Pavement Association (NAPA), 2003.
C. *Design, Construction, and Maintenance of Open-Graded Friction Courses, Information Series 115*, NAPA, 2002.
D. *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, PA, 1997 or latest edition.
E. *Standards of the American Association of State Highway and Transportation Officials* (AASHTO), 1998 or latest edition.
F. *Section 02725 - General Porous Pavement and Groundwater Infiltration Beds*, specification from NAPA Porous Asphalt Seminar handout, Cahill Associates, Inc., 2004.
G. *Correlations of Permeability and Grain Size*, Russell G. Shepherd, Groundwater 27 (5), 1989.
H. *Groundwater*, R. Allan Freeze and John A. Cherry, 1979.

PART 2 PRODUCTS

2.1 MATERIALS

A. Porous Media Infiltration Beds

Below the porous asphalt itself are located the porous media infiltration beds (Figure F-2), from top to bottom: a 4” – 8” (10 - 20 cm) (minimum) thick layer of choker course of washed crushed stone (8” is preferable to alleviate compaction issues with the porous asphalt); an 8” to 12” (20 cm to 30 cm) minimum thickness layer of filter course of poorly graded sand; 3” (8 cm) minimum thickness filter blanket that is an intermediate setting bed (pea gravel); and a reservoir course of washed crushed stone, thickness dependant on required storage and underlying native materials. Alternatively, the pea gravel layer could be thickened and used as the reservoir course depending upon subsoil suitability. This alternative simplifies subbase construction. For lower permeability native soils, perforated or slotted drain pipe is located in the stone reservoir course for drainage. This drain pipe can be daylighted to other stormwater management infrastructure. The fine gradation of the filter course is for enhanced filtration and delayed infiltration. The high air void content of the uniformly graded washed crushed stone reservoir course: maximizes storage of infiltrated water thereby allowing more time for water to infiltrate between storms; and creates a capillary barrier that arrests vertical water movement and in doing so prevents winter freeze-thaw and heaving. The filter blanket is placed to prevent downward migration of filter course material into the reservoir course. The optional underdrain in the reservoir course is for hydraulic relief (typically raised off of the bottom of the reservoir stone layer for enhanced groundwater recharge). Nonwoven geotextile filter fabric (geotextile) is used only for stabilizing the sloping sides of the porous asphalt system excavation and not to be used on the bottom of the system unless needed for structural reasons.

1. Choker Course

Material for the choker course and reservoir course shall meet the following:

Maximum Wash Loss of 0.5%
Minimum Durability Index of 35
Maximum Abrasion Loss of 10% for 100 revolutions, and maximum of 50% for 500 revolutions.

Material for the choker course and reservoir course shall have the AASHTO No. 57 and AASHTO No. 3 gradations, respectively, as specified in Table F-7. If the AASHTO No. 3 gradation cannot be met, AASHTO No. 5 is acceptable with approval of the Engineer. AASHTO no. 3 is also suitable for the choker course.

2. Filter course material

Filter course material shall have a hydraulic conductivity (also referred to as coefficient of permeability) of 10 to 60 ft/day at 95% standard proctor compaction unless otherwise approved by the Engineer. Great care needs to be used to not over compact materials. Over-compaction results with loss of infiltration capacity. The filter course material is a medium sand. In order to select an appropriate gradation, coefficient of permeability may be estimated through an equation that relates gradation to permeability, such as described in *Correlations of Permeability and Grain Size* (Shepherd, 1989) or in *Section 8.7 Estimation of Saturated Hydraulic Conductivity* (Freeze and Cherry, 1979). The hydraulic conductivity should be determined by ASTM D2434 and reported to the Engineer.

3. Filter blanket material

Filter blanket material between the filter course and the reservoir course shall be an intermediate size between the finer filter course above, and the coarser reservoir course below, for the purpose of preventing the migration of a fine setting bed into the coarser reservoir material. An acceptable gradation shall be calculated based on selected gradations of the filter course and reservoir course using criteria outlined in the *HEC 11* (Brown and Clyde, 1989). A pea-gravel with a median particle diameter of 3/8” (9.5 mm) is commonplace.

4. Reservoir Coarse

Reservoir Coarse thickness is dependent upon the following criteria (that vary from site to site):

a. A 4" (10 cm) minimum thickness of reservoir course acts as a capillary barrier for frost heave protection. The reservoir course is located at the interface between subbase and native materials.

b. 4-in. (10 cm) minimum thickness if the underlying native materials are either well drained (Hydrologic Group A soils).

c. 8-in. (30 cm) minimum thickness if subdrains are installed. Subdrains insure that the subbase is well drained

d. Subdrains, if included, are elevated a minimum of 4" (10 cm) from the reservoir course bottom to provide storage and infiltration for the water quality volume. If the system is lined ,

e. Subbase thickness is determined from subbase materials having sufficient void space to store the design storm,

> **Example:** If the precipitation is 5.1" (13 cm) of rainfall depth, and the reservoir void space is 30%, then the minimum subbase thickness = 5.1"/0.3 = 17" (43.2 cm).

f. Pavement system and subbase thickness are $\geq$ 0.65 * design frost depth for area.

> **Example:** N. Smithfield, RI, 42" (107 cm) = $D_{maximum\ frost}$, therefore, the *minimum* depth to the bottom of the subbase = 0.65(42") = 27" (69 cm).

5. Optional Bottom Liner

Bottom Liner is only recommended for aquifer protection or infiltration prevention. This liner is to be located at the interface between subbase and native materials and is dependent upon the following:

a. As with any infiltration system, care must be taken when siting porous asphalt systems close to locations where hazardous materials are handled/trafficked, or where high contaminant loading may threaten groundwater, or where infiltration is undesirable (nearby foundations, slope stability, etc.). See Section 5.3.1.

b. Suitable liners may include Hydrologic Group D soils, HDPE liners, or suitable equivalent. See Section 5.2.2 (WVTS liners).

Figure F-2 Typical Parking Area Cross-Section for Pervious Pavement System

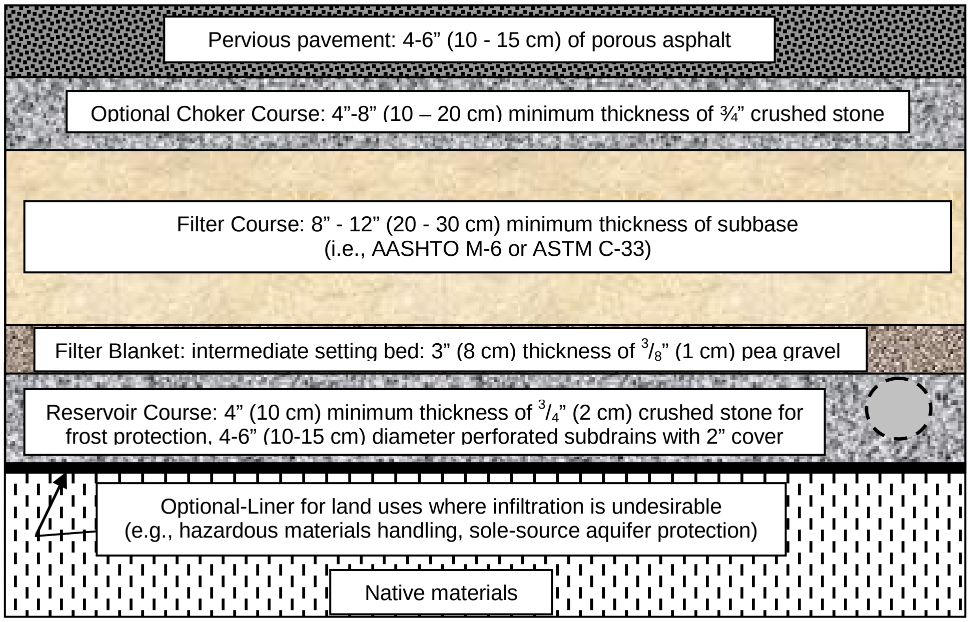

Table F-7 Gradations and compaction of choker, filter, and reservoir course materials.

US Standard Sieve Size (inches/mm)	Percent Passing (%)			
	Choker Course (AASHTO No. 57)	**Filter Course (AASHTO No. M-6)**	**Reservoir Course (AASHTO No.3)**	**Reservoir Course Alternative* (AASHTO No.5)**
6/150	-		-	
2½/63	-		100	-
2 /50	-		90 – 100	-
1½/37.5	100		35 – 70	100
1/25	95 - 100		0 – 15	90 – 100
¾/19	-		-	20 - 55
½/12.5	25 - 60		0 - 5	0 - 10
3/8/9.5	-	100	-	0 - 5
#4/4.75	0 - 10	70-100	-	
#8/2.36	0 - 5		-	
#200/0.075		0 – 6**		
% Compaction ASTM D698 / AASHTO T99	95	95	95	95

* Alternate gradations (e.g. AASHTO No. 5) may be accepted upon Engineer's approval.
** Preferably less than 4% fines

c. Filter fabrics or geotextile liners are not recommended for use on the bottom of the porous asphalt system (at the base of the stone reservoir subbase) if designing for infiltration. Filter fabric usage in stormwater filtration has been known to clog prematurely. Graded stone filter blankets are recommended instead.

d. Geotextile filter fabrics may be used if designing on poor structural, and low conductivity soils. Fabric usage would be limited to the bottom and sides of the excavation. No fabric is to be used within the subbase, only on the perimeter.

6. <u>Non-woven geotextile filter fabric</u>

Filter fabric is *only recommended* for the sloping sides of the porous asphalt system excavation. It shall be Mirafi 160N, or approved equal and shall conform to the specifications in Table F-8. Mirafi ® 160N is a non-woven geotextile composed of polypropylene fibers, which are formed into a stable network such that the fibers retain their relative position. 160N is inert to biological degradation and resists naturally encountered chemicals, alkalis, and acids.

7. <u>Alternative Applications and Residential Driveways</u>.

The recommendations above are based on a commercial parking application for both traffic and contaminant load. Alternative applications such as residential driveways and low use applications may justify the use of alternative subbase thicknesses for the porous media beds, filter blanket, and geotextiles. Residential driveway applications have been designed with a subbase limited to only an 8" compacted choker course. Variations should consider structural load requirements for material thickness, and contaminant load for filter course thickness. A reduced total system thickness will subject the pavement to greater freeze thaw susceptibility.

Table F-8 Non-woven geotextile filter fabric properties.

Mechanical Properties	**Test Method**	Unit	**Minimum Average Roll Values**	
			MD*	CD**
Grab Tensile Strength	ASTM D 4632	kN (lbs)	0.71 (160)	0.71 (160)
Grab Tensile Elongation	ASTM D 4632	%	50	50
Trapezoid Shear Strength	ASTM D 4533	kN (lbs)	0.27 (60)	0.27 (60)
Mullen Burst Strength	ASTM D 3786	kPa (psi)	2100 (305)	2100 (305)
Puncture Strength	ASTM D 4833	kN (lbs)	0.42 (95)	0.42 (95)

Mechanical Properties	**Test Method**	Unit	**Minimum Average Roll Values**	
			MD*	CD**
Apparent Opening Size (AOS)	ASTM D 4751	mm (US Sieve)	0.212 (70)	0.212 (70)
Permittivity	ASTM D 4491	sec^{-1}	1.4	1.4
Permeability	ASTM D 4491	cm/sec	0.22	0.22
Flow Rate	ASTM D 4491	lpm/m^2 (gpm/ft^2)	4,477 (110)	4,477 (110)
UV Resistance (at 500 hours)	ASTM D 4355	% strength retained	70	70

Physical Properties	**Test Method**	**Unit**	**Typical Value**
Weight	ASTM D 5261	g/m^2 (oz/yd^2)	217 (6.4)
Thickness	ASTM D 5199	mm (mils)	1.9 (75)
Roll dimension (width x length)		m (ft)	4.5 x 91 (15 x 300)
Roll area		m^2 (yd^2)	410 (500)
Estimated roll weight		kg (lb)	99 (217)

*MD - Machine Direction; **CD - Cross-machine Direction

B. Porous Asphalt Mix

1. Mix materials

Mix materials consist of modified performance grade asphalt binder (PGAB), coarse and fine aggregates, and optional additives such as silicone, fibers, mineral fillers, fatty amines, and hydrated lime. Materials shall meet the requirements of the NAPA's Design, Construction, and Maintenance of Open-Graded Friction Courses, Information Series 115 (2002), except where noted otherwise below or approved in writing by the Engineer.

2. Polymer Modified PGAB and Mix Designs.

The asphalt binder shall be a polymer and/or fiber modified Performance Graded asphalt binder (PGAB) used in the production of Superpave Hot Mix Asphalt (HMA) mixtures. Ideally for maximum durability, the PGAB shall be two grades stiffer than that required for dense mix asphalt (DMA) parking lot installations, which is often achieved by adding a polymer and/or fiber. Mix designs will meet or exceed criteria listed in Table F-10.

The PGAB polymer modifiers are to be either styrene butadiene rubber (SBR) or styrene butadiene styrene (SBS). SBS is typically reserved for large projects as terminal pre-blending is required. SBR is feasible for smaller projects as it can be blended at the plant or terminal blended. The quantity of rubber solids in the SBR shall typically be 1.5-3% by weight of the bitumen content of the mix.

The dosage of fiber additives shall be either 0.3 percent cellulose fibers or 0.4 percent mineral fibers by total mixture mass. Fibers are a simple addition either manually for a batch plant or automated for larger drum plants. The binder shall meet the requirements of AASHTO M320.

The PGAB may be pre-blended or post-blended. The pre-blended binder can be pre-blended at the source or at a terminal. For post-blended addition, the modifier can either be in-line blended or injected into the pugmill at the plant.

The following asphalt mix designs are recommended:

a. PG 64-28 with 5 pounds of fibers per ton of asphalt mix. This mix is recommended for smaller projects with lower traffic counts or loading potential. This mix is manageable at common batch plants.

b. Pre-Blended PG 64-28 SBS with 5 pounds of fibers per ton of asphalt mix. This mix is recommended for large projects > 1acre where high durability pavements are needed. The SBS will be supplied by an approved PGAB supplier holding a Quality Control Plan approved by the RIDOT. A Bill of Lading (BOL) will be delivered with each transport of PG 64-28 SBS. A copy of the BOL will be furnished to the QA inspector at the Plant.

c. Post-Blended PG 64-28 SBR with 5 pounds of fibers per ton of asphalt mix. This mix is recommended for projects where high durability pavements are needed. The SBR will be supplied by a HMA plant approved to perform in-line blending or blending by injection into the pugmill. A Post-Blended SBR Binder Quality Control Plan (Table F-9) will be submitted to the Engineer for approval at least 10 working days prior to production.

d. Pre-Blended PG 76-22 modified with SBS and 5 pounds of fibers per ton of asphalt mix. This mix is recommended for large sites anticipating high wheel load (H-20) and traffic counts for maximum durability. The SBS will be supplied by an approved PGAB supplier holding a Quality Control Plan approved by the RIDOT. A Bill of Lading (BOL) will be delivered with each transport of PG 76-22 SBS. A copy of the BOL will be furnished to the QA inspector at the Plant.

e. Post-Blended PG 76-22 modified with SBR and 5 pounds of fibers per ton of asphalt mix. This mix is recommended for large sites anticipating high wheel load (H-20) and traffic counts for maximum durability. The SBR will be supplied by a HMA plant approved to perform in-line blending or blending by injection into the pugmill. A Post-Blended SBR Binder Quality Control Plan (Table F-9) will be submitted to the Engineer for approval at least 10 working days prior to production.

f. Quality control plans may be altered at the discretion of the Engineer and based on feasible testing as suggested by the asphalt producer. Certain QC testing requirements during production may not be feasible for small projects in which limited asphalt is generated. Some testing methods cannot be completed during the time needed during small batch (less than approximately 50 tons of porous asphalt mix) production. The feasibility should be assessed with the Engineer and producer.

3. Anti-Stripping Mix Additives.

The mix shall be tested for moisture susceptibility and asphalt stripping from the aggregate by AASHTO T283. If the retained tensile strength (TSR) < 80% upon testing, a heat stable additive shall be furnished to improve the anti-stripping properties of the asphalt binder. Test with one freeze-thaw cycle (rather than five recommended in NAPA IS 115). The amount and type of additive (e.g. fatty amines or hydrated lime) to be used shall be based on the manufacturer's recommendations, the mix design test results, and shall be approved by the Engineer. Silicone shall be added to the binder at the rate of 1.5 mL/m3 (1 oz. per 5000 gal). Fibers may be added per manufacturer and NAPA IS 115 recommendation if the draindown requirement cannot be met (<0.3% via ASTM D6390) provided that the air void content requirement is met (>18%, or >16% as tested with CoreLok device). Additives should be added per the relevant DOT specification and NAPA IS 115.

4. Coarse Aggregate.

Coarse aggregate shall be that part of the aggregate retained on the No. 8 sieve; it shall consist of clean, tough, durable fragments of crushed stone, or crushed gravel of uniform quality throughout. Coarse aggregate shall be crushed stone or crushed gravel and shall have a percentage of wear as determined by AASHTO T96 of not more than 40 percent. In the mixture, at least 75 percent, by mass (weight), of the material coarser than the 4.75 mm (No. 4) sieve shall have at least two fractured faces, and 90 percent shall have one or more fractured faces (ASTM D5821). Coarse aggregate shall be free from clay balls, organic matter, deleterious substances, and a not more than 8.0% of flat or elongated pieces (>3:1) as specified in ASTM D4791.

5. Fine Aggregate.

The fine aggregate shall be that part of the aggregate mixture passing the No. 8 sieve and shall consist of sand, screenings, or combination thereof with uniform quality throughout. Fine aggregate shall consist of durable particles, free from injurious foreign matter. Screenings shall be of the same or similar materials as specified for coarse aggregate. The plasticity index of that part of the fine aggregate passing the No. 40 sieve shall be not more than 6 when tested in accordance with AASHTO T90. Fine aggregate from the total mixture shall meet plasticity requirements.

Table F-9 Post-Blended SBR Binder QC Plan Requirements

The QC Plan will contain:
1. Company name and address 2. Plant location and address 3. Type of Facility 4. Contact information for the Quality Control Plan Administrator 5. QC Tests to be performed on each PGAB 6. Name(s) of QC Testing Lab to perform QC and Process Control testing. 7. Actions to be taken for PG Binders and SBR in Non compliance 8. List of mechanical controls (requirements below) 9. List of process controls and documentation (requirements below)
List of Mechanical Controls
1. Liquid SBR no-flow alert system with an “alert” located in the control room and automatic documentation of a no flow situation on the printout 2. Provide means of calibrating the liquid SBR metering system to a delivery tolerance of 1%. 3. A batching tolerance at the end of each day’s production must be within 0.5% of the amount of SBR solids specified. 4. Mag-flow meter (other metering system may be considered) 5. Method of sampling liquid SBR
List of Process Controls and Documentation
1. Printouts of liquid SBR and PG binder quantities must be synchronized within one minute of each other 2. SBR supplier certification showing the percent of SBR solids in liquid SBR 3. Test results of a lab sample blended with the specified dosage of SBR. At a minimum, provide the name of the PGAB and liquid SBR suppliers, and PGAB information such as grade and lot number, and SBR product name used for the sample. 4. MSDS sheet for liquid SBR 5. Handling, storage, and usage requirements will be followed as required by the liquid SBR manufacturer 6. At a minimum, provide a table showing proposed rate of SBR liquid (L/min.) in relation to HMA production rate (tons per hour, TPH) for the % solids in liquid SBR, quantity of SBR specified for HMA production, and the specific gravity of the SBR. 7. QCT or QC Plan Administrator must be responsible for documenting quantities, ensuring actual use is within tolerance, etc. All printouts, calculations, supplier certifications etc. must be filed and retained as part of the QCTs daily diary/reports. 8. Method and Frequency of testing at the HMA plant, including initial testing and specification testing.
*This Plan shall be submitted to the Engineer 10 days before production.

6. Porous Asphalt Mix Design Criteria.

The Contractor shall submit a mix design at least 10 working days prior to the beginning of production. The Contractor shall make available samples of coarse aggregate, fine aggregate, mineral filler, fibers and a sample of the PGAB that will be used in the design of the mixture. A certificate of analysis (COA) of the PGAB will be submitted with the mix design. The COA will be certified by a laboratory meeting the requirements of AASHTO R18. The Laboratory will be certified by the RIDOT, regional equivalent (e.g. NETTCP), and/or qualified under ASTM D3666. Technicians will be certified by the regional certification agency (e.g. NETTCP) in the discipline of HMA Plant Technician.

Bulk specific gravity (SG) used in air void content calculations shall not be determined and results will not be accepted using AASHTO T166 (saturated surface dry), since it is not intended for open graded specimens (>10% AV). Bulk SG shall be calculated using AASHTO T275 (paraffin wax) or ASTM D6752 (automatic vacuum sealing, e.g. CoreLok). Air void content shall be calculated from the bulk SG and maximum theoretical SG (AASHTO T209) using ASTM D3203.

The materials shall be combined and graded to meet the composition limits by mass (weight) as shown in Table F-10.

Table F-10 Porous Asphalt Mix Design Criteria.

Sieve Size (inch/mm)	Percent Passing (%)
0.75/19	100
0.50/12.5	85-100
0.375/9.5	55-75
No.4/4.75	10-25
No.8/2.36	5-10
No.200/0.075 (#200)	2-4
Binder Content (AASHTO T164)	6 - 6.5%
Fiber Content by Total Mixture Mass	0.3% cellulose or 0.4% mineral
Rubber Solids (SBR) Content by Weight of the Bitumen	1.5-3% or TBD
Air Void Content (ASTM D6752/AASHTO T275)	16.0-22.0%
Draindown (ASTM D6390)*	≤ 0.3 %
Retained Tensile Strength (AASHTO 283)**	≥ 80 %
Cantabro abrasion test on unaged samples (ASTM D7064-04)	≤ 20%
Cantabro abrasion test on 7 day aged samples	≤ 30%

*Cellulose or mineral fibers may be used to reduce draindown.

**If the TSR (retained tensile strength) values fall below 80% when tested per NAPA IS 131 (with a single freeze thaw cycle rather than 5), then in Step 4, the contractor shall employ an antistrip additive, such as hydrated lime (ASTM C977) or a fatty amine, to raise the TSR value above 80%.

C. Porous Asphalt Mix Production

1. Mixing Plants.
Mixing plants shall meet the requirements of hot mix asphalt plants as specified in the RIDOT or regional equivalent unless otherwise approved by the Engineer.

2. Preparation of Asphalt Binder.
The asphalt material shall be heated to the temperature specified in the RIDOT specification Part 400 (if using a DOT spec for the mix) in a manner that will avoid local overheating. A continuous supply of asphalt material shall be furnished to the mixer at a uniform temperature.

3. Preparation of Aggregates.
The aggregate for the mixture shall be dried and heated at the mixing plant before being placed in the mixer. Flames used for drying and heating shall be properly adjusted to avoid damaging the aggregate and depositing soot or unburned fuel on the aggregate.

4. Mineral filler
Mineral filler if required to meet the grading requirements, shall be added in a manner approved by the Engineer after the aggregates have passed through the dryer.

5. Mixing.
The above preparation of aggregates does not apply for drum-mix plants. The dried aggregate shall be combined in the mixer in the amount of each fraction of aggregate required to meet the job-mix formula and thoroughly mixed prior to adding the asphalt material.

The dried aggregates shall be combined with the asphalt material in such a manner as to produce a mixture that when discharged from the pugmill is at a target temperature in the range that corresponds to an asphalt binder viscosity of 700 to 900 centistokes and within a tolerance of ± 11 °C (± 20 °F).

The asphalt material shall be measured or gauged and introduced into the mixer in the quantity determined by the Engineer for the particular material being used and at the temperature specified in the relevant specification.

After the required quantity of aggregate and asphalt material has been introduced into the mixer, the materials shall be mixed until a complete and uniform coating of the particles and a thorough distribution of the asphalt material throughout the aggregate is secured. The mixing time will be regulated by the Engineer.

All plants shall have a positive means of eliminating oversized and foreign material from being incorporated into the mixer.

6. QC/QA During Production

The Contractor shall provide at Contractors' expense and the Engineer's approval a third-party QA Inspector to oversee and document mix production. All mix testing results during production should be submitted to the QA Inspector.

The QC plan may be altered at the discretion of the Engineer and based on feasible testing as suggested by the asphalt producer. Certain QC testing requirements during production may not be feasible for small projects in which limited asphalt is generated. Some testing methods cannot be completed during the time needed during small batch production. The feasibility should be assessed with the Engineer and producer.

The mixing plant shall employ a Quality Control Technician (QCT). The QCT will perform QC/QA testing and will be certified in the discipline of HMA Plant Technician by the relevant certifying agency (e.g. NETTCP in New England). The Contractor shall sample, test and evaluate the mix in accordance with the methods and minimum frequencies in Table F-11 and the Post-Blended SBR Binder Quality Control Plan (if applicable).

Table F-11 QC/QA testing requirements during production.

Test	Min. Frequency	Test Method
Temperature in Truck at Plant	6 times per day	
Gradation	greater of either (a) 1 per 500 tons, (b) 2 per day, or (c) 3 per job	AASHTO T30
Binder Content	greater of either (a) 1 per 500 tons, (b) 2 per day, or (c) 3 per job	AASHTO T164
Air Void Content	greater of either (a) 1 per 500 tons, (b) 2 per day, or (c) 3 per job	ASTM D6752
Binder Draindown	greater of either (a) 1 per 500 tons, (b) 1 per day, or (c) 1 per job	ASTM D6390

If an analyzed sample is outside the testing tolerances immediate corrective action will be taken. After the corrective action has been taken the resulting mix will be sampled and tested. If the re-sampled mix test values are outside the tolerances the Engineer will be immediately informed. The Engineer may determine that it is in the best interest of project that production is ceased. The Contractor will be responsible for all mix produced for the project.

Testing Tolerances During Production. Testing of the air void content, binder draindown, and TSR shall be within the limits set in Table F-11. The paving mixture produced should not vary from the design criteria for aggregate gradation and binder content by more than the tolerances in Table F-12.

Table F-12. QC/QA testing tolerances during production.

Sieve Size (inch/mm)	Percent Passing
0.75/19	-
0.50/12.5	±6.0
0.375/9.5	±6.0
No.4/4.75	±5.0
No.8/2.36	±4.0
No.200/0.075 (#200)	±2.0
%PGAB	+0.4, -0.2

Should the paving mixture produced vary from the designated grading and asphalt content by more than the above tolerances, the appropriate production modifications are to be made until the porous asphalt mix is within these tolerances.

Samples of the mixture, when tested in accordance with AASHTO T164 and T30, shall not vary from the grading proportions of the aggregate and binder content designated by the Engineer by more than the respective tolerances specified above and shall be within the limits specified for the design gradation.

7. Plant Shutdown and Rejection of Mix.
Should the porous asphalt mix not meet the tolerances specified in this section upon repeat testing, the Engineer may reject further loads of mix. Mix that is loaded into trucks during the time that the plant is changing operations to comply with a failed test shall not be accepted, and should be recycled at the plant.

8. Striping Paint
Striping paint shall be latex, water-base emulsion, ready-mixed, and complying with pavement marking specifications PS TT-P-1952.

PART 3 EXECUTION

3.1 INSTALLATION

A. Porous Media Beds

Protection of native materials from over compaction is important. Proper compaction of select subbase materials is essential. Improper compaction of subbase materials will result in either 1) low pavement durability from insufficient compaction, or 2) poor infiltration due to over-compaction of subbase. Care must be taken to assure proper compaction as detailed below.

1. Grade Control

   a. Establish and maintain required lines and elevations. The Engineer shall be notified for review and approval of final stake lines for the work before construction work is to begin. Finished surfaces shall be true to grade and even, free of roller marks and free of puddle-forming low spots. All areas must drain freely. Excavation elevations should be within +/- 0.1 ft (+/- 3 cm).

b. If, in the opinion of the Engineer, based upon reports of the testing service and inspection, the quality of the work is below the standards which have been specified, additional work and testing will be required until satisfactory results are obtained.

c. The Engineer shall be notified at least 24 hours prior to all porous media bed and porous pavement work.

2. Subgrade Preparation

a. Native subgrade refers to materials beyond the limit of the excavation. The existing native subgrade material under all bed areas shall NOT be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement. Compaction is acceptable if an impermeable liner is used at the base of the porous asphalt system and infiltration is not desired.

b. Where erosion of the native material subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake or equivalent and light tractor.

c. Bring subgrade to line, grade, and elevations indicated. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction before the placing of the stone subbase.

d. All bed bottoms are as level as feasible to promote uniform infiltration. For pavements subbases constructed on grade, soil or fabric barriers should be constructed along equal elevation for every 6-12" of grade change to act as internal check dams. This will prevent erosion within the subbase on slope.

