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 ~~off-site~~ 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 ~~“stormwater~~:

(1) Stormwater, when not properly controlled and treated, causes pollution of the waters of the state~~…” and “development~~, 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~~…” The Bay~~

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Act of 2007 requires DEM and CRMC to amend the 1993 Stormwater Design and Installation Standards Manual to: 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) (a) Maintain pre-development groundwater recharge to predevelopment levelsand infiltration on site to the maximum extent practicable;

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

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

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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

[1] In an effort to maintain pre-development rates in natural waterways, 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.

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 methods throughout. This revised manual provides appropriate guidance for stormwater management on new development and , 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. Additionally, certain local municipalities have stormwater ordinances. 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. Municipal officials can use the manual to support local stormwater management programs by incorporating or referencing the manual into local ordinances. The stormwater management standards and performance criteria outlined in the manual should be applied to the maximum extent practicable[1] for single-family lots of record..[2]

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.

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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

[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, (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] 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.

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.

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. ~~This chapter defines the link between land use/activity, watershed planning, site planning and design, and stormwater management controls and summarizes why LID and stormwater management measures are necessary to protect receiving waters from the~~

~~adverse impacts of uncontrolled stormwater runoff. This chapter will describe the use of LID as a tool for maintaining watershed health and contributing to community character while allowing for future growth and development.~~

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. ~~Twelve~~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 ~~low impact development~~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 ~~four groups of~~ acceptable structural ~~best management practices (~~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 ~~four~~five groups of structural BMPs include (1) Wet Vegetated Treatment Systems (WVTS), (2) Infiltration Practices, (3) Filtering Systems, (4) Green Roofs, and (~~4~~5) Open Channel Practices.

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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 ~~Plan~~ Checklist
The Stormwater Management ~~Plan~~ 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: ~~Landscaping~~Vegetation Guidelines and Planting List
~~Good landscaping~~Plantings can often be an important factor in the performance and community acceptance of many stormwater BMPs. The ~~Landscaping~~Planting Guide provides general background on how to determine the appropriate ~~landscaping region and hydrologic zone~~vegetation for BMPs in Rhode Island. ~~Appendix B also includes tips on how to establish more functional landscapes within stormwater BMPs.~~ General p~~lan~~dscap~~t~~ing 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 describes techniques~~appendix provides guidance for retrofitting existing developed sites to improve or enhance the water quality mitigation functions of the sites. ~~It includes New England examples, and~~ 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 ~~M~~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 ~~best management practice.~~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

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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 wet vegetated treatment practicesWVTSs, 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 sections on plan submission checklists, miscellaneous hydrologic design/analysis methods, approved testing requirements (e.g., soils testing for infiltration), and miscellaneous design details, and pollutant loading analysis methods and information.

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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 4th-order or larger.

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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 a DEM Guidance document that has been designed to help engineers produce the best possible applications. In particular, these

~~guidance sheets are intended to provide designers with a brief conceptual overview of how to perform a hydrological analysis as well as a sample of the TR55 method. In addition, these guidance sheets provide some direction on hydraulic modeling techniques.~~

1.4 How to Use this Manual

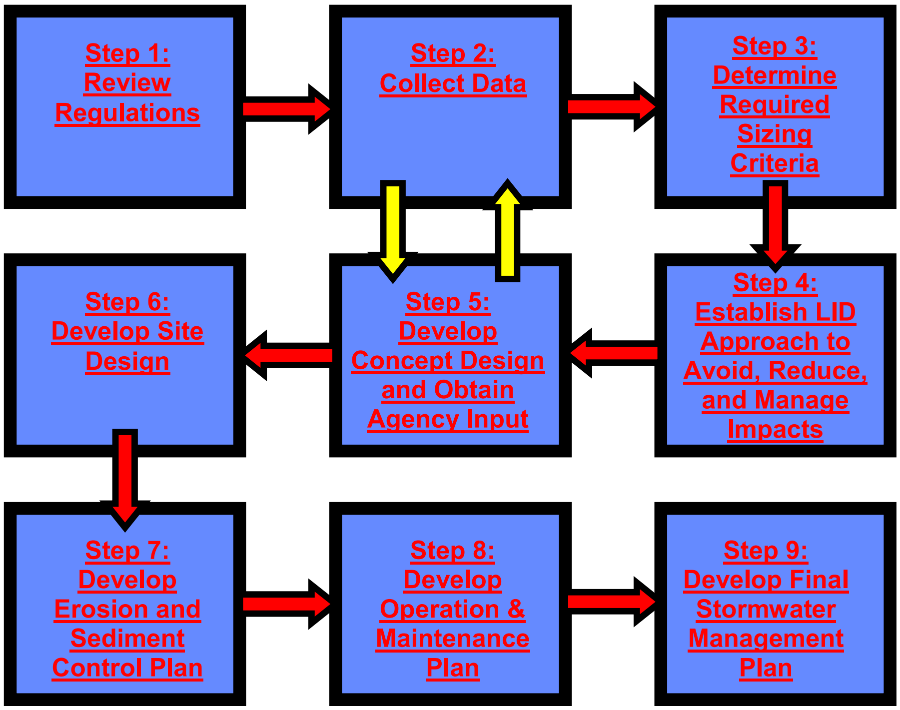
This manual can be used for many purposes and by many different parties. The four most common users are likely designers, ~~municipalities~~municipal officials, property owners, and regulatory program reviewers.

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 ~~twelve (12)~~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 ~~12~~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 ~~subwatershed~~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

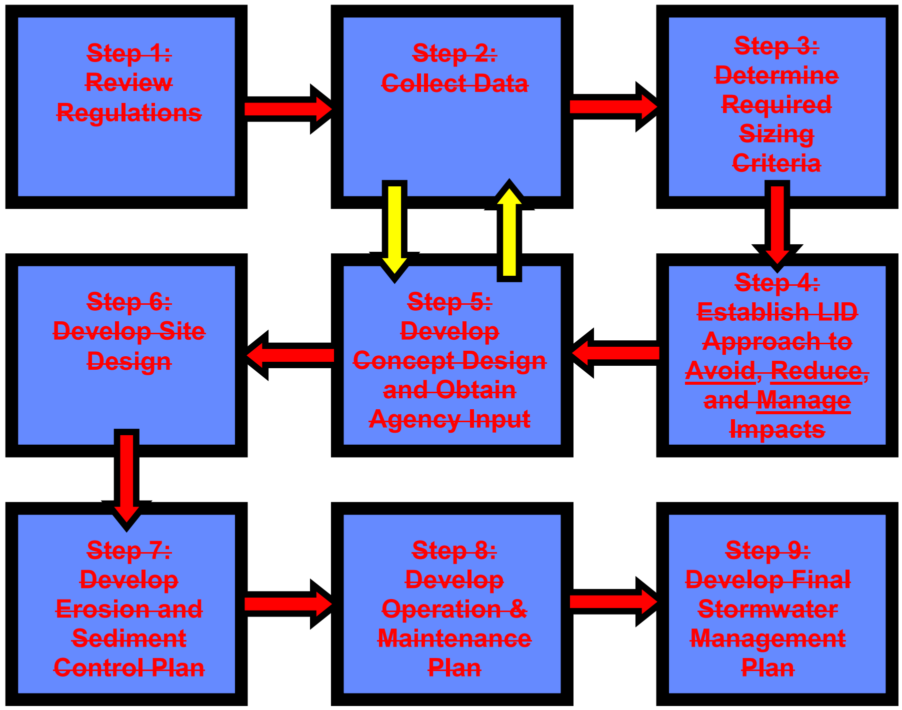
Figure 1-1 Steps to Designing the Stormwater Management System



-wastewater treatment systems (OWTS) and drinking water wells (private and public); assess existing contamination potential; evaluate receiving water conditions; establish where in a ~~subwatershed~~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.

~~Figure 1-1 Steps to Designing the Stormwater Management System~~



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 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 ~~coldwater fish habitat,~~ cold-water fishery, additional restrictions apply for surface detention practices ~~are prohibited.~~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 project and having more than 40% existing impervious surface coverage, modified stormwater management requirements (Section 3.2.6) will apply. ~~For~~For infill projects and redevelopment sites with less than 40% existing impervious surface coverage, the stormwater management requirements will be the same as other new development projects with the important distinction that the applicant 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 techniques and/or structural BMPs, have been implemented on-site to the maximum extent practicable. Designers should discuss infill and redevelopment 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 ~~twelve~~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 ~~T~~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 ~~I.~~J.

Contact Information

To ensure that the project meets the State's regulatory requirements, applicants should consult the following offices at ~~RI~~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.

~~RI~~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 Manual

Acronym	Term

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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
DEM	Rhode Island Department of Environmental Management
DO	Dissolved ~~o~~Oxygen
DOH	Rhode Island Department of Health
DOT	~~Rhode island~~ 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

Acronym	Term
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
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

Acronym	Term
OWTS	Onsite wastewater treatment system
P	Precipitation depth
Pb	Lead
Pj	Rainfall correction factor
PCB	Polychlorinated biphenyls
PCV	Polyvinyl chloride
~~P.E.~~PE	Professional Engineer
ppm	Parts per ~~M~~million
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
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

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Acronym	Term
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

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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 pre-treatment, 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.

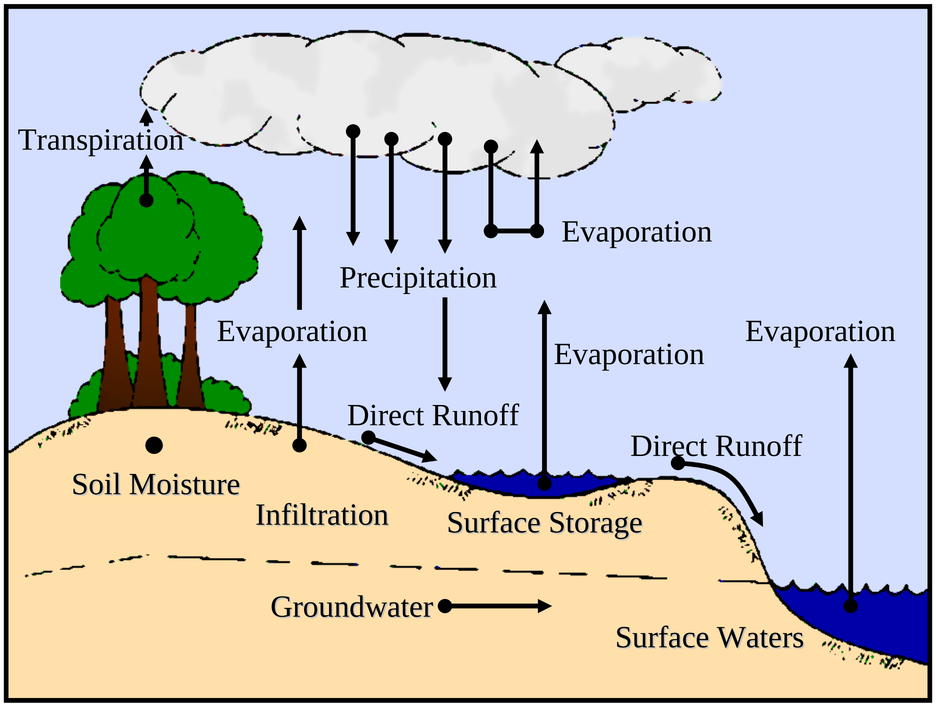
2.1 WHAT IS STORMWATER RUNOFF?

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.

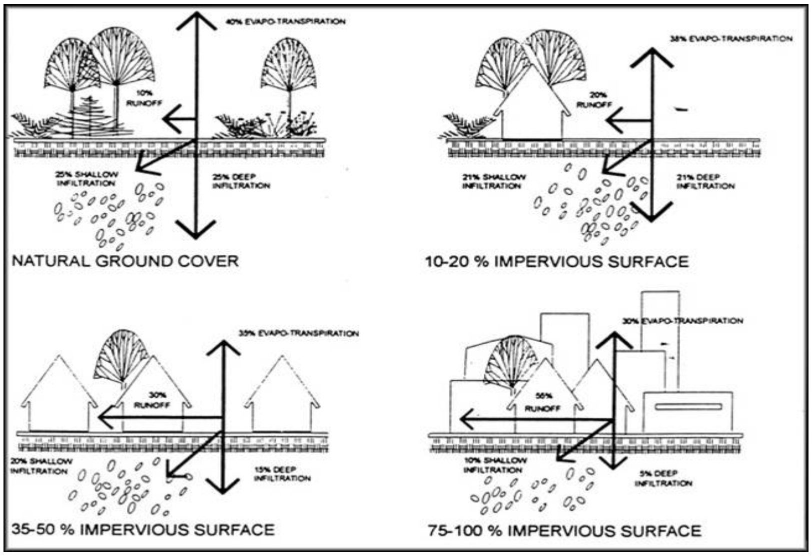
Additional impacts occur after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces interrupt infiltration mechanisms by not allowing rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated 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 (~~CDEP, 2004).~~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 three types, which include:

- Impacts to Natural Stream Channels;
- Impacts to Water Quality; 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

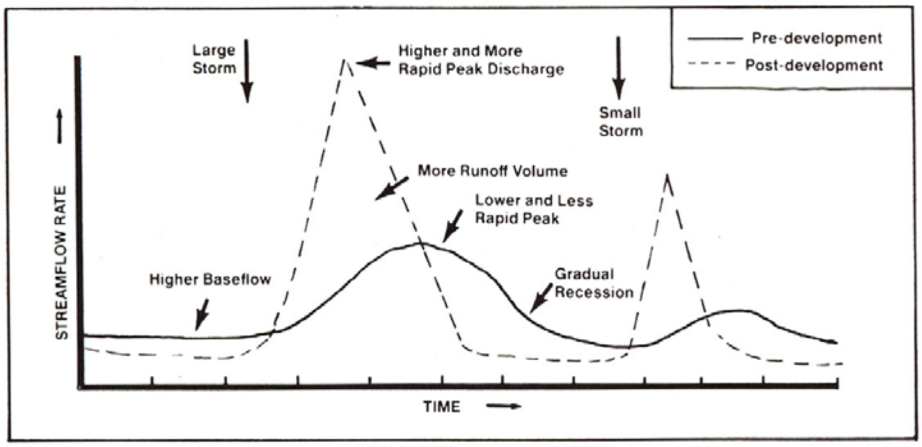
Increased runoff volumes and peaks increase the frequency, duration and severity of flows that overtop stream banks and cause flooding. An example of severe flooding in Rhode Island occurred in the Pocasset River Watershed in 2001. This watershed has lost approximately 700 acres of wetland since 1939, 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

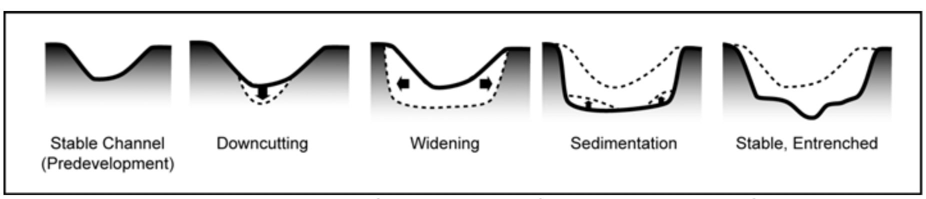
When upstream channels erode, sediment particles are carried and deposited downstream. The deposits replace the natural streambed with shifting sands, silts and muck.

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 ~~onsite~~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 ~~dissolved oxygen~~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 ~~Dissolved oxygen~~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	~~Dissolved oxygen~~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	~~Dissolved oxygen~~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)

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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

Constituent	Units	Concentration
Lead[1]	μg/l	50.7
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 ~~dissolved oxygen~~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

Receiving Environment	Impacts
	• Contaminated drinking water supplies
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 runoffs into nearby streams and stream temperature. Increased temperatures can reduce ~~dissolved oxygen~~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 ~~dissolved oxygen~~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 ~~(especially subdivision)~~ 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 ~~tw~~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 Region	24-~~Hour~~hour (Type III) Rainfall Amount (inches)						
	1-Year*	2-Year**	5-Year**	10-Year**	25-Year**	50-Year**	100-Year**
Northern: Providence County	~~2.7~~3.1	3.4	4.2	5.0	6.2	7.5	8.9

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RI Region	24-~~Hour~~hour (Type III) Rainfall Amount (inches)						
	1-Year*	2-Year**	5-Year**	10-Year**	25-Year**	50-Year**	100-Year**
Eastern: Newport & Bristol Counties	3.2~~.7~~	3.4	4.3	5.1	6.3	7.6	9.1
Southern: Kent & Washington Counties	3.2~~.7~~	3.5	4.4	5.2	6.4	7.7	9.3

~~*Source: U.S. Department of Commerce and Weather Bureau, Technical Paper No. 40, May 1961; Exhibit 2-3.1 CT-RI, April 1982.~~
~~**Adapted~~All rainfall values (except the 1-year) were adapted from: Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada and data from the Northeast Regional Climate Center (NRCC) for the following stations: Providence TF Green Airport, Woonsocket, and Kingston for station period of record through October 2008.
* The NRCC and NRCS Beta website (http://precip.eas.cornell.edu/) "Extreme Precipitation in New York & New England: An Interactive Web Tool for Extreme Precipitation Analysis" was used to determine the 1-year rainfall data. Site was accessed in March 2010.

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

[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.

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the requirements and exemptions[1] described in Section 3.3.2~~;~~. In addition, applicants may be required to provide a water budget analysis for proposed groundwater dewatering~~ at a site is not allowed.~~. Recharge volume 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. 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 ~~pathogens~~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 ~~from a site~~ must be ~~adequately~~ treated before discharge~~ in accordance with the requirements~~. The amount that must be treated from each rainfall event is known as the required water quality volume (WQ_v) and ~~exemptions~~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~~ management systems, which may include both structural stormwater controls and nonstructural practices (using the Stormwater Credit in Chapter Four), must be designed~~, 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 ~~requirements at each discharge location based on the water quality volume (one inch over the impervious area): 90%~~efficiencies: 85% removal of total suspended solids (TSS), ~~90% removal of bacteria, and either 40~~60% removal of pathogens, 30% removal of total phosphorus (TP) for discharges to freshwater systems, ~~or~~and 30% removal of total nitrogen (TN) for discharges to saltwater ~~systems. Structural systems~~or tidal systems. Based upon results published in the scientific literature, the structural BMPs listed in Chapter Five ~~can be assumed to~~will meet these standards when properly designed, constructed, and maintained~~ to treat 100% of the water quality volume. The objective of this standard is to reduce the water quality impacts from stormwater on downstream waters.~~. Pretreatment is required for water quality treatment practices where specified in the design guidelines within Chapter Five.

[1] 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.

BMPs targeted to remove ~~specific~~other pollutant(s) of concern and/or to achieve higher pollutant removal efficiencies may be required ~~at a minimum~~ for impaired receiving waters, drinking water reservoirs, bathing beaches, shellfishing grounds, tributaries thereto, and~~/or~~ for those areas where watershed plans, including Special Area Management Plans (SAMPs) or Total Maximum Daily Load (TMDLs~~) have been completed.~~), 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 ~~jurisdictional waters~~streams (and any contiguous natural or vegetated wetlands) as described in Section 3.3.4. Consult DEM's Water Quality Regulations, Fish and Wildlife Division to determine if a project is in a watershed 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 predevelopment peak discharges are not exceeded. Downstream overbank flood protection must be provided by attenuating the post development peak discharge rate to the predevelopment 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.