3. Porous Media Bed Installation

a. Subbase refers to materials below pavement surface and above native subgrade. Upon completion of subgrade work, the Engineer shall be notified and shall inspect at his/her discretion before proceeding with the porous media bed installation.

b. Sideslope geotextile and porous media bed aggregate shall be placed immediately after approval of subgrade preparation. Any accumulation of debris or sediment which has taken place after approval of subgrade shall be removed prior to installation of geotextile at no extra cost to the Owner.

c. Place sideslope geotextile in accordance with manufacturer's standards and recommendations. Adjacent strips of geotextile shall overlap a minimum of sixteen inches (16"). Secure geotextile at least four feet (1.2 m) outside of the bed excavation and take any steps necessary to prevent any runoff or sediment from entering the storage bed.

d. Install filter course aggregate in 8-inch maximum lifts to a MAXIMUM of 95% standard proctor compaction (ASTM D698 / AASHTO T99). Install aggregate to grades indicated on the drawings.

e. Install choker, gravel, and stone base course aggregate to a MAXIMUM of 95% compaction standard proctor (ASTM D698 / AASHTO T99). Choker should be placed evenly over surface of filter course bed, sufficient to allow placement of pavement, and notify Engineer for approval. Choker base course thickness shall be sufficient to allow for even placement of the porous asphalt but no less than 4-inches (10 cm) in depth.

f. The density of subbase courses shall be determined by AASHTO T 191 (Sand-Cone Method), AASHTO T 204 (Drive Cylinder Method), or AASHTO T 238 (Nuclear Methods), or other approved methods at the discretion of the supervising engineer.

g. The infiltration rate of the compacted subbase shall be determined by ASTM D3385 or approved alternate at the discretion of the supervising engineer. The infiltration rate shall be no less 5-30 ft/day or 50% of the hydraulic conductivity (D2434) at 95% standard proctor compaction (refer to section 2.1.A.5).

h. Compaction of subbase course material shall be done with a method and adequate water to meet the requirements. Rolling and shaping shall continue until the required density is attained. Water shall be uniformly applied over the subbase course materials during compaction in the amount necessary for proper consolidation.

i. Rolling and shaping patterns shall begin on the lower side and progress to the higher side of the subbase course while lapping the roller passes parallel to the centerline. Rolling and shaping shall continue until each layer conforms to the required grade and cross-section and the surface is smooth and uniform.

j. Following placement of subbase aggregate, the sideslope geotextile shall be folded back along all bed edges to protect from sediment washout along bed edges. At least a four-foot edge strip shall be used to protect beds from adjacent bare soil. This edge strip shall remain in place until all bare soils contiguous to beds are stabilized and vegetated. In addition, take any other necessary steps to prevent sediment from washing into beds during site development. When the site is fully stabilized, temporary sediment control devices shall be removed.

4. QC/QA requirements for Porous Media Bed Construction.
QC/QA activities are summarized in Table F-13.

B. Porous Asphalt Pavement Installation

1. Mixing Plant

The mixing plant, hauling and placing equipment, and construction methods shall be in conformance with NAPA IS 131 and applicable sections of the RIDOT's specification for asphalt mixes. The use of surge bins shall not be permitted.

Table F-13 QC/QA requirements for porous media bed construction.

Activity	Schedule
Contractor to notify Engineer for approval	24 hours in advance of start of work
Contractor to employ soil inspector acceptable to Engineer	NA
Contractor to employ staking and layout control inspector acceptable to Engineer	NA
Contractor to employ site grading inspector acceptable to Engineer	NA
Contractor to employ pavement work inspector acceptable to Engineer	NA
Contractor to notify Engineer for approval	after subgrade preparation, before construction of porous media bed
Contractor to notify Engineer for approval	after choker course placed, before placement of pavement

2. Hauling Equipment.

The open graded mix shall be transported in clean vehicles with tight, smooth dump beds that have been sprayed with a non-petroleum release agent or soap solution to prevent the mixture from adhering to the dump bodies. Mineral filler, fine aggregate, slag dust, etc. shall not be used to dust truck beds. The open graded mix shall be covered during transportation with a suitable material of such size sufficient to protect the mix from the weather and also minimize mix cooling and the prevention of lumps. When necessary, to ensure the delivery of material at the specified temperature, truck bodies shall be insulated, and covers shall be securely fastened. Long hauls, particularly those in excess of 25 miles (40 km), may result in separation of the mix and its rejection.

3. Placing Equipment.

The paver shall be a self-propelled unit with an activated screed or strike-off assembly, capable of being heated if necessary, and capable of spreading and finishing the mixture without segregation for the widths and thicknesses required. In general, track pavers have proved superior for Porous Asphalt placement. The screed shall be adjustable to provide the desired cross-sectional shape. The finished surface shall be of uniform texture and evenness and shall not show any indication of tearing, shoving, or pulling of the mixture. The machine shall, at all times, be in good mechanical condition and shall be operated by competent personnel.

Pavers shall be equipped with the necessary attachments, designed to operate electronically, for controlling the grade of the finished surface.

The adjustments and attachments of the paver will be checked and approved by the Engineer before placement of asphalt material.

Pavers shall be equipped with a sloped plate to produce a tapered edge at longitudinal joints. The sloped plate shall be attached to the paver screed extension.

The sloped plate shall produce a tapered edge having a face slope of 1:3 (vertical: horizontal). The plate shall be so constructed as to accommodate compacted mat thickness from 35 to 100 mm (1 1/4 to 4 inches). The bottom of the sloped plate shall be mounted 10 to 15 mm (3/8 to 1/2 inch) above the existing pavement. The plate shall be interchangeable on either side of the screed.

Pavers shall also be equipped with a joint heater capable of heating the longitudinal edge of the previously placed mat to a surface temperature of 95 °C (200 °F), or higher if necessary, to achieve bonding of the newly placed mat with the previously placed mat. This shall be done without undue breaking or fracturing of aggregate at the interface. The surface temperature shall be measured immediately behind the joint heater. The joint heater shall be equipped with automated controls that shut off the burners when the pavement machine stops and reignite them with the forward movement of the paver. The joint heater shall heat the entire area of the previously placed wedge to the required temperature. Heating shall immediately precede placement of the asphalt material.

4. <u>Rollers.</u>
Rollers shall be in good mechanical condition, operated by competent personnel, capable of reversing without backlash, and operated at speeds slow enough to avoid displacement of the asphalt mixture. The mass (weight) of the rollers shall be sufficient to compact the mixture to the required density without crushing of the aggregate. Rollers shall be equipped with tanks and sprinkling bars for wetting the rolls.

Rollers shall be two-axle tandem rollers with a gross mass (weight) of not less than 7 metric tons (8 tons) and not more than 10 metric tons (12 tons) and shall be capable of providing a minimum compactive effort of 44 kN/m (250 pounds per inch) of width of the drive roll. All rolls shall be at least 1 m (42 inches) in diameter.

A rubber tired roller will not be required on the open graded asphalt friction course surface.

5. Conditioning of Existing Surface.
Contact surfaces such as curbing, gutters, and manholes shall be painted with a thin, uniform coat of Type RS-1 emulsified asphalt immediately before the asphalt mixture is placed against them.

6. Temperature Requirements.
The temperature of the asphalt mixture, at the time of discharge from the haul vehicle and at the paver, shall be between 135-163°C (275 to 325°F), within 6 °C (10 °F) of the compaction temperature for the approved mix design.

7. Spreading and Finishing.
The Porous Asphalt shall be placed either in a single application at 4 inches (10 cm) thick or in two lifts. If more than one lift is used, great care must be taken to insure that the porous asphalt layer join completely. This means: keeping the time between layer placements minimal; keeping the first layer clear from dust and moisture, and minimizing traffic on the first layer.

The Contractor shall protect all exposed surfaces that are not to be treated from damage during all phases of the pavement operation.

The asphalt mixture shall be spread and finished with the specified equipment. The mixture shall be struck off in a uniform layer to the full width required and of such depth that each course, when compacted, has the required thickness and conforms to the grade and elevation specified. Pavers shall be used to distribute the mixture over the entire width or over such partial width as practical. On areas where irregularities or unavoidable obstacles make the use of mechanical spreading and finishing equipment impractical, the mixture shall be spread and raked by hand tools.

No material shall be produced so late in the day as to prohibit the completion of spreading and compaction of the mixture during daylight hours, unless night paving has been approved for the project.

No traffic will be permitted on material placed until the material has been thoroughly compacted and has been permitted to cool to below 38 °C (100 °F). The use of water to cool the pavement is not permitted. The Engineer reserves the right to require that all work adjacent to the pavement, such as guardrail, cleanup, and turf establishment, is completed prior to placing the wearing course when this work could cause damage to the pavement. On projects where traffic is to be maintained, the Contractor shall schedule daily pavement operations so that at the end of each working day all travel lanes of the roadway on which work is being performed are paved to the same limits. Suitable aprons to transition approaches, where required, shall be placed at side road intersections and driveways as directed by the Engineer.

8. Compaction.

Immediately after the asphalt mixture has been spread, struck off, and surface irregularities adjusted, it shall be thoroughly and uniformly compacted by rolling. The compaction objective is 16% - 19% in place void content (Corelock).

Breakdown rolling shall occur when the mix temperature is between 135-163°C (275 to 325°F).

Intermediate rolling shall occur when the mix temperature is between 93-135°C (200 to 275°F).

Finish rolling shall occur when the mix temperature is between 66-93°C (150 to 200°F).

The cessation temperature occurs at approximately 79°C (175°F), at which point the mix becomes resistant to compaction. If compaction has not been done at temperatures greater than the cessation temperature, the pavement will not achieve adequate durability.

The surface shall be rolled when the mixture is in the proper condition and when the rolling does not cause undue displacement, cracking, or shoving.

Rollers or oscillating vibratory rollers, ranging from 8-12 tons, shall be used for compaction. The number, mass (weight), and type of rollers furnished shall be sufficient to obtain the required compaction while the mixture is in a workable condition. Generally, one breakdown roller will be needed for each paver used in the spreading operation.

To prevent adhesion of the mixture to the rolls, rolls shall be kept moist with water or water mixed with very small quantities of detergent or other approved material. Excess liquid will not be permitted.

Along forms, curbs, headers, walls, and other places not accessible to the rollers, the mixture shall be thoroughly compacted with hot or lightly oiled hand tampers, smoothing irons or with mechanical tampers. On depressed areas, either a trench roller or cleated compression strips may be used under the roller to transmit compression to the depressed area.

Other combinations of rollers and/or methods of compacting may be used if approved in writing by the Engineer, provided the compaction requirements are met.

Unless otherwise specified, the longitudinal joints shall be rolled first. Next, the Contractor shall begin rolling at the low side of the pavement and shall proceed towards the center or high side with lapped rollings parallel to the centerline. The speed of the roller shall be slow and uniform to avoid displacement of the mixture, and the roller should be kept in as continuous operation as practical. Rolling shall continue until all roller marks and ridges have been eliminated.

Rollers will not be stopped or parked on the freshly placed mat.

It shall be the responsibility of the Contractor to conduct whatever process control the Contractor deems necessary. Acceptance testing will be conducted by the Engineer using cores provided by the Contractor.

Any mixture that becomes loose and broken, mixed with dirt, or is in any way defective shall be removed and replaced with fresh hot mixture. The mixture shall be compacted to conform to the surrounding area. Any area showing an excess or deficiency of binder shall be removed and replaced. These replacements shall be at the Contractor's expense.

If the Engineer determines that unsatisfactory compaction or surface distortion is being obtained or damage to highway components and/or adjacent property is occurring using vibratory compaction equipment, the Contractor shall immediately cease using this equipment and proceed with the work in accordance with the fifth paragraph of this subsection.

The Contractor assumes full responsibility for the cost of repairing all damages that may occur to roadway or parking lot components and adjacent property if vibratory compaction equipment is used. After final rolling, no vehicular traffic of any kind shall be permitted on the surface until cooling and hardening has taken place, and in no case within the first 48 hours. For small batch jobs, curing can be considered to have occurred after the surface temperature is less than 100 ºF (38 ºC). Curing time is preferably one week, or until the entire surface temperature cools below 100 ºF (38 ºC). Provide barriers as necessary at no extra cost to the Owner to prevent vehicular use; remove at the discretion of the Engineer.

9. Joints.

Joints between old and new pavements or between successive day's work shall be made to ensure a thorough and continuous bond between the old and new mixtures. Whenever the spreading process is interrupted long enough for the mixture to attain its initial stability, the paver shall be removed from the mat and a joint constructed.

Butt joints shall be formed by cutting the pavement in a vertical plane at right angles to the centerline, at locations approved by the Engineer. The Engineer will determine locations by using a straightedge at least 4.9 m (16 feet) long. The butt joint shall be thoroughly coated with Type RS-1 emulsified asphalt just prior to depositing the pavement mixture when pavement resumes.

Tapered joints shall be formed by tapering the last 450 to 600 mm (18 to 24 inches) of the course being laid to match the lower surface. Care shall be taken in raking out and discarding the coarser aggregate at the low end of the taper, and in rolling the taper. The taper area shall be thoroughly coated with Type RS-1 emulsified asphalt just prior to resuming pavement. As the paver places new mixture on the taper area, an evenly graduated deposit of mixture shall complement the previously made taper. Shovels may be used to add additional mixture if necessary. The joint shall be smoothed with a rake, coarse material discarded, and properly rolled.

Longitudinal joints that have become cold shall be coated with Type RS-1 emulsified asphalt before the adjacent mat is placed. If directed by the Engineer, joints shall be cut back to a clean vertical edge prior to applying the emulsion.

10. Surface Tolerances.

The surface will be tested by the Engineer using a straightedge at least 4.9 m (16 feet) in length at selected locations parallel with the centerline. Any variations exceeding 3 mm (1/8 inch) between any two contact points shall be satisfactorily eliminated. A straightedge at least 3 m (10 feet) in length may be used on a vertical curve. The straightedges shall be provided by the Contractor.

Work shall be done expertly throughout, without staining or injury to other work. Transition to adjacent impervious asphalt pavement shall be merged neatly with flush, clean line. Finished pavement shall be even, without pockets, and graded to elevations shown on drawing.

Porous pavement beds shall not be used for equipment or materials storage during construction, and under no circumstances shall vehicles be allowed to deposit soil on paved porous surfaces.

11. Repair of Damaged Pavement.

Any existing pavement on or adjacent to the site that has been damaged as a result of construction work shall be repaired to the satisfaction of the Engineer without additional cost to the Owner.

12. Striping Paint

a. Vacuum and clean surface to eliminate loose material and dust.
b. Paint 4-inch wide parking striping and traffic lane striping in accordance with layouts of plan. Apply paint with mechanical equipment to produce

uniform straight edges. Apply in two coats at manufacturer's recommended rates. Provide clear, sharp lines using white traffic paint

c. Color for Handicapped Markings: Blue

C. QC/QA for Paving Operations

1. The full permeability of the pavement surface shall be tested by application of clean water at the rate of at least 5 gpm (23 lpm) over the surface, using a hose or other distribution devise. Water used for the test shall be clean, free of suspended solids and deleterious liquids and will be provided at no extra cost to the Owner. All applied water shall infiltrate directly without large puddle formation or surface runoff, and shall be observed by the Engineer.

2. Testing and Inspection: Employ at Contractor's expense an inspection firm acceptable to the Engineer to perform soil inspection services, staking and layout control, and testing and inspection of site grading and pavement work. Inspection and list of tests shall be reviewed and approved in writing by the Engineer prior to starting construction. All test reports must be signed by a licensed Engineer.

3. Test in-place base and surface course for compliance with requirements for thickness and surface smoothness. Repair or remove and replace unacceptable work as directed by the Engineer.

4. Surface Smoothness: Test finished surface for smoothness using a 10-foot straightedge applied parallel with and at right angles to the centerline of the paved area. Surface will not be accepted if gaps or ridges exceed 3/16 of an inch.

5. QC/QA requirements during paving are summarized in Table F-14.

Table F-14 QC/QA requirements during paving.

Activity	Schedule/ Frequency	Tolerance
Inspect truck beds for pooling (draindown)	every truck	NA
Take surface temp. behind joint heater	each pull	6°C (10°F) of compaction temp
Consult with Engineer to determine locations of butt joints	as needed	NA
Test surface smoothness & positive drainage with a 10 ft straightedge	after compaction	4.5 mm (3/16")
Consult with Engineer to mark core locations for QA testing	after compaction	NA
Hose test with at least 5 gpm water	after compaction	immediate infiltation, no puddling

PART 4. REFERENCES

CalTrans, January 2003, California Stormwater BMP Handbook 3 of 8 New Development and Redevelopment, California Dept. of Transportation, Sacramento, CA www.cabmphandbooks.com

USEPA, September, 1999, Storm Water Technology Fact Sheet: Infiltration Drainfields, Number: 832F99018 USEPA, Office of Water, Washington, DC http://www.epa.gov/npdes/pubs/infltdrn.pdf

USEPA, September 2004, Stormwater Best Management Design Guide: Volume 1 General Considerations, Office of Research and Development, EPA/600/R-04/121, Washington, D.C.

Vermont Agency of Transportation, 2006, 2006 Standard Specifications for Construction Book, Division 700, Section 708, Montpelier, VT. http://www.aot.state.vt.us/conadmin/2006StandardSpecs.htm

Wisconsin Department of Natural Resources, Feb. 2004, Site Evaluation for Stormwater Infiltration(1002), Wisconsin Department of Natural Resources Conservation Practice Standards Madison, WI

F.4.2 Pervious Concrete Notes and Specifications

Pervious concrete pavement does not look or behave like typical concrete pavements. The finished surface is not tight and uniform, but is open and varied. Surface irregularities and minor amounts of surface raveling are normal. Traditional concrete testing procedures for strength and slump are not applicable. Pervious Concrete is tested instead for consistency, void content and thickness; methods which are outlined in this document to help assure a long life, drainable pavement.

Owners, architects and engineers are strongly encouraged to visit locations where pervious concrete pavement has been installed before making the decision to use the material.

Technical assistance and installation training is available from your local cement and concrete associations. Planning, design, materials and construction information can be provided. The following associations can provide guidance:

Northern New England Concrete Promotion Association
50 Market Street
Suite 1A #221
South Portland, ME 04106
Phone: (888)875-3232
Fax: (207)221-1126
Email: info@nnecpa.org
Web: www.nnecpa.org

Northeast Cement Shippers Association
1580 Columbia Turnpike
Building 1, Suite 1
Castleton, NY 12033
Telephone: (518) 477-4925 / 4926
Facsimile: (518) 477-4927
Web: www.necementshippers.com

National Ready Mix Concrete Association
900 Spring Street
Silver Spring, MD 20910
Phone: 301-587-1400
888-84NRMCA (846-7622)
Fax 301-585-4219
www.perviouspavements.org
Email: info@nrmca.org

PORTLAND CEMENT PERVIOUS CONCRETE PAVEMENT

PART 1 GENERAL

1.01 Scope of Work:

A. The Work to be completed under this contract includes the furnishing of all labor, materials and equipment necessary for construction of Portland Cement Pervious Concrete Pavement for streets, parking & pedestrian areas in conformance with the plans and specifications.

1.02 References:

A. American Concrete Institute
   1. ACI 305 "Hot Weather Concreting"
   2. ACI 522 "Report on Pervious Concrete"
   3. ACI Flatwork Finisher Certification Program
   4. ACI Field Technician Certification Program

B. American Society for Testing and Materials
   1. ASTM C29 "Test for Bulk Density (Unit Weight) and Voids in Aggregate"
   2. ASTM C33 "Specification for Concrete Aggregates"
   3. ASTM C42 "Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete."
   4. ASTM C94 Specification for Ready-Mixed Concrete
   5. ASTM C 117 "Test Method for Material Finer than 75-Jlm (No. 200) Sieve in Mineral Aggregates by Washing."
   6. ASTM Cl38 "Test Method for Density (Unit Weight), Yield and Air Content (Gravimetric) of Concrete."
   7. ASTM CI40 "Test Methods for Sampling and Testing Concrete Masonry Units and Related Units"
   8. ASTM C150 "Specification for Portland Cement"
   9. ASTM C 172 "Practice for Sampling Freshly Mixed Concrete"
   10. ASTM C260 "Specification for Air-Entraining Admixtures for Concrete"
   11. ASTM C494 "Specification for Chemical Admixtures for Concrete"
   12. ASTM C595 "Specification for Blended Hydraulic Cements"
   13. ASTM C618 "Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete."
   14. ASTM C989 "Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars."
   15. ASTM CIOn "Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation."
   16. ASTM C 1602 "Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete"
   17. ASTM 01557 "Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3)."
   18. 03385 "Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer"
   19. ASTM E329 "Specification for Agencies Engaged in the Testing

and/or Inspection of Materials Used in Construction."

1.03 Quality Assurance:

A. Prospective contractors shall attend a pre-bid meeting where the pervious concrete pavement process will be described by industry representatives.

B. Prior to award the contractor shall submit evidence of two successful Pervious Concrete Pavement projects including but not limited to the following:

1. Project name and address, owner name and contact information
2. Test results including density (unit weight), void content and thickness

This requirement may be waived by the owner provided the contractor can demonstrate successful experience in the concrete industry and constructs test panel(s) for inspection and testing.

C. At least two members, or 30% of the crew (whichever is greater) shall be certified by the ACI Flatwork Finisher program and be NRMCA Certified Pervious Concrete Technicians.

1.04 Special Equipment: Pervious concrete requires specific equipment for compaction and jointing. The pavement shall be jointed and compacted using the methods listed.

A. Rolling compaction shall be achieved using a steel pipe that spans the width of the section placed and exerts a vertical pressure of at least 10 psi on the concrete.

B. When joints are placed in pervious pavements, they may be constructed by rolling, forming or sawing.

Rolled joints shall be formed using a "salt roller" to which a beveled fin with a minimum depth of y.. The thickness of the slab has been welded around the circumference of a steel roller. Sawed joints shall be constructed using an early entry or wet saw.

1.05 Submittals: Prior to commencement of the work the contractor shall submit the following:

A. Concrete materials:

1. Proposed concrete mixture proportions including all material weights, volumes, density (unit weight), water cement ratio, and void content.
2. Aggregate type, source and grading.
3. Cement and admixture manufacturer certifications

B. Qualifications: Evidence of qualifications listed under Quality Assurance.

C. Project details: Specific plans, details, schedule, construction procedures and quality control plan.

D. Subcontractors: List all materials suppliers and subcontractors to be used on the project.

1.06 Test Panels: Prior to construction, test panel(s) shall be placed and approved by the owner. The owner is permitted to waive this requirement based on contractor qualifications.

A. Test panel(s) shall be constructed in accordance with the plans and specifications. A minimum 225 sq. ft panel size shall be placed, jointed and cured using materials, equipment, and personnel proposed for the project.

B. Quality: Test panels shall have acceptable surface finish, joint details, thickness, porosity and curing procedures and shall comply with the testing and acceptance standards listed in the Quality Control section of this specification.

C. If test panels placed at the site are found to be deficient in thickness, density (unit weight) or percentage of voids, or of an unacceptable appearance, they shall be removed and taken to an approved landfill or recycling facility. If test panels are found to be satisfactory, they may be left in-place and included in the completed work.

PART 2 MATERIALS

2.01 Cement: Portland cement Type II or V conforming to ASTM Cl50 or Portland cement Type IP or IS conforming to ASTM C595.

2.02 Supplementary Cementitious Materials:

A. Class F Fly ash conforming to ASTM C618

B. Ground Iron Blast-Furnace Slag conforming to ASTM C989

2.03 Chemical Admixtures:

A. Air entraining agents shall comply with ASTM C260.

B. Chemical Admixtures shall comply with ASTM C494.

C. Hydration stabilizers are permitted to be used when it is necessary to increase concrete placement time to 90 minutes and improve finishing operations.

2.04 Aggregates:

A. Coarse aggregate shall comply with ASTM C33. Size 8 (3/8" to No. 16) or Size 89 (3/8 in. to No. 50) shall be used unless an alternate size is approved for use based on meeting the project requirements. Fine aggregate complying with ASTM C33, if used, shall not exceed 3 cu. ft.

B. Larger aggregate sizes may increase porosity but can decrease workability. Avoid well graded aggregates as they may reduce porosity, and may not provide adequate void content.

C. Where available, natural rounded aggregates are recommended.

2.05 Water: Water shall comply with ASTM C 1602.

2.06 Mixture Proportions: The composition of the proposed concrete mixtures shall be submitted to the owner's representative for review and/or approval and shall comply with the following provisions unless an alternative composition is demonstrated to comply with the project requirements.

A. Cementitious Content: For vehicle pavements, total cementitious content shall not be less than 630 lbs/cy. For pedestrian pavements, total cementitious shall not be less than 600 lbs/cy.

B. Supplementary cementitious content: Fly ash: 25% maximum. Slag: 50% maximum

C. Water / Cementitious Ratio: Maximum 0.30 for vehicle pavements and 0.35 for pedestrian pavements.

D. Aggregate Content: The bulk volume of aggregate per cubic yard shall be equal to 27 cubic foot when calculated from the dry rodded density (unit weight) determined in accordance with ASTM C29 jigging procedure.

E. Admixtures: Admixtures shall be used in accordance with the manufacturer's instructions and recommendations.

F. Mix Water: The quantity of mixing water shall be established to produce a pervious concrete mixture of the desirable workability to facilitate placing, compaction and finishing to the desired surface characteristics.

PART 3
EXECUTION

3.01 Subgrade:

A. Material: The top 6 inches shall be composed of granular or gravelly soil that is predominantly sandy with no more than a moderate amount of silt or clay. Granular sub-base may be placed over the subgrade.

B. Permeability: Subgrade shall have a minimum permeability of 0.5 inch per hour determined in accordance with ASTM 03385.

C. Compaction: Compact sub-grade to a minimum 90% and a maximum 95%. Over-compaction can inhibit subgrade percolation. Compaction shall be in accordance with ASTM 01557.

D. Fill: If fill material is required to bring the subgrade to final elevation, it shall be clean and free of deleterious materials. It shall be placed in 6-inch maximum layers, and compacted by a mechanical vibratory compactor to a minimum density of 90% in accordance with ASTM 01557.

E. Moisture: The subgrade moisture content shall be 1% - 3% above optimum as determined by ASTM 01557.

F. Verify subgrade preparation, grade, and conduct permeability & density tests for conformance to project requirements.

3.02 Formwork:

A. Form materials are permitted to be of wood or steel and shall be of width to the depth of the pavement.
Forms shall be of sufficient strength and stability to support mechanical equipment without deformation of plan profiles following spreading, strike-off and compaction operations. Forms may have a removable spacer placed above the depth of pavement. The spacers shall be removed following placement and vibratory strike-off to allow roller compaction.

3.03 Mixing and Hauling:

A. Production: Pervious concrete shall be manufactured and delivered in accordance with ASTM C 94.

B. Mixing: Mixtures shall be produced in central mixers or in truck mixers. When concrete is delivered in agitating or non-agitating units, the concrete shall be mixed in the central mixer for a minimum of 1.5 minutes or until a homogenous mix is achieved. Concrete mixed in truck mixers shall be mixed at the speed designated as mixing speed by the manufacturer for 75

- 100 revolutions.

C. Transportation: The pervious concrete mixture may be transported or mixed on site and discharge of individual loads shall be completed within one (1) hour of the introduction of mix water to the cement. Delivery times may be extended to 90 minutes when a hydration stabilizer is used.

D. Discharge: Each truckload will be visually inspected for consistency of concrete mixture. Water addition is permitted at the point of discharge to obtain the required mix consistency provided a measurable quantity is used before more than 0.5 cubic yard of concrete is discharged. A minimum of 30 revolutions at the manufacturer's designated mixing speed shall be required following the addition of any water to the mix. Discharge shall be a continuous operation and shall be completed as quickly as possible. Concrete shall be deposited as close to its final position as practical and such that discharged concrete is incorporated into previously placed plastic concrete.

3.04 Placing and Finishing:

A. The Contractor shall provide either slip form or vibratory form riding equipment to place the concrete unless otherwise approved by the Owner or Engineer in writing. Use of roller screeds is preferred. Internal vibration shall not be permitted. Unless otherwise permitted placement procedures shall utilize a mechanical vibratory screed to strike off the concrete 1;i" to 3/4" above final height, utilizing the form spacers described in Formwork.

B. Placed concrete shall not be disturbed while in the plastic state. Low spots after the screeding operation shall be filled up and tamped with hand tampers.

C. Following strike-off, remove spacers and compact the concrete to the form level, utilizing a steel roller, a plate compactor or other method approved by the Owner. Care shall be taken during compaction that sufficient compactive force is achieved without excessively working the concrete surface that might result in sealing off the surface porosity.

D. Hand tampers shall be used to compact the concrete along the slab edges immediately adjacent to the forms.
After compaction, inspection and repair, no further finishing shall be performed on the concrete. Surface curing shall begin immediately.

E. The pervious concrete pavement shall be compacted to the required cross-section and shall not deviate more than +/- 3/8 inch in 10 feet from profile grade.

3.05 Jointing

A. Joints in pervious pavements can be precluded at the option of the owner.

B. Control (contraction) joints shall be installed at regular intervals not to exceed 20 feet, or two times the width of the placement. The control joints shall be installed at 1/4 the depth (to a maximum depth of 1/3*")* of the thickness of the pavement. These joints must be installed in the plastic concrete by tooling method.

C. Jointing plastic concrete: Joints installed in the plastic concrete shall be constructed utilizing a small roller as described in the Special Equipment section of this specification. When this option is used it shall be performed immediately after roller compaction and prior to curing.

D. Jointing hardened concrete: Saw-cuts shall be made as soon as the pavement has hardened sufficiently to prevent raveling and uncontrolled cracking. Early entry sawing occurs later with pervious concrete than with conventional concrete. For either method, the curing cover shall be removed and the surface kept misted to prevent moisture loss. After sawing the curing cover shall be securely replaced for the remainder of the curing cycle.

E. Transverse construction joints: Transverse construction joints shall be installed whenever placing is suspended for 30 minutes or whenever concrete is no longer workable.

F. Isolation joints: Isolation joints shall used when abutting fixed vertical structures such i.e. light pole bases, building foundations, etc. Isolation material shall be positioned before concrete is placed and shall be the depth of the pavement section.

3.06 Curing:

A. Curing procedures shall begin no later than 20 minutes after final placement operations have been completed. The pavement surface shall be covered with a minimum of six (6) mil thick polyethylene sheet or other approved covering material. The cover shall overlap all exposed edges and shall be secured to prevent dislocation due to winds or adjacent traffic conditions. For additional guidance on hot weather concreting, see ACI 305.

B. The low water/cement ratio and high amount of exposed surface of pervious concrete makes it especially susceptible to drying out. Immediately after screeding, the surface shall be kept moist and evaporation prevented using a spray applied curing compound and/or evaporation retarder immediately after screeding.

C. The curing cover shall remain securely in place for a minimum of 7 days. No vehicular traffic shall be permitted on the pavement until curing is complete and no truck traffic shall be permitted for at least 14 days. The owner has the option of permitting earlier traffic opening times.

3.07 Quality Control:

A. The owner shall employ a testing laboratory that conforms to the requirements of ASTM E329 and ASTM CI077. All personnel engaged in testing shall be certified by the American Concrete Institute as ACI Concrete Field Technicians or equivalent.

B. Traditional portland cement pavement testing procedures based on strength and slump control are not applicable to this type of pavement material.

C. Concrete tests shall be performed for each 150 cubic yards or fraction thereof with a minimum of one test for each day's placement.

D. Plastic concrete shall be sampled in accordance with ASTM C 172 and density (unit weight) measured in accordance with ASTM C 138. The density (unit weight) of the delivered concrete shall be +/- 5 pcf of the design density (unit weight).

E. Plastic void content shall be calculated as per ASTM Cl38, Gravimetric Air Determination and compared to the void percentage required by the Hydraulic design. Unless otherwise specified, Void content shall be between 15% and 25%.

F. Hardened concrete shall be tested at a rate of one set of three cores per 150 cy of concrete placed on one day or fraction thereof. The cores shall be drilled in accordance with ASTM C 42. The cores when measured for length shall not be more than Y2 inch less than the specified design thickness.

G. The cores shall be tested for density (unit weight) and void content using ASTM 140. Density (unit weight) shall be +/- 5 pcf of the design unit weight. Void content shall be not be greater than 2% below the specified design void content. Void content shall calculated as follows:

$$\% \text{ Voids} = I - (Dd/Di) * 100$$

where: Dd = oven dried density of core

Di = immersed density of core

3.08 Basis of Payment

A. Pervious concrete pavement shall be paid for based on the square yard (foot) of in-place product including materials and labor. Payment shall be reduced for the following deficiencies:

Deficiency	**Measurement**	**Payment Reduction**
Thickness	1/2" to 1"	25%
Thickness	Greater than - 1"	remove and replace
Void Content	Greater than 3%	25%
	specified void content	

END OF SECTION

"This specification is intended solely for use by professional personnel who are competent to evaluate the significance and limitations of the information provided and who will accept responsibility for the application of this information. The authors disclaim any and all responsibility and liability for the accuracy and the application of the information contained in this publication to the full extent permitted by law. "

F.5 Construction Standards/Specifications for Filter BMPs

F.5.1 Sand Filter Specifications

F.5.1.1 Material Specifications for Sand Filters

The allowable materials for sand filter construction are detailed in Table F-16.

F.5.1.2 Sand Filter Testing Specifications

Underground sand filter applications, facilities within sensitive groundwater aquifers, and filters designed to serve urban LUHPPLs are to be tested for watertightness prior to placement of filter layers. The systems should be tested for watertightness using the US EPA test procedures as described below and included in the Onsite Wastewater Treatment Systems Manual (USEPA, 2002). Hydrostatic or vacuum tests, and manway risers and inspection ports should be included in the test. The professional association representing the materials industry of the type of tank construction (e.g., the National Pre-cast Concrete Association) should be contacted to establish the appropriate testing criteria and procedures. Test criteria for precast concrete are presented below in Table F-15.

Table F-15 Watertightness Testing Procedure/Criteria for Precast Concrete Tanks (USEPA, 2002)

Standard	Hydrostatic test		Vacuum test	
	Preparation	Pass/fail criterion	Preparation	Pass/fail criterion
C 1227, ASTM (1993)	Seal tank, fill with water, and let stand for 24 hours. Refill tank.	Approved if water level is held for 1 hour	Seal tank and apply a vacuum of 2 in. Hg.	Approved if 90% of vacuum is held for 2 minutes.
NPCA (1998)	Seal tank, fill with water, and let stand for 8 to 10 hours. Refill tank and let stand for another 8 to 10 hours.	Approved if no further measurable water level drop occurs	Seal tank and apply a vacuum of 4 in. Hg. Hold vacuum for 5 minutes. Bring vacuum back to 4 in. Hg.	Approved if vacuum can be held for 5 minutes without a loss of vacuum.

All overflow weirs, multiple orifices and flow distribution slots to be field-tested as to verify adequate distribution of flows.

F.5.1.3 Sand Filter Construction Specifications

Provide sufficient maintenance access; 12-ft-wide road with legally recorded easement. Vegetated access slopes to be a maximum of 10%; gravel slopes to 15%; paved slopes to 25%.

Absolutely no runoff is to enter the filter until all contributing drainage areas have been stabilized.

Surface of filter bed to be *completely level*.

All sand filters should be clearly delineated with signs so that they may be located when maintenance is due.

Surface sand filter applications shall be planted with appropriate grasses per Appendix B and RIDOT specification section L.01.

F.5.1.4 Specifications Pertaining to Sand Filters Designed Underground

Provide manhole and/or grates to all underground and below grade structures. Manholes shall be in compliance with RIDOT specification section 702 - Manholes, Inlets, and Catch Basins but diameters should be 30in minimum (to comply with OSHA confined space requirements) but not too heavy to lift. Aluminum and steel louvered doors are also acceptable. Ten-inch long (minimum) manhole steps (12 in o.c.) shall be cast in place or drilled and mortared into the wall below each manhole. A 5 ft minimum height clearance (from the top of the sand layer to the bottom of the slab) is required for all permanent underground structures. Lift rings are to be supplied to remove/replace top slabs. Manholes may need to be grated to allow for proper ventilation; if required, place manholes *away* from areas of heavy pedestrian traffic.

Underground sand filters shall be constructed with a dewatering gate valve located just above the top of the filter bed should the bed clog.

Underground sand beds shall be protected from trash accumulation by a wide mesh geotextile screen to be placed on the surface of the sand bed; screen is to be rolled up, removed, cleaned and re-installed during maintenance operations.

Table F-16 Material Specifications for Sand Filters

Parameter	Specification	Size	Notes
Sand	clean AASHTO M-6 or ASTM C-33 concrete sand	0.02" to 0.04"	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. No rock dust can be used for sand.
Peat	ash content: < 15% pH range: 5.2 to 4.9 loose bulk density 0.12 to 0.15 g/cc	n/a	The material must be Reed-Sedge Hemic Peat, shredded, uncompacted, uniform, and clean.
Underdrain gravel	RIDOT Specs. Sec. 300 AASHTO M-43	0.25" to 0.75"	Must be washed, clean gravel; refer to Appendix Section F.4.1, Part 2 for applicable material specs.
Geotextile Fabric (if required)	ASTM D-751 (puncture strength - 125 lb.) ASTM D-1117 (Mullen Burst Strength - 400 psi) ASTM D-1682 (Tensile Strength - 300 lb.)	0.08" thick equivalent opening size of #80 sieve	Must maintain 125 gpm per sq. ft. flow rate. Note: a 4" pea gravel layer may be substituted for geotextiles meant to separate filter layers.
Impermeable Liner (if required)	ASTM D 751 (thickness) ASTM D 412 (tensile strength 1,100 lb., elongation 200%) ASTM D 624 (Tear resistance - 150 lb./in) ASTM D 471 (water adsorption: +8 to -2% mass)	30 mil thickness	Liner to be ultraviolet resistant. A geotextile fabric should be used to protect the liner from puncture.
Underdrain Piping	RIDOT Specs. Sec. 703 ASTM D-1785 or AASHTO M-278	4-6" rigid schedule 40 PVC	3/8" perf. @ 6" on center, 4 holes per row; minimum of 3" of gravel over pipes; not necessary underneath pipes
Concrete (Cast-in-place)	See RIDOT Specs. Sec. 600 f'c = 3500 psi, normal weight, air-entrained; reinforcing bars to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28 day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved local or RI standards* requires design drawings sealed and approved by a RI-licensed structural PE.
Concrete (pre-cast)	See RIDOT Specs. Sec. 600 per pre-cast manufacturer	n/a	SEE ABOVE NOTE
non-rebar steel	ASTM A-36	n/a	structural steel to be hot-dipped galvanized ASTM A123

Table F-17 Sand/Organic Filter System Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Pre-construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Facility location staked out		
2. Excavation		
Size and location		
Side slopes stable		
Foundation cleared of debris		
If designed as exfilter, excavation does not compact subsoils		
Foundation area compacted		
3. Structural Components		
Dimensions and materials		
Forms adequately sized		

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
Concrete meets standards		
Prefabricated joints sealed		
Underdrains (size, materials)		
4. Completed Facility Components		
24-hour water filled test		
Contributing area stabilized		
Filter material per specification		
Underdrains installed to grade		
Flow diversion structure properly installed		
Pretreatment devices properly installed		
Level overflow weirs, multiple orifices, distribution slots		
5. Final Inspection		
Dimensions		
Surface completely level		
Structural components		
Proper outlet		
Ensure that site is properly stabilized before flow is directed to the structure.		

Comments:

Actions to be Taken:

F.5.2 Construction Specifications for Bioretention Systems

F.5.2.1 Material Specifications

The allowable materials to be used in bioretention area are detailed in Table F-18.

F.5.2.2 Bioretention Soil

The soil should be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches. No other materials or substances should be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The bioretention soil should be free of noxious weeds.

The bioretention system shall utilize planting soil having a composition as follows:

Sand: 85-88%
Soil fines: 8 to 12% (no more than 2% clay)
Organic Matter*: 3 to 5%

*Note: For bioretention applications with a soil depth of less than 4 feet, add 20% (by volume) of well aged (3 months), well aerated, leaf compost (or approved equivalent) to the above planting soil mixture. Where soil fines content is less than 12%, add a corresponding % of leaf compost.

A textural analysis is required to ensure the bioretention soil meets the specification listed above. The bioretention soil should also be tested for the following criteria:

pH range	5.2 - 7.0
magnesium	not to exceed 32 ppm
phosphorus P_2O_5	not to exceed 69 ppm
potassium K_2O	not to exceed 78 ppm
soluble salts	not to exceed 500 ppm

All bioretention areas should have a minimum of one test. Each test should consist of both the standard soil test for pH, phosphorus, and potassium and additional tests of organic matter, and soluble salts.

Since different labs calibrate their testing equipment differently, all testing results should come from the same testing facility.

Should the pH fall out of the acceptable range, it may be modified (higher) with lime or (lower) with iron sulfate plus sulfur.

F.5.2.3 Mulch Layer Specifications.

A finely shredded, well-aged organic hardwood mulch is the preferred accepted mulch; a finely shredded, well-aged organic dark pine mulch may be accepted on a case-by-case basis. Bark dust mulches and wood chips will float and move to the perimeter of the bioretention area during a storm event and are not acceptable.

Shredded mulch must be well aged (6-12 months) for acceptance.

Mix approximately ½ the specified mulch layer into the planting soil to a depth of approximately 4 inches to help foster a highly organic surface layer.

F.5.2.4 Compaction

It is very important to minimize compaction of both the base of the bioretention area and the required backfill. When possible, use excavation hoes to remove original soil. If bioretention area is excavated using a loader, the contractor should use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction resulting in reduced infiltration rates and storage volumes and is not acceptable. Compaction will significantly contribute to design failure.

Compaction can be alleviated at the base of the bioretention facility by using a primary tilling operation such as a chisel plow, ripper, or subsoiler. These tilling operations are performed to refracture the soil profile through the 12-in compaction zone. Substitute methods must be approved by the engineer. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment.

When backfilling the bioretention facility, place soil in lifts 12in or greater. Do not use heavy equipment within the bioretention basin. Heavy equipment can be used around the perimeter of the basin to supply soils and sand. Grade bioretention materials with light equipment such as a compact loader or a dozer/loader with marsh tracks.

F.5.2.5 Plant Installation

The plant root ball should be planted so 1/8th of the ball is above final grade surface. Root stock of the plant material should be kept moist during transport and on-site storage. The diameter of the planting pit should be at least six inches larger than the diameter of the planting ball. Set and maintain the plant straight during the entire planting process. Thoroughly water ground bed cover after installation.

Trees should be braced using 2 in x 2 in stakes only as necessary and for the first growing season only. Stakes are to be equally spaced on the outside of the tree ball.

Grasses and legume seed should be tilled into the soil to a depth of at least one inch. Grass and legume plugs should be planted following the non-grass ground cover planting specifications.

The planting soil specifications provide enough organic material to adequately supply nutrients from natural cycling. The primary function of the bioretention structure is to improve water quality. Adding fertilizers defeats, or at a minimum, impedes this goal. Only add fertilizer if compost or mulch is used to amend the soil. Rototill urea fertilizer at a rate of 2 pounds per 1,000 square feet.

F.5.2.6 Underdrains

Underdrains should be in accordance with RIDOT specification section 703 – Underdrains and Combination Underdrains and the following provisions, as applicable.

Underdrains should be placed on a minimum 3'-0" wide section of filter cloth. Pipe is placed next, followed by the gravel bedding. The ends of underdrain pipes not terminating in an observation well should be capped.

The main collector pipe for underdrain systems should be constructed at a minimum slope of 0.5%. Observation wells and/or clean-out pipes must be provided (one minimum per every 1,000 square feet of surface area).

F.5.2.7 Miscellaneous

The bioretention facility may not be constructed until all contributing drainage area has been stabilized.

Table F-18 Materials Specifications for Bioretention

Parameter	Specification	Size	Notes
Planting Soil	sand 85-88% soil fines 8 - 12% (≤ 2% clay) organics 3 - 5%	n/a	USDA soil types loamy sand or sandy loam
Mulch	shredded hardwood mulch preferred	n/a	aged 6 months, minimum
Geotextile	Class “C” apparent opening size (ASTM-D-4751) grab tensile strength (ASTM-D-4632) burst strength (ASTM-D-4833)	n/a	for use over underdrains (extend 1 – 1.5 ft each side) and as necessary on sides of bioretention basin
Sand (2”-4” layer over choker stone)	AASHTO M-6 or ASTM C-33	0.02” to 0.04”	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. No rock dust can be used for sand.
Choking Stone Layer (4” layer pea gravel)	AASHTO M43 (ASTM D 448) No. 8 or 89 gravel	0.375” to 0.75”	
Underdrain Gravel	RIDOT Specs. Sec. 703 AASHTO M-43	1.0”	Double-washed and clean of fines
Underdrain Piping	RIDOT Specs. Sec 703 ASTM D 1785 or AASHTO M-278	4 to 6” rigid schedule 40 PVC	3/8” perf. @ 6” on center, 4 holes per row; minimum of 3” of gravel over pipes; not necessary underneath pipes
Poured-in-place Concrete (if required)	See RIDOT Specs. Sec. 600; f’c = 3,500 lb. @ 28 days, normal weight, air-entrained; reinforcing bars to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28-day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved standards* requires design drawings sealed and approved by a RI-licensed structural PE.

Table F-19 Bioretention Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
If designed as exfilter, soil testing for permeability		
Facility location staked out		
2. Excavation		
Size and location		
Lateral slopes completely level		
If designed as exfilter, ensure that excavation does not compact subsoils.		
Longitudinal slopes within design range		
3. Structural Components		
Stone diaphragm installed correctly		

CONSTRUCTION SEQUENCE	SATISFACTORY/ UNSATISFACTORY	COMMENTS
Outlets installed correctly		
Underdrain		
Pretreatment devices installed		
Soil bed composition and texture		
4. Vegetation		
Complies with planting specs		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
5. Final Inspection		
Dimensions		
Proper stone diaphragm		
Proper outlet		
Soil/ filter bed permeability testing		
Effective stand of vegetation and stabilization		
Construction generated sediments removed		
Contributing watershed stabilized before flow is diverted to the practice		

Comments:

Actions to be Taken:

F.6 Construction Standards/Specifications for Extensive Green Roofs

Extensive rooftops are commonly designed for maximum thermal and hydrological performance and minimum weight load. Construction specifications will vary based on the specific manufacturer's recommendations. General specifications for the planting media, filter layer, and drain layer are provided below, as adapted from the LID Manual for Michigan (SEMCOG, 2008).

F.6.1 Planting Media

Growth media should be a soil-like mixture containing not more than 15% organic content (wet combustion or loss on ignition methods). The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and 'soil' structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Non-capillary Pore Space at Field Capacity, 0.333 bar (TMECC 03.01, A)	>= 15% (vol)
Moisture Content at Field Capacity (TMECC 03.01, A)	>= 12% (vol)
Maximum Media Water Retention (FLL)	>= 30% (vol)
Alkalinity, Ca CO3 equivalents (MSA)	<= 2.5%
Total Organic Matter by Wet Combustion (MSA)	3-15% (dry wt.)
pH (RCSTP)	6.5-8.0
Soluble Salts (DTPA saturated media extraction)"(RCSTP)	<= 6 mmhos/cm
Cation exchange capacity (MSA)	>= 10 meq/100g
Saturated Hydraulic Conductivity for Single Media Assemblies (FLL)	>= 0.05 in/min
Saturated Hydraulic Conductivity for Dual Media Assemblies (FLL)	>= 0.30 in/min

Grain-size Distribution of the Mineral Fraction - ASTM-D422 (CCREF, 2004)

<u>Single Media Assemblies:</u>	
Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	<= 5%
Pct. Passing US#60 sieve	<= 10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	0 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

Dual Media Assemblies:	
Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	5-15%
Pct. Passing US#60 sieve	10-25%
Pct. Passing US#18 sieve	20 - 50%
Pct. Passing 1/8-inch sieve	55 - 95%
Pct. Passing 3/8-inch sieve	90 -100%

Macro- and micro-nutrients shall be incorporated in the formulation in initial proportions suitable for support the specified planting.

F.6.2 Filter layer

Between the planting media and drain layer lays a filter. The filter usually comprises one or two layers of non-woven geotextile, where one of the layers may be treated with a root inhibitor (*i.e.* copper or a mild herbicide). Extensive green roofs usually employ plants with easy-to-control roots. Since root and media particle diameters can vary, filters should be specified for different media and plant types to ensure adequate flow rates for a given planting mix without losing too much silt or allowing excessive root penetration.

The Filter Layer should provide a durable separation between the drainage and growth media layers (Only lightweight non-woven geotextiles are recommended for this function).

- Unit Weight (ASTM-D3776) <= 4.25 oz/yd2
- Grab tensile (ASTM-D4632) <= 90 lb
- Mullen Burst Strength (ASTM-D4632) >= 135 lb/in
- Permittivity (ASTM-D4491) >= 2 per second

F.6.3 Protective Layer

The Protective Layer should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended. At present only FLL, the German Research Society for Landscape Development and Landscape Design (***F****orschungsgesellschaft* ***L****andschaftsentwicklung* ***L****andschaftsbau e.V*.) offers a recognized test for root-barriers. Several FLL-certified materials are available in the United States. Interested American manufactures can submit products for testing to FLL-certified labs.

F.7 Construction Standards/Specifications for Open Channels

F.7.1 Material Specifications

The recommended construction materials for open channels and filter strips are detailed in Table F-20.

F.7.1.1 Dry Swales

Roto-till soil/gravel interface approximately 6in to avoid a sharp soil/gravel interface.

Permeable soil mixture should meet the bioretention planting soil specifications.

Check dams, if required, shall be placed as specified.

Side slopes to be 2:1 minimum; (3:1 or greater preferred).

No gravel or perforated pipe is to be placed under driveways.

Seed with flood/drought resistant grasses; see Appendix B for guidance, and RIDOT specification section L.01.

Bottom width to be 8 ft maximum to avoid braiding; larger widths may be used if proper berming is supplied (i.e., barrier between minimum widths). Width to be 2 ft minimum.

F.7.1.2 Wet Swales

Excavate into undisturbed soils; do not use an underdrain system.

Table F-20 Open Channel Materials Specifications

Parameter	Specification	Size	Notes
Dry swale soil	sand 85-88% soil fines 8 - 12% (≤ 2% clay) organics 3 - 5%	n/a	USDA soil types loamy sand or sandy loam, soil with a higher percent organic content is preferred
Dry swale sand	ASTM C-33 fine aggregate concrete sand	0.02 in to 0.04 in	
Check Dam (pressure treated)	RIDOT Specs. Sec. 207 AWPA Standard C6	6 in x 6 in or 8 in x 8 in	*do not* coat with creosote; embed at least 3ft into side slopes
Check Dam (natural wood)	RIDOT Specs. Sec. 207 Black Locust, Red Mulberry, Cedars, Catalpa, White Oak, Chestnut Oak, Black Walnut	6 in to 12 in diameter; notch as necessary	*do not* use the following, as these species have a predisposition towards rot: Ash, Beech, Birch, Elm, Hackberry, hemlock, Hickories, Maples, Red and Black Oak, Pines, Poplar, Spruce, Sweetgum, Willow
Filter Strip sand/gravel pervious berm	sand: per dry swale sand gravel; AASHTO M-43	sand: 0.02 in to 0.04 in gravel: 2 in to 1 in	mix with approximately 25% loam soil to support grass cover crop; see Bioretention planting soil notes for more detail.
Gravel diaphragm and curtain drain	ASTM D 448	varies (No. 6) or (1/8 in to 3/8 in)	use clean bank-run gravel
underdrain gravel	RIDOT Specs. Sec. 703 AASHTO M-43	1.0 in	
underdrain	RIDOT Specs. Sec. 703 ASTM D -1785 or AASHTO M-278	4-6 in rigid Schedule 40 PVC	3/8 in perf. @ 6 in o.c.; 4 holes per row
Geotextile	See RIDOT Standards and Specs	n/a	
riprap	RIDOT Specs. Sec. 920	varies	

Table F-21 Open Channel System Construction Inspection Checklist

Project:

Location:

Site Status:

Date:

Time:

Inspector:

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility location staked out		
2. Excavation		
Size and location		
Side slope stable		
Soil permeability		
Groundwater / bedrock		
Lateral slopes completely level		
Longitudinal slopes within design range		
Excavation does not compact subsoils		

CONSTRUCTION SEQUENCE	SATISFACTORY / UNSATISFACTORY	COMMENTS
3. Check dams		
Dimensions		
Spacing		
Materials		
4. Structural Components		
Underdrain installed correctly		
Inflow installed correctly		
Pretreatment devices installed		
5. Vegetation		
Complies with planting specifications		
Topsoil adequate in composition and placement		
Adequate erosion control measures in place		
6. Final inspection		
Dimensions		
Check dams		
Proper outlet		
Effective stand of vegetation and stabilization		
Contributing watershed stabilized before flow is routed to the facility		

Comments:

Actions to be Taken:

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APPENDIX G: POLLUTION PREVENTION AND SOURCE CONTROLS

G.1 Overview

Pollution prevention techniques must, to the extent practicable, be incorporated into all site designs, especially at commercial and light industrial sites, to minimize the potential impact those activities may have on stormwater runoff quality. Preventative source controls must also be applied in residential development, particularly in preventing floatables (trash and debris) from entering storm sewer drainage systems.

G.2 General Pollution Prevention Design Features

Inlets to stormwater management systems should incorporate trash racks wherever practicable. Storm drain marking (e.g., stenciling) to discourage dumping must also be provided at each inlet. Maintenance plans must include a schedule for regular maintenance and inspection of trash racks.

G.3 Solid Waste Containment

Proper containment of solid waste will prevent it from entering drainage systems and polluting waterways. At a minimum, apply the following pollution prevention practices:

- Trash and recycling receptacles must be provided with regular collection at all sites;
- Industrial and commercial sites must include regular street sweeping (at least annually) in their maintenance plans; and
- Pet waste stations that provide bags and waste containers are recommended at all residential developments and must be provided at multiunit dwellings, such as apartments, town houses, and condominiums.

G.4 Roads and Parking Area Management

Roads and parking areas constitute a large portion of Rhode Island’s impervious surfaces and are often directly connected to storm drain systems. These impervious areas contribute relatively high concentrations of a wide variety of pollutants, including sediment, nutrients, metals, and volatile organic compounds (VOCs), among other constituents. The discussion below addresses guidance requirements related to road and parking area management:

G.4.1 Street and Parking Lot Sweeping

Street sweeping helps to remove sediment and debris from paved surfaces, reducing potential pollutant transport to waterbodies. Street and parking lot sweeping may also reduce the need for maintenance of pretreatment devices, such catch basins and forebays that precede WVTSs or bioretention areas.

Street sweeping is a requirement for municipalities pursuant to Phase II of the RIPDES Stormwater Regulations and is also recommended for private entities. Currently, available street sweeping technology is not considered to meet the water quality treatment standard and should not be relied on for TSS removal, but does help as a pretreatment practice.

Debris collected from some streets and parking lots (e.g., LUHPPLs) may be regulated as a hazardous waste. For these cases, debris must be disposed of in accordance with appropriate practice and applicable regulatory standards. Appendix A of the *Rules and Regulations for Composting Facilities and Solid Waste Management Facilities,* which is entitled “Management of Street Sweepings in Rhode Island,” should be reviewed. For further information, contact the DEM Office of Waste Management.

G.4.2 Deicing and Salt Storage

Deicing and sanding operations are often necessary for safety during winter storms; however, the materials used create water quality problems. Use deicing chemicals and sand judiciously. Consider the information in Table G-1 when selecting a deicer.

Table G-1 Comparison of Environmental Effects of Common Roadway Deicers

Media	**Sodium Chloride (NaCl)**	**Calcium Chloride ($CaCl_2$)**	**Calcium magnesium acetate (CMA) ($CaMgC_2H_3O_2$)**	**Sand (SiO_2)**
Soils	Cl complexes release heavy metals; Na can breakdown soil structure and reduce permeability	Ca can exchange with heavy metals, increase soil aeration and permeability.	Ca and Mg can exchange with heavy metals.	Gradually will accumulate on soil.
Vegetation	Salt spray/splash can cause leaf scorch and browning or dieback of new plant growth up to 50 feet from road; osmotic stress can result from salt uptake; grass is more tolerant than trees and woody plants.		Little effect.	Accumulates on and around low vegetation.
Groundwater	Mobile Na and Cl ions readily reach groundwater, and concentration levels can temporarily increase in areas of low flow during spring thaws. Ca and Mg can release heavy metals from soil.			No known effect.
Surface Water	Can cause density stratification in small lakes having closed basins, potentially leading to anoxia in lake bottoms; often contain nitrogen, phosphorus, and trace metals as impurities, often in concentrations greater than 5 ppm.		Depletes dissolved oxygen in small lakes and streams when degrading.	Accumulated sand alters stream geometry and habitat

Media	Sodium Chloride (NaCl)	Calcium Chloride ($CaCl_2$)	Calcium magnesium acetate (CMA) ($CaMgC_2H_3O_2$)	Sand (SiO_2)
Aquatic Biota	Little effect in large or flowing bodies at current road salting amounts; small streams that are end points for runoff can receive harmful concentrations of Cl; Cl from NaCl generally not toxic until it reaches levels of 1,000-36,000 ppm.		Can cause oxygen depletion.	Accumulation of particles to stream bottoms degrades habitat, clogs gills.

Source: Adapted from Ohrel, 2000

Sand and deicing chemicals should be stored under cover so as to prevent their exposure to stormwater; the DEM Groundwater Quality Rules require that deicer materials be covered in areas where the groundwater is classified GAA or GA. Table G-2 provides recommendations appropriate for storage and use of deicers. Storage of these materials may be regulated as an industrial activity. Contact DEM's Stormwater Program in the Office of Water Resources for further information.

Table G-2 Recommendations to Reduce Deicer Impacts

Activity	Recommendation
Storage	• Salt storage piles should be completely covered, ideally by a roof, and at a minimum, by a weighted tarp, and stored on impervious surfaces. The DEM Groundwater Quality Rules require that deicer materials be covered in areas where the groundwater is classified GAA or GA. • Runoff should be contained in appropriate areas. • Spills should be cleaned up after loading operations. The material may be directed to a sand pile or returned to salt piles. • Avoid storage in drinking water supply areas, water supply aquifer recharge areas, and public wellhead protection areas.
Application	• Application rate of deicing materials should be tailored to road conditions (i.e., high versus low volume roads). • Trucks should be equipped with sensors that automatically control the deicer spread rate. • Drivers and handlers of salt and other deicers should receive training to improve efficiency, reduce losses, and raise awareness of environmental impacts.