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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.

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. 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 more than 40% existing impervious surface coverage, stormwater quality and recharge[1] shall be managed for water quality[2] 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 water quality treatmentand recharge management for at least 50% of the redevelopment area; or
- Use on-site structural BMPs to provide water quality treatmentand recharge 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 water quality treatmentand recharge 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.

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[1] For redevelopment sites with more than 40% existing impervious surface coverage, only Standards 2 and 3 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.

[2] For redevelopment sites with more than 40% existing impervious surface coverage, only water quality must be addressed. Recharge and peak flow control only need to be addressed to the maximum extent practicable. However, DEM may required peak flow on a case-by-case basis within a watershed with a history of flooding problems.

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- 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 and 3 need be applied. 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 ~~for large storm events.~~ . 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 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.

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

Stormwater discharges from land uses with higher potential pollutant loads (~~referred to as~~ ~~"~~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. In addition, infiltration practices shall 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. In these areas where infiltration is not appropriate, other LID practices can be used, as long as they are lined

[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.

(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.
	Alternative Paving Surfaces[2]	A practice that stores the water quality volume in the void spaces of a clean~~, crushed stone~~ 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).

[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.

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Group	Practice[1]	Description
		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.

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3.2.9 Minimum Standard 9: Illicit Discharges

All illicit discharges to stormwater management systems are prohibited, including discharges from ~~onsite wastewater treatment systems (~~OWTS~~),~~, and sub-drains and French drains near OWTSs that do not meet the State's OWTS Rules (~~S~~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 Erosion and Sedimentation Control

Erosion and sedimentation control (ESC) practices must be utilized during the construction phase as well as during any land disturbing activities. ESC practices must meet the following minimum design criteria: temporary sediment trapping practices must be sized ~~for~~to store 1 inch of runoff~~,~~, from the contributing area or per the sediment volume method (Rhode Island Soil Erosion and Sediment Control Handbook), whichever is greater; and temporary conveyance practices must be sized to handle the peak flow from the 10-year, 24-hour (Type III) design storm. ESC practices must be designed according 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. The objective of this standard is to prevent erosion and sedimentation from construction site runoff.

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; ~~and~~
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.

~~3.2.12 Minimum Standard 12: Stormwater Management Plan~~

~~All 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).~~

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, ~~and~~ wetlands, and jurisdictional wetland buffers;
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 ~~landscaping~~ , native vegetation that encourages retention and ~~planting of native vegetation 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;~~ and~~
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 ~~c~~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)

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

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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.

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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.

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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~~, crushed stone~~ 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.
	Alternative Paving Surfaces	A practice that stores the water in the void spaces of a clean~~, crushed stone~~ 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 should 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

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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:

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- Impervious cover is measured from the site plan and includes all impermeable surfaces (i.e., paved and gravel roads, driveways and parking lots, sidewalks, rooftops, and patios).
- Off-site areas shall be assessed based on their "pre-developme~~d~~nt condition" for computing the water quality volume (i.e., treatment of only on-site areas is required). However, if an ~~offsite~~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~~,~~ ~~crushed stone~~ 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]
	Alternative Paving Surfaces	A practice that stores the water quality volume in the void spaces of a clean~~, crushed stone~~ 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

[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.

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Group	Practice	Description
		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 RoofsOpen Channels	Dry SwaleExtensive	An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix.Rooftop vegetated with low, drought-tolerant plant species and a shallow planting media designed for performance. Not typically designed for public access.
	Wet SwaleIntensive	An openRooftop vegetated channel or depressionwith trees and shrubs with a deeper planting soil and walkways, typically designed to retain water or intercept groundwater for water quality treatment.both performance and public access.
Open ChannelsGreen Roofs	ExtensiveDry Swale	Rooftop vegetated with low, drought-tolerant plant species and a shallow planting media designed for performance. Not typically designed for public access.An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix.
	IntensiveWet Swale	RooftopAn open vegetated with trees and shrubs with a deeper planting soil and walkways, typicallychannel or depression designed to retain water or intercept groundwater for both performance and public access.water quality treatment.

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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 ~~can~~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:

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

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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 $WQ_v \div$ total ~~watershed~~drainage area)

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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 $WQ_v \div A$)

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 ~~jurisdictional waters (including~~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.

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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 ~~peak discharge rates.~~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-developme~~d~~nt conditions.
- ~~Detention time for~~The required minimum CP_v shall be computed using the ~~one-year storm is defined by~~ methodology developed in 1987 by Harrington (See Appendix H.4) or by calculating 65% of the ~~center of mass method. This method evaluates~~direct runoff volume from the ~~difference in time between~~ post-development 1-year, 24-hour (Type III) storm based on one of the ~~center of mass of the inflow and outflow hydrographs. Some TR-55~~approved models ~~calculate~~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 ~~automatically.~~(24 hours).

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The CP_v criterion ~~is~~can be waived for sites that:

- ~~Discharge~~Direct discharge to a large river (i.e., 4th-order stream~~), lake, estuary,~~. 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~~ where the development area is less than 5% of the watershed area upstream of the development site~~.
- 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.

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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, assuming an "ultimate buildout condition" 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:

- ~~Discharge~~Direct discharge to a large river (i.e., 4th-order stream. See Appendix I for State-wide list and map of stream order), ~~lake, estuary,~~bodies of water > 50.0 acres in surface area (i.e., lakes, ponds, reservoirs), or tidal waters~~ where the development area is less than 5% of the watershed area upstream of the development site~~.
- 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).

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

- ~~The models TR-55 and TR-20 (or approved equivalent) will be used for determining peak discharge rates.~~
- ~~The standard for characterizing pre-development land use for on-site areas shall be woods, meadow, or rangeland. For agricultural land, use a curve number representing rangeland.~~
- ~~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, assuming an "ultimate buildout condition" upstream.~~
- ~~The length of sheet flow used in time of concentration calculations is limited to no more than 150 feet for predevelopment 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.~~

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

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~~site~~disturbed area 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

~~Site Size~~Area of Disturbance (acres)	Impervious Cover (%)[1]
>5 to10	>75
>10 to 25	>50
>25 to 50	>25
>50	all ~~sites~~projects

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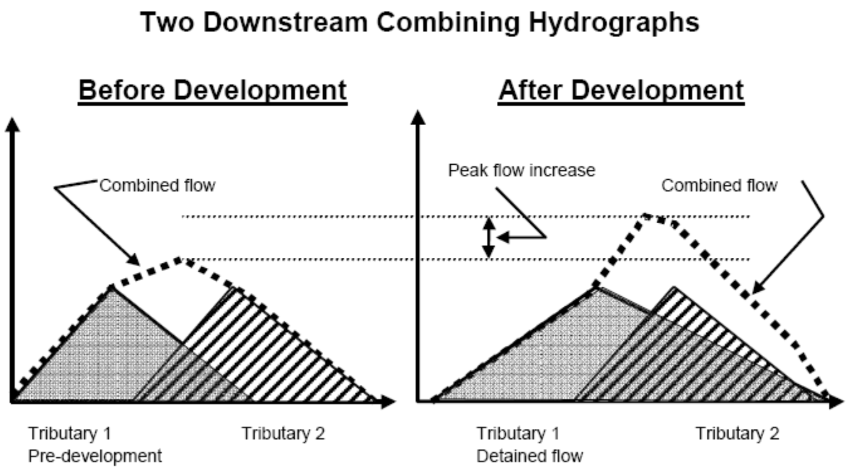
A number of hydrologists have noted that overbank and extreme flood control approaches do not always provide full downstream control from the out-of-bank events, due to differences in timing of individual peak discharges in the downstream portion of the watershed. Depending on the shape and land use 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.

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

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



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 ~~site~~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 ~~storms.~~, 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**
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.

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

Source: HW Group File Photo

resources. LID approaches reduce the loading of sediments, nutrients, and pathogens 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 ~~best management practices~~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, ~~and~~ 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 ~~landscaping~~ , native vegetation that encourages retention and ~~planting of native vegetation 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.

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These objectives must be formally documented according to the Stormwater Management ~~Plan~~ 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

[1] Both avoiding and minimizing the impacts will rec 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.

a site is just as important as stormwater treatment for resource protection.

Source: R. Arendt, File Photo

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 ~~"time of concentration" and "curve number"~~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.

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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 ~~to reduce the effective impervious cover (EIC)~~[1] 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.

[1] ~~The total impervious cover of a site includes all impervious areas on the land surface, including but not limited to pavement, roofs, roadways, or other human structures having a curve number (CN) of 98 or greater. The EIC of a site is the portion of the total impervious cover that is directly connected to the storm drain network. EIC usually includes roadways, driveways, and other impervious surfaces, such as rooftops, that are hydraulically connected to the drainage network. However, if a roof drain transporting rooftop runoff is directed to a pervious, vegetated area of sufficient length to infiltrate into the ground, it is considered disconnected and is not included as EIC.~~

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 Manage the Impacts, at the Source include the following:

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- 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 (a.k.a., rain gardens),, 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, and 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.

"Mitigation of Runoff" incorporates many of the structural LID BMPs appropriate for water quality treatment in accordance with Minimum Standard 3, which are included in Chapter Five, with detailed design requirements and guidance. These include wet vegetated treatment systems (WVTS), infiltration practices, filtering practices (including green roofs and bioretention areas), and open vegetated channels. LID pretreatment practices such as filter strips and grass channels are described in Chapter Six. Source control techniques such as street sweeping and pet waste management are described in Appendix G.

- 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 surfacesareas (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 the pervious surfaces used to satisfy the credita QPA, and provided further that the proposal satisfies all the other requirements set forth hereinin this section.

~~"Qualifying Pervious Areas" (QPAs)~~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 ~~2~~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

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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

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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 not segregated 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 prevent 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 square footft^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 as applied to rooftop runoff disconnection..
- 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 RI-certifiedDEM-licensed Class IV Soil Evaluatorsoil evaluator or RI-registered PE shall also confirm that the depth to groundwater is 18 inches

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or greater. The soil evaluation must identify the soil texture, HSG~~,~~ (from NRCS soil maps), and depth to groundwater.

- If a QPA is located in less permeable soils (HSG "C"), the water table depth and ~~permeability~~soil texture shall be evaluated by a ~~Registered Professional Engineer~~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 shall comply with the setbacks established for structural infiltration BMPs (e.g., 50 feet away from any OWTS components – such as a soil absorption system or leach field).
- 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.
- ~~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 amended, tilled and revegetated once construction is complete.~~
- The Operation and Maintenance Plan required by Minimum Standard ~~10~~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.

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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 ~~recharge volume (~~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 = ~~r~~Required impervious area to be directed to a QPA (acres)
F = Recharge factor based on ~~Hydrologic Soil Group (~~HSG~~)~~ (dimensionless)
I = Impervious area (acres)

Recharge Factors Based on ~~Hydrologic Soil Group (~~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)

[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.

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;

~~Required recharge area (Re_a)~~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)

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 ~~four~~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 ~~four~~five groups of structural BMPs include the following: (1) Wet Vegetated Treatment Systems, (2) Infiltration Practices, (3) Filtering Systems, (4) Green Roofs, and (~~4~~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.

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

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

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

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

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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~~, crushed stone~~ 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]
	Alternative Paving Surfaces	A practice that stores the water quality volume in the void spaces of a clean~~, crushed stone~~ 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.
~~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.~~
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.

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[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.

Group	Practice	Description
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.

5.2 Wet Vegetated Treatment Systems (WVTS)

Description: ~~Wet Vegetated Treatment Systems (WVTS)~~Shallow WVTS designs are practices that have a permanent pool equivalent to the entire WQ_v and ~~emergent vegetation. WVTS can be created by either excavating an existing depression or creating embankments. Two design variants include the Shallow WVTS~~ 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.

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KEY CONSIDERATIONS

~~CONVEYANCE~~

- ~~Minimum flowpath of 2:1 (length to width)~~
- ~~Flowpath maximized~~

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.
- 25% of the WQ_v in deepwater zones, 35% of the total surface area in depths six inches or less, and 65% of the total surface area shallower than 18 inches.

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 one or more basins or chambers filled with gravel. The portion of the WQ_v provided above the permanent pool should drain ~~in~~over 24 h~~ou~~rs.
- Maintain substrate in saturated condition.

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.

STORMWATER MANAGEMENT SUITABILITY

- ✓ Water Quality
- ☐ Recharge
- ✓ Channel Protection
- ✓ Overbank Flood Control

Accepts LUHPPL Runoff: *Yes*

(3 feet of separation distance required to water table)

IMPLEMENTATION CONSIDERATIONS

M	Capital Cost
	Maintenance Burden~~:~~:
M ~~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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LANDSCAPING LandscapingVEGETATION • 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 feetft from maximum surface elevation, with 15 foot additional setback for structures. • Donor plant material must not be from natural wetlands. MAINTENANCE REQUIREMENTS • O/M planOperation 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.	**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

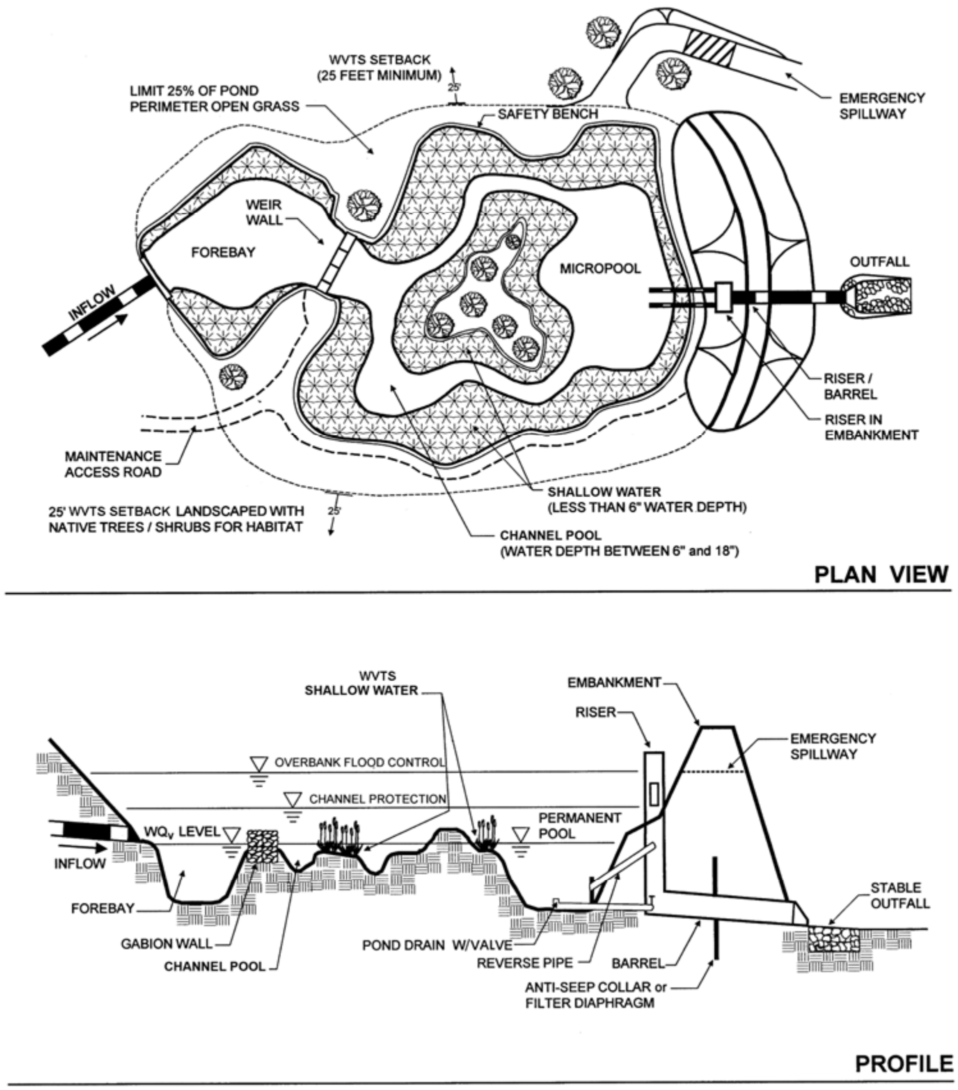

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Figure 5-2 Gravel WVTS – Alternative 1