Activity	Recommendation
Other	• Identify ecosystems such as wetlands that may be sensitive to salt. • Use calcium chloride and CMA in sensitive ecosystem areas. • To avoid over-application and excessive expense, choose deicing agents that perform most efficiently according to pavement temperature. • Monitor the deicer market for new products and technology.

Source: Adapted from Ohrel, 2000.

G.4.3 Snow Disposal

Improper snow disposal can be a threat to public health and the environment. Disposal should consider site selection, site preparation and maintenance, and emergency snow disposal locations and procedures. Refer to DEM's Snow Disposal Policy for more details on these topics, which are summarized below.

G.4.3.1 Site Selection

The key to selecting effective snow disposal sites is to locate them adjacent to or on pervious surfaces in upland areas away from water resources and wells. At these locations, snow meltwater can filter in to the soil, leaving behind sand and debris, which can be removed in the springtime. When selecting a site for snow disposal, adhere to the following guidelines:

- Avoid dumping snow into any waterbody, including rivers, reservoirs, ponds, lakes, wetlands, bays, or the ocean. In addition to water quality impacts and flooding, snow disposed of in open water can cause navigational hazards when it freezes.
- Do not dump snow within a Wellhead Protection Area (WHPA) of a public water supply well, or within 200 feet of a private well, where road salt may contaminate water supplies.
- Avoid dumping snow in sanitary landfills and gravel pits. Snow meltwater will create more contaminated leachate in landfills posing a greater risk to groundwater. In gravel pits, there is little opportunity for pollutants to be filtered out of the meltwater because groundwater is close to the land surface.
- Avoid disposing of snow on top of storm drain catch basins or in stormwater drainage swales or ditches. Snow combined with sand and debris may block a storm drainage system, causing localized flooding. In addition, a high volume of sand, sediment, and litter released from melting snow may be quickly transported through the drainage system into surface water.

G.4.3.2 Site Selection Procedures

It is important that the municipal Department of Public Works or Highway Department, and other appropriate municipal offices work together to select appropriate snow disposal sites. The following steps should be taken:

- Estimate how much snow disposal capacity is needed for the season so that an adequate number of disposal sites can be selected and prepared;
- Identify sites that could potentially be used for snow disposal such as municipal open space (e.g., parking lots or parks);
- Sites located in upland locations that are not likely to impact sensitive environmental resources should be selected first; and
- If more storage space is needed, prioritize the sites with the least environmental impact (using the site selection criteria and the online Environmental Resource Map as a guide).

Environmental Resource Map

An interactive map containing a wide variety of GIS data layers of interest to local planning or zoning board members, consultants, or anyone else needing a general mapping of soils, wetlands, land use patterns, regulatory overlay districts and other environmental information can be accessed via the internet at the following address: http://www.state.ri.us/dem/maps/index.htm.

This interactive map can be used to identify publicly owned open spaces and approximate locations of sensitive environmental resources (locations should be field verified where possible).

G.4.3.3 Site Preparation and Maintenance

In addition to carefully selecting disposal sites before the winter begins, it is important to prepare and maintain these sites to maximize their effectiveness. The following maintenance measures should be undertaken for all snow disposal sites:

- A silt fence or equivalent barrier should be placed securely on the down-gradient side of the snow disposal site;
- To filter pollutants out of the meltwater, a 50-foot vegetative buffer strip should be maintained during the growth season between the disposal site and adjacent waterbodies;
- Debris should be cleared from the site prior to using the site for snow disposal; and
- Debris should be cleared from the site and properly disposed of at the end of the snow season.

G.4.3.4 Emergency Snow Disposal

Under normal winter conditions, storage, and disposal of snow should be done exclusively in upland areas, not in or adjacent to waterbodies or wetlands. However, under extraordinary conditions when upland snow storage options are exhausted, it may be necessary to dispose of snow near or in certain waterbodies. The following guidance does not constitute a Clean Water Act permit for such disposal. However, in an emergency situation, DEM is unlikely to pursue an enforcement action for snow disposal by governmental entities into or near certain waters if conducted in accordance with the conditions identified below.

As mentioned earlier, it is important to estimate the amount of snow disposal capacity you will need so that an adequate number of upland disposal sites can be selected and prepared. If despite your planning, designated upland disposal sites have been exhausted, snow may be disposed of at other locations that meet the criteria in Section G.4.3.2.

Under extraordinary conditions, when all upland snow disposal options are exhausted, disposal of snow that is not obviously contaminated with road salt, sand, and other pollutants may be allowed near (within 50 feet of) or in certain waterbodies under certain conditions. In these dire situations, notify the DEM – Office of Water Resources, RIPDES Program at 222-4700 (or 222-3070 after normal business hours) before disposing of snow in a waterbody. If upland disposal is not available, and snow needs to be removed/relocated for safety reasons, then as a last resort waterways may be used in accordance with the following conditions:

- Dispose of snow in open water with adequate flow and mixing to prevent ice dams from forming;
- Do not dispose of snow in coastal or freshwater wetlands, eelgrass beds, vegetated shallows, vernal pools, shellfish beds, mudflats, outstanding resource waters, drinking water reservoirs and their tributaries, Wellhead Protection Areas (WHPAs), or other areas designated by the State as being environmentally sensitive;
- In coastal communities, preference should be given to disposal in salt water if it is available;
- Do not dispose of snow where trucks may cause shoreline damage or streambank damage or erosion; and
- Consult with appropriate municipal officials to ensure that snow disposal in water complies with local ordinances and bylaws.

G.4.4 Driveway and Parking Lot Sealants

Driveway and parking lot sealants are a major source of polycyclic aromatic hydrocarbons (PAHs) in our environment. There are two types of sealant: asphalt based and coal-tar based. Both types of sealant contain PAHs, but the coal-tar based sealants have a far higher concentration of PAHs (as much as 70 times higher than asphalt based). As the sealants wear down, small particles of sealant are washed off by stormwater into surface waters. PAHs have been found to be toxic to aquatic life, with bottom dwelling organisms most at risk since PAHs tend to attach to sediment rather than dissolve in water. Also, in recognition of the human health effects of PAHs, DEM has adopted the US EPA water column human health criteria for PAHs in the DEM Water Quality Regulations. Because of the high concentrations of PAHs in coal-tar based sealants, DEM recommends that coal-tar based sealants not be used. For more information, see: US Geological Survey Fact Sheet 2005-3147, "Parking Lot Sealcoat: A Major Source of Polycyclic Aromatic Hydrocarbons (PAHs) in Urban and Suburban Environments."

G.5 Hazardous Materials Containment

As applicable, project proponents must provide a completed Stormwater Pollution Prevention Plan in accordance with the Rhode Island Pollution Discharge Elimination System Regulations. At a minimum, the following practices should be incorporated as part of site design:

- Site designs must incorporate adequate indoor storage of hazardous materials as the primary method for preventing problems related to stormwater;
- Diversion through devices such as curbing and berms should be incorporated wherever stormwater has the potential to runoff into hazardous materials storage areas; and
- Secondary containment must be included wherever spills might occur (e.g., fueling and hazardous materials transfer and loading areas). Oil/grit separators and other manufactured treatment devices may temporarily contain certain spills and contaminated stormwater. However, these devices should be used as backup for tighter containment practices.

G.6 Septic System Management

Approximately one-third of Rhode Islanders use some form of onsite wastewater treatment system (i.e., septic system, cesspool, etc.). When septic systems fail, they may become a major source of pollution to surface and groundwater. Discharge from failed systems is often carried to surface water via stormwater runoff. Stormwater management plans must discuss appropriate operation and management for all onsite wastewater treatment systems (OWTSs) on the project site. Use of regular inspections in accordance with the procedures of *Septic System Checkup: The Rhode Island Manual for Inspections* is recommended.

G.7 Lawn, Garden, and Landscape Management

Lawns are a significant feature of urban landscapes. Estimates of turf and lawn coverage in the United States are as high as 30 million acres, which, if lawns were classified as a crop, would rank as the fifth largest in the country after corn, soybeans, wheat, and hay (Swann and Schueler, 2000). This large area of managed landscape has the potential to contribute to urban runoff pollution due to overfertilization, overwatering, overapplication of pesticides, and direct disposal of lawn clippings, leaves, and trimmings. Also, erosion from bare patches of poorly managed lawns contribute sediment to watercourses, and disposal of lawn clippings in landfills can reduce the capacity of these facilities to handle other types of waste.

The following standards for grounds management must be incorporated into stormwater management plans:

Lawn conversion - Grasses require more water and attention than alternative groundcovers, flowers, shrubs, or trees. Alternatives to turf are especially recommended for problem areas such as lawn edges, frost pockets, shady spots, steep slopes, and soggy areas. Vegetation that is best suited to the local conditions should be selected.

Soil building - Grounds operation and maintenance should incorporate soil evaluation every 1 to 3 years to determine suitability for supporting a lawn, and to determine how to optimize growing conditions. Consider testing soil characteristics such as pH, fertility, compaction, texture, and earthworm content.

Grass selection - Grass seed is available in a wide range of cultivated varieties, so homeowners, landscapers, and grounds managers are able to choose the grass type that grows well in their particular climate, matches site conditions, and is consistent with the property owner's desired level of maintenance. When choosing ground cover, consideration should be given to seasonal variations in rainfall and temperature. Table G-3 lists turfgrass types and their level of tolerance to drought:

Table G-3 Drought Tolerance of Turfgrass Types

Turfgrass Type	Drought Tolerance
Fine-leaved Fescues	High
Tall Fescue	↓
Kentucky Bluegrass	
Perennial Ryegrass	
Bentgrasses	Low

Mowing and thatch management - To prevent insects and weed problems, property owners should mow high, mow frequently, and keep mower blades sharp. Lawns should not be cut shorter than 2 to 3 inches, because weeds can grow more easily in short grasses. Grass can be cut lower in the spring and fall to stimulate root growth, but not shorter than 1 ½ inches.

Fertilization - If fertilizing is desired, consider the following points:

- Most lawns require little or no fertilizer to remain healthy. Fertilize no more than twice a year - once in May-June, and once in September-October;
- Fertilizers are rated on their labeling by three numbers (e.g., 10-10-10 or

12-4-8), which refer to their Nitrogen (N) – Phosphorus (P) – Potassium (K) concentrations. Fertilize at a rate of no more than ½ pound of nitrogen per 1000 square feet, which can be determined by dividing 50 by the percentage of nitrogen in the fertilizer;

- Apply fertilizer carefully to avoid spreading on impervious surfaces such as paved walkways, patios, driveways, etc., where the nutrient can be easily washed into stormdrains or directly into surface waters;
- To encourage more complete uptake, use slow-release fertilizers that is those that contain 50 percent or more water-insoluble nitrogen (WIN);
- Grass blades retain 30-40 percent of nutrients applied in fertilizers. Reduce fertilizer applications by 30 percent, or eliminate the spring application of fertilizer and leave clippings on the lawn where they will degrade and release stored nutrients back to the soil; and
- Fertilizer should not be applied when rain is expected. Not only does the rain decrease fertilizer effectiveness, it also increases the risk of surface and ground water contamination.

Weed management - A property owner must decide how many weeds can be tolerated before action is taken to eradicate them. To the extent practicable, weeds should be dug or pulled out. If patches of weeds are present, they can be covered for a few days with a black plastic sheet; a technique called solarization. Solarization kills the weeds while leaving the grass intact. If weeds blanket a large enough area, the patch can be covered with clear plastic for several weeks, effectively “cooking” the weeds and their seeds. The bare area left behind after weeding should be reseeded to prevent weeds from growing back. As a last resort, homeowners can use chemical herbicides to spot-treat weeds.

Pest management - Effective pest management begins with maintenance of a healthy, vigorous lawn that is naturally disease resistant. Property owners should monitor plants for obvious damage and check for the presence of pest organisms. Learn to distinguish beneficial insects and arachnids, such as green lacewings, ladybugs, and most spiders, from ones that will damage plants.

When damage is detected or when harmful organisms are present, property owners should determine the level of damage the plant is able to tolerate. No action should be taken if the plant can maintain growth and fertility. If controls are needed, there are a variety of low-impact pest management controls and practices to choose from, including the following:

- Visible insects can be removed by hand (with gloves or tweezers) and placed in soapy water or vegetable oil. Alternatively, insects can be sprayed off a plant with water, or in some cases vacuumed off of larger plants;
- Store-bought traps, such as species-specific, pheromone-based traps or colored sticky cards, can be used;

- Sprinkling the ground surface with abrasive diatomaceous earth can prevent infestations by soft-bodied insects and slugs. Slugs can also be trapped by falling or crawling into small cups set in the ground flush with the surface and filled with beer;
- In cases where microscopic parasites, such as bacteria and fungi, are causing damage to plants, the affected plant material can be removed and disposed of. (Pruning equipment should be disinfected with bleach to prevent spreading the disease organism);
- Small mammals and birds can be excluded using fences, netting, tree trunk guards, and, as a last resort, trapping. (In some areas trapping is illegal. Property owners should check local codes if this type of action is desired); and
- Property owners can encourage/attract beneficial organisms, such as bats, birds, green lacewings, ladybugs, praying mantis, ground beetles, parasitic nematodes, trichogramma wasps, seedhead weevils, and spiders that prey on detrimental pest species. These desirable organisms can be introduced directly or can be attracted to the area by providing food and/or habitat.

If chemical pesticides are used, property owners should try to select the least toxic, water soluble, and volatile pesticides possible. All selected pesticides should be screened for their potential to harm water resources. Although organophosphate pesticides, such as diazinon and chlorpyrifos, are popular because they target a broad range of pests and are less expensive than newer, less toxic pesticides, they rank among the worst killers of wildlife, and often pose the greatest health risk. Synthetic pyrethroids are more selective, and typically much less toxic than organophosphates, yet they can harm beneficial insects. When possible, pesticides that pose the least risk to human health and the environment should be chosen. A list of popular pesticides, along with their uses, their toxicity to humans and wildlife, EPA's toxicity rating, and alternatives to the listed chemicals, is available from *The Audubon Guide to Home Pesticides*, (http://www.audubon.org/bird/pesticides/).

Sensible irrigation - Most New England lawns will survive without irrigation. Grasses will normally go dormant in warm, dry periods (June-September) and resume growth when moister is more plentiful. However, if watering is desired, consider the following points:

Established lawns need no more than one inch of water per week (including precipitation) to prevent dormancy in dry periods. Watering at this rate should wet soil to approximately 4-6 inches and will encourage analogous root growth. If possible, use timers to water before 9:00 a.m., preferably in the early morning to avoid evaporative loss. Use drought-resistant grasses (see "grass selection" above) and cut grass at 2-3 inches to encourage deeper rooting and heartier lawns.

APPENDIX H: ASSORTED DESIGN TOOLS

Appendix H provides additional information to help designers with the incorporation of stormwater BMPs at their site, including approved testing requirements (e.g., soils testing for infiltration), miscellaneous design details, pollutant loading analyses, and the TR-55 "short-cut" sizing technique.

H.1 Infiltration, Filter, and Dry Swale Soil Testing Requirements

The following was adapted from the Massachusetts Stormwater Manual, Volume 3 (2008).

H.1.1 General Notes Pertinent to All Testing

1. For infiltration practices and infiltrating permeable paving practices, a minimum field infiltration rate of 0.5 inches per hour is required; areas yielding a lower rate preclude these practices. For infiltration practices, if the minimum f_c exceeds 8.3 inches per hour, the WQ_v must be treated by a separate upstream BMP. For filtering and dry swale practices, no minimum infiltration rate is required if these facilities are designed with a "day-lighting" underdrain system; otherwise, these facilities require a 0.5 inch per hour rate.
2. Number of required tests is based on the size of the proposed facility (Table H-1).
3. Testing is to be conducted by a qualified professional. This professional shall be a DEM-licensed Class IV soil evaluator or RI-registered PE.

H.1.1.1 Initial Feasibility Testing

Feasibility testing should be conducted to determine whether full-scale testing is necessary and is meant to screen unsuitable sites and reduce testing costs. A soil boring is not required at this stage.

Initial testing could involve either one field test per facility, regardless of type or size, or previous testing data, such as the following:

- Septic percolation testing on-site, within 200 feet of the proposed BMP location, and on the same contour [can establish initial rate, water table and/or depth to bedrock];
- Previous written geotechnical reporting on the site location as prepared by a qualified geotechnical consultant; and
- NRCS Soil Mapping *showing an unsuitable soil group* such as a hydrologic group "D" soil in a low-lying area.

If the results of initial feasibility testing as determined by a qualified professional show that an infiltration rate of greater than 0.5 inches per hour is probable, then the number of *design test* pits shall be per the following table. An encased soil boring may be substituted for a test pit, if desired.

Table H-1 Infiltration Testing Summary

Type of Facility	Design Testing
Infiltration Practice*/Infiltrating Permeable Pavement Practices	1 infiltration test and 1 test pit per 5,000 ft^2
Filter Practice**	1 infiltration test and 1 test pit per 5,000 ft^2 (no underdrains required if infiltration rate > 0.5 in/hr***)
Dry Swale**	1 infiltration test and 1 test pit per 1,000 ft of dry swale (no underdrains required if infiltration rate > 0.5 in/hr ***)

*For use with residential rooftop runoff, testing requirements are reduced to 1 infiltration test and 1 test pit per 5 lots assuming consistent terrain and NRCS soil series. If terrain and soil series are not consistent, then requirements increase to 1 infiltration test and 1 test pit per 1 lot.
**When proposed as a treatment/infiltration system. If proposed as strictly a filtration practice, infiltration testing analysis not strictly required but a test pit or boring is required to verify depth to seasonal high groundwater or bedrock.
***Underdrain installation still strongly suggested.

H.1.1.2 Documentation

Infiltration testing data shall be documented, which shall also include a description of the infiltration testing method, if completed. This is to ensure that the tester understands the procedure.

H.1.2 Test Pit/Boring Requirements

1. Excavate a test pit or dig a standard soil boring to a depth of 4 ft below the proposed facility bottom.
2. Determine depth to groundwater table (if within 4 ft of proposed bottom) upon initial digging or drilling, and again 24 hours later when conducting soil borings or drilling wells. A DEM-licensed Class IV soil evaluator or RI-registered PE may establish seasonal high groundwater depth in test pits based on redoximorphic features and need not revisit the site 24 hours later.
3. Conduct Standard Penetration Testing (SPT) every 2 ft to a depth of 4 ft below the facility bottom when conducting soil borings.
4. Determine USDA textures at the proposed bottom and 4 ft below the bottom of the BMP.
5. Determine depth to bedrock (if within 4 ft of proposed bottom).
6. The soil description should include all soil horizons.
7. The location of the test pit or boring shall correspond to the BMP location; test pit/soil boring stakes are to be left in the field for inspection purposes and shall be clearly labeled as such.

H.1.3 Field Infiltration Testing Requirements

Field test methods to assess saturated hydraulic conductivity must simulate the "field-saturated" condition and must be conducted at the depth of the bottom of the proposed infiltrating practice. Design infiltration rates shall be determined by using a factor of safety of 2 from the field-derived value. See ASTM D5126-90 (2004) Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone. The saturated hydraulic conductivity analysis must be conducted by the DEM-licensed Class IV soil evaluator or RI-registered PE. Acceptable tests include:

- Guelph permeameter - ASTM D5126-90 Method
- Falling head permeameter – ASTM D5126-90 Method
- Double ring permeameter or infiltrometer - ASTM D3385-03[3], D5093-02[4], D5126-90 Methods
- Amoozemeter or Amoozegar permeameter – Amoozegar 1992

H.1.4 Laboratory Testing

Grain-size sieve analysis and hydrometer tests where appropriate may be used to determine USDA soils classification and textural analysis. Visual field inspection by a qualified professional may also be used, provided it is documented. *The use of lab testing to establish infiltration rates is prohibited.*

H.1.5 Bioretention Testing

All areas tested for application of bioretention facilities shall be back-filled with a suitable sandy loam planting media. The borrow source of this media, which may be the same or different from the bioretention area location itself, must be tested as follows:

If the borrow area is virgin, undisturbed soil, one test is required per 5,000 ft^2 of borrow area; the test consists of “grab” samples at one foot depth intervals to the bottom of the borrow area. All samples at the testing location are then mixed, and the resulting sample is then lab-tested to meet the following criteria:

1. USDA minimum textural analysis requirements: A textural analysis is required from the site stockpiled topsoil. If topsoil is imported, then a texture analysis shall be performed for each location where the top soil was excavated.
2. Minimum requirements:

Sand	85-88%
Silt	8 - 12%
Clay	0 - 2%
Organics	3 - 5% in form of leaf compost

[3] ASTM D3385-03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer**.**

[4] ASTM D5093-02 Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.

3. The soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than one inch.
4. Consult the bioretention construction specifications (Appendix F) for further guidance on preparing the soil for a bioretention area.

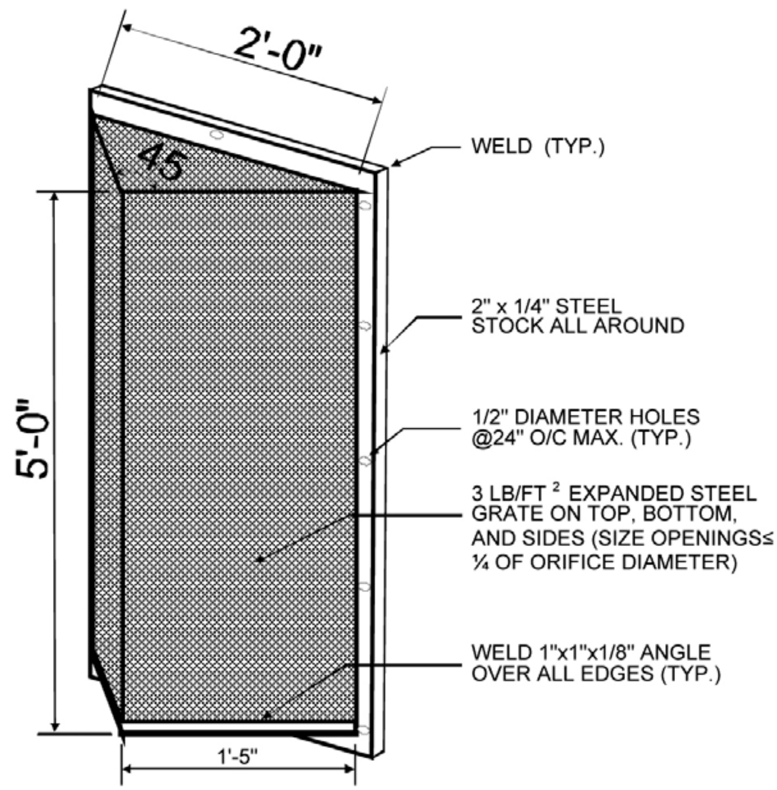
H.2 MISCELLANEOUS BMP DETAILS

This section contains miscellaneous design schematics for compliance with performance criteria, including:

H.2.1 Low-flow Orifice Protection

Outlet control structures typically use orifices of varying sizes to control discharge from certain stormwater BMPs. Low-flow orifices (typically <6" diameter) can easily clog with trash and vegetative debris. Figures H-1 through H-3 illustrate a few examples of protective measures to prevent clogging and keep the BMPs functioning properly.

Figure H-1 Trash Rack for Low-flow Orifice



NOTES FOR TRASH RACK

1. TRASH RACK TO BE CENTERED OVER OPENING.
2. STEEL TO CONFORM TO ASTM A-36.
3. ALL SURFACES TO BE COATED WITH ZRC COLD GALVANIZING COMPOUND AFTER WELDING.

Figure H-2 Expanded Trash Rack Protection for Low-flow Orifice

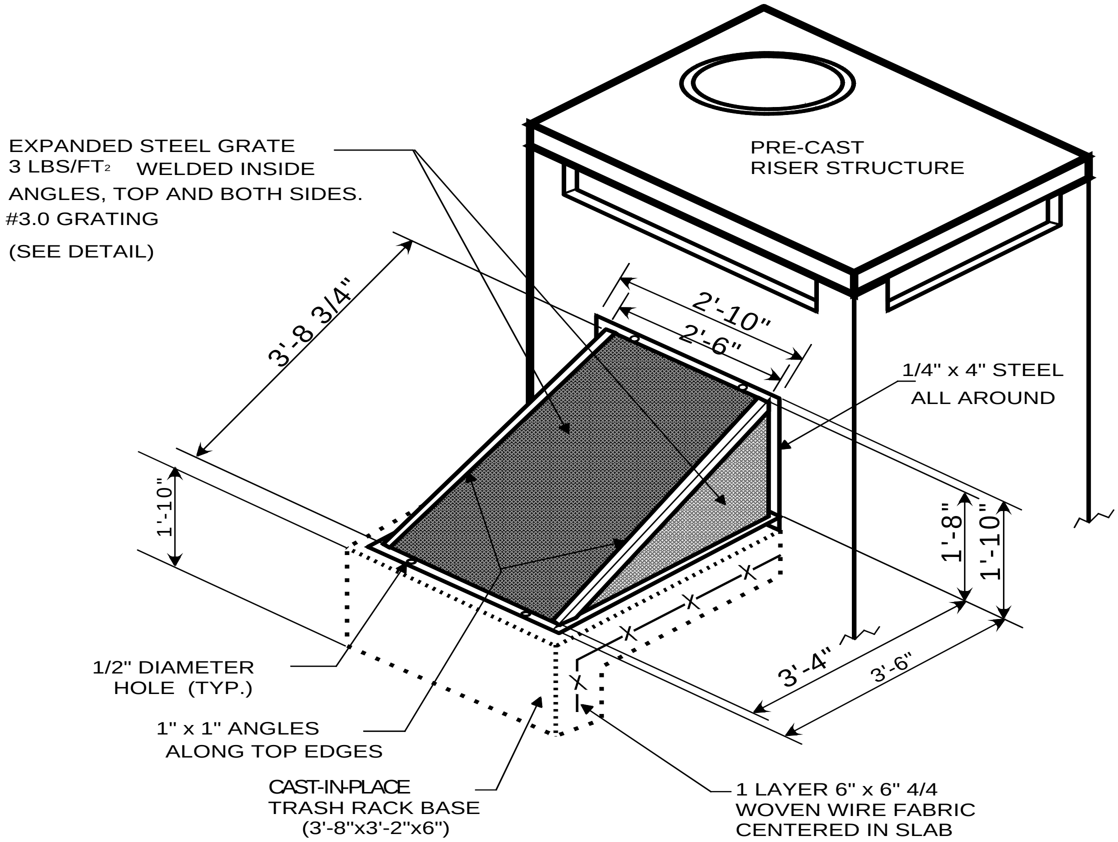
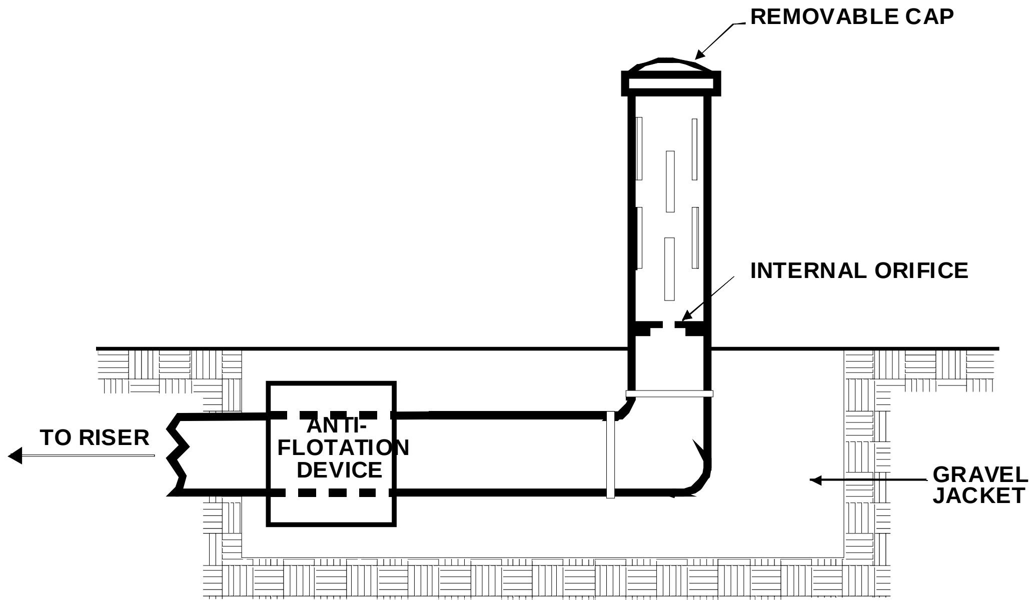


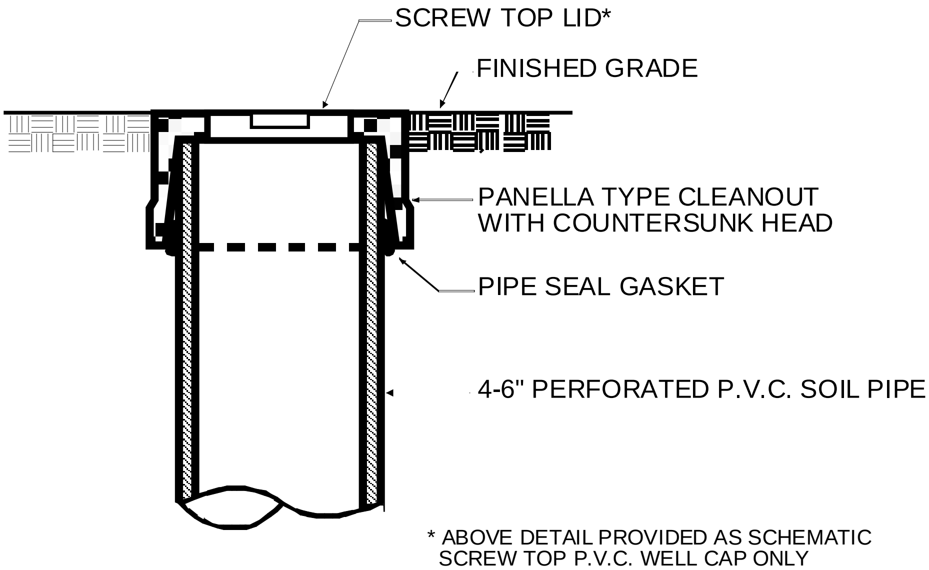
Figure H-3 Internal Control for Orifice Protection



H.2.2 Observation Well/Cleanout

Infiltration and filtering practices require an observation well/cleanout for inspections and maintenance. One example that can be used in a parking lot is the flush-mounted observation well shown below in Figure H-4.

Figure H-4 Observation Well/Cleanout for Infiltration and Filtering Practices



EACH OBSERVATION WELL / CLEANOUT SHALL INCLUDE THE FOLLOWING:

1. FOR AN UNDERGROUND FLUSH MOUNTED OBSERVATION WELL / CLEANOUT, PROVIDE A TUBE MADE OF NON-CORROSIVE MATERIAL, SCHEDULE 40 OR EQUAL, AT LEAST THREE FEET LONG.

2. THE TUBE SHALL HAVE A FACTORY ATTACHED CAST IRON OR HIGH IMPACT PLASTIC COLLAR WITH RIBS TO PREVENT ROTATION WHEN REMOVING SCREW TOP LID. THE SCREW TOP LID SHALL BE CAST IRON OR HIGH IMPACT PLASTIC THAT WILL WITHSTAND ULTRA-VIOLET RAYS.

H.2.3 On-line Versus Off-line

Best management practices can be designed to receive all of the flow from a given area (on-line) or to receive only a portion of the flow (off-line), such as the water quality volume. Off-line BMPs may need to be paired with another practice for volume control, depending on the site characteristics.

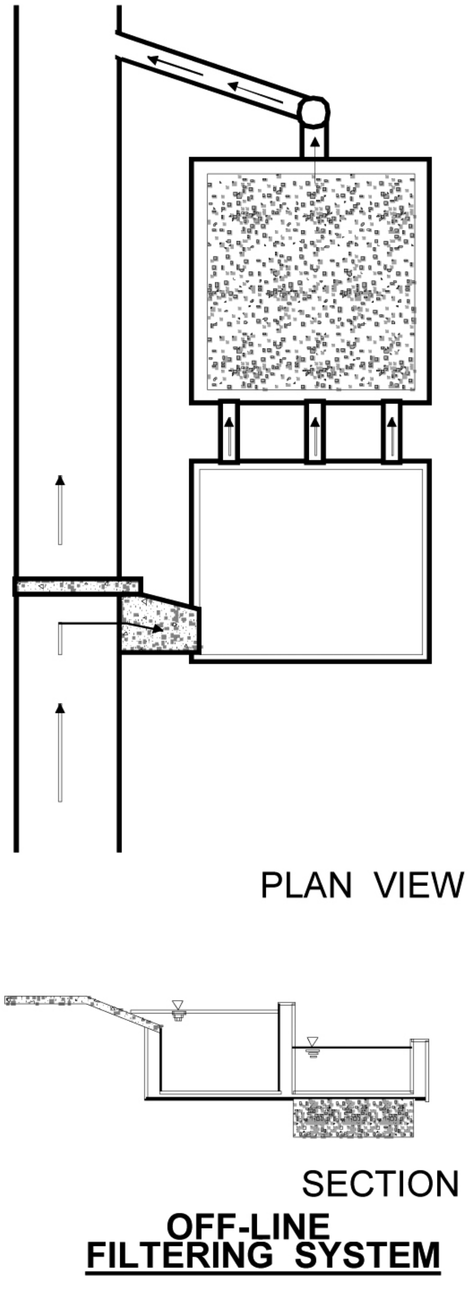
Flow diversion structures, also called flow splitters, are designed to deliver flows up to the design water quality flow (WQ_f) or water quality volume (WQ_v) to off-line stormwater treatment practices. Flows in excess of the WQ_f or WQ_v are diverted around the treatment facility with minimal increase in head at the flow diversion structure to avoid surcharging the treatment facility under higher flow conditions. Flow diversion structures are typically manholes or vaults equipped with weirs, orifices, or pipes to bypass excess runoff. A number of design options exist. An example of an on-line vs. an off-line filtering practice is shown in Figure H-5. Figure H-6 illustrates one example of a flow splitter that may be used to divert low flows to an off-line BMP for treatment or recharge while allowing larger flows to exit via the outflow pipe to a quantity control BMP or perhaps direct discharge to a water body, based on required site criteria. Other equivalent designs that achieve the result of diverting flows in excess of the WQ_f or WQ_v around the treatment facility, including bypasses or overflows located inside the facility, are also acceptable.

The following general procedures are recommended for design of flow diversion structures:

- Locate the top of the weir or overflow structure at the maximum water surface elevation associated with the WQ_f, or the water surface elevation in the treatment practice when the entire WQv is being held, whichever is higher.
- Determine the diversion structure dimensions required to divert flows in excess of the WQ_f using standard equations for a rectangular sharp-crested weir, uniform flow in pipes or channels, or orifice depending on the type of diversion structure.
- Provide sufficient freeboard in the stormwater treatment practice and flow splitter to accommodate flow over the diversion structure.
- Limit the maximum head over the flow diversion structure to avoid surcharging the stormwater treatment practice under high flow conditions. Flow to the stormwater treatment practice at the 100-year water surface elevation should not increase the WQ_f by more than 10 percent.

Design diversion structures to withstand the effects of freezing, frost in foundations, erosion, and flotation due to high water conditions. These structures should be designed to minimize clogging potential and to allow for ease of inspection and maintenance.

Figure H-5 On-line Versus Off-line Schematic



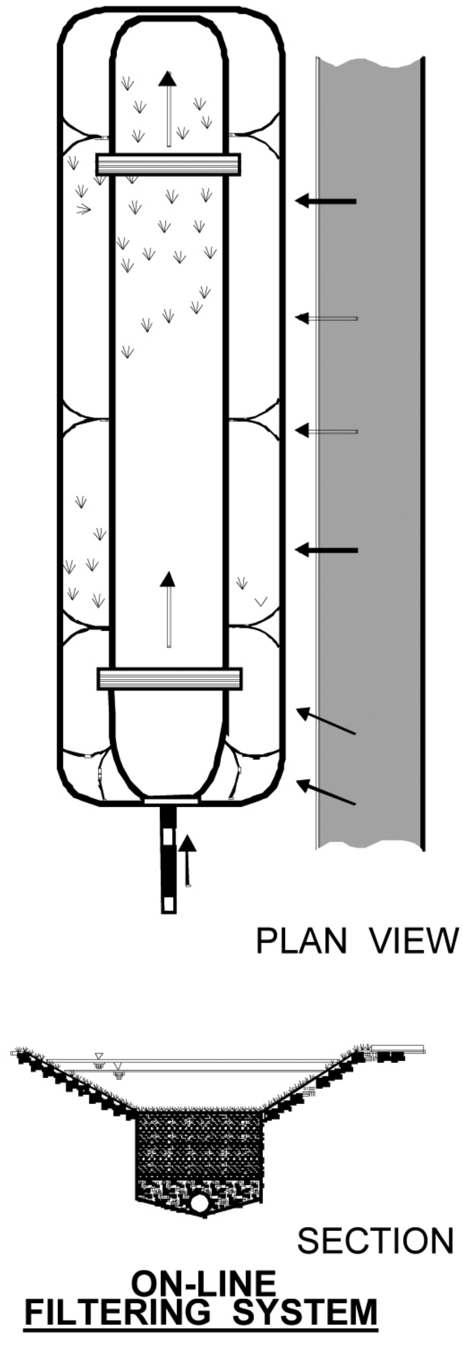
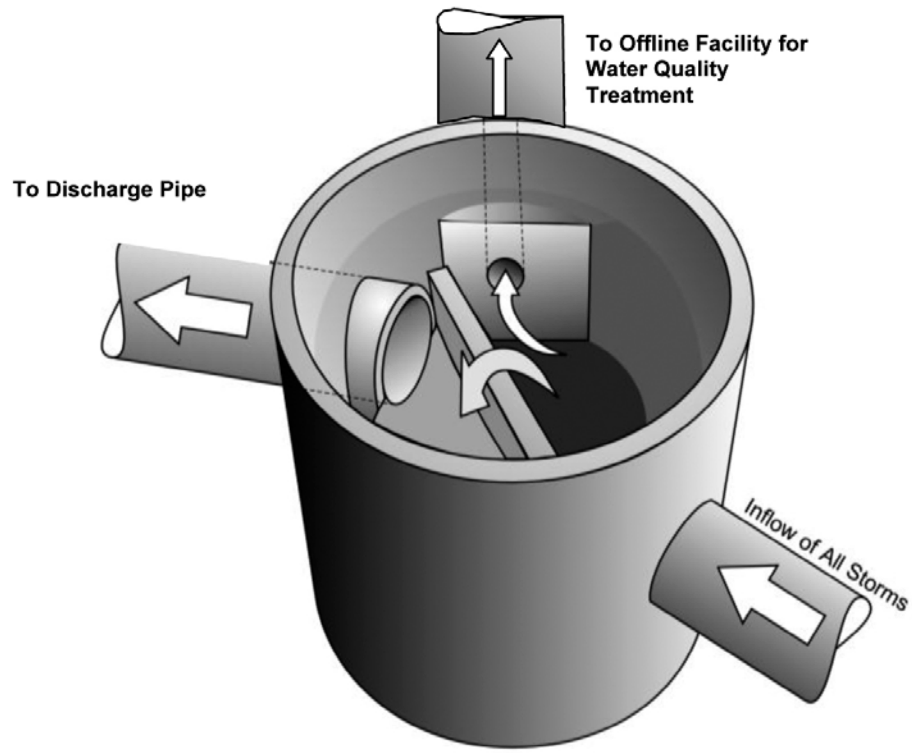
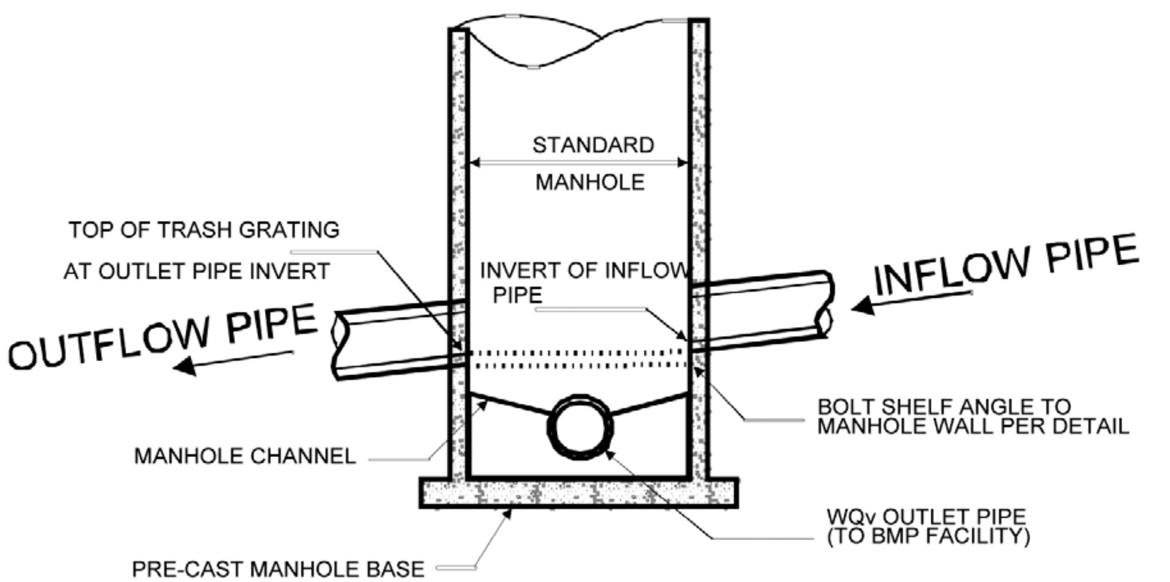


Figure H-6 Flow Splitter Structures





NOTE: ALUMINUM TRASH GRATE
IN TWO SEMICIRCULAR SECTIONS

H.2.4 Level Spreaders

Level spreaders are devices designed to uniformly distribute flow over a large area to prevent erosive flows and promote infiltration. There are several level spreader designs that differ based on the peak rate of inflow, the duration of use, the type of pollutant, and the site conditions. All designs follow the same basic principles: water enters the spreader through overland flow, a pipe, ditch or swale; the flow is distributed throughout a long linear shallow trench or behind a low berm; and then water flows over the berm/ditch uniformly along the entire length. Level spreaders can be used during construction or as a part of post-construction stormwater control. They are particularly useful to diffuse flow through vegetated buffers adjacent to waterbodies, in areas requiring a vegetative filter strip to pretreat runoff, and as a segment of a stormwater treatment series of BMPs where concentrated flow presents design constraints, such as with some filtering practices. One example of a level spreader is illustrated below in Figure H-7.

Required Elements

- A level spreader shall be installed in an undisturbed or finished area.
- The level spreader lip shall be constructed with a maximum slope of 0.1% along its length.
- Runoff entering a level spreader must not contain significant amounts of sediment. An upstream sediment removal practice may be required in addition to the level spreader.

Design Guidance

- A level spreader should disperse onto a vegetated slope that has a gradient of less than 10:1 (H:V).
- The lip can be constructed of either stabilized grass for low flows, or timber/concrete for higher flows.
- The length of the level spreader lip is dependent on the volume of water that must be discharged, but the minimum length for the level spreader lip is 6 feet.
- Stormwater flowing over the lip should be limited to a depth of approximately 6 inches and a velocity of 1 fps for the design storm.
- The maximum drainage area for a level spreader should be 2.5 acres for maximum efficiency.

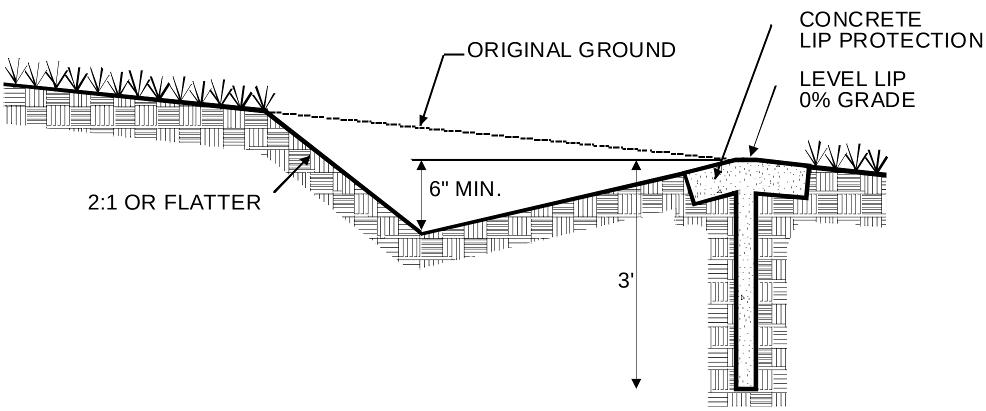
Sample Calculation:

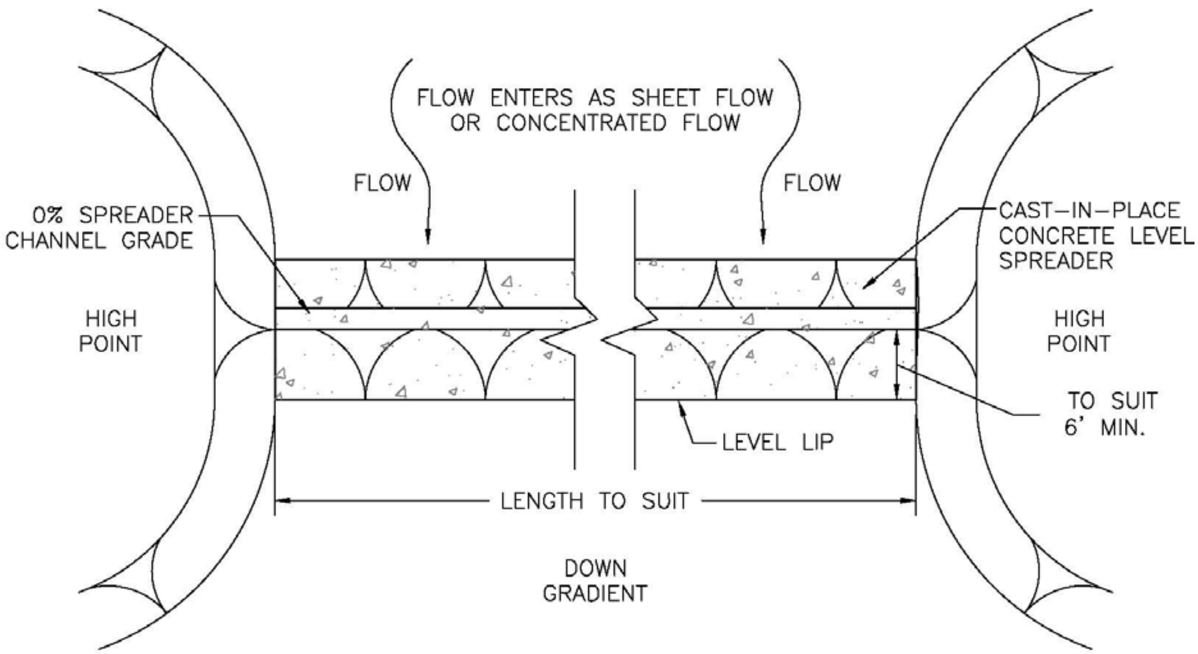
A level spreader is proposed to disperse the runoff from the 1-year storm event, with a peak discharge rate (q) of 5 cfs. Calculate the required length of the level spreader.

Length (L) = peak discharge rate (q) / [maximum velocity (v) * depth (d)]
L = 5 cfs / (1 fps * 0.5 ft) = 10 feet

A level spreader with a 10-foot lip is required for this example.

Figure H-7 Concrete Level Spreader - Profile and Plan Views





H.3 Pollutant Loading Analyses

H.3.1 Introduction

On a case by case basis, the permitting agency may require applicants to document that a particular project does not unduly contribute to, or cause, water resource degradation (generally for sensitive resource areas or where an elevated concern for water quality exists) or to document a reduction in pollutant load (generally, as a consequence of a TMDL requirement). In these cases, applicants may be required to calculate potential stormwater pollutant loadings for projects for pre-development and post-development conditions.

When such an analysis is required of the applicant, the Simple Method (Schueler, 1987) can be used to demonstrate urban stormwater pollutant loadings. The Simple Method requires estimates of annual rainfall, site percent impervious cover, land use type, and pollutant loading coefficients based on land use.

For a more detailed description of this method refer to Controlling Urban Runoff: A practical manual for planning and designing urban BMPs (Schueler, 1987). Table H-2 provides event mean concentrations (EMCs) in milligrams per liter (mg/L) for typical pollutants of concern associated with stormwater runoff (# col/100ml for bacteria). There may be an interest in calculating the loading rates of other pollutants not listed in this table. If this is necessary, an applicant shall use EMC data from a reliable source, as approved by the permitting agency, based on the land use category. These EMCs must be documented by scientific studies and referenced by the applicant.

The method outlined in this section is most often applied to calculating loadings to surface water bodies. Other pollutant loading methods may be acceptable, provided the applicant submits the methodology and data used along with the reasoning for the chosen method. All information supplied by the applicant will be reviewed by the permitting agency to determine the relevance of the model to the situation.

H.3.2 Overview of the Simple Method

Stormwater pollutant export load (L, in pounds or billion colonies) from a development site can be determined by solving the following equation:

(Eq 1.) $L = [(P)(Pj)(Rv)/12](C)(A)(2.72)$

Where:

- P = rainfall depth (inches)
- Pj = rainfall correction factor
- Rv = runoff coefficient expressing the fraction of rainfall converted to runoff
- C = flow-weighted mean concentration of the pollutant in urban runoff (mg/L)
- A = contributing drainage area of development site (acres)
- 12, and 2.72 are unit conversion factors

For bacteria, the conversion factor is modified, so the loading equation is:

(Eq 1a.) $L = 1.03(10^{-3})[(P)(Pj)(Rv)](C')(A)$

Where:

P = rainfall depth (inches)
Pj = rainfall correction factor
Rv = runoff coefficient expressing the fraction of rainfall converted to runoff
C' = flow-weighted mean bacteria concentration (#col/100 ml)
A = contributing drainage area of development site (acres)
1.03 is a unit conversion factor

Table H-2 Median EMC Values for Differing Land Use Categories

Pollutant (mg/l)	Land Use Category				
	Residential	Commercial	Industrial	Highways	Undeveloped/Rural[3]
TSS	100[1]	75[1]	120[1]	150[1]	51
TP	0.3	0.2	0.25	0.25	0.11
TN	2.1	2.1	2.1	2.3	1.74
Cu	.005	.096	.002	.001	-
Pb	.012	.018	.026	.035	-
Zn	.073	.059	.112	.051	-
BOD	9.0	11.0	9.0	8.0	3.0
COD	54.5	58.0	58.6	100.0	27.0
Bacteria*	7000	4600	2400	1700	300

Sources:

1 Caraco (2001); default values from Watershed Treatment Model, from several individual assessments
2 (shaded) Maestre and Pitt (2005); National Stormwater Quality Database, v 1.1
3 CDM (2004) Merrimack River Watershed Assessment Study, Screening Level Model
* Bacteria concentration in #col/100 ml.

<u>P (depth of rainfall)</u>

The value of P selected depends on the time interval over which loading estimates are necessary (usually annual rainfall – See Figure H-8).

Appropriate annual rainfall values for a site specific location can be interpolated from Figure H-8 or obtained from the Northeast Regional Climate Center. If a load estimate is desired for a specific design storm (e.g., 10-year 24-hour, Type III storm), the user can supply the relevant value of P derived from Table 3-1. Caution is required as EMCs vary as a function of rainfall amount and intensity and those presented in Table H-2 are median values from a range of storms more representative of long-term loading. If a load is desired from a larger storm such as the 10-year, 24 hour, Type III storm, applicants shall provide appropriate documentation of the source of the EMC used. All rainfall data used in the analysis must be applicable to site location and referenced for review.

<u>Pj (correction factor)</u>
Use a value of 0.9 for Pj. This represents the percentage of annual rainfall that produces runoff. When solving the equation for individual storms, a value of 1.0 should be used for Pj.

<u>Rv (runoff coefficient)</u>
Rv is the measure of site response to rainfall events and is calculated as:

(Eq 2.) Rv = r/p

Where:
r = storm runoff (inches)
p = storm rainfall (inches)

The Rv for a site depends on soil type, topography, and vegetative cover. However, for annual pollutant loading assessments, the primary influence on Rv is the degree of watershed imperviousness. The following equation has been empirically derived from the Nationwide Urban Runoff Program studies (USEPA, 1983) and is used to establish a value for Rv.

(Eq 3.) Rv = 0.05 + 0.009(%I)

Where:
%I = the percent of site imperviousness

A value for I can be calculated by summing the areas of all impervious surfaces (e.g., buildings, driveways, roads, parking lots, sidewalks, etc.) and dividing this area by the total contributing drainage area. If more than one land use is present at the site, divide the impervious portion of each land use by its respective total area.

<u>A (drainage area)</u>
The total contributing drainage area (acres) can be obtained from site plans.

<u>C (pollutant concentration)</u>
Choose the appropriate value of C from Table H-2.

<u>Sample calculations:</u>

A 30-acre undeveloped parcel is to be developed into a residential subdivision with the remaining 10 acres converted to a commercial plaza. Assume the commercial land use area has impervious surfaces covering 85% of the area, while the residential subdivision has 35% impervious surfaces. Also assume the entire 30-acre site has all drainage directed to one outlet (into a coastal pond). This site is located in an area that receives approximately 45 inches of precipitation per year, say Providence. What would be the potential annual loading rate of total nitrogen (TN) to the coastal salt pond from this site without the installation of onsite BMPs; compare pre- and post-development scenarios.

Pre-development conditions

Undeveloped site: (Eq.3) Rv = 0.05 + 0.009(%I) = 0.05 + 0.009(0) = 0.05

(Eq.1) L = [(P)(Pj)(Rv)/(12)](C)(A)(2.72); from Table H-2, C = 1.74 mg/l

L = [(45)(0.9)(0.05)/12](1.74)(30)2.72 = ***24.0 lbs TN/year***

Post-development conditions

Residential: (Eq.3) Rv = 0.05 + 0.009(%I) = 0.05 + 0.009(35) = 0.365

(Eq.1) L = [(P)(Pj)(Rv)/(12)](C)(A)(2.72); from Table H-2, C = 2.1 mg/l

L = [(45)(0.9)(0.365)/12](2.1)(20)2.72 = ***140.7 lbs TN/year***

Commercial: (Eq.3) Rv = 0.05 + 0.009(%I) = 0.05 + 0.009(85) = 0.815

(Eq. 1) L = [(P)(Pj)(Rv)/(12)](C)(A)(2.72); from Table H-2, C = 2.1 mg/l

L = [(45)(0.9)(0.815)/12](2.1)(10)2.72 = ***157.1 lbs TN/year***

Total annual nitrogen loading from the developed site = 140.7 + 157.1 = ***297.8 lbs TN/year***

Conclusion: Development of the site results in a net increase of 273.8 lbs of nitrogen (297.8 – 24.0) into the coastal salt pond per year.

Now evaluate the same example except for Bacteria:

Pre-development conditions

Undeveloped site: (Eq.3) Rv = 0.05 + 0.009(%I) = 0.05 + 0.009(0) = 0.05

(Eq 1a.) $L = 1.03(10^{-3})[(P)(Pj)(Rv)](C')(A))$*; from Table H-2, C' = 300 col/100 ml*

$L = [1.03(10^{-3})(45)(0.9)(0.05)](300)(30) =$ ***18.8 Billion Colonies/year***

Post-development conditions

Residential: (Eq.3) Rv = 0.05 + 0.009(%I) = 0.05 + 0.009(35) = 0.365

(Eq 1a.) $L = 1.03(10^{-3})[(P)(Pj)(Rv)](C')(A))$*; from Table H-2, C' = 7,000 col/100 ml*

L = [1.03(10^{-3})(45)(0.9)(0.365)](7,000)(20) = ***2,131.6 Billion Colonies/year***

Commercial: (Eq.3) Rv = 0.05 + 0.009(%I) = 0.05 + 0.009(85) = 0.815

(Eq 1a.) L = 1.03(10^{-3})[(P)(Pj)(Rv)](C')(A)); from Table H-2, C' = 4,600 col/100 ml

L = [1.03(10^{-3})(45)(0.9)(0.815)](4,600)(10) = ***1,563.9 Billion Colonies/year***

Total annual bacteria loading from the developed site = 2,131.6 + 1563.9 = ***3,695.5 Billion Colonies/year***

Conclusion: Development of the site results in a net increase of ***3,676.7 Billion Colonies/year*** *(3695.5 – 18.8) into the coastal salt pond per year.*

Applicants will frequently need to evaluate the potential pollutant removal effectiveness of stormwater practices when conducting a pollutant loading analysis. To do this, applicants can use the rated pollutant removal effectiveness as listed in Tables H-3 and H-4 as a basis of estimating pollutant removal. These values have been derived from a variety of sources based on actual monitoring data and modified, where appropriate, to reflect the specific design and sizing criteria contained in Chapters Five, Six, and Seven.

In some cases, the pollutant removal rating values use median values from prior monitoring studies when the studies included a significant number of facilities of similar design criteria as those required in this manual. In other cases, the 75th quartile values (or high end) are reported where it is recognized that the prior monitoring was of insufficient sample size or was of practices with design criteria not as robust as those required in this manual. Lastly, in many cases, there is insufficient prior monitoring of practices for some or all of the reported pollutants, but primary pollutant removal mechanisms are similar to other practices; thus, a removal value is assigned, based on general literature values and/or as a policy decision. In addition, most of the design criteria for water quality BMPs incorporate pre-treatment requirements, such as the requirement for a forebay or grass channel prior to infiltration. In these cases, the rated removal efficiency of the practice is for the total system. For example, the gravel WVTS has a rated TSS removal of 86%; this accounts for the TSS removal of both the required forebay and the gravel bed/permanent pool.