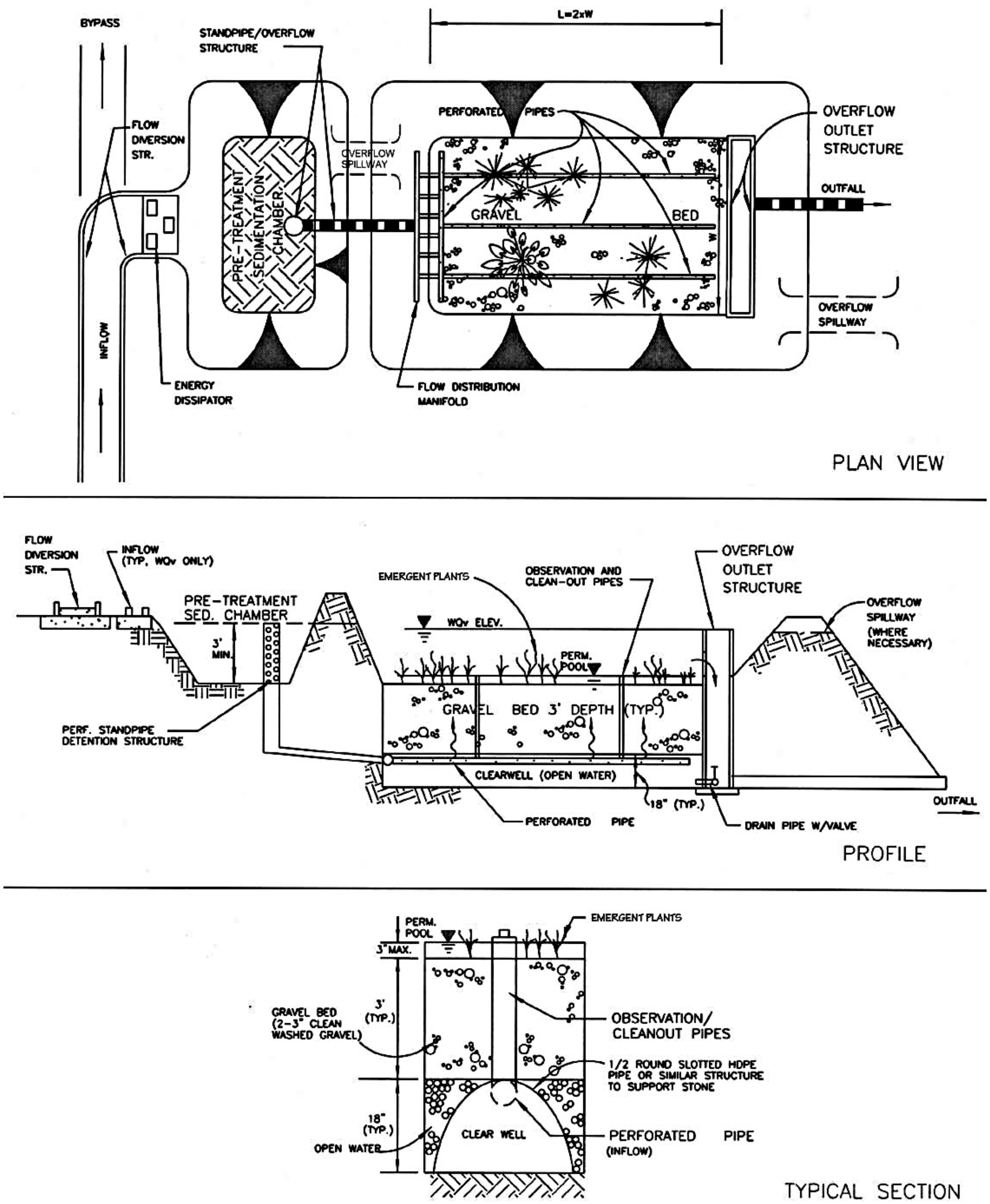

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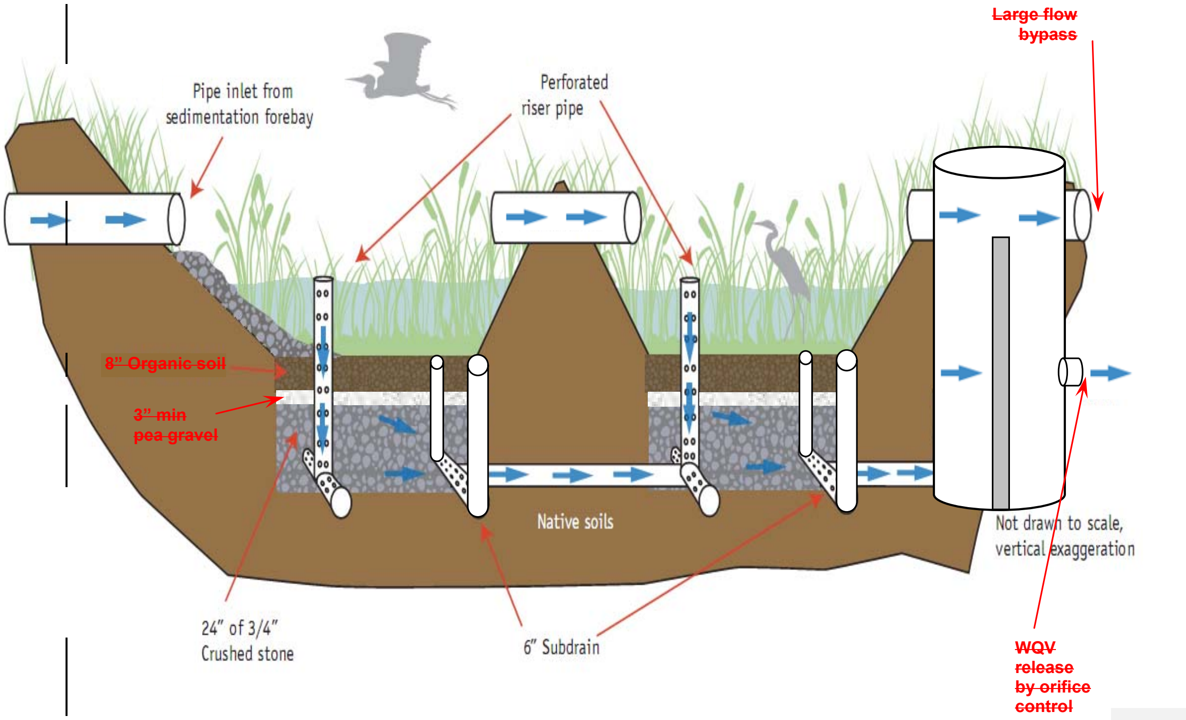
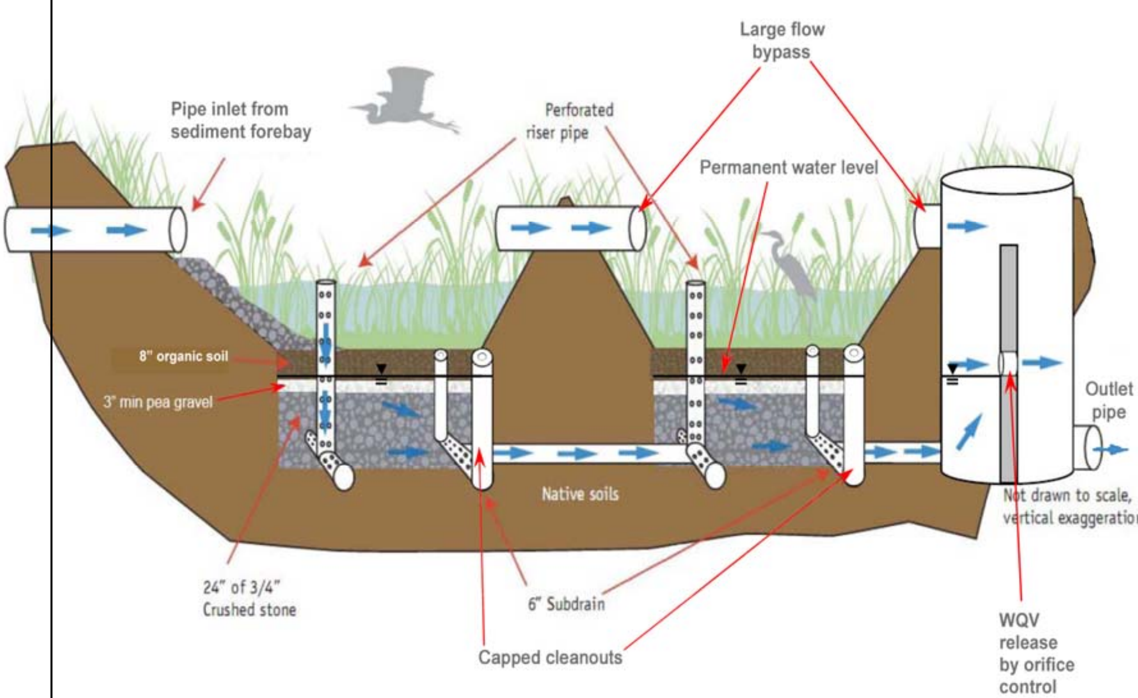
Figure 5-3 Gravel WVTS – Alternative 2





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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, subject to agreement by 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 jurisdictional waters, includingstreams 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, but 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

- ~~A forebay shall be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the WVTS.~~

[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.

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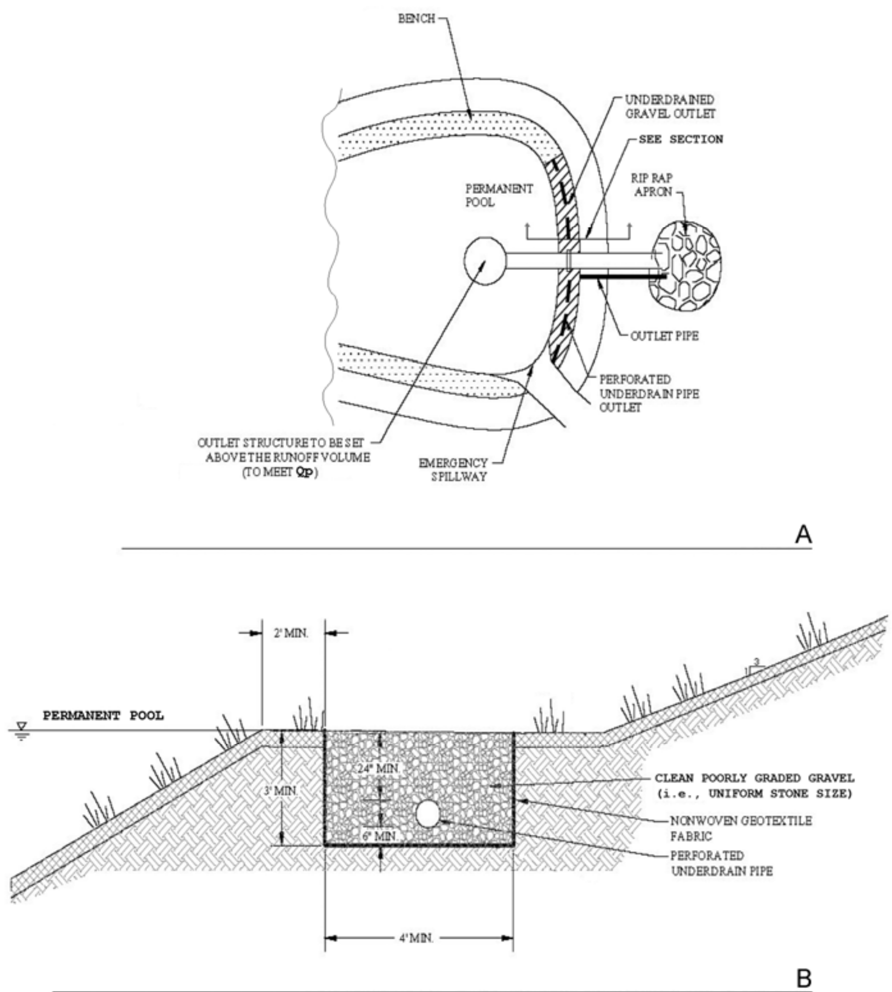
- Flow paths from the inflow points to the outflow points of WVTS shall be maximized through the use of BMP geometry and features such as berms and islands.

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

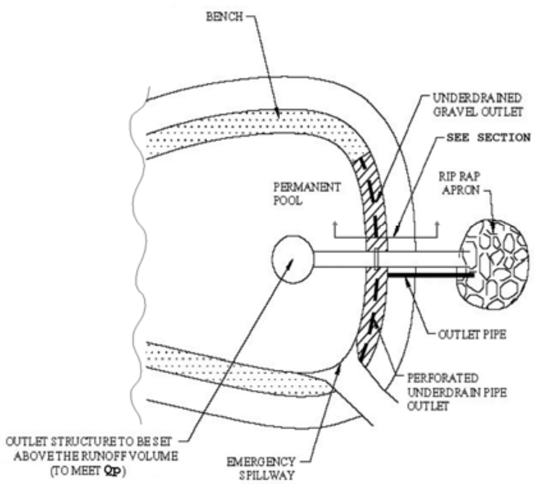


Adapted from Maine Stormwater Manual (2006)

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

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



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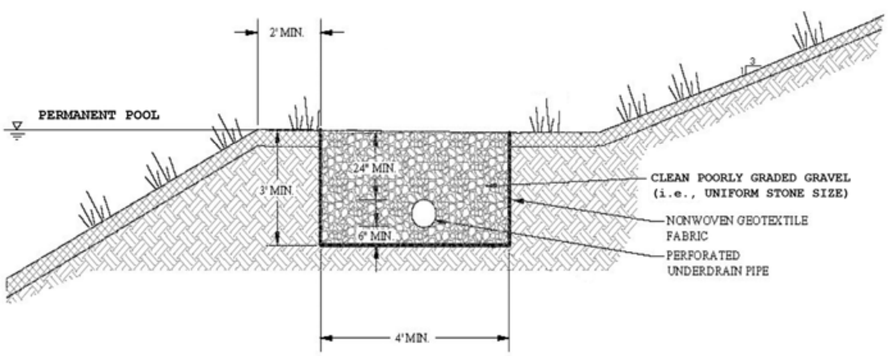

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- permanent pool or at the base of the gravel bed ~~for maximum treatment as an upfilter.~~.
- A Gravel WVTS designed with an organic soil layer at the surface should have vertical perforated riser pipes that deliver stormwater from the surface down 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.

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Adequate Outfall Protection

Required Elements

- 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 ~~is~~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 ~~jurisdictional waters~~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 ~~well-drained~~poorly-graded gravel (i.e., uniform stone size - refer to Figure 5-4).

Design Guidance

- 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

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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 ~~in~~over 24 hrs. The practice may also have an additional orifice for draining the CP_v ~~in~~over 24 hours.

WVTS Liners

~~Design Guidance~~

Required Elements

- When a WVTS is located in medium to coarse sands and above the seasonal high groundwater table, a liner ~~may~~shall be ~~needed~~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 x 10^{-5} cm/sec), (b) a 30 mil poly-liner, (c) bentonite, or (d) use of chemical additives.

Design Guidance

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- 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 ~~water quality volume (~~WQ_v~~)~~, and shall be four to six 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 storage volume counts toward the total WQ_v requirement.~~
- 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.

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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: At least 25% of the WQ_v shall be in ~~deepwater~~"deep water zones" with a depth greater than four feet, a minimum of 35% of the total surface of area shall have a depth of six inches or less, and at least 65% of the~~ir~~ total surface area shall be shallower than 18 inches.
- 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 ~~above~~ the ~~gravel as~~ open, extended detention (ED) storage volume~~.~~ above the gravel, as applicable. The portion of the WQ_v ~~should~~provided above the permanent pool shall drain ~~in~~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 marsh).
- 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~~ inches,~~", should be leveled (constructed with a surface slope of zero), and should be underlain by 3 ~~in.~~" 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). ~~This path may be achieved by constructing internal berms or islands (e.g., high marsh wedges or rock filter cells).~~
- For a Gravel WVTS: length to width ratio of ~~0.5~~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.
- ~~For Gravel WVTS, stormwater should enter through the bottom of the gravel bed and filter up through the practice for greatest pollutant removal.~~

~~5.2.5 Landscaping~~

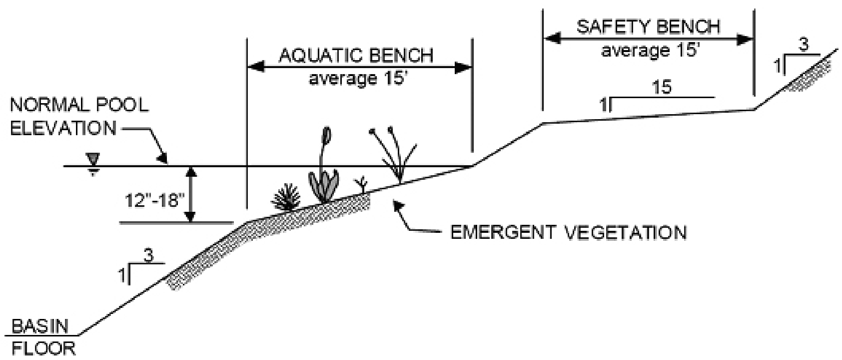
5.2.5 Vegetation

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)



~~Landscaping~~Planting Plan

Required Elements

- A ~~plandscapt~~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, ~~planting plan~~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.
- ~~The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the WVTS and setbacks.~~

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. ~~The setback shall be contiguous with other setback areas that are required by other regulations. An additional setback may be provided to permanent structures.~~
- 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.

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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 ~~to 6~~ 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%~~ of Shallow WVTS~~ 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 ~~jurisdictional waters~~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.~~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.

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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 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

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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 sized sufficiently to ensure that no clogging shall occur.

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Design Guidance

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- 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.

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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

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- 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, ~~Dry Wells, and Alternative Paving Surfaces. Alternative Paving Surfaces are discussed in Section 5.4~~and Dry Wells.

KEY CONSIDERATIONS

FEASIBILITY

- Minimum soil infiltration rate of 0.5 inches per hour.
- Soils less than 20% clay, and 40% silt/clay.
- Natural slope less than 15%.
- Cannot accept LUHPPL runoff~~ or be used in an area of soil contamination~~.
- Separation from seasonal high groundwater table and bedrock of at least three (3) feet except for strictly residential land uses, for which it may be reduced to two (2) feet.

CONVEYANCE

- Flows exiting the practice through vegetation must be non-erosive (3.5 to 5.0 ~~fps~~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.
- ~~50% pretreatment if f_c >2.0 inches/hour.~~
- ~~100% pretreatment in areas with f_c >5.0 inches/hour.~~
- 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.

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*

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~~LANDSCAPING~~ VEGETATION • Upstream area shall be completely stabilized before flow is directed to the practice. MAINTENANCE REQUIREMENTS • 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.	Key: L=Low M=Moderate H=High **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

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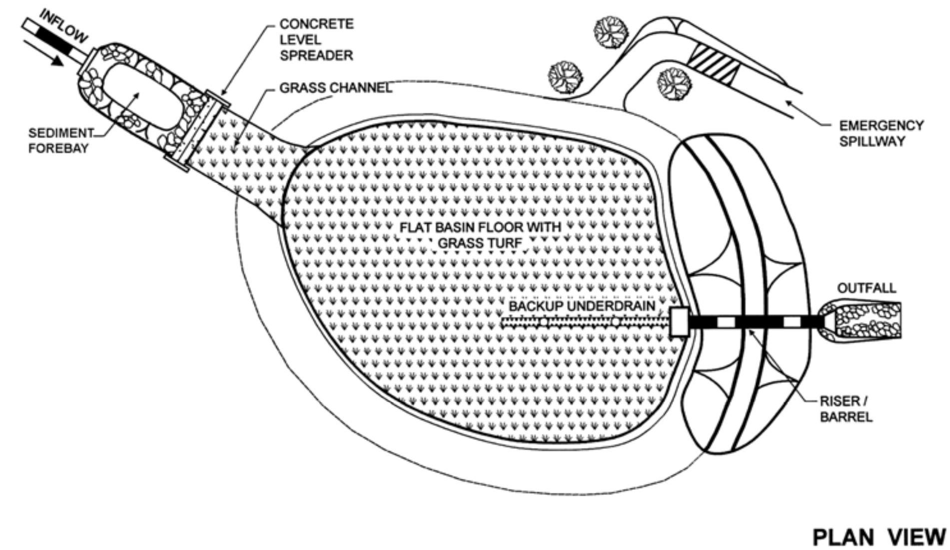
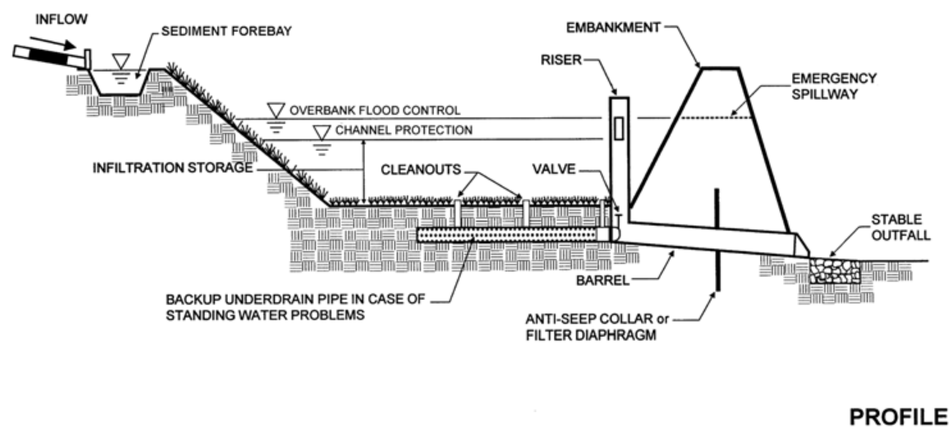
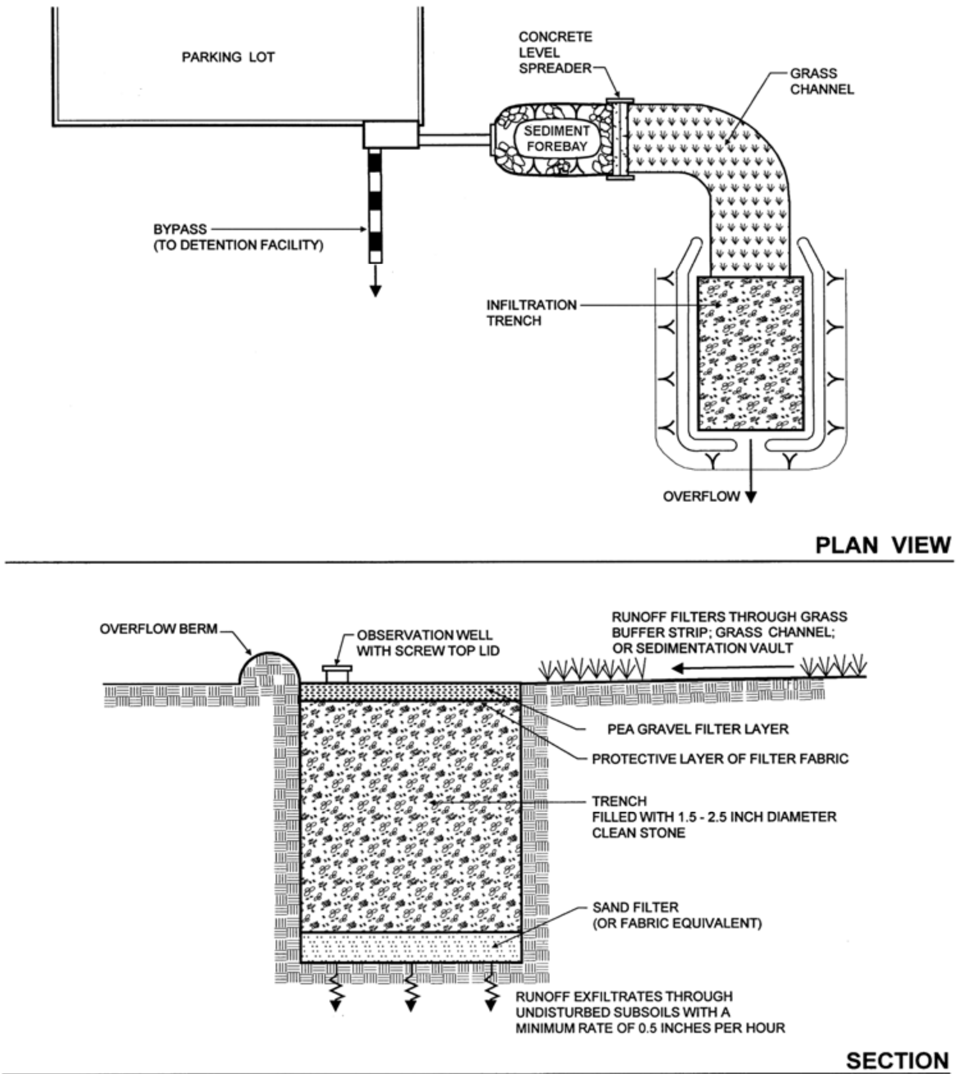
Figure 5-6 Infiltration Basin





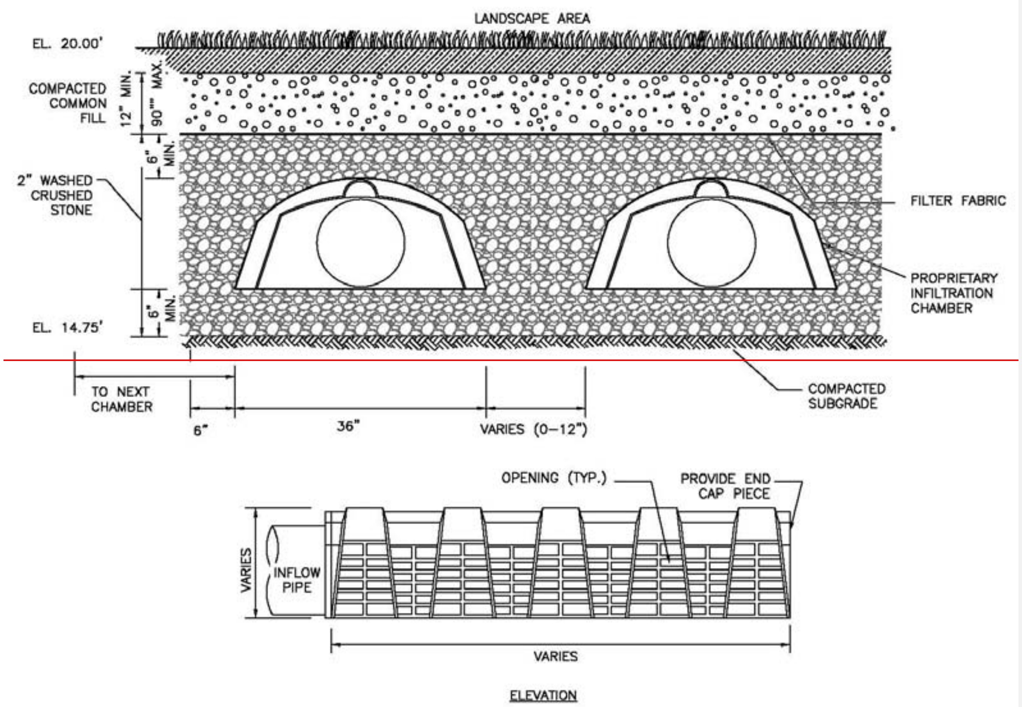
Adapted from MDE, 2000

Figure 5-7 Infiltration Trench



Adapted from MDE, 2000

Figure 5-8 Underground Infiltration Chambers



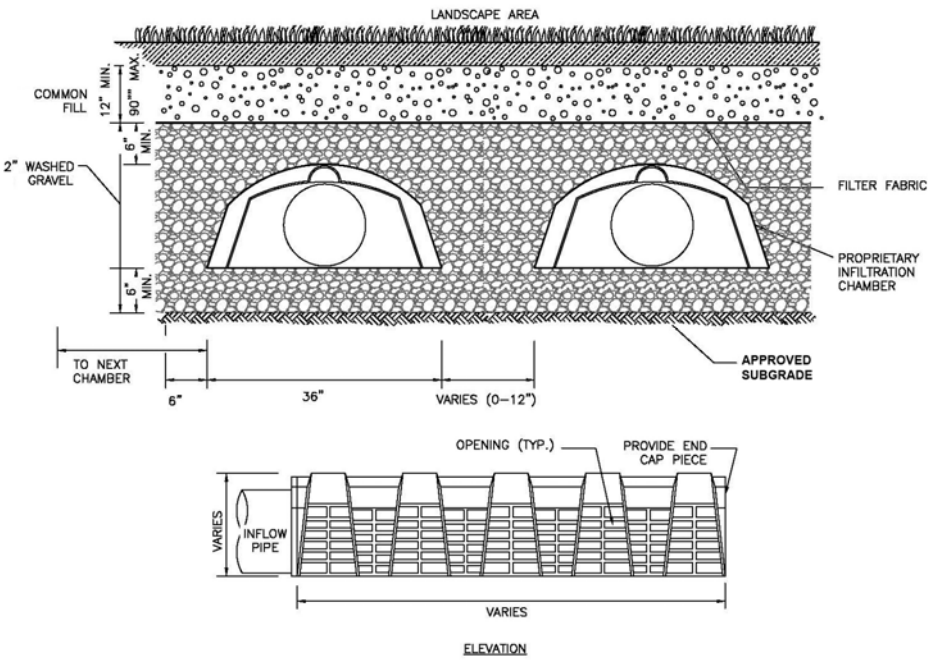
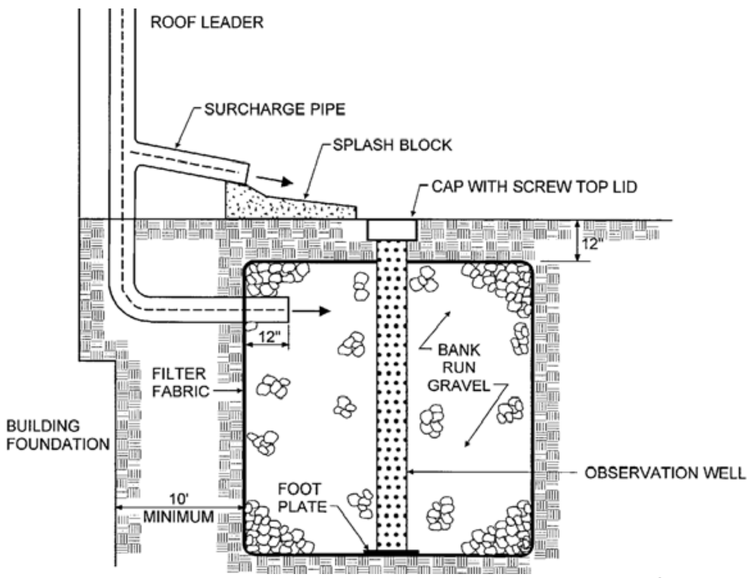


Figure 5-9 Dry Well



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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 ~~5 in/hr). 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].~~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). Extraordinary care should be taken to assure that long-term infiltration rates are achieved through the use ~~of performance bonds,~~ post-~~-~~construction inspection and long-term maintenance. ~~Infiltration within sand/gravel formations that have very high permeability rates may allow for infiltration of large volumes of stormwater. In these formations, where soil infiltration rate exceeds 5 in/hr, applicants must provide treatment of 100% of the WQ_v prior to direct infiltration. Infiltration practices can be used for treating the WQ_v only if located within 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.~~ Roof runoff from non-LUHPPL sites can be infiltrated directly, without pretreatment, and counted toward both Re_v and WQ_v requirements.

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5.3.1 Feasibility

Required Elements

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- 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 ~~(f_c)~~ 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 ~~two borings~~one boring or test ~~pits per infiltration facility~~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/clay content of less than 40%.
- ~~Infiltration practices shall be located a minimum of 50 feet from areas with natural slopes greater than 15%.~~
- The bottom of ~~I~~infiltration practices cannot be located in fill~~.~~ with the exception for

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~~[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.~~

strictly residential land uses, for which the bottom of practices may be located in up to two (2) feet of fill consisting of material suitable for long-term infiltration. 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 LUHPPL land usesLUHPPLs or activities mustshall not be directed to an infiltration facility. In addition,
- The bottom of the, infiltration facility shall be separated by at least three (3) feet vertically from the seasonal high groundwater table (SHGT) or 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 two (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.

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Table 5-2 Minimum Horizontal Setbacks from Infiltration Facilities

	Minimum Horizontal Setbacks	
	From residential dry wells and infiltration facilities for private driveways (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	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

[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 residential dry wells and infiltration facilities for private driveways (ft)	From all other infiltration facilities (ft)
Coastal Features	50	50
All Other Surface Waters	50	50
Up-gradient from Natural slopes > %15	50	50
Down-gradient from Building Structures	10	25
Up-gradient from Building Structures	10	50
Onsite Wastewater Treatment Systems (OWTS)	25	25

*Refer to DEM Onsite Wastewater Treatment System Rules Figures 14-16 for maps of the drinking water impoundments.

Design Guidance

- The maximum contributing area to infiltration chambers and trenches should generally be less than 5 acres.shall 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.
- ~~The bottom of the infiltration facility shall be separated by at least three (3) feet vertically from the seasonally high groundwater table (SHGT) or 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. On a case-by-case basis and at the discretion of the approving agency, the distance may be reduced to two (2) feet when no private wells are within 500 feet of the facility and runoff is from strictly residential land uses.~~
- ~~Infiltration facilities must meet current UIC setbacks, as follows:~~
  - ~~Infiltration facilities shall be located at least 400 feet horizontally from any public drinking water supply well.~~
  - ~~Residential dry wells and infiltration facilities for private driveways shall be located at least 25 feet horizontally from all private drinking water wells; all other infiltration facilities shall be located at least 100 feet horizontally from all private drinking water wells.~~
  - ~~Infiltration facilities shall be located at least 200 feet horizontally from all surface water supplies and tributaries.~~
  - ~~Infiltration facilities shall be located at least 150 feet horizontally from all coastal ponds.~~

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- Infiltration facilities shall be located at least 50 feet horizontally from all non-critical surface waters.
- Infiltration practices cannot be placed in locations that cause water problems (such as seepage which may cause slope failure) to downgrade properties.
- Infiltration trenches, chambers, and basins shall be setback 25 feet down-gradient and 100 feet up-gradient from building structures (excluding residential dry wells, which shall have a minimum 10-foot separation from building structures) and at least 25 feet from onsite wastewater treatment systems (OWTS).

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.

5.3.2 Conveyance

Required Elements

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 as a regional flood control practice.exclusively to manage CP_v and Q_p (see Chapter Seven).

5.3.3 Pretreatment

Required Elements

Required Elements

- For infiltration basins, chambers, and trenches, a minimum pretreatment volume of at least 25% of the WQ_v must be provided prior to entry to an infiltration facility, and can be provided in the form of a sedimentation basin, filter strip, grass channel,

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- If the f_c for the underlying soils is greater than 2.0 inches per hour, pretreatment of at least 50% of the WQ_v must be provided by an acceptable treatment practice (e.g., bioretention, dry swale, gravel WVTS).
- If the f_c for the underlying soils is greater than 5.0 inches per hour, 100% of the WQ_v shall be pre-treated by an acceptable treatment practice prior to entry into an infiltration facility.
  - Grass channel
  - Filter strip
  - Sediment forebay
  - Deep sump catch basin AND one 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.

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Pretreatment Techniques to Prevent Clogging

Infiltration basins or trenches shall have redundant methods to protect the long-term integrity of the infiltration rate. Three or more of the following techniques must be installed for infiltration basins or trenches:

- Grass channel (see Chapter Six for pretreatment design guidance)
- Grass filter strip (see Chapter Six for pretreatment design guidance)
- Bottom sand layer (6” minimum)
- Upper sand layer (6” minimum with filter fabric at the sand/gravel interface)
- Use of washed gravel (1/8” to 3/8”)
- Deep sump catch basin (see Chapter Six for pretreatment design guidance)

Design Guidance

- Alternatively to the pretreatment methods listed above, a sediment forebay may be provided and sized to capture the pretreatment volume (25% WQ_v).
- The sides of infiltration chambers, trenches, and dry wells should be lined with an acceptable filter fabric that prevents soil piping.
- In infiltration trench designs, incorporate filter fabric over washed gravel or sand above the coarse gravel treatment reservoir to serve as a filter layer.

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 (~~sides~~i.e., sidewalls are not considered in sizing~~).~~), unless 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-~~2~~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.
- ~~Calculate~~One method to calculate the surface area of infiltration trenches ~~as~~is to use the following equation:

$$A_p = \sout{V_w}V / (nd_t + \sout{f_c T}f_c t/12)$$

Where:

A_p	=	surface area at the bottom of the trench (ft^2)
~~V_w~~V	=	design volume (e.g., WQ_v) (ft^3)
n	=	porosity of gravel fill (assume 0.~~4~~33)
d_t	=	trench depth (separated ~~at least three feet~~ from seasonal~~ly~~ high groundwater as required) (ft)
f_c	=	design infiltration rate (in/hr)
~~T~~t	=	time to fill trench (hours) (assumed to be 2 hours for design purposes)

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

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~~Vw~~V = L~~*[(w*d*n) – (#*~~ [(wdn) – (#A$_c$n) + (#A$_c$~~*n) + (#*Ac) + (w* f$_c$ *T)~~ + (wf$_c$t/12)]

Where:

~~Vw~~V	=	design volume (e.g., WQ_v) (ft^3)
L	=	length of infiltration facility (ft)
w	=	width of infiltration facility (ft)
~~h~~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.~~4~~33)
f_c	=	design infiltration rate (in/hr)
~~T~~t	=	time to fill chambers (hours) (assumed to be 2 hours for design purposes)

~~**Table 5-2 Design Infiltration Rates for Different Soil Texture Classes (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~~
~~Sandy Clay Loam~~	~~0.17~~	~~0.0002~~
~~Clay Loam~~	~~0.09~~	~~0.0001~~
~~Silty Clay Loam~~	~~0.06~~	~~0.0001~~
~~Sandy Clay~~	~~0.05~~	~~0.0001~~
~~Silty Clay~~	~~0.04~~	~~0.0001~~
~~Clay~~	~~0.02~~	~~0.0000~~

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

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

Where:

A_b	=	surface area at the bottom of the basin (ft^2)
~~Vw~~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~~t	=	time to fill basin (hours) (assumed to be 2 hrs for design purposes)

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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 0.4 should be used to design stone reservoirs for infiltration practices.

5.3.5 The bottom of the stone reservoir should be completely flat or nearly so (i.e.,Vegetation

- 0.5% slope) in order that infiltrated runoff will be able to infiltrate through the entire bottom surface area.

5.3.5 Landscaping

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 only constructing the infiltration practice last, connecting upstream drainage areas only onceafter construction is complete, and the contributing area is stabilized. In addition, the Erosion and Sediment ControlESC plan for the site shall clearly indicate how sediment will be prevented from entering the site of an infiltration facility. Normally, using diversion berms around the perimeter of the infiltration practice, along with immediate vegetative stabilization and/or mulching, does this.
  - 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.

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- 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 ~~stone reservoirs (~~trenches~~)~~ or ~~perforated pipes (~~chambers~~)~~, which are used to temporarily store runoff prior to infiltration, the practice should ideally not be completely covered by an impermeable surface~~s~~ unless significant design constraints exist.

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~~Design Guidance~~

- ~~OSHA trench safety standards should be consulted 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.~~
- ~~In the absence of evidence of contamination, removed debris may be taken to a landfill or other permitted facility.~~

- 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

FEASIBILITY

- Infiltrating permeable paving practices:
  - Minimum soil infiltration rate of 0.5 inches per hour.
  - Soils less than 20% clay, and 40% silt/clay.
  - Cannot accept LUHPPL runoff.
  - Separation from groundwater table and bedrock of at least three (3) feet except for strictly residential land uses, for which it may be reduced to two (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.

STORMWATER MANAGEMENT SUITABILITY

- ✓ 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

- Legally binding maintenance agreement.
- Never to serve as a temporary sediment control device.