In general, where pollutant loading assessments are requested, applicants may use the rated removal values as a basis for estimating pollutant load. However, other pollutant removal estimates may be acceptable, provided the applicant submits the source of these estimates and data used. All information supplied by the applicant will be reviewed by the permitting agency to determine the relevance of the removal estimates to the situation.

Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs

Water Quality BMPs (those meeting Min. Std 3)		Median Pollutant Removal Efficiency (%)			
		TSS	TP	TN	Bacteria
WVTS	Shallow WVTS	85%[2]	48%[3]	30%[2]	60%[2]
	Gravel WVTS	86%[3]	53%[1]	55%[3]	85%[2]
Infiltration Practices	Infiltration Basin	90%[2]	65%[3]	65%[2]	95%[2]
	Infiltration Trench	90%[2]	65%[3]	65%[2]	95%[2]
	Subsurface Chambers	90%[2]	55%[2]	40%[2]	90%[2]
	Dry Well	90%[2]	55%[2]	40%[2]	90%[2]
	Permeable Paving	90%[1]	40%[1]	40%[2]	95%[2]
Filters	Sand Filter	86%[3]	59%[3]	32%[3]	70%[2]
	Organic Filter	90%[2]	65%[2]	50%[2]	70%[2]
	Bioretention	90%[1]	30%[2]	55%[2]	70%[2]
	Tree Filter	90%[1]	30%[2]	55%[2]	70%[2]
Green Roofs	Extensive	90%[4]	30%[4]	55%[4]	70%[4]
	Intensive	90%[4]	30%[4]	55%[4]	70%[4]
Open Channels	Dry Swale	90%[1]	30%[2]	55%[2]	70%[2,6]
	Wet Swale	85%[3]	48%[3]	30%[2]	60%[2]

Table H-4 BMP Pollutant Removal Rating Values for Other BMPs

Other BMPs		**Median Pollutant Removal Efficiency (%)**			
		TSS	TP	TN	Bacteria
Pretreatment BMPs	Grass Channel	70%[1,2]	24%[3]	40%[2]	NT
	Sediment Forebay	25%[4]	8%[5]	3%[5]	12%[5]
	Filter Strip	25%[4]	ND	ND	ND
	Deep Sump Catch Basin	25%[4]	NT	NT	NT
	Hydrodynamic Device	25%[1]	NT	NT	NT
	Oil and Grit Separator	25%[4]	NT	NT	NT
Storage BMPs	Dry Extended Detention Basin	50%[2]	20%[2]	25%[2]	35%[2]
	Wet Extended Detention Basin	80%[3]	52%[3]	31%[3]	70%[3]
	Underground Storage Vault[2]	20%[2]	15%[2]	5%[2]	25%[2]

"ND" Specifies No Data
"NT" Specifies No Treatment
References
1 (UNHSC, 2007b)
2 (CWP, 2007)
3 (Fraley-McNeal, et al., 2007)
4 (prescribed value based on general literature values and/or policy decision)
5 (50% of reported values of low end for extended detention basins)
6 Presumed equivalent to bioretention; will require diligent pollutant source control to manage pet wastes in residential areas

Estimating Pollutant Removal of BMPs

Using the rated efficiencies from Tables H-3 and H-4, applicants can reduce post-development loadings to receiving waters when BMPs are designed, installed, and maintained in accordance with the provisions of this manual.

Example Calculation

The 10-acre commercial project (annual TN load = 157.1 #) is designed to be managed by a gravel WVTS.

The load reduced by the BMP is: 157.1 (.55) = 86.4 lbs TN/year.

The net loading to the bay is: 157.1 – 86.4 = ***70.7 lbs TN/year****.*

Estimating Pollutant Removal of BMPs in Series

In some cases, applicants may have one or more BMPs installed in a series as a so-called "treatment train." In these cases, available research has shown that the pollutant removal efficiency of specific BMPs, for specific pollutants, is reduced for subsequent BMPs in the treatment train arrangement. As stormwater migrates through the treatment train, coarser-grained particles are preferentially removed by the prior BMP, leaving progressively finer particles for practices down the line. The result is that for pollutants associated with fine particulates, removal efficiency drops off significantly (e.g., TSS and TP, in particular).

To account for this phenomenon, a widely applied and generally accepted method has been to discount the rated removal efficiency of the second BMP by a factor of between 75% and 50%, with subsequent BMPs being reduced accordingly (see ARC, 2001).

The Georgia Manual Method applies BMP removals as follows:

- 100% of the rated TSS removal efficiency (E_{TSS}) to the first BMP
    - o If E_{TSS} > 80% for the first BMP; E for the second BMP = 50% (regardless of the pollutant constituent).
    - o IF E_{TSS} <80% for the first BMP; E for the second BMP = 75% (regardless of the pollutant constituent).
- For succeeding BMPs, E is applied at either 50% or 75% depending on the equivalent E_{TSS} for the preceding BMPs (regardless of the pollutant constituent).

This method does not apply to bacteria, where removal is more a function of die-off than settling/attenuation; thus, the full efficiency is applied to subsequent BMPs.

Example Calculation

Using the example from above, the 10-acre commercial site first drains through a grass channel (designed in accordance with the guidance in Chapter Six) prior to a gravel WVTS (designed in accordance with the guidance in Chapter Five).

Removal efficiencies:
Grass channel: $E_{TSS} = 70\%$; $E_{TN} = 40\%$
Gravel WVTS: $E_{TSS} = 86\%$; $E_{TN} = 55\%$

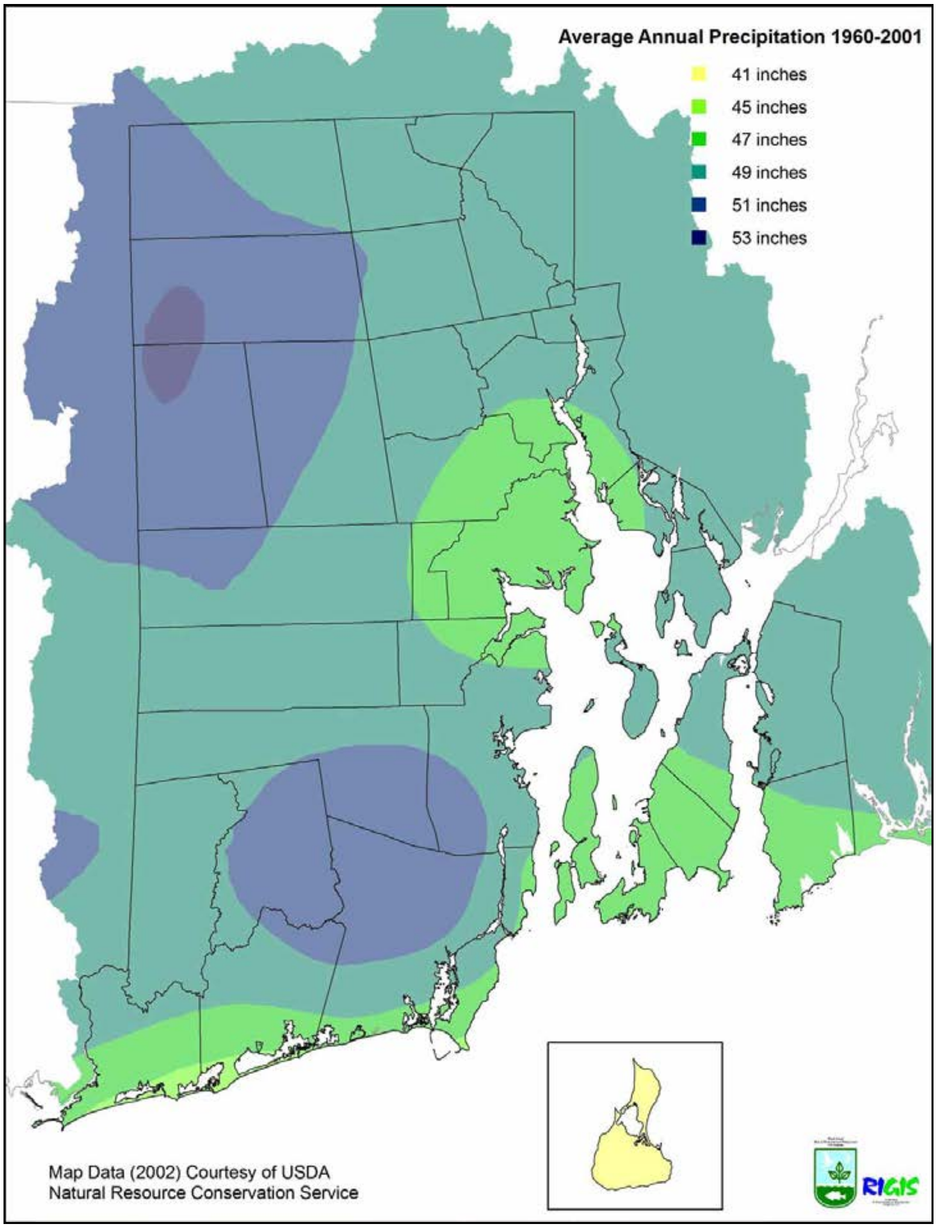
Since treatment train goes from grass channel to gravel WVTS, and E_{TSS} *is <80% for the grass channel, reduce the rated TN removal of the second BMP by 25% (*E_{TN} *= 75% of the rated value). The new net loading reduction can be calculated:*

Load reduced by grass channel: 157.1 (.40) = 62.8 lbs/yr;
remaining load = 157.1 – 62.8 = 94.3 lbs TN/year

Load reduced by gravel WVTS: 94.3 [(.75)(.55)] = 38.9 lbs/yr;

The net loading to the bay: 94.3 – 38.9 = ***55.4 lbs TN/year***

Figure H-8 Average Annual Precipitation Values for Rhode Island



H.4 TR-55 "SHORT-CUT" SIZING TECHNIQUE

This section presents a modified version of the TR-55 short-cut sizing approach. The method was modified by Harrington (1987), for applications where the peak discharge is very small compared with the uncontrolled discharge. This often occurs in the 1-year, 24-hour Type III detention sizing.

Using TR-55 guidance (NRCS, 1986), the unit peak discharge (q_u) can be determined based on the curve number and time of concentration. Knowing q_u and T (extended detention time), q_O/q_I (peak outflow discharge/peak inflow discharge) can be estimated from Figure 9.9.

Figure H-10 can also be used to estimate V_s/V_r. When q_O/q_I is <0.1 and off the graph, V_s/V_r can also be calculated using the following equation for Type II/III rainfall distributions:

$$V_s/V_r = 0.682 - 1.43\,(q_O/q_I) + 1.64\,(q_O/q_I)^2 - 0.804\,(q_O/q_I)^3$$

Where:
- V_s = required storage volume (acre-feet)
- V_r = runoff volume (acre-feet)
- q_O = peak outflow discharge (cfs)
- q_I = peak inflow discharge (cfs)

Figure H-9 Detention Time vs. Discharge Ratios (Source: MDE, 2000)

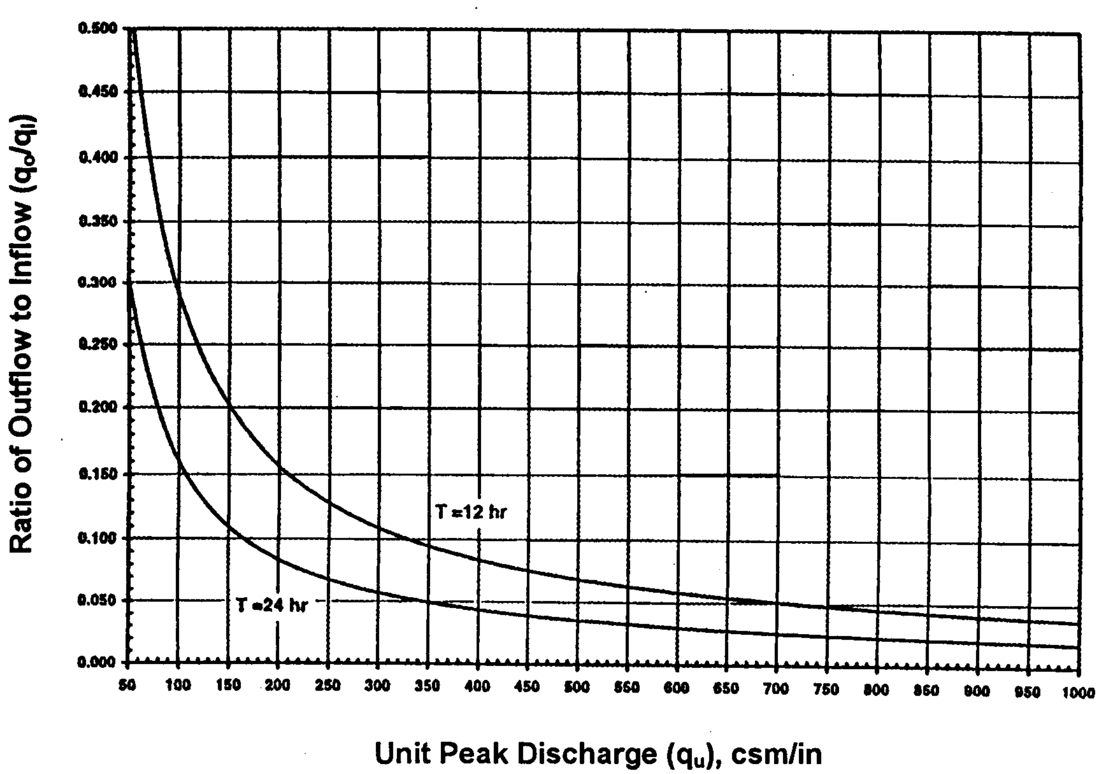
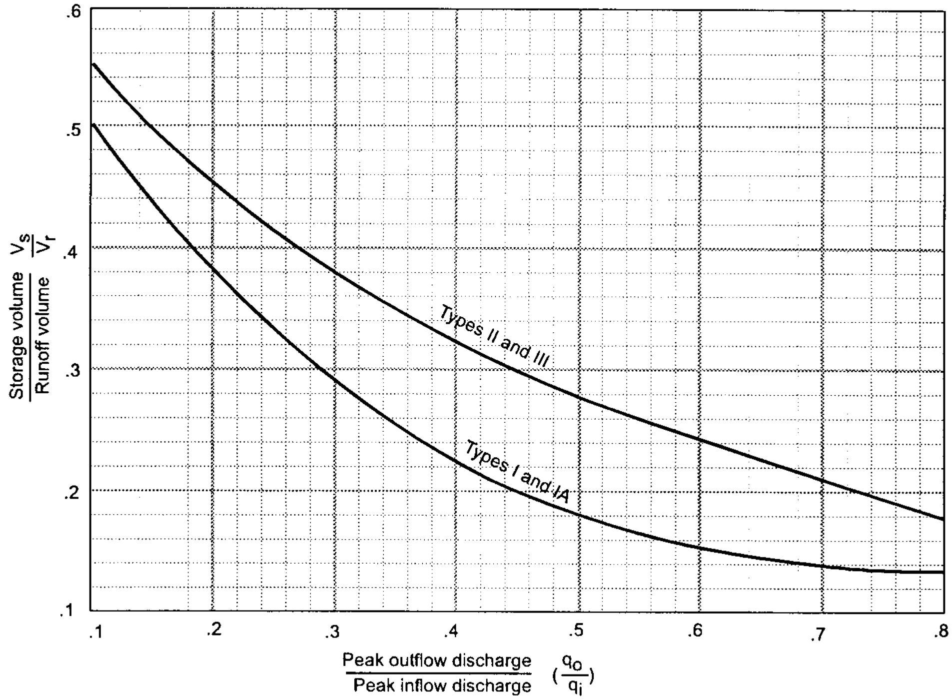


Figure H-10 Approximate Detention Basin Routing For Rainfall Types I, IA, II, and III. (Source: TR-55, 1986)



Example for calculating <u>channel protection volume</u> (CP_v):

For this example, the 1-year runoff from a hypothetical project in Providence County is 1.173 ac-ft = 51,096 ft^3, the composite CN for the project drainage area is 68, and the t_c is 15.1 minutes (0.25 hr).

Thus, the Initial abstraction (I_a) = 0.941, the 1-year precipitation (P) = 3.1"; I_a/P = 0.304.

From Exhibit 4-III of NRCS TR-55, read q_u = 450 csm/in (csm = cfs/mi^2). From Figure H-9, for T= 24 hours, read ratio of q_o/q_i = 0.04. Since q_o/q_i < 0.1 and off the graph shown in Figure H-10, use the equation provided above to find V_s/V_r where $V_s = CP_v$.

$$CP_v / V_r = 0.682 - 1.43\,(q_O/q_I) + 1.64\,(q_O/q_I)^2 - 0.804\,(q_O/q_I)^3$$
$$CP_v / V_r = 0.682 - 1.43\,(0.04) + 1.64\,(0.04)^2 - 0.804\,(0.04)^3 = 0.627.$$

$$CP_v = 0.627 * V_r = 0.627\,(51{,}096\ ft^3) = \mathbf{32{,}037\ ft^3}$$

Notice that the "short-cut" routing equation from Section 3.3.4 uses a CP_v / V_r = 0.65 and 0.65 > 0.627 that we calculated here; this is because the short-cut method calculates the <u>maximum</u> detention volume required.

APPENDIX I: RHODE ISLAND RIVER AND STREAM ORDER

This appendix includes a list of the rivers and streams in Rhode Island that are 4th order or larger. The CP_v and Q_p requirements of Minimum Standards 4 and 5 (Chapter Three) are waived for projects directly discharging stormwater to one of these rivers/streams unless a downstream analysis is performed and demonstrates that additional controls are necessary. The numbers for each river or stream correspond with the River and Stream Order Map included as Figure I-1.

1. **Cady Brook**; Stream Order = 4
   From Connecticut border to confluence with Mowry Meadow Brook south of Reynolds Road.
   RI0005047R-08 and RI0005047R-03

2. **Clear River (see also #5)**; Stream Order = 4
   From confluence of Clear River and Dry Arm Brook through Wilson Reservoir to confluence with Nipmuc River, northwest of Manley Drive to intersection of Brayton Avenue and Sherman Farm Road.
   RI0001002R-05C

3. **Round Top Brook**; Stream Order = 4
   From its confluence with Chockalog River, east of Round Top Road to confluence with Nipmuc River.
   RI0001002R-11

4. **Nipmuc River**; Stream Order = 4
   From its confluence with Round Top Brook, east of Round Top Road.
   RI0001002R-08

5. **Clear River (see also #2)**; Stream Order = 5
   From its confluence with Nipmuc River, at intersection of Brayton Avenue and Sherman Farm Road. To its ending point with Branch River and Chepachet River east of Pelletie Drive.
   RI0001002R-05C

6. **Stingo Brook**; Stream Order = 4
   From point where two of its tributaries join, north of Chesnut Hill Road and Capron Way to its ending into Chepachet River northeast of its crossing John Steere Road.
   RI0001002R-20

7. **Chepachet River (see also #8)**; Stream Order = 4
   From confluence with Stingo Brook, northeast of Stingo Brook crossing of John Steere Road to point where river splits north of Main Street.
   RI0001002R-03

8. **Chepachet River (see also #7)**; Stream Order = 5
   From point where river splits, north of Main Street, to ending at Branch River and Clear River.
   RI0001002R-03

9. **Branch River**; Stream Order = 5
   From point where Clear River, Chepachet River, and Branch River meet east of Pelletie Drive through Slatersville Reservoir, to the confluence with the Blackstone River just west of the intersection of Franklin Way with Saint Pail Street.
   RI0001002R-01A and RI0001002R-01B

10. **Blackstone River (see also #11 & 13)**; Stream Order = 6
   From the Massachusetts border the Blackstone enters Rhode Island as two separate rivers until its confluence with the Branch River, just west of the intersection of Franklin Way with Saint Paul Street.
   RI0001003R-01A

11. **Blackstone River (see also #10 & 13);** Stream Order = 6
   Enters from the MA border between Canal Street and Harris Avenue to its confluence with Mill River just north of end of Florence Drive.
   RI0001003R-01A

12. **Mill River**; Stream Order = 5
   Enters from the MA border just west of Diamond Hill Road and ends at Blackstone River just north of end of Florence Drive.
   RI0001003R-03

13. **Blackstone River (see also #10 & 11)**; Stream Order = 6
   From the intersection of the Mill River, Peters River and the Blackstone, north of Florence Street to the point where it enters Narragansett Bay.
   RI0001003R-01A and RI0001003R-01B

14. **East Sneech Brook to Abbott Run Brook (see also #15)**; Stream Order = 4
   Each Sneech Brook from confluence with Sylvyns Brook North of Nate Whipple Highway and Sneech Pond Road intersection. Flows into Arnold Mills Reservoir. Abbott Run Brook originates at Arnold Mills Reservoir at an unnamed street off of N. Attleboro Road to the MA border south of I-295. Through Rawson Pond and Howard Pond.
   RI0001006R-01A and RI0001006R-03

15. **Abbott Run Brook (see also #14)**; Stream Order = 4
    From MA border east of Curran Road through Robin Hollow Pond through Happy Hollow Pond and ends at the Blackstone River near Mill Street.
    RI0001006R-01B

16. **Ten Mile River**; Stream Order = 4
    Enters from MA border, northeast corner of the state near Crest Drive, runs parallel to Pine Crest Drive then back into MA. Enters RI again near Central Avenue through Slater Park Pond through Central Pond and Turner Reservoir and ends at Omega Pond near intersection of Roger Williams Avenue and Magnolia Street.
    RI0004009R-01B and RI0004009L-01A

17. **Woonasquatucket River**; Stream Order = 4
    Enters the Woonasquatucket Reservoir and begins at intersection with Farnum Pke. Flows into Stillwater Pond and exits from two different locations, joins again and enters Georgiaville Pond, exits near Stillwater Road and ends with its confluence with Moshassuck River and into Narragansett Bay.
    RI0002007R-10A, RI0002007R-10B, RI0002007R-10C and RI0002007R-10D

18. **Stillwater River**; Stream Order = 4
    From point where an unnamed tributary confluences with Stillwater River near Pleasant View Avenue and Spragueville Road intersect to where it enters the Woonasquatucket Reservoir.
    RI0002007R-09

19. **Moshassuck River**; Stream Order = 4
    From the point where Moshassuck River and West River intersect near the I-95N Branch Avenue exit ramps, to its confluence with the Woonasquatucket River.
    RI0003008R-01B and RI0003008R-01C

20. **Ponagansett River**; Stream Order = 4, 5
    The stream order 4 begins with confluence of Shippee Brook with Ponagansett River in between Windsor Road and E. Killingly Road. Flows through Barden Reservoir. Stream order 5 begins at exit of Barden Reservoir west of intersection of Hemlock Road and Ponagansett Road and ends at Scituate Reservoir north of Hemlock Road.
    RI0006015R-20

21. **Hemlock Brook**; Stream Order = 4
    Begins with confluence of Hemlock Brook with Paine Brook just north of Anthony Road. Ends at Barden Reservoir at Hemlock Road.
    RI0006015R-10

22. **North Branch Pawtuxet River**; Stream Order = 5
Begins at Scituate Reservoir at Scituate Avenue. Ends at confluence with South Branch Pawtuxet River to become the Main Stem Pawtuxet River.
RI0006016R-06A and RI0006016R-06B

23. **South Branch Pawtuxet River**; Stream Order = 4
Begins at Flat River Reservoir at Gatehouse Farm Road. Ends at confluence with North Branch Pawtuxet River to become Main Stem Pawtuxet River.
RI0006014R-04A and RI0006014R-04B

24. **Big River**; Stream Order = 4
Begins at confluence of Carr River with Big River south of Noosnck Hill Road. Ends at Reynolds Pond.
RI0006012R-02

25. **Main Stem Pawtuxet River**; Stream Order = 5
Begins at point where the North Branch and South Branch of the Pawtuxet River meet north of Providence Street. Ends at Broad Street where it enters Narragansett Bay.
RI0006017R-03

26. **Pocasset River**; Stream Order = 4
Begins at confluence with Simmons Brook. Flows through Print Works Pond and ends at the Main Stem Pawtuxet River north of O'Keefe Lane.
RI0006018R-03A and RI0006018-03B

27. **Moosup River**; Stream Order = 4, 5
Stream order 4 begins when West Meadow Brook flows into Moosup River west of Johnson Road. Stream order 5 begins from confluence of Bucks Horn Brook with Moosup River west of Lewis Farm Road to CT/RI border north of Nicholas Road.
RI0005011R-03

28. **Bucks Horn Brook**; Stream Order = 4
From confluence with Warwick Brook east of Cahoone Road to the confluence with the Moosup River west of Lewis Farm Road.
RI0005011R-01

29. **Hunt River**; Stream Order = 4
From confluence with Fry Brook through Potowomut Pond ending at Narragansett Bay at Forge Road.
RI0007028R-03B, RI0007028R-03C and RI0007028R-03D

30. **Adamsville Brook**; Stream Order = 4
From eastern RI border with MA east of Crandall Road to confluence of an unnamed tributary with Adamsville Brook east of the intersection of Crandall Road and the southern end of Stoney Hollow Road.
RI0009041R-01

31. **Unnamed Tributary of Adamsville Brook**; Stream Order = 4
From confluence with Adamsville Brook east of the intersection of Crandall Road and the southern end of Stoney Hollow Road to confluence with another unnamed tributary east of Crandall Road and north of East Road (unnamed rds).
RI0009041R-01

32. **Saugatucket River**; Stream Order = 4
From confluence with Indian Run Brook at Columbia Street, north of Church Street to outfall at Narragansett Bay near Route 1A.
RI00010045R-05B and RI00010045R-05C

33. **Usquepaug River**; Stream Order = 4
Begins at Glen Rock Reservoir just north of Old Usquepaugh Road. Ends at its confluence with the Pawcatuck River northeast of Zachary Bend Road.
RI0008039R-25

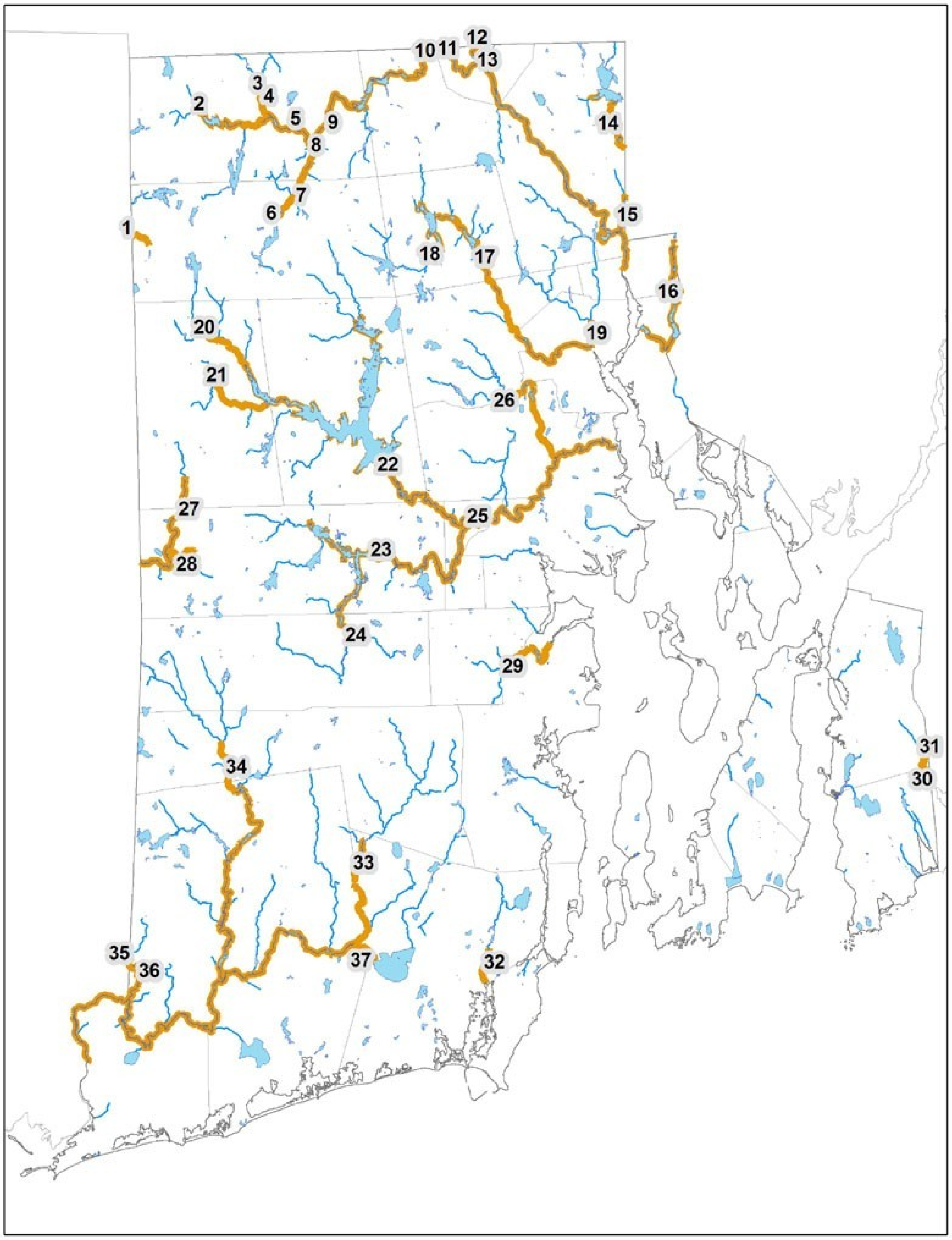
34. **Wood River**; Stream Order = 4
Begins when Falls River and Flat River join north of Ten Rod Road. Flows through Wyoming Pond and Alton Pond before ending at the Pawcatuck River one mile north of Burdickville Road.
RI0008040R-16A, RI0008040R-16B, RI0008040R-16C and RI0008040R-16D

35. **Unnamed Tributary of Parmenter Brook**; Stream Order = 4
Begins where Parmenter Brook joins an unnamed tributary and flows into CT south of I-95. Enters back into RI north of High Street and ends at Ashaway River at Wellstown Road.
RI0008039R-37

36. **Ashaway River**; Stream Order = 4
Begins at Wellstown Road with confluence of an unnamed tributary of Parmenter Brook. Ends at Pawcatuck River west of Laurel Street at CT/RI border.
RI0008039R-02A and RI0008039R-02B

37. **Pawcatuck River**; Stream Order = 4, 5, 6
Stream order 4 begins at Wordens Pond about one mile east of Biscuit City Road. Stream order 5 beings at confluence of Pawcatuck River with Usquepaug River and continues until stream order 6 beings at RI/CT border about 2000 feet north of the end of White Rock Road. Ends at Broad Street where it flows into Little Narragansett Bay.
RI0008039R-18A, RI0008039R-18B, RI0008039R-18C, RI0008039R-18D and RI0008039R-18E

Figure I-1 River and Stream Order Map. Streams Fourth-order and Greater are Highlighted in Yellow.