POLLUTANT REMOVAL

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 ~~three~~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 ~~are mixed with a very low content of fine sand, so that they have 10%-25% void space and a runoff coefficient that is almost zero. Required construction specifications for porous asphalt and pervious concrete are located in Appendix F.~~
- ~~Paving stones (also known as unit pavers) are impermeable blocks made of brick, stone, or concrete, set on a prepared sand base. The joints between the blocks are filled with sand or stone dust to allow water to percolate to the subsurface. Runoff coefficients range from 0.1 – 0.7, depending on rainfall intensity, joint width, and materials. Some concrete paving stones have an open cell design to increase permeability.~~
- ~~Grass pavers (also known as turf blocks) are a type of open-cell unit paver in which the cells are filled with soil and planted with turf. The pavers, made of concrete or synthetic material, distribute the weight of traffic and prevent compression of the underlying soil. Runoff coefficients are similar to grass, 0.15 to 0.6.~~

- ~~**Each of these products is**~~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.

~~**Figure 5-10 Alternative Paving Surfaces (Source: MA EOEA, 2006)**~~

~~**Figure 5-11 Typical Cross-section of Porous Asphalt (UNHSC, 2008)**~~

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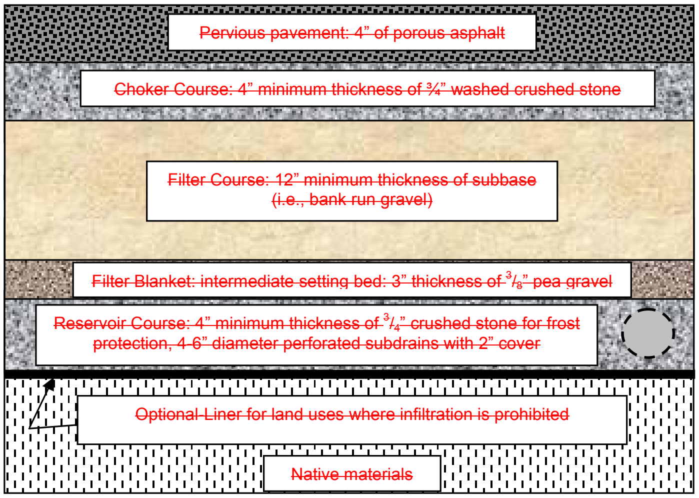

- **Pavers**. This type of permeable paving surface includes permeable solid blocks (minimum void ratio of 15%), as well as open-cell grids filled with either gravel or with sandy soil and then planted with turf, set on a prepared base course that doubles as a reservoir for the stormwater before it infiltrates into the subsoil or is directed to a downstream facility.

Treatment Suitability: ~~Alternative~~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. Permeable paving practices can be used for treating the WQ_v only if located within the soil profile at least three (3) feet vertically from the seasonally high groundwater table or bedrock layer. Where a TMDL or CRMC goal requires maximum treatment of runoff, the bottom of permeable paving practices shall be within the B soil horizon or another BMP is required.~~ -construction inspection and long-term maintenance.

There are ~~three~~two categories of permeable pavement:

- ~~Full exfiltration – performs as an infiltration facility.~~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.
- ~~Partial exfiltration – performs as an infiltration and detention facility. The base stores runoff, with some infiltration into the underlying soil, and some discharging via pipes at bottom of base.~~
- ~~No exfiltration – used for detention only.~~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

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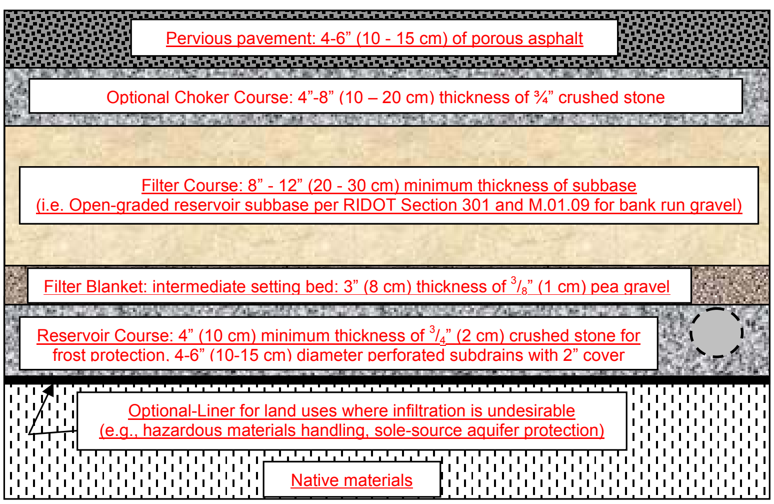
sites with high groundwater, bedrock, LUHPPL, and areas with fill soils. If designed as a detention system, infiltration restrictions noted in Section 5.4.1 do not apply; refer to Chapter Seven design requirements for detention structures.

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

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- 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 (f_c) 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 infiltrationg practice is one test hole per 5,000 ft^2, with a minimum of two boringsone boring or test pit per infiltration facility (taken within the proposed limits of the facility).
- UnderlyingFor infiltrating permeable paving practices, underlying soils shall also have a clay content of less than 20% and a silt/clay content of less than 40%.
- 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 two (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. In addition).
- 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 three (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 two (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 (ft)
Public Drinking Water Supply Well – Drilled (rock), Driven, or Dug	200
Public Drinking Water Supply Well – Gravel Packed, Gravel Developed	400
Private Drinking Water Wells	100
Surface Water Drinking Water Supply Impoundment* with Supply Intake	200

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Tributaries that Discharge to the Surface Drinking Water Supply Impoundment*	100
Coastal Features	50
All Other Surface Waters	50
Up-gradient from Natural slopes > %15	50
Down-gradient from Building Structures	25
Up-gradient from Building Structures	50
Onsite Wastewater Treatment Systems (OWTS)	25

*Refer to DEM Onsite Wastewater Treatment System Rules Figures 14-16 for maps of the drinking water impoundments.

- 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%).

Design Guidance

- The permitting agencies may reduce the minimum horizontal setbacks for infiltrating permeable pavements on a case-by-case basis in medium- to low-density 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 ~~contamination has been~~contaminated soil is removed and the site ~~has been~~is remediated~~.~~, or if approved by DEM on a case-by-case basis.

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- To avoid excessive nitrogen loading to coastal embayments, permeable pavements are not permitted to receive runoff from other areas (i.e., they may only be used to manage precipitation that falls directly on the permeable pavement area).
- The bottom of the infiltration facility shall be separated by at least three (3) feet vertically from the seasonally high groundwater table (SHGT) or 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. On a case-by-case basis and at the discretion of the approving agency, the distance may be reduced to two (2) feet when no private wells are within 500 feet of the facility and runoff is from strictly residential land uses.
- Infiltration facilities must meet current UIC setbacks, as follows:
  - Infiltration facilities shall be located at least 400 feet horizontally from any public drinking water supply well.
  - Infiltration facilities for private driveways shall be located at least 25 feet horizontally from all private drinking water wells; all other infiltration facilities shall be located at least 100 feet horizontally from all private drinking water wells.
  - Infiltration facilities shall be located at least 200 feet horizontally from all surface water supplies and tributaries.
  - Infiltration facilities shall be located at least 150 feet horizontally from all coastal ponds.
  - Infiltration facilities shall be located at least 50 feet horizontally from all non-critical surface waters.
- Permeable paving practices shall be setback 25 feet down-gradient from building structures and at least 25 feet from onsite wastewater treatment systems (OWTS).
- This practice is not appropriate for high traffic/high speed areas, due to load bearing limitations and clogging potential (≥ 1,000 vehicle trips/day).
- To avoid frost heave, design base to drain quickly (depth > 24 inches).
- Use permeable paving only on gentle slopes (less than 5%).

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Design Guidance

- Alternative 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. Contributing drainage areas should be minimal (i.e., runoff from upgradient impermeable or permeable surfaces should be minimal).
- Typically, reservoirs consist of uniformly sized washed crushed stone, 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.

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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.

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Design Guidance

- Permeable pavement areas should include dewatering methods in the event of failure. Dewatering can be accomplished with underdrain pipe systems that accommodate drawdown.

5.4.3 Pretreatment

Design Guidance

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

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5.4.4 Treatment

Required Elements

- Permeable pavement practicespavements 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 ofwhich 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 (singleuniform size material), must maintain adequate evaluate bearing capacity against storage 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.
- DesignFor infiltrating permeable pavements, design infiltration rates (f_c) should be determined by using Table 5-2.3 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.

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- Calculate the surface area of alternative paving surfaces as:

$$A_p = V_w / (nd_t + f_c T/12)$$

Where:

A_p = surface area (ft^2)
V_w = design volume (e.g., WQ_v) (ft^3)
n = porosity of gravel fill (assume 0.4)
d_t = depth of aggregate base (separated at least three feet from seasonally high groundwater) (ft)
f_c = infiltration rate (in/hr)
T = time to fill (hours) (assumed to be 2 hours for design purposes)

- 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 0.433 shall be used to design stone reservoirs for infiltration practices.
- TheFor infiltrating permeable pavements, the bottom of the stone reservoir should be completely flat, or nearly so, in order that infiltrated runoff will be able to infiltrate through the entire bottom surface area.

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5.4.5 Landscaping

- 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

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Required Elements

- Other adjacent construction shall be completed and site stabilized before ~~connection to a permeable pavement area~~installation of reservoir materials. A dense and vigorous vegetative cover shall be established over ~~the~~any contributing pervious drainage areas before runoff can be accepted into the facility.
- ~~Grass pavers~~Pavers that are planted with grass require ~~grasses~~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 ~~grass~~grid pavers.
- ~~Mow upland and adjacent areas, and seed bare areas.~~

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 ~~under~~where infiltrating permeable pavement ~~with infiltration~~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.

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Design Guidance

- Alternative 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.
- Keep adjacent landscape areas well maintained and stabilized (erosion gullying quickly corrected).
- Post signs identifying permeable pavement.
- Do not repave or reseal with impermeable materials.
- Grass paversPavers planted with grass need mowing and often need reseeding of bare areas.
- For paving stones/bricks, periodically add joint material (e.g., sand) to replace material that has been transported.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 grass pavers and some paving stones.
- 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.

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5.5 Filtering Systems

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 ~~(a.k.a., rain gardens), Tree Filters, and~~ , and Tree Filters~~**Green Roofs**. Green Roofs are discussed in Section 5.6~~.

Source: HW Group File Photo

KEY CONSIDERATIONS: SAND/ORGANIC FILTERS

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

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" ~~perforated pipe minimum~~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
- ~~System~~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.

~~LANDSCAPING~~VEGETATION
- Contributing area stabilized before runoff is directed to ~~the~~ 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.

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: *~~No~~Yes*

High Density/Ultra-Urban: *Yes*

Drainage Area: *~~2~~ 10 acres max.*

Soils: *No restrictions*

Other Considerations:

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

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• 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. **KEY CONSIDERATIONS: BIORETENTION/TREE FILTERS** FEASIBILITY • Bottom of filter at or above SHGW. • Top of filter at least 3ft above SHGW. CONVEYANCE • Provide overflow for the 1-yearyr 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 should generallyto have a four-foot2-4ft deep planting soil bed, a surface mulch layer, and a 6"-9" ponding layer. • Soil media as detailed in Appendix F. LANDSCAPINGVEGETATION • Detailed plandscapting 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.	Key: L=Low M=Moderate H=High **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

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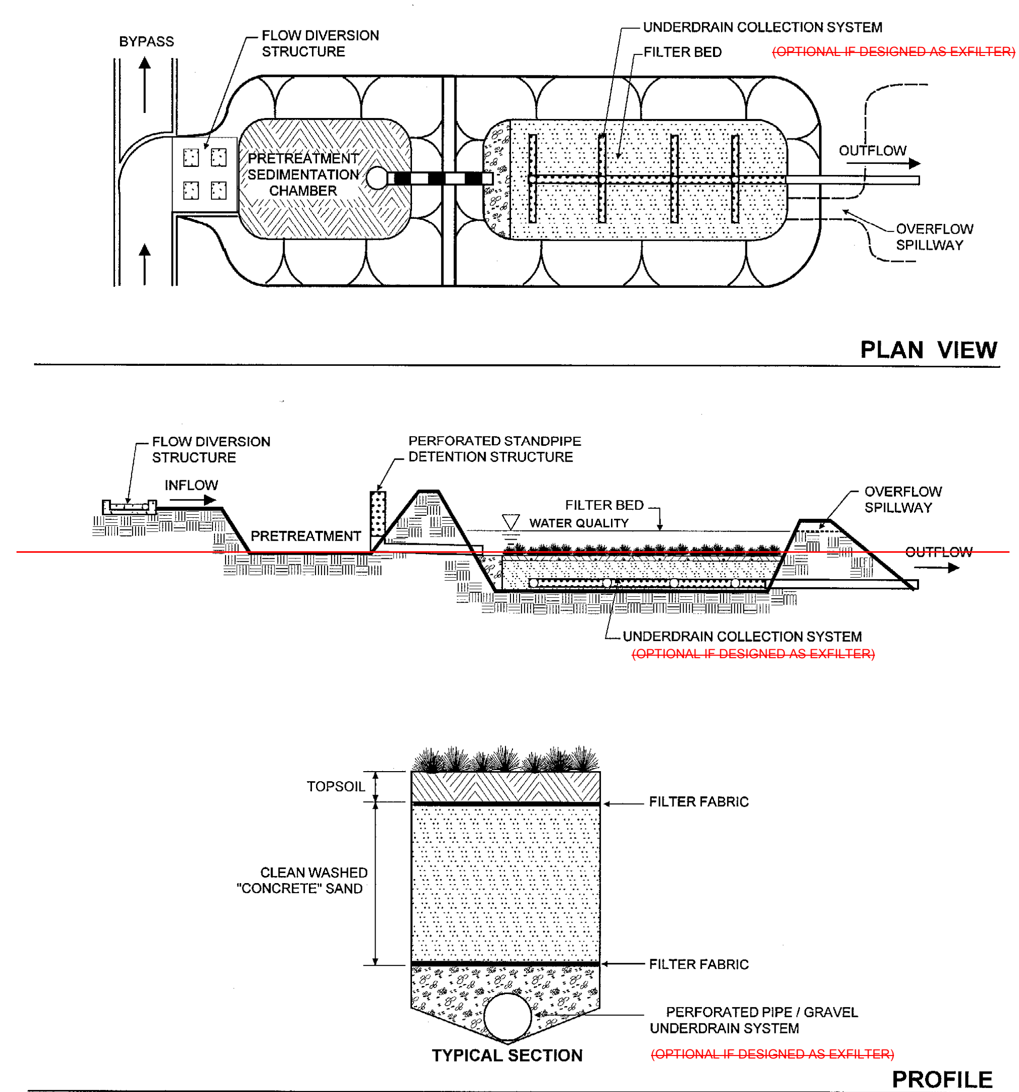
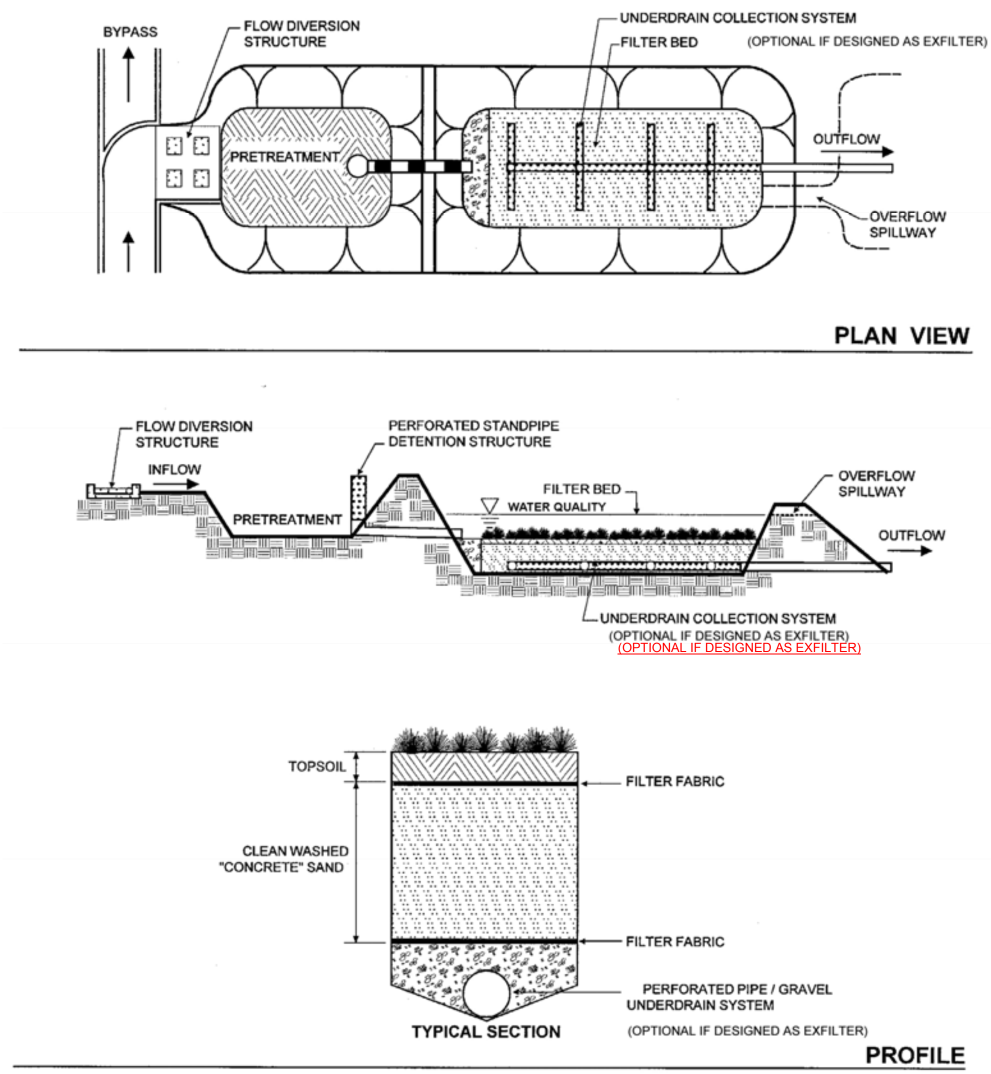
~~MAINTENANCE REQUIREMENTS (SAND/ORGANIC FILTERS):~~ • ~~Legally binding maintenance agreement.~~ • ~~Sediment cleaned out of sedimentation chamber when it reaches more than 12" in depth.~~ • ~~Vegetation limited to 18".~~ • ~~Sediment chamber cleaned if drawdowns exceed 36 hours.~~ • ~~Trash and debris removal.~~ • ~~Silt/sediment removed from filter bed after it reaches one inch.~~ • ~~If water ponds on the filter bed for greater than 48 hours, remove material, and replace.~~ ~~MAINTENANCE REQUIREMENTS (BIORETENTION/TREE FILTERS):~~ • ~~Inspect and repair/replace treatment area components.~~ • ~~Stone drop/diaphragm (at least 6") provided at the inlet.~~ • ~~Remulch annually.~~ • ~~Vegetation pruning, harvesting.~~	**POLLUTANT REMOVAL – ALL FILTERS** F — 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