APPENDIX J: TECHNOLOGY ASSESSMENT PROTOCOL (TAP) FOR INNOVATIVE AND EMERGING TECHNOLOGIES

J.1 INTRODUCTION

New innovative and cost-effective technologies for managing stormwater are constantly emerging, making it difficult for stormwater guidance and regulations to adapt. Rather than have regulators and local communities depend on data from a variety of sources, this protocol has been developed for evaluating the performance and applicability of any new treatment practices. New treatment practices must undergo a third-party evaluation using the Technology Assessment Protocol (TAP) prior to approval for usage for both primary treatment and pretreatment purposes. Reciprocity is given for practices approved elsewhere under TARP (*Technology Acceptance Reciprocity Partnership*) and TAPE (*Technology Assessment Protocol– Ecology*) provided that any deficiencies are addressed with respect to the eleven Minimum Standards presented in Chapter Three.

The Technology Assessment Protocol (TAP) describes testing and reporting procedures to evaluate the effectiveness of innovative and emerging stormwater treatment technologies. The objectives of this protocol are to characterize, with a reasonable level of statistical confidence, an emerging technology's effectiveness in removing pollutants from stormwater runoff for an intended application. The protocol requires an independent third-party verification that will ensure stormwater treatment systems meet the stormwater performance goals and criteria for new development, redevelopment and retrofit situations established in this manual.

Approval will be contingent on submission of objective, verifiable data that meets the Performance Standards and Criteria outlined in Chapter Three. Stormwater treatment technologies will be designated as either i) primary treatment practices for meeting water quality criteria, or ii) pretreatment, and/or quantity control (i.e., CP_v and Q_p) stormwater management practices. Achieving primary treatment designation is dependent upon meeting the Minimum Standard 3. By obtaining accurate and relevant data, the regulatory community can assess performance claims for a particular best management practices (BMPs).

The TAP is adapted largely from 2 assessment protocols: TAPE (*Technology Assessment Protocol– Ecology*), and TARP (*Technology Acceptance Reciprocity Partnership*). The performance statistics review is adapted from the guidance documents from TAPE and USEPA (Geosyntec 2009) entitled Urban Stormwater BMP Performance Monitoring. The TAP addresses limitations in the TARP protocol with respect to the need for standardized reporting to facilitate rapid review and approval based on recommendations from the ASCE/EWRI Task Committee on Guidelines for Certification of Manufactured Stormwater BMPs.

The TAP strongly recommends parallel testing evaluation under rigorous and uniform conditions. The utility of parallel testing is that site characteristics (land use, contaminant loading, sediment characteristics) are consistent for all tested practices and rainfall event characteristics (depth, intensity, duration, antecedent dry period) will be uniform for given performance periods. Identical site and rainfall characteristics enable rigorous performance evaluations that would otherwise complicate direct performance comparisons. This is especially critical given the well know limitations of stormwater solids sampling and its implications on performance testing.

J.2 Purpose Of This Guidance Document

This guidance defines a testing protocol and process for evaluating and reporting on the performance and appropriate uses of existing and emerging stormwater treatment technologies. Approval will be contingent on submission of objective, verifiable data that meets the Standards and Performance Criteria outlined in Chapter Three of the Rhode Island Stormwater Manual. Stormwater treatment technologies will be designated as either i) primary treatment practices for meeting water quality criteria, or ii) pretreatment, and quantity control stormwater management practices. Achieving primary treatment designation is dependent upon meeting the Minimum Standard 3.

By obtaining accurate and relevant data, the regulatory community can assess performance claims for particular best management practices (BMPs). This document can be used to evaluate the effectiveness of public domain and proprietary BMPs for the protection of water resources. The development and use of innovative, cost-effective stormwater management technologies are encouraged.

The permitting agency or designated alternate will be responsible for reviewing and administering approvals.

The financial burden for system testing lies with the proponent of the emerging technology. The regulatory entities will not provide funding for this work.

J.3 Independent Third Party

The TAP requires independent third party work for all reports that contain field data regardless of where this data were collected.

Parties that do not have a direct financial interest in the outcome of testing a treatment practice (e.g., public agencies' testing of public domain treatment facilities) are not required to obtain an independent third party review.

At a minimum, an independent professional must:

- Complete the data validation report verifying that monitoring was conducted in accordance with an approved QAP; and
- Prepare a Technology Evaluation Report (TER) that includes a testing results, summary, conclusions, and comparison with the Minimum Standard 3.

J.4 Treatment Performance Goals

Treatment performance goals are the Standards and Performance Criteria outlined in the Minimum Standard 3. These include performance measures for solids, phosphorous, nitrogen, and bacteria. There are several categories of solids in stormwater. These include total solids, total suspended solids, suspended solids concentration, total dissolved solids, and gross solids. For treatment performance goals, for the purposes of the TAP, performance is measured with respect to total suspended solids. Total solids refers to all particles regardless of size.

J.4.1 Primary Treatment

The stormwater performance goals are outlined in Minimum Standard 3. Systems will be approved for primary treatment if they meet the TSS, bacteria, TP, and TN standards.

J.4.2 Pretreatment Applications

The pretreatment menu facility choices do not meet Minimum Standard 3. They are designed to improve water quality and enhance the effective design life of practices by concentrating the maintenance to a specific, easily serviceable location. The pretreatment applications generally apply to all treatment systems where pretreatment is needed to assure and extend performance of the downstream basic or enhanced treatment facilities.

J.5 Technology Assessment Protocol (TAP) Methodology

J.5.1 Objectives of the Test Protocol

The objectives of this protocol are to characterize, with a reasonable level of statistical confidence, an emerging technology's effectiveness in removing pollutants from stormwater runoff and to compare test results with proponents' claims.

J.5.2 Primary Treatment Level Designation

Primary treatment level designation is granted based on the information submitted and best professional judgment. Submitting the appropriate amount of data does not guarantee that primary treatment designation will be given. Decisions are based on system performance and other factors such as maintenance burden, operation, and integrity. Technologies not granted primary treatment will automatically be considered as pretreatment or secondary treatment.

J.5.3 Quality Assurance Plan (QAP)

Before initiating testing, a quality assurance plan (QAP) must be prepared based on this protocol. The QAP must be submitted for review before conducting field tests. The QAP must specify the procedures to be followed to ensure the validity of the test results and conclusions. A person with good understanding of analytical chemistry methods should develop the QAP in consultation with the analytical laboratory. The QAP author should also be knowledgeable about field sampling and data validation procedures.

QAP guidance includes the following basic elements:

Title Page;
Table of contents;
Project organization and schedule;
Background information and information about the technology to be tested;
Sampling design, including field procedures, sampling methods;
Method quality objectives, including statistical goals;
Laboratory procedures;
Field and laboratory quality control;
Data management procedures;
Data review, verifications and validation; and
Interim progress report(s) during the testing program.

The QAP must specify the name, address, and contact information for each organization and individual participating in the performance testing. Include project manager, test site owner/manager, field personnel, consultant oversight participants, and analytical laboratory that will perform the sample analyses. Identify each study participant's roles and responsibilities and provide key personnel resumes. In addition, provide a schedule documenting when the vendor's equipment will be installed, the expected field testing start date, projected field sampling completion, and final project report submittal. It is recommended that time be allocated for initial startup and testing of the treatment system and monitoring equipment. Vendors should allow up to three months for QAP review and approval.

J.5.4 Field Testing and Site Characterization

The TAP recommends parallel testing evaluation under rigorous and uniform conditions. Field test sites should be consistent with the technology's intended applications. Sites must provide influent concentrations typical of stormwater for those land use types [1]. Include the following information about the test site:

- Field test site catchment area, tributary land uses, (roadway, commercial, high-use site, residential, industrial, etc.) and amount of impervious cover.
- Description of potential pollutant sources in the catchment area (e.g., parking lots, roofs, landscaped areas, sediment sources, exterior storage, or process areas).
- Baseline stormwater quality information to characterize conditions at the site. For sites that have already been developed, it is recommended that

[1] National median stormwater concentrations contains about 43, 49, 81, and 99 mg/L TSS for commercial, residential, industrial, and freeway land use classifications respectively (NSQD, 2005). As a guideline for other contaminants, refer to the National Stormwater Quality Database for ranges in pollutant concentrations in stormwater for various land uses.

the investigator collect baseline data to provide a sizing basis for the practice, and to determine whether site conditions and runoff quality are conducive to performance testing.

- Site map showing catchment area, drainage system layout, and treatment practice and sampling equipment locations.
- Catchment flow rates (i.e., water quality design flow, 1-year, 10-year, and 100-year peak flow rates) at 15-minute and 1-hour time steps as provided by an approved continuous runoff model.
- Make, model, and capacity of the treatment device, if applicable.
- Location and description of the closest receiving water body.
- Description of bypass flow rates and/or flow splitter designs necessary to accommodate the treatment technology.
- Description of pretreatment system, if required by site conditions or technology operation.
- Description of any known adverse site conditions such as climate, tidal influence, high groundwater, rainfall pattern, steep slopes, erosion, high spill potential, illicit connections to stormwater catchment areas, industrial runoff, etc.

J.5.5 Stormwater Data Collection Requirements

The following stormwater data and event requirements are given below to assist in developing the sampling plan.

Table J-1 Stormwater Data Collection Requirements

Item	Stormwater Data Collection Requirement
1	Water level in practice shall be continuously recorded throughout the field testing program, including non-sampled storms and non-rainfall days.
2	Range of recorded water levels shall extend below normal, low flow or dry weather level in practice to above treatment capacity
3	Recorded water levels shall be plotted along with rainfall.
4	Include a description of each maintenance task performed, reason for maintenance, quantities of sediment removed, and a discussion of any anomalous, irregular, or missing maintenance data.
5	To determine practice's required maintenance interval, the minimum duration of the overall field testing program shall be one year beginning at installation, commissioning or the beginning of the removal rate testing, whichever is greater.
6	Storm event must have a minimum total rainfall depth of 0.1 inches.
7	Inter-event dry period between storms shall begin when runoff from prior storm ceases.
8	Minimum of 20 storms sampled, although 25 or more are recommended.
9	Storms do not need to be consecutive.
10	Peak runoff of at least 3 storms shall exceed 75% of the practice's capacity.
11	Minimum total rainfall for all storms sampled shall be 15 inches.
12	Minimum number of samples collected shall be 10 for storms lasting longer than 1 hour or more.
13	Minimum number of samples collected shall be 6 for storms lasting less than 1 hour.
14	Samples shall be taken over time to cover a minimum of 70% of total runoff volume.
15	Rainfall shall be recorded continuously during events with max time interval of 5 minutes for runoff collection based on time and max rainfall interval of 0.01 inches for runoff collection based on volume.
16	Rainfall shall be recorded throughout the sampling program.
17	Rainfall from non-sampled events can be recorded with same gauge or obtained from a nearby gauge provided that gauge has minimum recording interval of 1 hour.
18	1) Max. 15 minute rainfall intensity for shall be 5 in/hr (i.e. 1.25 in/15-min).
19	2) Max. total rainfall shall be 3in.
20	3) 1 storm sampled may exceed previous two requirements.

J.5.6 Stormwater Field Sampling Procedures

This section describes field sampling procedures necessary to ensure the quality and representativeness of the collected samples. This section presents discussions on sampling methodology (e.g., discrete versus composite sampling), flow monitoring, target pollutant selection, sample handling and preservation, and field QA/QC.

J.5.6.1 Sampling methods.

Collect samples using automatic samplers, except for chemical constituents that require manual grab samples. Use teflon tubing if samples will be analyzed for organic contaminants. To use automatic sampling equipment for insoluble TPH/oil, a determination is needed that any TPH/oil adherence to the sampling equipment is accounted for and meets QA/QC objectives. This determination requires support with appropriate data. The responsible project professional should certify that the sampling equipment and its location would likely achieve the desired sample representativeness, aliquots, frequency, and compositing at the desired influent/effluent flow conditions.

The following three sampling methods have been identified for evaluating whether new treatment technologies will meet the stormwater treatment goals:

> 1. Automatic flow-weighted composite sampling. Collect samples over the storm event duration and composite them in proportion to flow. This sampling method generates an event mean concentration and can be used to determine whether the treatment technology meets the pollutant removal goals on an average annual basis. For this method, samples should be collected over the entire runoff period. As a guideline, at least 10 aliquots should be composited, covering at least 70 percent of each storm's total runoff volume. The greater the number of aliquots and storm coverage the greater the confidence that the samples represent the event mean concentration for the entire storm.
>
> *2.* Discrete flow composite sampling. For this method, program the sampler to collect discrete flow-weighted samples. Combine samples representing relatively constant inflow periods (e.g., less than 20 percent variation from the median flow) to assess performance under specific flow conditions. The monitoring approach must also address the effect of lag time within the practice that would affect the comparability of influent and effluent samples paired for purposes of evaluating a particular flow rate. One way to achieve this is to set the flow pacing so that each discrete sample bottle fills when the total runoff volume passing the sampler is equal to 8 times the treatment unit's detention volume. Other ways to account for lag time may also be considered.
>
> Proponents can use this method to determine whether the treatment technology achieves the pollutant removal goals at the design hydraulic

loading rate. For this method, collect samples over a flow range that includes the manufacturer's recommended treatment system design flow rate. Sample other flow ranges if needed to characterize the efficiencies of the practice over a reasonable range of hydraulic loading rates. Distribute samples over a range of flow rates from 50-150% of the practice's design loading rate. This technique is necessary for practices where the influent and effluent flowrate are nearly equal because the system does not control the effluent flowrate (e.g., swirl separators). This technique is required to verify how the practice functions at varying flowrates.

3. Combination method. For flow-through practices, proponents can use a combination of the above two methods to evaluate treatment goals. For the combination method, collect discrete flow composite samples as allowed during a single storm event and process for analysis. Composite the remaining bottles in the sampler into a single flow-weighted composite sample to capture the entire runoff event for analysis. Mathematically combine the results from the discrete flow composite samples and the single flow-weight composite sample to determine the overall event mean concentration.

J.5.6.2 Sampling locations.

Provide a site map showing all monitoring/sampling station locations and identify the equipment to be installed at each site. To accurately measure system performance, samples must be collected from both the inlet and outlet from the treatment system. Sample the influent to the treatment technology as close as possible to the treatment practice inlet. Samples should represent the total runoff from the catchment area. To ensure that samples represent site conditions, design the test site so that influent samples can be collected from a pipe that conveys the total influent to the unit. To avoid skewing influent pollutant concentrations, sample the influent at a location unaffected by accumulated or stored pollutants in, or adjacent to, the treatment practice.

Influent, effluent, and bypass sampling shall be conducted upstream and downstream of any practice diversions and/or bypass so that the entire sampled storm runoff can be included in sampling. In some instances bypass sampling may not be possible.

Sample the effluent at a location that represents the treated effluent. If bypass occurs, measure bypass flows and calculate bypass loadings using the pollutant concentrations measured at the influent station. In addition, be aware that the settleable or floating solids, and their related bound pollutants, may become stratified across the flow column in the absence of adequate mixing. Collect samples at a location where the stormwater flow is well-mixed.

J.5.6.3 Sampler installation, operation, and maintenance.

Provide a detailed sampling equipment description (make and model) as well as equipment installation, operation, and maintenance procedures. Discuss sampler installation (e.g., suction tube intake location relative to flow conditions at all sampling locations, field equipment security and protection), automatic sampler programming (e.g., composite versus discrete sampling, proposed sampling triggers and flow pacing scheme), and equipment maintenance procedures. Install and maintain samplers in accordance with manufacturer's recommendations. Indicate any deviations from manufacturer's recommendations. Provide a sampling equipment maintenance schedule. When developing the field plan, pay particular attention to managing the equipment power supply to minimize the potential for equipment failure during a sampling event.
Note: Tygon or teflon tubing may be used for sampling conventional parameters and metals.

J.5.6.4 Flow monitoring.

Measure and record flow into and out of the treatment practice on a continuous basis over the sampling event duration. The appropriate flow measurement method depends on the nature of the test site and the conveyance system. Depth-measurement practices and area/velocity measurement practices are the most commonly used flow measurement equipment. For offline systems or those with bypasses, measure flow at the bypass as well as at the inlet and outlet. Describe the flow monitoring equipment (manufacturer and model number), maintenance frequency and methods, and expected flow conditions (e.g., gravity flow or pressure flow) at the test site. For offline flow, describe the flow splitter that will be used and specify the bypass flow set point. Identify site conditions, such as tidal influence or backwater conditions that could affect sample collection or flow measurement accuracy. Flow should be logged at a 5-minute or shorter interval, depending on site conditions.

J.5.6.5 Rainfall monitoring.

Measure and record rainfall at 15-minute intervals or less during each storm event from a representative site. Indicate the type of rain gauge used (e.g., an automatic recording electronic rain gauge, such as a tipping bucket connected to a data logger, that records rainfall in 0.01 inch increments), provide a map showing the rain gauge location in relation to the test site, and describe rain gauge inspection and calibration procedures and schedule. Install and calibrate equipment in accordance with manufacturer's instructions. At a minimum, inspect the rain gauge after each storm and if necessary, maintain it. In addition, calibrate the gauge at least twice during the field test period. If the onsite rainfall monitoring equipment fails during a storm sampling event, use data from the next-closest, representative monitoring station to determine whether the event meets the defined storm guidelines. Clearly identify any deviations in the TER report. Nearby third party rain gauges may only be used in the event of individual rain gauge failure and only for the period of failure. If third party rain gauges are used to fill in data gaps, establish a regression relationship between site and third party gauges and use the regression equation to adjust the third-party data to represent site rainfall when needed.

J.5.6.6 Sampling for TSS, SSC, Nutrients, and Bacteria

Standardized test methods should be used such as EPA's Methods and Guidance for the Analysis of Water and the American Public Health Association's Standard Methods for the Examination of Water and Wastewater. Other nationally recognized organizations, such as American Water Works Association (AWWA) and NSF International, have produced standards that may be used.

This protocol defines TSS as matter suspended in stormwater, excluding litter, debris, and other gross solids. It is recognized that TSS (Standard Methods 2540D) has limitations with respect to bias due to particle size and representativeness. As a result it is recommended that samples are also tested for Suspended Sediment Concentration (SSC) (ASTM D-3977). SSC has been shown to show excellent representativeness for load and total solids (Roseen et al., 2009(a)). TSS is the current regulatory measure and SSC is being reported as a superior measure although not regulated.

Sampling for nutrients will include dissolved inorganic nitrogen (DIN, SM 4500, EPA Method 353.2), Total Kjeldahl Nitrogen (TKN, EPA Method 351.2), total nitrogen (TN), soluble reactive phosphate (orthophosphate) (SRP, EPA Method 365.3), and total phosphorous (TP, EPA Method 365.3).

Sampling for bacteria will include Total Coliform (EPA Method 1604), Enterococci (EPA Method 1106.1), and Escherichia coli (EPA Method 1103.1). Not all measures will be appropriate in all conditions. E. coli is salt intolerant and may not be present in certain locations where deicing is common or saline water is present.

It is understood that sampling and analyses for nutrients and bacteria can be problematic for 6-hour holding times with anything other than grab samples. Automated samplers will need to maintain sample storage at 1-4°C. As per method (1604) for drinking water samples, they should be analyzed within 30 hours of collection for bacteria. Nutrients can be stored longer at near frozen temperatures (Avanzino and Kennedy, 1993).

To determine percent reduction, the samples must represent the vertical cross section (be a homogeneous or well-mixed sample) of the sampled water at the influent and the effluent of the practice. Select the sampling location and place and size the sampler tubing with care to ensure the desired representativeness of the sample and the stormwater stream. The site professional should select the method using best professional judgment. Performance goals apply on an average annual basis to the entire annual discharge volume (treated plus bypassed).

Accumulated Sediment Sampling Procedures

Measure the sediment accumulation rate to help demonstrate facility performance and design a maintenance plan. Practical measurement methods would suffice, such as measuring sediment depth, immediately before sediment cleaning and following test completion. Particle size distribution (PSD) analyses are determined using wet sieving and hydrometer (ASTM Standard D 422 – 63).

Use several grab samples (at least four) collected from various locations within the treatment system to create a composite sample. This will ensure that the sample represents the total sediment volume in the treatment system. For QA/QC purposes, collect a field duplicate sample (see following section on field QA/QC). Keep the sediment sample at 4^{O} C during transport and storage prior to analysis. If possible, remove and weigh (or otherwise quantify) the sediment deposited in the system. Quantify or otherwise document gross solids (debris, litter, and other particles). Use volumetric sediment measurements and analyses to help determine maintenance requirements, calculate a TS mass balance, and determine if the sediment quality and quantity are typical for the application.

J.5.6.7 Sampling for PSD

To meet the solids removal goals, treatment technologies must be capable of removing TSS across the size fraction range typically found in urban runoff. Field data show most TSS particles are silt sized particles. PSD analyses must be performed for 3 paired events per year for influent, effluent, and accumulated residual sediments at the end of the monitoring period. Comparisons of PSD in the influent and effluent and the accumulated residual sediments will demonstrate the particle range of sediments removed and un-removed. PSD data can also provide information regarding total solids transport during a storm.

Of the analytical procedures available, the Coulter Counter (Model 3) and the laser-diffraction method are used for samples obtained by auto-sampler and for measuring smaller particles. Sieving can only be used to quantify large volume samples with sediment volumes typically in excess of 500 grams. Due to the potential differences in precision among analytical procedures (Webb, 2000), use the same analytical apparatus and procedure for each evaluation test program. A recommended PSD analytical procedure using laser diffraction instrumentation and sieve analysis is included. It must be recognized that PSDs obtained by optical measure (laser diffraction and Coulter Counter) will have limited direct comparison with sieving and hydrometer analysis. Refer to Pitt (2002) for a comprehensive discussion on PSD in stormwater runoff.

J.6 Field Quality Assurance and Quality Control (QA/QC)

The field QA/QC section describes the measures that will be employed to ensure the representativeness, comparability, and quality of field samples. Field QA/QC should include the elements listed below:

J.6.1 Equipment calibration

Describe the field equipment calibration schedule and methods, including automatic samplers, flow monitors, and rainfall monitors. The accuracy of the flow meters is very important so their calibration should be carefully conducted by the site professional in accordance with manufacturer's recommendations.

J.6.2 Recordkeeping

Maintain a field logbook to record any relevant information noted at the collection time or during site visits. Include notations about any activities or issues that could affect the sample quality (e.g., sample integrity, test site alterations, maintenance activities, and improperly functioning equipment). At a minimum, the field notebook should include the date and time, field staff names, weather conditions, number of samples collected, sample description and label information, field measurements, field QC sample identification, and sampling equipment condition. Also, record measurements tracking sediment accumulation. In particular, note any conditions in the tributary basin that could affect sample quality (e.g., construction activities, reported spills, other pollutant sources). Provide a sample field data form in the QAP.

J.6.3 Laboratory Quality Assurance Procedures

Laboratories performing stormwater sample analysis must be certified by a national or state agency regulating laboratory certification or accreditation programs. Report results in the TER or use level designation application. Include a table with the following:

- Analyte
- Sample matrix
- Laboratory performing the analysis
- Number of samples
- Analytical method (include preparation procedures as well as specific methods especially when multiple options are listed in a method)
- Reporting limits for each given analytical method (include the associated units).

J.6.4 Data Management Procedures

Include a quality assurance summary with a detailed case narrative that discusses problems with the analyses, corrective actions if applicable, deviations from analytical methods, QC results, and a complete definitions list for each qualifier used. Specify field/laboratory electronic data transfer protocols (state the percent of data that will undergo QC review) and describe corrective procedures. Corrections to data entries should include initials of the person making the correction and the date corrected. Indicate where and how the data will be stored.

J.6.5 Data Review, Verification, and Validation

Describe procedures for reviewing the collection and handling of the field samples.

Establish the approach that will be used to determine whether samples meet all flow sampling and rainfall criteria.

Validation requires thoroughly examining data quality for errors and omissions. Establish the process for determining whether data quality objectives have been met. Include a table indicating percent recovery (%R) and relative standard deviation (RSD) for all QC samples. Determine whether precision and bias goals have been met. Establish a procedure to review reporting limits to determine whether non-detected values exceed reporting limit requirements.

Analyze all data for statistical significance. Guidance on appropriate statistics can be found in Section J.9 Data Evaluation Methodology Statistics and other related reports (Pitt, 2002 & Burton and Pitt, 2001). Statistical data analyses should include:

Exploratory Data Analysis
Exploratory data analysis should be used to observe overall data characteristics. These plots should include: 1) probability plots, 2) time series scatter plots, 3) grouped notched box and whisker plots to examine influent and effluent conditions.

Parametric and Nonparametric Tests for Paired Data Observations.
In the simplest case for monitoring the effectiveness of treatment alternatives, comparisons can be made of inlet and outlet conditions to determine the level of pollutant removal and the statistical significance of the concentration differences. Non-parametric tests for evaluating stormwater controls should use the basic sign test for paired data. The Mann-Whitney signed rank test has more power than the sign test, but it requires that the data distributions be symmetrical.

Regression Analyses
The use of a Regression of EMCs (influent versus effluent) should be used to determine the treatment performance, along with an analysis of variance, to determine the statistical relevance of the resulting overall regression equation and equation terms. The treatment performance can then be evaluated with the respect to the Minimum Standards.

J.7 TECHNICAL EVALUATION REPORT (TER)

After testing has been completed, submit a TER to DEM or CRMC. The TER supports the technologies ability to obtain a primary treatment level designation. If it is accepted for primary treatment, the technology and will be added to future Stormwater Management Manuals. The TER must contain performance data from a minimum of one test site, and a statement of the QAP objectives including the vendor’s performance claims for specific land uses and applications.

A prescriptive reporting approach is provided to insure completeness of reporting and to facilitate an effective and rapid review. The reporting guidelines are from the ASCE/EWRI Task Committee on Guidelines for Certification of Manufactured Stormwater BMPs (Roseen et al., 2009(b)).

The framework is listed below.

1. Summary: Executive Summary with rated performance rating, Study Summary, Data Collection Summary
2. Definitions
3. Site Conditions: longitude, latitude, land cover type, land use activities, site conditions, site elevations and slopes, location of sampling equipment, location of on-site stormwater collection system, and a description of any upstream BMPs
4. Technology Description:
   a) The specific device used (model number, size, operating rate or volumetric flow rate)
   b) Functionality of treatment mechanisms including pretreatment and bypass requirements
   c) Physical description: engineering plans, site installation requirements
   d) Sizing methodology used for test: either manufacturers sizing methodology or agency specific sizing requirements (flows, volumes, runoff depth, etc.)
   e) Maintenance procedures
5. Test Methods and Procedures
   a) Particle size for influent, effluent, and residuals, mass based, concentration based
   b) Water quality parameters monitored
   c) Data Quality Objectives (DQO), QA methods, and measurement accuracy for the observations
   d) Measuring instruments, sampling frequency, and sampling program information
   e) Sampling Locations and Peak Concentration Timing
6. Testing and Sampling Event Characteristics:
   a) Storm date, depth, antecedent dry period, intensity, duration, season, type of runoff (precipitation, snowmelt, groundwater, etc.)
   b) Number of influent and effluent aliquots; storm volume, % storm treated influent, effluent, peak flow rate, calculation of peak reduction and lag coefficients, number of storms exceeding design criteria.
   c) Comparisons with Data Quality Objectives
   d) System timeline (start and completion, sample events, rainfall events, maintenance occurrence)
   e) Water level within system and rainfall for testing duration
7. Performance Results and Discussion:
   a) Event mean concentrations for influent and effluent with summary statistics (N, mean, median, coefficient of variation, standard deviation, one –tailed sign t-test)
   b) Detection limits and confidence intervals
   c) Performance metrics: removal efficiency for EMC and mass loads, efficiency ratio
   d) Statistical Evaluation: time series plot, box and whisker with confidence intervals, effluent probability method, linear regression.

   e) Solids characterization: influent, effluent, residuals particle size analysis
   f) Accumulated mass reductions
   g) Individual Storm Reports with event characteristics (6a and 6b), combination event hydrograph and hyetograph with sample times; system performance characteristics (7a-c), monitoring details
   h) Quality Assurance, rejection criteria and rejection summary.
   i) Maintenance findings: discussion on recommended maintenance schedules
8. Conclusions, Performance Claims, and Limitations
9. Appendices: Raw data and credentials
10. Third Party Review. The testing and reporting, if not performed by an independent professional third party, must be reviewed. The independent review should include a review summary and observation of at least one monitoring event.