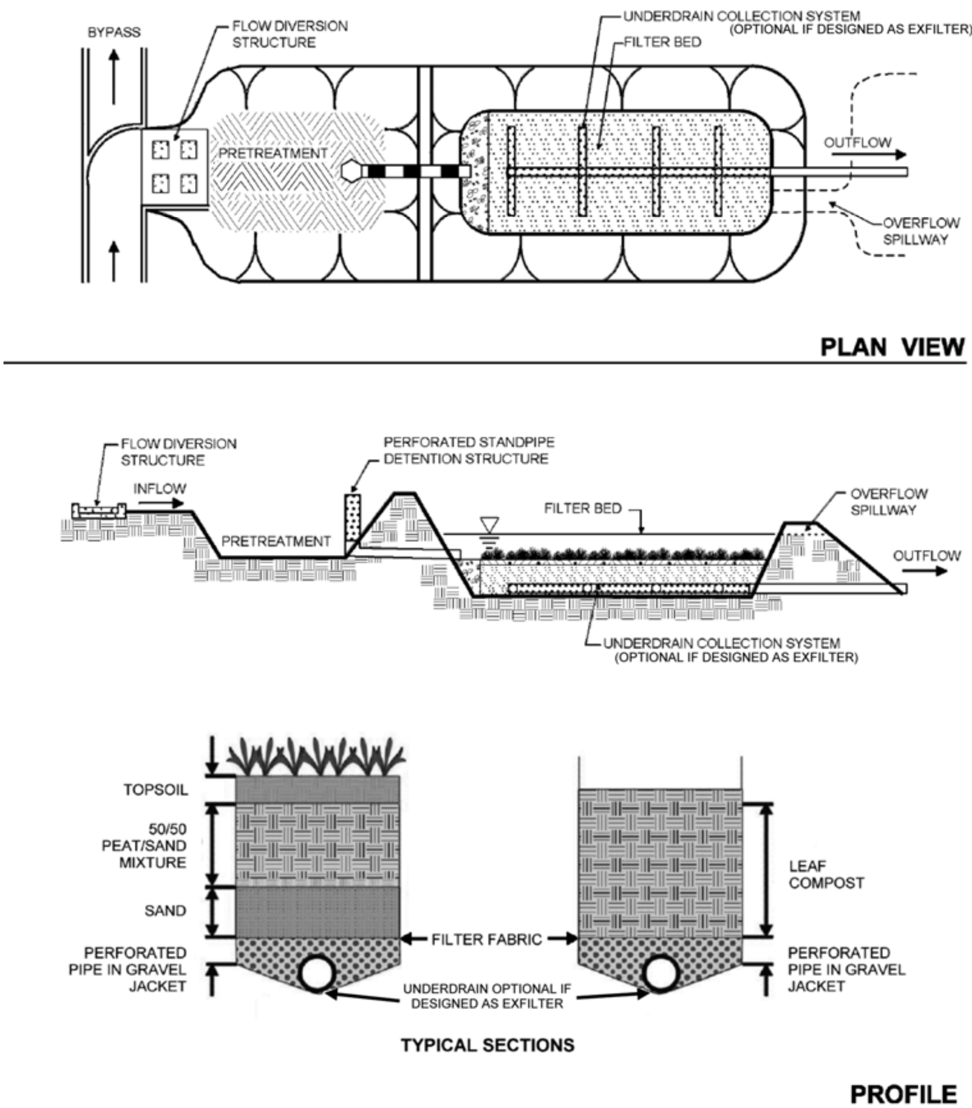
Figure 5-12 Sand Filter

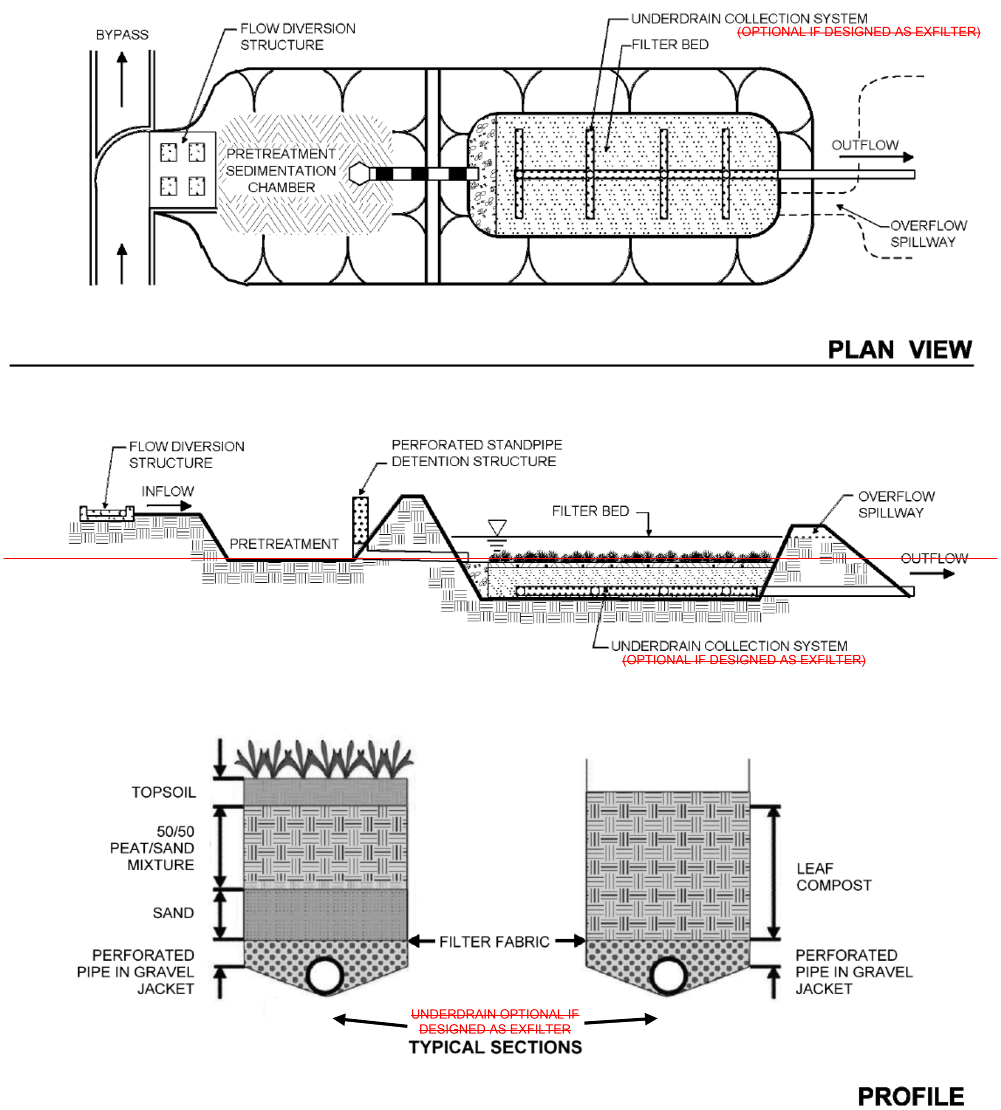




Adapted from MDE, 2000

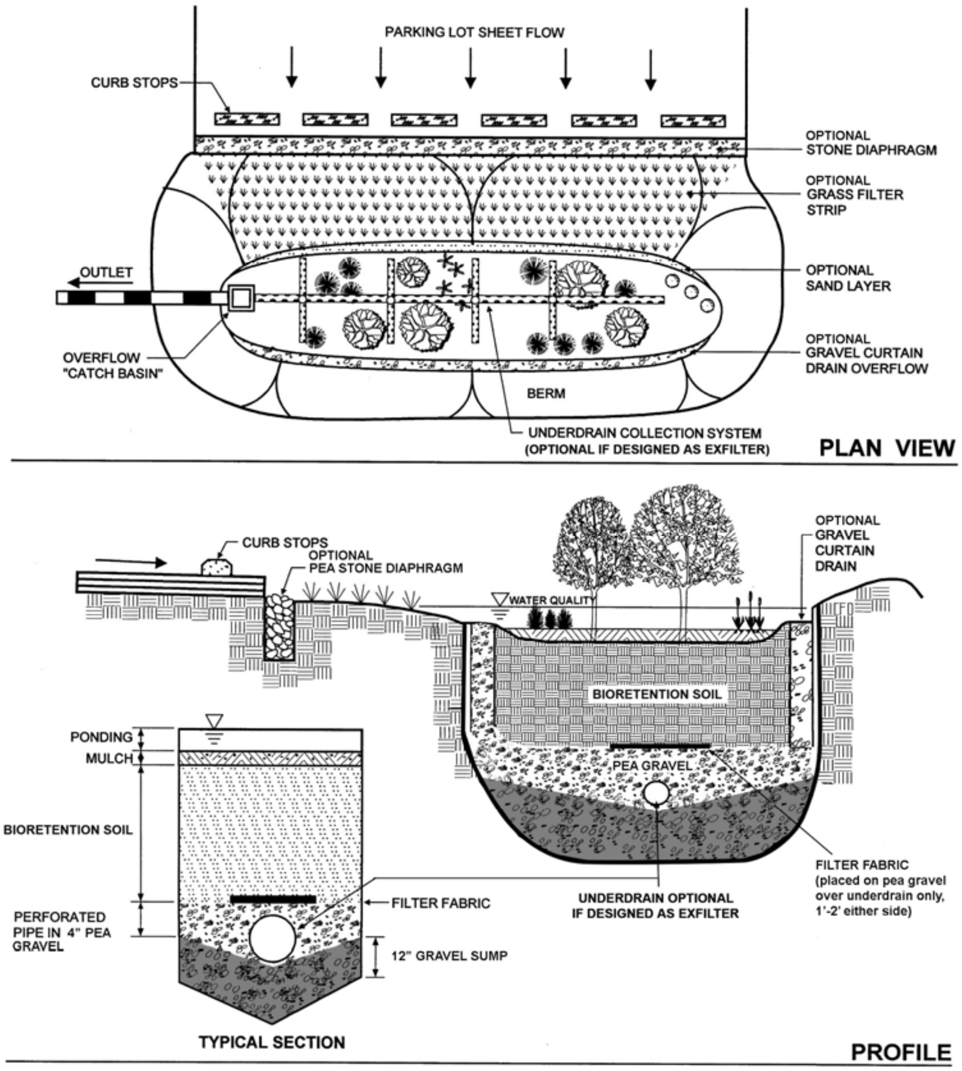
Figure 5-13 Organic Filter





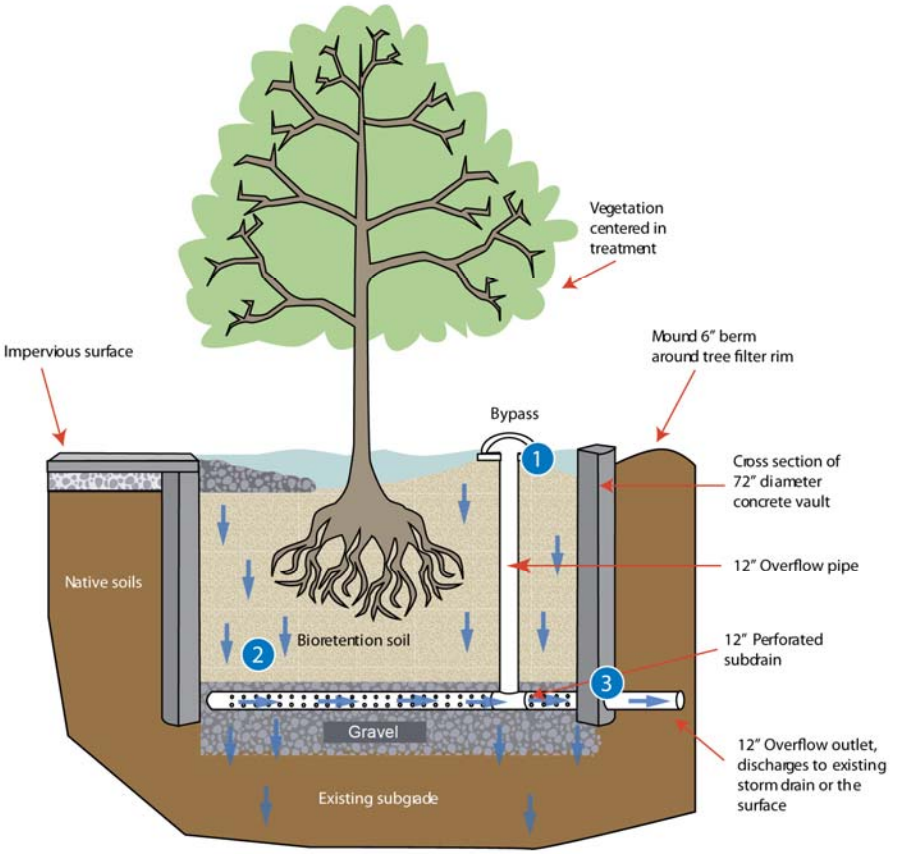
Adapted from MDE, 2000

Figure 5-14 Bioretention ~~(a.k.a, Rain Garden)~~



Adapted from MDE, 2000

Figure 5-15 Tree Filter



Source: adapted from UNHSC, 2007

5.5.1 Feasibility

Required Elements

- The bottom of filtering systems shall be located at or above the seasonally high groundwater table. The top of filtering systems shall be located at least 3 feet above the seasonally high groundwater table.

Design Guidance

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

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- 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.

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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).
- ~~Bioretention shall be equipped with a minimum 4" perforated pipe underdrain in a pea gravel layer, and a 12" gravel drainage blanket. Filter fabric shall 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).~~

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.

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

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.

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 ~~BMPs~~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 ~~prior to filtration.~~ . 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: ~~S~~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

~~Design Guidance~~

- ~~Sand~~ and organic ~~filter beds typically have a minimum depth~~filters shall be sized based on the principles of ~~18 inches~~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

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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 12 inchessand and organic filters may be approvedreduced to 12" on a case-by-case basis as demonstrated by the designer that 18 inches" 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.
- The filter area for sand and organic filters should be sized based on the principles of Darcy's Law. A coefficient of permeability (k) should 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 required filter bed 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 filter bed (ft)
t_f = Design filter bed drain time (days)
(2 days is recommended maximum t_f for bioretention)

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5.5.5 Landscaping

- 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.
- LandscapingVegetation is critical to the performance and function of bioretention areas; therefore, a plandscapting plan must be provided that follows the general landscaping 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 and prepare the necessary plans.

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:

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- Sediment shall be cleaned out of the ~~sedimentation chamber~~sediment forebay when it accumulates to a depth of more than ½ the design depth. Vegetation within the ~~sedimentation chamber~~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 ~~inches.~~".
- ~~A stone drop or diaphragm of at least six inches should be provided at the inlet of bioretention facilities (pea gravel diaphragm). Areas devoid of mulch shall be re-mulched on an annual basis. Dead or diseased plant material shall be replaced.~~
- 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.

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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	STORMWATER MANAGEMENT SUITABILITY
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.	☐ 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

MAINTENANCE REQUIREMENTS	POLLUTANT REMOVAL
• 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).	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

"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.

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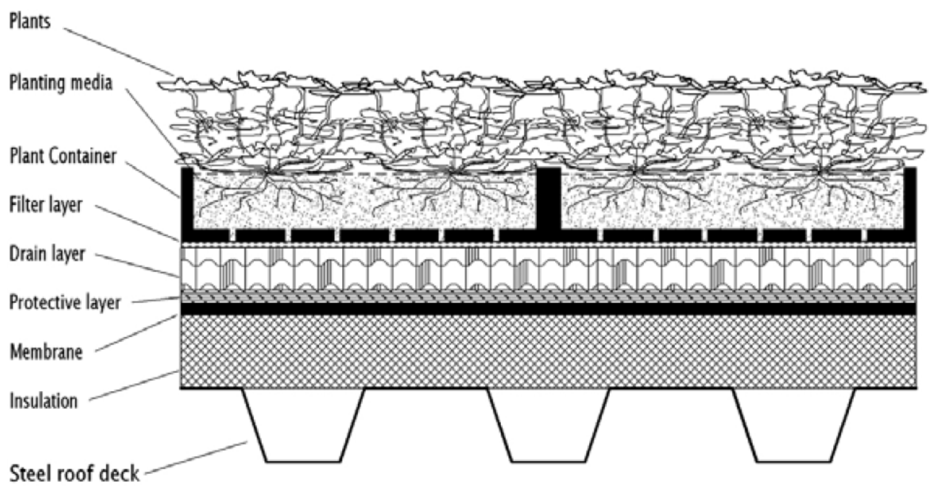
~~Treatment Suitability: Green roofs can meet water quality treatment goals only, and are not appropriate for Re_v, CP_v, or Q_p.~~

Figure 5-16 Extensive Green Roof Construction Cross Section



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

~~5.6.1~~5.6.2 Feasibility

Required Elements

- 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.

Design Guidance

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- 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.

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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.

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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.

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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.

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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 ~~in~~inches), but a thicker mat can provide additional insulation and root restriction.

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The critical specification for a drain layer is the maximum volumetric flow rate, which is determined based on the design precipitation of 1 ~~in~~inch for WQ_v. Minimum passage area should be standardized for various locations. Since the drain layer supports the

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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.*

~~5.6.5 Landscaping~~

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 ~~precultivation~~pre-cultivation (followed by transplant to the roof), direct seeding and seasonal issues~~.~~ (Halsall, 2007~~)~~).

~~5.6.6~~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.

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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 ~~two~~2 feet.
- ~~Soil~~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:

- ~~Permeable~~Bioretention soil layer (~~dry swale~~Dry Swale)
- Emergent plants (~~wet swale~~Wet Swale)

Key: L=Low M=Moderate H=High

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MAINTENANCE REQUIREMENTS:

- 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.