J.7.1 Confidential Information Submitted by the Applicant

Certain records or other information furnished in the TER may be deemed confidential. In order for such records or information to be considered confidential, the proponent of such technology must certify that the records or information relate to the processes of production unique to the manufacturer, or would adversely affect the competitive position of such manufacturer if released to the public or to a competitor. The proponent must request that such records or information be made available only for the confidential use.

To make a request for confidentiality, clearly mark only those pages that contain confidential material with the words “confidential.” Include a letter of explanation as to why these pages are confidential. A notice will be sent granting or denying the confidentiality request.

J.7.2 Treatment Efficiency Calculation Methods

Calculate several efficiencies, as applicable. Consider lag time and steady-state conditions to calculate loads or concentrations of effluents that represent the same hydraulic mass as the influent. State the applicable performance standard on the table or graph.

For technologies sized for long residence times (hours versus minutes), the proponent must consider cumulative event mean performance of several storms, wet season or annual time periods. For short residence times (several minutes), event mean comparisons are recommended. For discrete short-time step residence times (few minutes), the proponent should consider lag times for influent/effluent comparisons.

Method #1: Individual storm reduction in pollutant concentration.

The reduction in pollutant concentration during each individual storm calculated as:

$$\frac{100[A-B]}{A}$$

Where: A = flow-weighted influent concentration B = flow-weighted effluent concentration

Method #2: Aggregate pollutant loading reduction.

Calculate the aggregate pollutant loading removal for all storms sampled as follows:

$$\frac{100[A-B]}{A}$$

Where: A = (Storm 1 influent concentration) * (Storm 1 volume) + (Storm 2 influent concentration) * (Storm 2 volume) +… (Storm N influent concentration) * (Storm N volume)

B = (Storm 1 Effluent concentration) * (Storm 1volume) + (Storm 2 effluent concentration) +…(Storm N effluent concentration) * (Storm N volume)

Concentrations are flow-weighted and flow = average storm flow or total storm volume (vendor’s choice)

Method #3: Individual storm reduction in pollutant loading.

Calculate the individual storm reduction in pollutant loading as follows:

$$\frac{100[A-B]}{A}$$

Where: A = (Storm 1 influent concentration) * (Storm 1 volume)

B = (Storm 1 effluent concentration) * (Storm 1 volume)

J.8 References

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J.9 Data Evaluation Methodology Statistics

Adapted from TAPE, original source by Robert Pitt, P.E., Ph.D.

The following is a step-by-step procedure for conducting the statistical analysis:

1. Exploratory Data Analysis
In all cases, simple plots need to be presented to observe overall data characteristics. These plots should include: 1) probability plots, 2) time series scatter plots, 3) grouped notched box and whisker plots to examine influent and effluent conditions. These plots must be presented along with statistical analyses to quantify the patterns observed.

2. Parametric and Nonparametric Tests for Paired Data Observations
Nonparametric statistical tests may be a better choice than typical parametric tests. If the data conditions allow parametric tests (at least normally distributed data, for example), then the parametric tests usually have more statistical power. However, few environmental data meet parametric statistical test requirements. If a parametric test is improperly selected, then the calculated results can be very unreliable. **In most cases, nonparametric test alternatives are available and should be used unless the more restrictive test conditions can be met.**

Nonparametric tests also have certain requirements and these need to be considered. Generally, if the COV of a data set is less than about 0.4 (unlikely for most stormwater information, except for pH), it may be possible to use standard parametric tests. Alternately, it may be possible to transform the data (typically by using log transformations) so the data is normally distributed if parametric tests are desired. The following paragraphs summarize some of the more useful nonparametric tests for evaluating stormwater controls.

Nonparametric paired tests are probably the most useful statistical test procedure when conducting stormwater control evaluations. The sign test is the basic nonparametric test for paired data. It is simple to compute and has no requirements pertaining to data distributions. A few “not detected” observations can also be accommodated. Two sets of data are compared. The differences are used to assign a positive sign if the value in one data set is greater than the corresponding value in the other data set, or a negative sign is assigned if the one value is less than the corresponding value in the other data set. The number of positive signs are added and a statistical table is used to determine if the number of positive signs found is unusual for the number of data pairs examined.

The Mann-Whitney signed rank test has more power than the sign test, but it requires that the data distributions be symmetrical (but with no specific distribution type). Without logarithmic, or other appropriate, transformations, this requirement may be difficult to justify for water quality data. This test requires that the differences between the data pairs in the two data sets be calculated and ranked before checking with a special statistical table. In the simplest case for monitoring the effectiveness of treatment alternatives, comparisons can be made of inlet and outlet conditions to determine the level of pollutant removal and the statistical significance of the concentration differences.

Friedman's test is an extension of the sign test for several related data groups. There are no data distribution requirements and the test can accommodate a moderate number of "non-detectable" values, but no missing values are allowed.

3. Regression Analyses

Regression analyses are very popular, but frequently misused. The use of the regression option in Microsoft Excel provides sufficient information for correct interpretation of the test results. Unfortunately, it is easy to place too much emphasis on the R^2 value when conducting a regression analysis, without first checking on the significance of the equation coefficients, and ensuring that the regression assumptions have been met. An analysis of variance (ANOVA) should always be conducted along with a regression analysis to determine the statistical relevance of the resulting overall regression equation and equation terms. These are always more useful than the traditional R^2 value when determining the acceptability of an equation. It is possible to have a statistically significant and useful model, with a seemingly low R^2 value.
In order to obtain the best and most useful regression analysis results, Burton and Pitt (2002) presented the following steps:

- Formulate the objectives of the curve-fitting exercise.
- Prepare preliminary examinations of the data, most significantly, prepare scatter plots, probability plots, and box and whisker plots
- Evaluate the data to ensure that regression is applicable and make suitable data transformations.
- Apply regression procedures to the selected alternative models.
- Evaluate the regression results by examining the coefficient of determination (R^2) and the results of the analysis of variance of the model (standard error analyses, and p values for individual equation parameters and overall model).
- Suggested: Conduct an analysis of the residuals (probability plot of residuals, plot of residuals against predicted model outcomes, and a plot of the residuals

against the time sequence when the data were obtained). The probability plot should indicate a random distribution of the residuals, while the other plots should indicate an even (and hopefully narrow) band straight across the plot, centered along the 0 residual value. If these plots are incorrect, then the resulting model is likely faulty and should be reconsidered. Data transformations and additional model coefficients can be used to improve residual behavior).

4. Summary of Results

List all the results based on the exploratory and complete data analyses. Include the statistical determinations for alpha and beta errors, calculated p-values, COV, regression equations and possibly other models and associated residual analyses.

5. Summary of the Statistics Methodology Used

As indicated above, the basic steps in the recommended statistical methodology include:

- Proper and balanced experimental design considering project objectives and expected characteristics
- Conducting initial experiments and initial data evaluations for quality control and general verification of methodology and experimental errors (do not make any major changes until sufficient data has been collected and evaluated to protect against premature experimental modifications).
- Conducting complete experiments
- Exploratory data analysis and other basic statistical tests (comparison tests, regression analyses, etc.)
- Additional statistical tests to investigate other data features (trends, complex interactions, etc.)
- Preparing project report, including recommendations.

J.10 LABORATORY METHODS

Table J-2 Recommended Analytical Procedures in Stormwater

Parameter	Analyte (or surrogate)	Method (in water)	Reporting Limit[a,b]
Conventional Parameters	Total suspended solids	EPA Method 160.2 or SM 2540D	1.0 mg/L
	Total dissolved solids	EPA Method 160.1 or SM 2540C	1.0 mg/L
	Settleable solids	EPA Method 160.5 or SM 2540F	1.0 mg/L
	Particle size distribution	Coulter Counter or Laser diffraction, or comparable method	
	pH	EPA Method 150.1 or SM 4500H^+	0.2 units
Nutrients	Total phosphorus	EPA Method 365.3 or SM 4500-P I	0.01 mg P/L
	Orthophosphate	EPA Method 365.3 or SM 4500-P G	0.01 mg P/L
	Total kjeldahl nitrogen	EPA Method 351.2	0.5 mg/L
	Nitrate-Nitrite	EPA Method 353.2 or SM 4500 -$NO3^-$ I	0.01 mg/L
Bacteria	Total Coliform	EPA Method 1604	1 colony forming unit/per sample volume or dilution
	Enterococci	EPA Method 1106.1	
	Escherichia coli	EPA Method 1103.1	

a. Reporting limits may vary with each lab. Reporting limits for your lab should be the same or below those given in the table.
b. All results below reporting limits should also be reported and identified as such. These results may be used in the statistical evaluations.
NA – Not applicable
SM – Standard Methods

Table J-3 Recommended Analytical Procedures in Sediment.

Parameter	Analyte (or surrogate)	Method (in Sediment)	Reporting Limit[a,b]
Grain-size	Total Solids	EPA Method 160.3 or SM 2540B	NA
	TVS	EPA Method 160.4 or SM 2540E	0.1%
	Grain-size	ASTM F312-97	
Bacteria	Total Coliform	EPA Method 1604	1 colony forming unit/per sample volume or dilution
	Enterococci	EPA Method 1106.1	
	Escherichia coli	EPA Method 1103.1	

a. Reporting limits may vary with each lab. Reporting limits for your lab should be the same or below those given in the table.
b. All results below reporting limits should also be reported and identified as such. These results may be used in the statistical evaluations
NA – Not applicable
SM – Standard Method

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APPENDIX K: HYDROLOGIC & HYDRAULIC MODELING GUIDANCE

The following checklist is provided to assist designers in complying with Minimum Standard #4 Conveyance and Natural Channel Protection and Minimum Standard #5 Overbank Flood Protection in this manual. This checklist was prepared by Nicholas A. Pisani, P.E. of DEM to help guide designers with the drainage design and submittal requirements under the DEM Freshwater Wetland Regulations. This design guidance should similarly be used when preparing applications to the CRMC under the *Rules and Regulations Governing the Protection of Freshwater Wetlands in the Vicinity of the Coast* and for applications under the Coastal Resources Management Program (CRMP). In some cases, the CRMC may waive some of these guidance elements for projects discharging stormwater directly to coastal waters under CRMP Section 300.6.

The CRMC and other State or local permitting entities may also have additional or somewhat different requirements in their regulations or regulatory guidance. Accordingly, the designer may wish to consult with the appropriate permitting agency before proceeding with the project design.

- A Hydrologic Analysis should include four components:
  - A Drainage Narrative
  - Pre- and Post-development Drainage Area Maps
  - A Drainage Diagram (node diagram)
  - Drainage Analysis Input and Output data

Note: For Drainage Area Maps, adequately label all drainage areas, detention storage and/or infiltration practices, and other BMPs. Labeling needs to be consistent with submitted drainage analysis.

DRAINAGE NARRATIVE

- The drainage narrative should include:
  - Provide a detailed description of existing condition hydrology;
  - Describe any existing drainage systems, and indicate their design capacities and their existing conditions;
  - The design storms for all proposed drainage systems/drainage facilities;
  - The design capacity of all proposed drainage systems;
  - Include a description of each of the design/analysis points. This description needs to address the downstream receiving destination of each design/analysis point;
  - Describe any upgradient areas (including off-site areas) that contribute drainage to any of the drainage areas included in the analysis;
  - Describe the site, including cover types, slopes, critical features, and/or constraints such as wetlands, steep slopes, utility corridors/easements, and pertinent site history;

- Indicate the analysis methods used and software packages used, including version references;
- Indicate the goals of the analysis, including all local, state, and federal parameters and goals addressed in the submittal;
- Describe the various water quality mitigation practices and water quantity mitigation (including mitigation of peak runoff discharge rates, and if necessary, total runoff volume) practices employed (see Appendix A);
- Summarize the results of the analysis, including summary of key input data (rainfall depths for each storm event analyzed, subwatershed areas, weighted curve numbers (CNs), and times of concentration (t_c)) and output data (peak runoff discharge rate, time of peak, and total runoff volume). In this comparison, also address the overall changes in drainage area to each design/analysis point; and
- Include a discussion of any and all diversion structures that may be included in the design.

DRAINAGE AREA MAPS

The following list serves as guidance for the preparation of existing (pre-development) condition and proposed (post-development) condition drainage area maps.

This guidance is intended to allow design engineers to prepare the drainage area maps which accompany submitted drainage analyses in a manner which allows for clear and expeditious review. Drainage area maps which include the items listed below will typically allow the reviewing staff to clearly observe the correlation between the site conditions (existing and proposed) that affect the production of runoff and the submitted analyses.

Drainage area maps prepared in accordance with the following guidelines need to accompany all engineering drainage analysis calculations for the determination of existing (pre-development) condition and proposed (post-development) condition peak runoff discharge rates.

- Separate drainage area maps should be submitted for existing (pre-project) and proposed (post-development) conditions;
- Provide one set of drainage area maps to accompany each drainage analysis copy;
- If possible, try to limit the size of sheets to 24” x 36”. However, if it is necessary to use a larger sheet due to the size of the watershed, this is acceptable. Because the drainage area maps are considered to be a component of the drainage analysis, and not part of the submitted plans, the 24” x 36” size limitation may be deviated from where appropriate;
- Drainage area boundaries or limits need to be complete. If drainage areas include upgradient areas which extend beyond the subject property, provide adequate drainage area mapping of off-site areas so as to depict the entirety of each drainage area;
- Provide a suitable scale for existing and proposed condition drainage area maps,

such as 1”=40’, 1”=50’, or 1”=100’. Scales which provide greater detail are acceptable. If the drainage area(s) is/are very large, the on-site map scale must be no smaller than 1”=100’. Smaller scale mapping (such as 1”-2,000’ USGS topography map scale or the 1”=1,320’ scale of the Soil Survey of Rhode Island maps) may be done for off-site areas;

- The existing and proposed condition drainage area maps need to compare the same overall area. Common analysis points are also needed for comparison of pre-development and post-development runoff discharge. Be sure to account for any post-development drainage areas which do not drain to a stormwater facility;
- Provide sufficient off-site detail, either on the drainage area maps or on accompanying maps of appropriate scale (such as USGS quadrangle maps), to provide the downstream destination of watercourses which leave the site. (For example, two streams leaving the site may converge to discharge to the same downstream river, or may diverge to flow to separate watersheds;
- Provide existing (pre-development) condition and proposed (post-development) condition topography. Do not illustrate proposed condition topography on the existing condition drainage area map. Provide at least a 2’ contour interval for the on-site topography. Topography for upgradient, off-site areas may utilize a 10’-contour interval (e.g., USGS topography);
- Indicate the property lines of the subject site and the proposed project limits on all submitted drainage area maps;
- Indicate the limits of wetland areas on-site, and depict approximate limits of off-site wetlands in the project vicinity (e.g., Soil Survey of Rhode Island maps and/or USGS quadrangle map information may be used for off-site areas);
- Indicate the designation of watercourses and water bodies in terms of applicable Freshwater Wetlands Program terminology (e.g., rivers, streams, ponds, areas subject to storm flowage (ASSFs). Include the names of water bodies, where applicable;
- The drainage area maps need to map and indicate the various cover types in each drainage area (see Urban Hydrology For Small Watersheds, 1986 (TR-55 Manual), Table 2.2), which are used to calculate the weighted curve number for each drainage area. Map and label the cover types (example: woods, brush, grass, impervious, etc,) along with pertinent hydrologic soil groups (A, B, C, or D), and applicable hydrologic conditions (i.e., good) within each subarea. Number each existing and proposed condition subarea. Please ensure that the labeling of the subareas is consistent with the submitted analysis;
- Indicate the t_c flow path of each drainage area (TR-55 Manual, Chapter 3); and
- Indicate all existing and proposed stormwater conveyance feature (swales, pipes, catch basins, drainage inlets, ditches, culverts, etc.) and stormwater management facilities and/or practices used for detention and/or water quality management purposes. Clearly indicate which areas these items serve. Label all proposed stormwater management facilities and/or BMPs. Please ensure that the labeling of the proposed stormwater facilities/BMPs is consistent with the submitted analysis.
- Provide a north arrow on each drainage map.
- For all proposed buildings, indicate the areas which drain to each respective drainage area. Also, indicate roof leaders and the drainage areas to which these

roof leaders are directed.

- Indicate the Qualifying Pervious Areas (QPAs) on the drainage area maps, as applicable.

DRAINAGE DIAGRAM

A drainage diagram (often referred to as a node diagram) is needed to allow the reviewer to observe the various flow paths of the analyses. This diagram is intended to indicate the drainage areas that produce the runoff being analyzed, the various reaches that convey this runoff, detention and/or infiltration facilities that detain and/or infiltrate runoff, and discharge locations that represent the various design/analysis points that are studied. Certain nodes may represent drainage structures with more than one discharge destination. These nodes are used to represent such structures as diversion manholes and similar facilities.

Drainage diagrams are used by the reviewer to observe and evaluate the model set-up of the submitted hydrologic analysis. These diagrams are used to relate the various inputs and outputs found in the submittal to the drainage area maps and to the plans.

- The drainage diagram should:
  - Provide pre-development and post-development drainage diagram;
  - Indicate drainage areas, reaches, ponds (including detention basins and/or infiltration facilities), pertinent drainage structures (such as diversion structures), and design/analysis points. Connect these nodes with arrows indicating flow direction; and
  - Label all features on the drainage diagram so as to be consistent with the submitted analysis. Labeling also needs to be consistent with the information depicted on the submitted drainage area maps.

DRAINAGE ANALYSIS INPUT AND OUTPUT DATA

- The drainage analysis inputs should:
  - Indicate the method of hydrologic analysis. A TR-55 or TR-20 based methodology is required for hydrologic analysis. If hydrologic software is used, indicate the name and version of the software package used;
  - Indicate the storm events analysis and the rainfall depths used;
  - Provide the input data used in the determination of weighted curve numbers. Include cover types, hydrologic soil group information, and hydrologic condition. Unless otherwise required, use an antecedent moisture condition II (AMC II), which represents normal antecedent moisture conditions;
  - Provide inputs for the t_c analysis;
  - Provide all equations and methodologies used in the hydrologic analysis;
  - Provide the elevation-area-storage inputs used in storage routing calculations. Provide at least two-foot intervals. Be sure that the bottom elevation and top elevation of the storage facility are included;

  - Indicate the initial storage condition of detention storage facilities;
  - Indicate the presence or consideration of any potential tailwater conditions.
  - Provide input data describing all outflow devices;
  - Provide the pertinent outflow equations used in the analysis of all outflow devices. Be sure to include all pertinent weir and/or orifice coefficients;
  - Indicate the routing method used in the analysis. The storage – indication method is required to be used for detention storage routing;
  - Provide input data regarding the calculation of all infiltration rates used in the analysis. Include pertinent soils testing to substantiate the infiltration rates used. Provide any calculations to convert rates to the input values used in the analysis;
  - Indicate the time span used in the analysis. Typically, a time span that covers hour 0 to hour 24 needs to be employed in the analysis; and
  - Indicate the time increment used in the analysis.

- Drainage analysis output information should include:
  - For each drainage area, provide the peak runoff discharge rate, the time to peak, and the total runoff volume produced in the pertinent Type III 24-hour storm event;
  - Provide the peak outflow rates (including exfiltration rates, if applicable) for all detention and/or infiltration facilities. For these facilities, also provide the peak water levels and peak storage in the pertinent storm events analyzed;
  - For infiltration systems, indicate the peak infiltration rates and the totals of volume infiltrated for each infiltration system; and
  - Many software packages provide the option of summary sheets that contain information on peak runoff discharge rates, times to peak, total runoff volume, peak volume stored in detention, and peak elevation within detention facilities. If possible, provide summary data.

- The analysis needs to provide a comparison of the peak runoff discharge rate, time to peak, and total runoff volume to each design/analysis point.
- Provide a hydraulic analysis of all proposed drainage conveyance systems. Indicate the design capacity of all components of the systems (e.g., catch basin, pipes, channels, etc.). Indicate whether such systems will successfully carry larger storm events in surcharge conditions or whether there will be ponding and/or overflow in certain locations.

- Plans:
  - Provide profiles of all drainage conveyance systems. Include pipe and channel slopes, pipe diameters, channel cross-sections, soil profiles in swales, bedding details, subdrain details, and types of construction materials;
  - Indicate the discharge location of all building roof leaders. If a building will discharge to more than one discharge location, these locations need to be indicated, along with the pertinent area of contributing rooftop;
  - Provide cross-sections and/or profiles of all detention and infiltration facilities. Include pertinent structural details of outlet structures, as such details may

relate to the selection of applicable discharge equations (e.g., weir, orifice equations) and/or discharge coefficients;
- Provide detailed cross-section drawings of all outlet structures. Include dimensions and materials of all flow control devices, including weirs and orifices;
- Include pertinent details of any and all proposed diversion structures;
- Include pertinent weir and/or orifice dimensions and elevations; and
- Include details of all proposed trash racks/debris screens.

THE FOLLOWING CHECKLIST MAY BE USED PRIOR TO SUBMITTAL (Based on staff experience, errors or omissions related to these areas resulted in applications being deemed incomplete)

- □ Ensure that a design analysis point is utilized for each separate receiving wetland area. If in doubt on where design/analysis points should be, seek input from review staff;
- □ Ensure that a pre-development vs. post-development analysis is provided for each design/analysis point;
- □ Ensure that adequate narrative is included for each design/analysis point;
- □ Be sure to include summary sheets from the submitted hydrologic analysis, if these are available;
- □ Ensure that plans adequately correlate to drainage area maps;
- □ Ensure that the drainage area maps correlate to the submitted hydrologic analysis;
- □ Ensure that drainage diagrams properly correlate to the hydrologic analysis;
- □ Ensure consistency of detention storage values with plan details;
- □ Ensure that drainage area maps are consistent with the drainage diagrams that form the basis of the hydrologic analysis. Be sure that labeling of the drainage area maps is consistent with that of the hydrologic analysis;
- □ Ensure that the plans properly correlate to the submitted analysis. Be especially careful of outlet structures;
- □ Ensure that sufficient topographic detail is provided so as to adequately substantiate the delineation of drainage area boundaries. Please ensure that this is the case for off-site areas as well as the subject property. (For off-site areas, it is not necessary to provide a level of topographic detail greater than found on a USGS quadrangle map. However, in instances where an off-site area is developed and includes a stormwater drainage system, the discharge point of the drainage system and its contributing area need to be investigated and included;
- □ Ensure that drainage area areas to existing isolated upland or wetland depressions are mapped. (Failure to do so will allow the existing condition analysis to present unrealistically high peak runoff discharge rates to a downgradient design/analysis point);
- □ Ensure that ground cover types are properly delineated, labeled, and described;
- □ Ensure that pervious land covers are properly represented by a “good” hydrologic condition;
- □ Ensure that the proper soil type and soil hydrologic group is mapped on the existing

condition drainage area map. Please note that field checking is encouraged before relying on the mapped soil type boundaries in the Soil Survey of Rhode Island. Often there will be some map error that may show upland soils in a wetland or vice versa. While the soils types involved are typically accurate, the exact boundaries should be weighed against on-site evaluations, available wetland edge determinations, and design judgment;

- Ensure that there is consistency between the plans and the analysis with respect to outlet devices;
- Ensure that the proper equations, coefficients, and dimensions are utilized for the evaluation of weirs and orifices. Check to ensure that compound weirs do not double-count flow. Check to ensure that flow is not allowed within the interstices of riprap in emergency overflow spillways, unless it is quantified in the analysis. (Typically, an internal barrier, such as a curb, may be placed within the riprap so as to block flow within riprap interstices);
- Ensure that the analysis properly evaluates hydrologic impacts at each design/analysis point. Please note that although an analysis may show that there will be a decrease in peak runoff discharge rates from a particular site, this may not guarantee that there will not be an increase at each design/analysis point. The submittal needs to address the level of impacts to each receiving water body;
- Take care in the selection of t_c flow paths. The t_c flow paths need to be reasonably accurate in their depiction of the hydraulically longest flow path of each drainage area;
- Do not use sheet flow lengths in excess of 150 feet for pre-development and 100 feet for post-development in the analysis;
- Be careful in the calculation of slopes in the t_c analysis. Also, be cautious in the selection of n-values. Please note that n-values in the TR-55 Manual that pertain to sheet flow may not be used in calculating channel flow velocities. Use n-values found in Chow (Chow, V. T., 1959. Open Channel Hydraulics) instead;
- Be sure to provide adequate soil test pit data to substantiate the determination of seasonal high groundwater table, bedrock, and design infiltration rate;
- Be sure to depict the elevation of the seasonal high groundwater table on all cross-section drawings of proposed BMPs;
- Be sure to address whether the delivery system for drainage to a proposed BMP will be capable of accommodating the peak discharge rate that the BMP is intended to accommodate. For example, if a proposed stormwater detention basin has been shown to reduce peak runoff discharges in a 100-year storm to pre-development rates, the designer needs to ensure that the proposed conveyance system that will deliver runoff to the proposed detention basin will be able to accommodate the 100-year runoff event without bypass of unmitigated runoff to the design/analysis point. Therefore, the proposed drainage system would either need to be designed for the 100-year event, would need to have capacity in a surcharge condition to carry the 100-year flow without unmitigated bypass to the design point, or there would need to be enough surface storage in the area being drained so as to prevent unmitigated discharge to the design/analysis point; and
- Be cautious regarding the initial conditions on detention ponds. Wet ponds need to be assumed to be full at the start of the storm event being modeled.

The following is a list of publications in the fields of hydrology and/or hydraulics that may be helpful in the preparation of stormwater management projects:

American Society of Civil Engineers, 1992. Design and Construction of Urban Stormwater Management Systems. "ASCE Manuals and Reports of Engineering Practice No. 77, WEF Manual of Practice FD-20." New York, NY.

American Society of Civil Engineers and the Water Pollution Control Federation, 1986. Design and Construction of Sanitary and Storm Sewers. ASCE Manuals and Reports of Engineering Practice No. 37, WPCF Manual of Practice No. 9, American Society of Civil Engineers, New York, New York, and Water Pollution Control Federation, Washington, DC.

Brater, E.F. and H.W. King, 1976. Handbook of Hydraulics. 6th ed., McGraw Hill Book Company, New York, NY.

Brown, S. A., S. M. Stein, and J.C. Warner, 2001. Urban Drainage Design Manual. Hydraulic Engineering Circular 22, Second Edition, Federal Highway Administration, FHWA-NHI-01-021, Washington, DC.

Chow, V. T., 1959. Open Channel Hydraulics. McGraw-Hill, New York, 1959.

Chow, V. T., D. R. Maidment, and L.W. Mays, 1988. Applied Hydrology. McGraw-Hill, New York, NY.

Dunne, T. and L. B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman and Company, San Francisco.

Johnson, F. L. and F. M. Chang, 1984. Drainage of Highway Pavements. Hydraulic Engineering Circular No. 12, Federal Highway Administration, FHWA-TS-84-202, Washington, DC.

Linsley, R.K. and J.B. Franzini, 1979. Water-Resources Engineering, 3rd ed., McGraw-Hill Book Company. New York, NY.

Maidment, D. R. ed. 1993. Handbook of Hydrology. McGraw-Hill Book Company. New York, NY.

McCuen, R. H., P.A. Johnson, and R.M. Ragan, 1996. Highway Hydrology. Hydraulic Design Series No. 2, Federal Highway Administration, FHWA-SA-96-067, McLean, VA.

Normann, J.M., R. J. Houghtalen, and W.J. Johnston, 1985. Hydraulic Design of Highway Culverts. Hydraulic Design Series No. 5, Federal Highway Administration, FHWA-IP-85-15, McLean, VA.

Novotny, V. and G. Chesters, 1981. Handbook of Nonpoint Pollution, Sources and Management. Van Nostrand Reinhold Company, New York, NY.

Ponce, V. M., 1989. Engineering Hydrology: Principles and Practices. Prentice- Hall Inc., Englewood Cliffs, NJ.

Richardson, E.V., D. B. Simons, and P. Y. Julien, 1990. Highways in the River Environment. FHWA-HI-90-016, Fort Collins, CO.

Schall, J. D. and E.V. Richardson, 1997. Introduction to Highway Hydraulics. Hydraulic Design Series Number 4. Federal Highway Administration, FHWA HI 97-028, Washington, DC.

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