POLLUTANT REMOVAL

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

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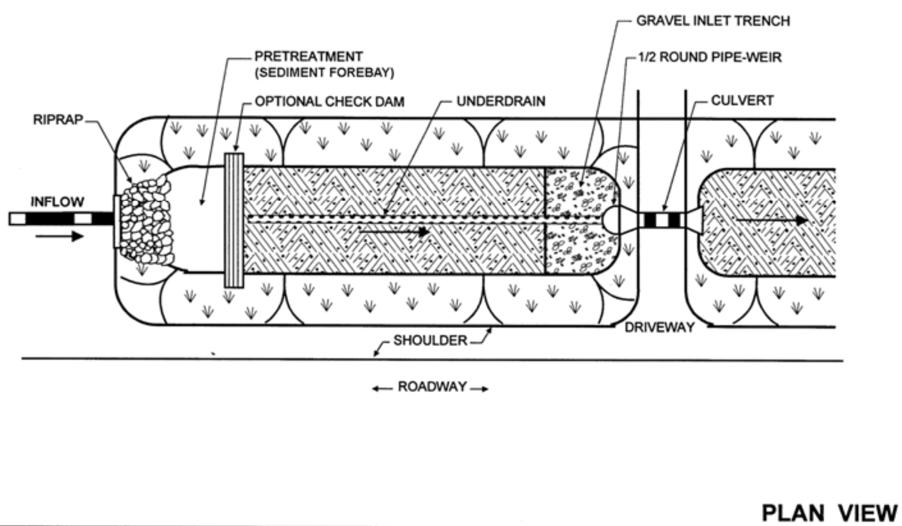
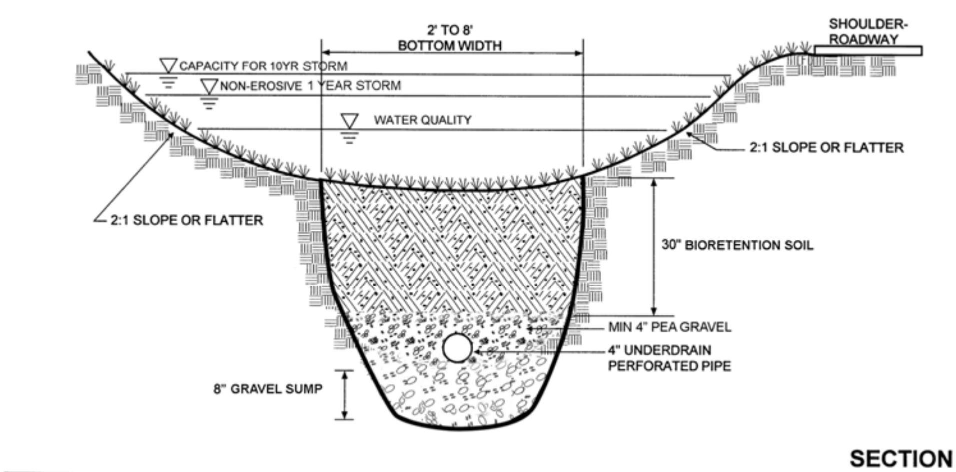
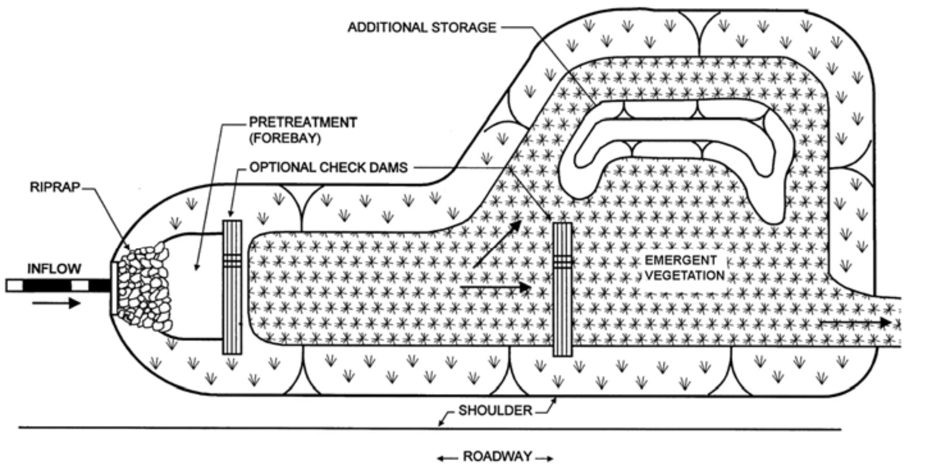
Figure 5-17 Dry Swale

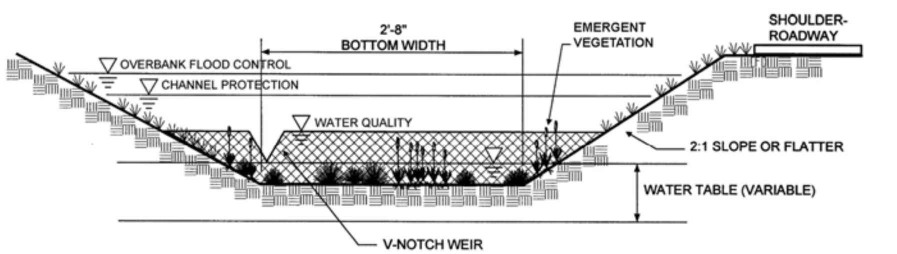




Adapted from MDE, 2000

Figure 5-18 Wet Swale





Adapted from MDE, 2000

5.7.1 Feasibility

Required Elements

- ~~The system~~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 ~~2.0~~4%, without check dams.
- Wet Swales are constructed in groundwater. The bottom of a Dry Swale shall be located at or above the seasonal~~ly~~ high groundwater table; the top of a Dry Swale shall be located at least 3 feet above the seasonal~~ly~~ high groundwater table.

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 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.~~
- 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 ~~2~~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~~-inch~~" drop onto a protected shelf (pea gravel diaphragm~~, see detail~~) to minimize the clogging potential of the inlet. Runoff from roads sh~~a~~oul~~l~~d 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~~-in~~" pea gravel bed, underlain ~~by~~ a ~~12" crushed stone (~~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 ~~and dry~~ swale length, width, depth, and slope shall be designed to temporarily accommodate the WQ_v through surface ponding ~~(wet swale) or filtration area (dry swale) to be released over a minimum 30-minute duration~~.
- ~~Shall design~~Dry swales shall consist of the following treatment components: A 30" deep bioretention soil bed, a surface mulch layer, and a 6" to 9" deep surface ponding area. 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 bed 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 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 ~~12".~~2 ft.
- ~~Soil media for the dry swale shall meet the specifications outlined for bioretention areas.~~

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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 in" 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.
- For the dry swale, the treatment design criteria are similar to those of a bioretention area. The filter area for dry swales should be sized based on the principles of Darcy's Law. A coefficient of permeability (k) should be used as follows:

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

The required filter bed 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) (2.5 feet is recommended for dry swales)
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 recommended maximum t_f for dry swales)

5.7.5 Landscaping

- 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

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

5.7.6 Maintenance

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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 ~~in~~inch range, with mandatory mowing once grass heights exceed 10 ~~in~~inches.

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- 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
- ~~Pollutant Removal~~
- Community and Environmental Benefit.

The ~~six~~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.

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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-~~3~~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	O	O	◗	◗	①	●
	Gravel WVTS	O	O	◗	◗	①	●
Infiltration	Infiltration Trench/Chambers	O	◗	O	O	●	◗
	Dry Wells	O	O	◗	◗	●	◗
	Shallow I-Basin	◗	◗	◗	◗	●	◗
	~~Pervious~~Permeable Pavement	O	O	◗	◗	②	◗
Filters	Sand Filter	◗	◗	◗	O	②	O
	Organic Filter	◗	◗	O	O	②	O
	Bioretention	O	◗	O	O	②	O
Green Roofs	Extensive	◗	◗	●	O	O	O
	Intensive	◗	◗	●	◗	O	O
Open Channels	Dry Swale	O	◗	O	◗	②	◗
	Wet Swale	O	◗	O	●	●	●

O: 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 not 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, ~~stormwater~~shallow WVTSs generally require a drainage area ~~approaching 25~~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. ~~Six~~ 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~~ly~~ 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.

~~*Minimum Surface Area.* This column indicates the minimum surface area required for a practice. This is only applicable to WVTS and Bioretention practices.~~

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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-~~4~~8 BMP Selection Matrix 2-Physical Feasibility

BMP Group	BMP Design	Soils	Water Table	Drainage Area (Ac)	~~Minimum Surface Area~~	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	~~0.15 acres~~	No more than 8%	3 to 5 ft
				5 min if not intercepting gw			
Infiltration	Infiltration Trench/ Chamber	~~f~~$_c$In-situ infiltration rate > 0.5~~*2~~ ~~inch~~in/hr *3	2 ft* for ~~non-wellhead~~strictly residential land uses; otherwise, 3 ft*	5 max	~~NA~~	No more than 6%	1 ft
	Dry Well			<1			1ft
	Infiltration Basin			10 max			3 ft
	~~PerviousP~~ermeable Pavement			NA		No more than 5%	NA ~~NA~~
Filters	Sand Filter	OK	Bottom of filter at or above WT*	10 max **	~~NA~~	~~no~~No more than 6%	2 to ~~7~~6 ft
	Organic Filter			5 max**		~~NA~~	~~2 to 4 ft~~
	Bioretention	Made Soil				~~50 sf~~	~~18 in - 5 ft~~
Green Roofs	Extensive	NA	NA	NA	~~NA~~	~~no~~No more than 20%	NA
	Intensive					No more than 6%	~~no more than 6%~~
Open Channels	Dry Swale	Made Soil	~~NA~~Bottom of filter at or above WT*	~~5 max~~5 max* to any 1 inlet, no limit if runoff enters via sheet flow		~~NA~~No more than 4%*, unless check dams are used ~~No more than 4%~~	18 in - 5 ft
	Wet Swale	OK	below WT			Typically <1%, unless check dams are used	1 ft ~~1 ft~~

[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.~~

[3] 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.

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Notes: OK= not restricted, WT= water table, ~~f_c =soil permeability~~ 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 inappropriate. Regulatory requirements under the Clean Water Act, ~~Total Maximum Daily Load (~~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 ~~2~~Two, water resource areas include: *groundwater, freshwater streams and rivers, ponds, lakes, wetlands, and coastal waters.* Table 5-~~6~~9 presents the key design variables and considerations that must be addressed for sites that drain to any of the above ~~critical resource~~ areas.

Table 5-~~5~~9 BMP Selection Matrix 3-Watershed

BMP Group	~~Critical Resource Area Specific Criteria~~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). ~~Prohibited for coldwater~~ Restrictions on discharges in cold-water fisheries.	OK	Provide long ED (> 48 hrs) for maximum bacteria dieoff.

BMP Group	Critical Resource Area Specific CriteriaReceiving Waters			
	Groundwater	Freshwater Streams and Rivers	Other Freshwaters (Ponds/Lakes/ Wetlands)	Coastal Waters
Infiltration	Must meet UIC setbacks from water supply wells and surface waters.	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.
Open Channels	Pre-treat LUHPPL	OK, should be linked w/ basin to provide CP_v or Q_p.	OK, Dry swaleWet Swale provides more TP removal than wet swaleDry Swale.	Poor bacteria removal. 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 4th-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. 44 (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.

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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 ~~matrix, Matrix 5~~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-~~6~~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 ~~matrix extends~~profile and separated by at least 3 feet ~~below bottom of practice;~~from the SHGT or bedrock (only 2 ft SD required for strictly residential land uses); if the in-situ infiltration rate ≥ ~~2~~ 8.3 in/hr ~~need 50~~, a separate BMP is needed to provide treatment of 100% WQv ~~pretreatment, ≥ 5 in/hr need 100%~~.
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.

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5.8.5 Step 5 - ~~Pollutant Removal~~Community and Environmental Benefit

~~*How do each of the BMP options compare in terms of pollutant removal?* In this step, the designer views removal of select pollutants to determine the best BMP options for water quality. Some practices have a better pollutant removal potential than others or have a better capability to remove certain pollutants.~~

~~This matrix examines the capability of each BMP option to remove specific pollutants from stormwater runoff. The matrix includes data for:~~

- ~~Total Suspended Solids~~
- ~~Total Phosphorous~~
- ~~Total Nitrogen~~

~~**Table 5-7 BMP Selection Matrix 5-Pollutant Removal**~~

~~**Water Quality BMPs**~~		~~**Median Pollutant Removal Efficiency (%)**~~		
		~~TSS~~	~~TP~~	~~TN~~
~~**WVTS**~~	~~Shallow WVTS~~	~~90%~~	~~48%~~[3]	~~70%~~[2]
	~~Gravel WVTS~~	~~99%~~[1]	~~55%~~[1]	~~99%~~[1]
~~**Infiltration Practices**~~	~~Infiltration Basin~~	~~90%~~	~~60%~~[4]	~~55%~~[4]
	~~Infiltration Trench~~	~~90%~~	~~60%~~[4]	~~55%~~[4]

	Subsurface Chambers	90%	60%[4]	55%[4]
	Dry Well	90%	60%[4]	55%[4]
	Porous Pavement	99%[1]	40%[1]	30%
Filters	Sand Filter	90%	40%	30%
	Organic Filter	90%[3]	60%[3]	40%[3]
	Bioretention	90%[1]	40%	30%[1]
	Tree Filter	90%	40%	30%
	Green Roof	90%	40%	30%
Open Channels	Dry Swale	90%	40%	30%
	Wet Swale	90%	40%	30%

Other BMPs		Median Pollutant Removal Efficiency (%)		
		TSS	TP	TN
Pretreatment BMPs	Grass Channels	70%[3]	30%[3]	40%[3]
	Sediment Forebays	25%	ND	ND
	Filter Strips	25%	ND	ND
	Deep Sump Catch Basin	25%	NT	NT
	Hydrodynamic Device	25%[1]	NT	NT
	Oil and Grit Separator	25%[3]	20%[3]	ND
Storage BMPs	Dry Extended Detention Basin	50% [2]	20% [2]	25% [2]
	Wet Extended Detention Basin	70%[3]	40%[3]	55%[3]

	~~Underground Storage Vault~~	~~25%~~	~~NT~~	~~NT~~

~~"ND" Specifies No Data~~
~~"NT" Specifies No Treatment~~
~~References~~
~~1 (UNHSC, 2007) - Note, for UNHSC Data TN is reported as DIN~~
~~2 (CWP, 2007)~~
~~3 (Winer, R., et al., 2000)~~
~~4 (Schueler, 1987)~~
~~Additional References:~~
~~(Claytor, Schueler, 1996), (USEPA Fact Sheet), (Strecker, E., et al., 2004)~~

~~5.8.6 Step 6 - Community and Environmental~~

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, ~~habitat~~cost, community acceptance, ~~cost~~safety, and ~~other environmental factors.~~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 ~~pre-treatment~~pretreatment maintenance burden and/or replacement burden. ~~Infiltration practices should not be used where prior subsurface contamination is present due to the increased threat of pollutant migration associated with increase hydraulic loading from infiltration systems.~~

~~The~~This last step assesses community and environmental ~~factors~~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 plan~~dscapt~~ing 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 ~~its buffer~~the surrounding area.

Table 5-~~8~~11 BMP Selection Matrix ~~6~~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	●	◗	●	○	●
	~~Pervious~~Permeable Pavement	~~◗~~●	◗	○	○	●
Filters	Sand Filter	●	●	◗	○	●
	Organic Filter	◗	●	○	○	◗
	Bioretention	◗	◗	◗	○	◗
Green Roofs	Extensive	◗	◗	○	○	◗
	Intensive	◗	●	○	○	○
Open Channels	Dry Swale	◗	◗	○	○	●
	Wet Swale	○	○	◗	◗	◗

○ High Benefit ~~and/or Low Limitations~~
◗ Medium Benefit ~~and/or Limitations~~
● Low Benefit ~~and/or High Limitations~~

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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

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Design Guidance

- 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.

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6.2.2 Design

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Required Elements

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- 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~~ly~~ 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;

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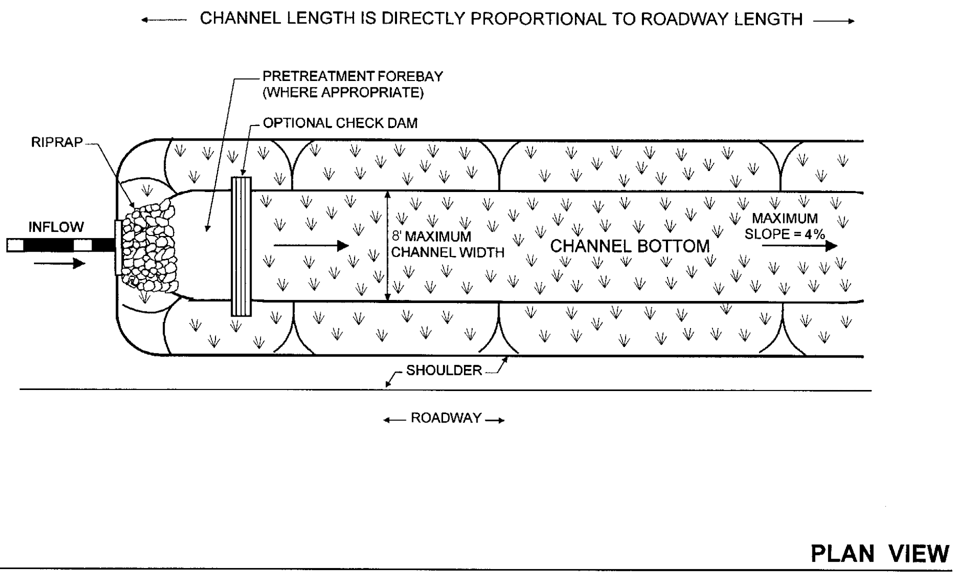
- Mowing and litter and debris removal; and/or
- Stabilization of eroded side slopes and bottom.

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



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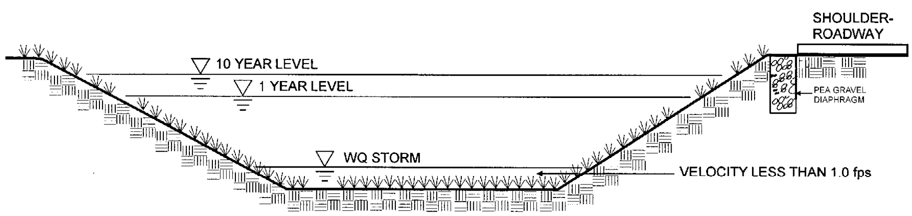

SECTION

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.

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Design Guidance

- 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'~~10	~~15'~~15	~~20'~~20	~~25'~~25	~~10'~~10	~~12'~~12	~~15'~~15	~~18'~~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.

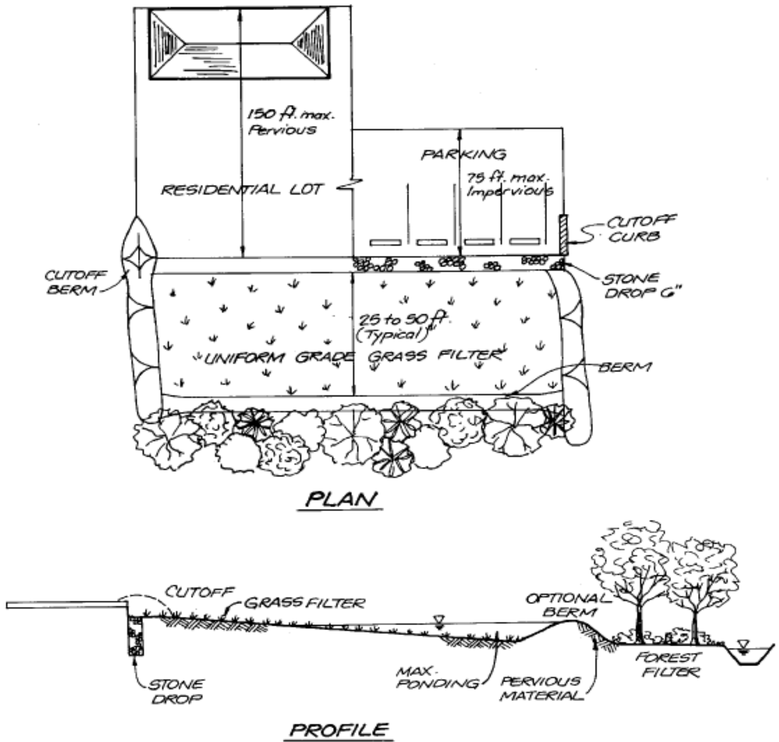
Required Elements

- 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 ~~buffer~~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 ~~coarse~~ 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*/86,400 sec~~ = %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:

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

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- 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.

Design Guidance

- 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

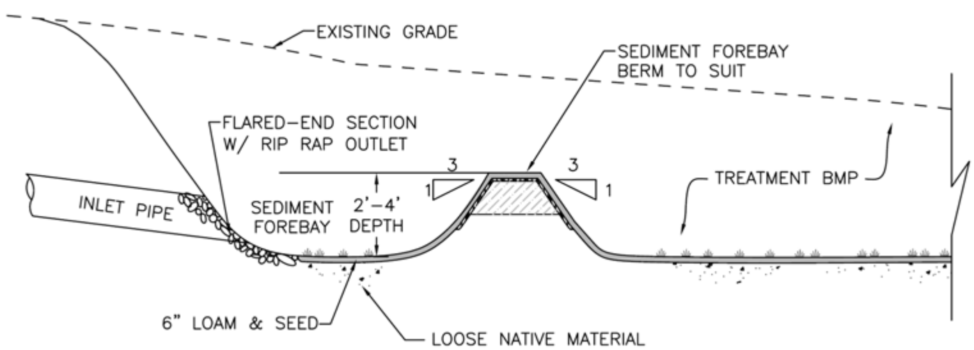
Required Elements

- 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.
- 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.~~25~~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.

~~Design Guidance~~

- Hooded outlets sh~~ou~~al~~d~~l be used in high litter land uses. Care sh~~ou~~al~~d~~l be taken to avoid damaging and displacing hoods during cleaning.

Design Guidance

- The inlet grate should have ~~a separation of one~~openings not more than 4 square ~~inch or less~~inches to prevent large debris from collecting in the sump.

6.5.3 Maintenance

Required Elements

- Inspections shall be performed a minimum of ~~4~~2 times a year~~.~~ (spring/fall). Units shall be cleaned ~~4 times a year or~~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.

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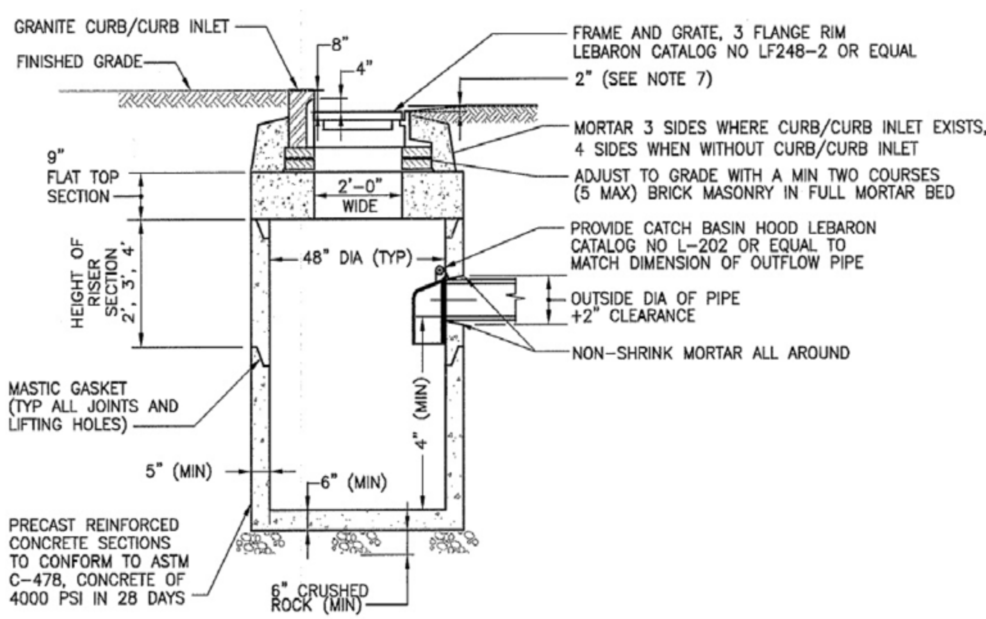
- Sufficient maintenance access shall be considered when designing the geometry of deep sump catch basins.

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~~. These include~~, including oil/grit separators~~ and ~~, hydrodynamic devices~~.~~, and a range of media filtration devices, among others. Recent studies (Schueler, 2000; Claytor, 2000; UNHSC, 2007) have shown that~~, with few exceptions,~~ these proprietary devices are not ~~effective in~~ capable of achieving the required water quality ~~standards~~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

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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. ~~. Proprietary devices should be designed per the manufacturer's recommendations.~~ 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.

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While proprietary devices must~~Oil/grit separators are particularly useful pretreatment practices for runoff from LUHPPLs that are expected to have high pollutant loads of oils and grease. While these should~~ be designed per the manufacturer's recommendations, the following design requirements and guidance apply.

6.6.1 Feasibility

Required Elements

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- ~~Oil/grit separators~~To qualify as an acceptable pretreatment device, proprietary devices shall remove a minimum of 25% TSS for the WQ_v or WQ_f, as verified by an independent third-party monitoring group.
- 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 ~~oil/grit separator shall~~proprietary device should generally not exceed 1 acre of impervious cover.

~~Design Guidance~~

- Potential site constraints include the presence of utilities, bedrock, and high water tables.
- ~~Oil~~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

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- ~~Oil/grit separators~~Flow-through proprietary devices shall be designed to treat runoff from the entire ~~water quality flow.~~
- ~~A~~WQ_f. For these devices, a minimum detention time of 60 seconds is required for the ~~water quality flow~~WQ_f.
- ~~Oil/grit separator volume~~ A storage proprietary device shall be sized based on ~~10% of~~ the ~~water quality volume; to allow~~required pretreatment volume (% WQ_v) or a designer must provide documentation that it is sized appropriately for ~~deposition of~~

~~sediment, only ½ the volume shall be used for detention purposes~~a verified minimum removal of 25% TSS.

- ~~All~~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 ~~oil/grit separators.~~ proprietary devices.

6.6.3 Maintenance

Required Elements

- ~~The oil/grit separator~~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. ~~Units~~Devices shall be cleaned at least 2 times a year, and the hazardous debris removed shall be disposed of in accordance with State and ~~F~~federal regulations by a properly licensed contractor.
- ~~Specific maintenance requirements as specified by the manufacturer shall be performed.~~

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

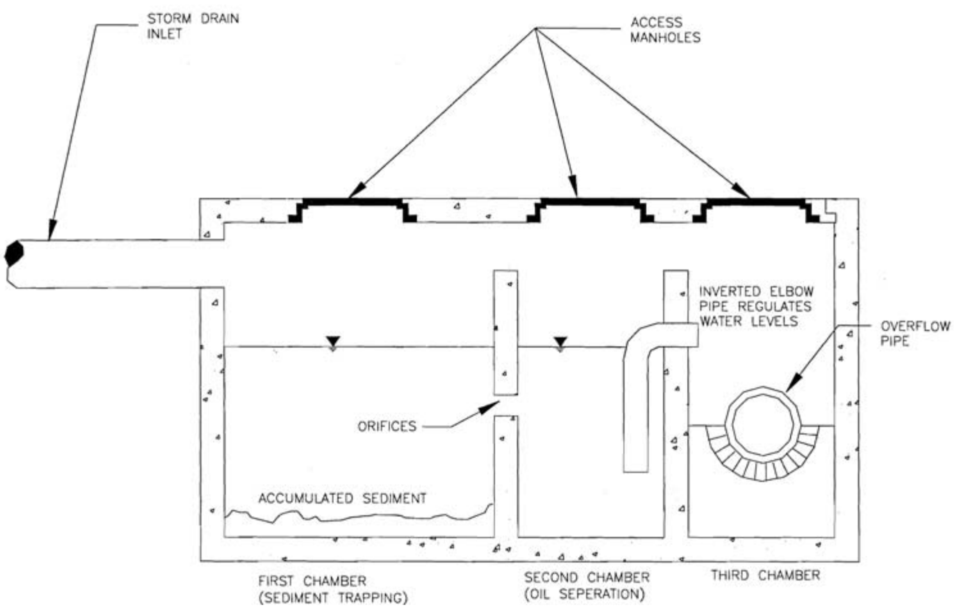

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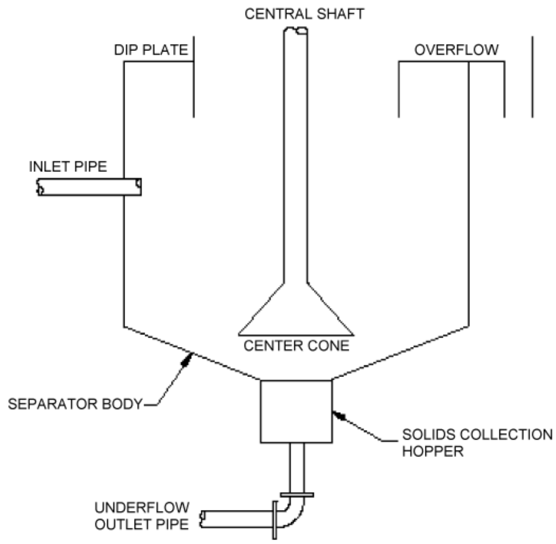
Figure 6-6 Hydrodynamic Device



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 (e.g., dry detention basins) 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 are defined as basins that do not haveneed a permanent pool and aremay be designed such that the groundwater table is at or below the bottom of the basin.

7.2.1 Feasibility

Required Elements

- 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, subject to agreement by the approving agency.

- The use of basins in watersheds draining to cold-water fisheries is restricted to prohibit discharges within 200 feet of jurisdictional waters, includingstreams 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.

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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.
- PermanentThe permanent pool of wet basins should be have a minimum 4' 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

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[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 x 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 CRCM 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

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Design Guidance

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

~~7.2.5 Landscaping~~

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.

~~Landscaping~~Planting Plan

Required Elements

- A plan~~dscap~~ting 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 and/or roads and parking lots shall be provided that extends 25 feet outward from the maximum water surface elevation of the basin. ~~The basin setback shall be contiguous with other setback areas that are required by other regulations.~~
- 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 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 ~~ground covers~~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 ~~jurisdictional waters~~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.

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.
- 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.

7.2.8 Non-clogging Low-flow Orifice

Required Elements

- When CP_v is required, a low-flow orifice shall be provided, with the size for 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 h~~ou~~rs and not more than 24 h~~ou~~rs 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 ~~the~~ gravel trench and adjacent soil; and
  - Shall utilize clean ~~well~~poorly-drained 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

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- 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 ~~the~~ 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

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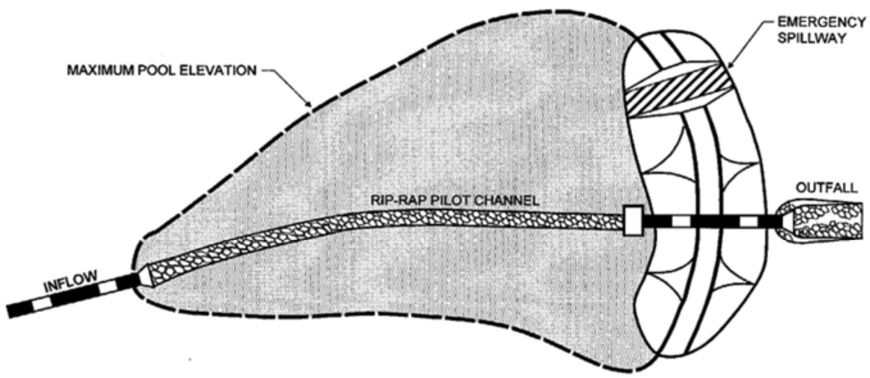
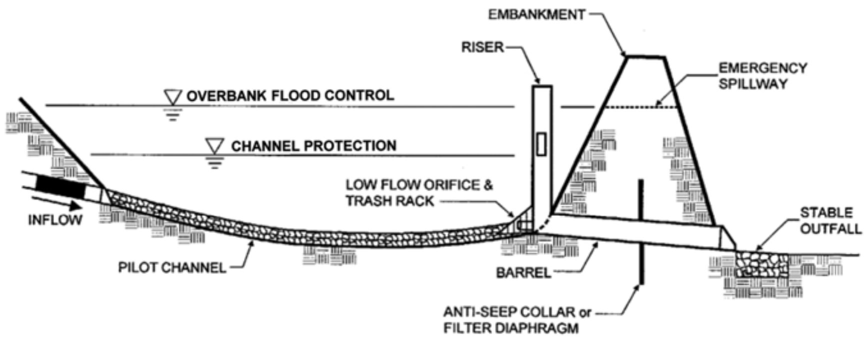


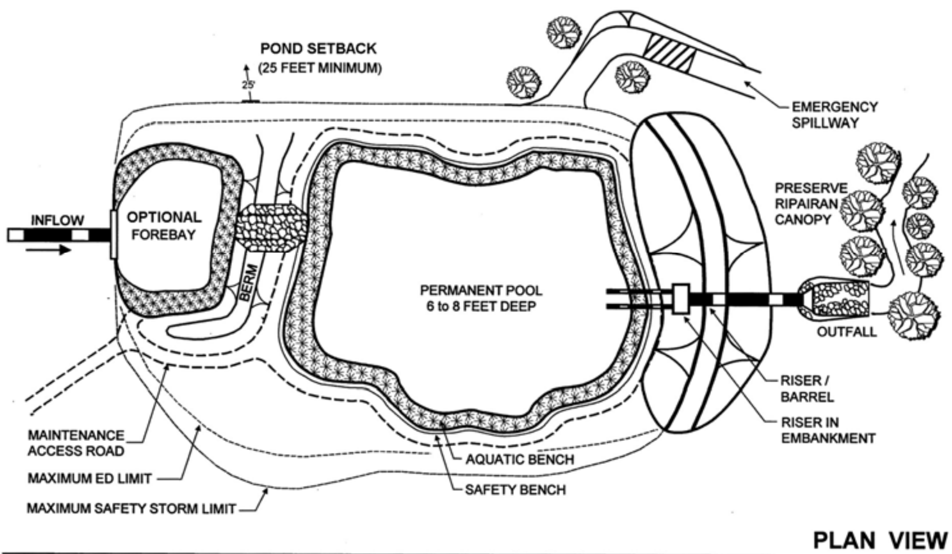
PLAN VIEW

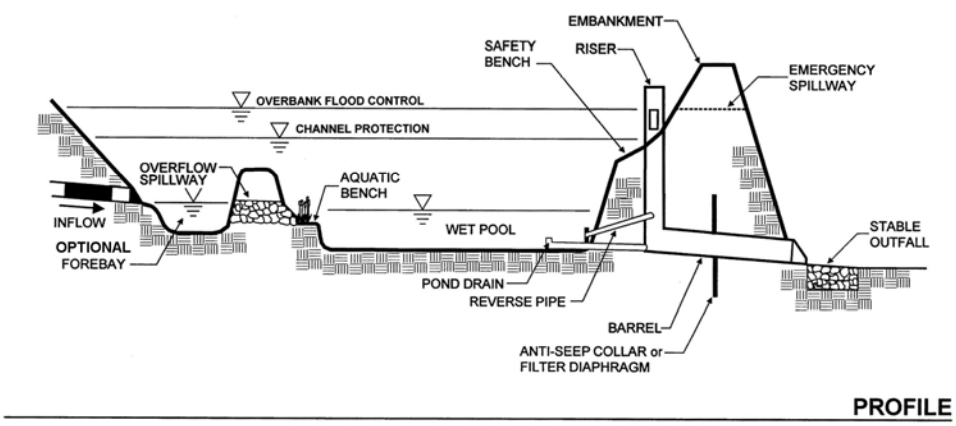


PROFILE

Adapted from MDE, 2000

Figure 7-2 Wet Extended Detention Basin





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~~Figure 7-2 Wet Extended Detention Basin~~

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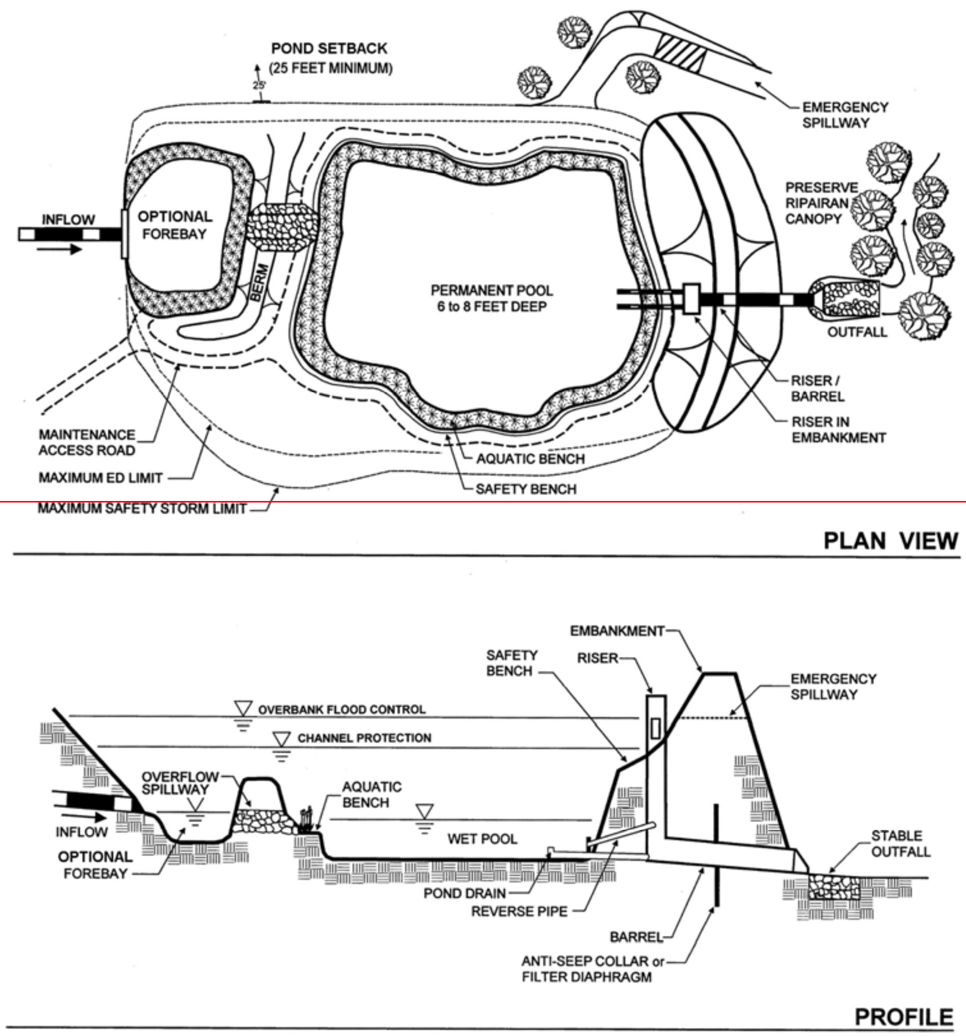

Adapted from MDE, 2000

7.3 Underground Storage Devices

Underground stormwater retention/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.

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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)

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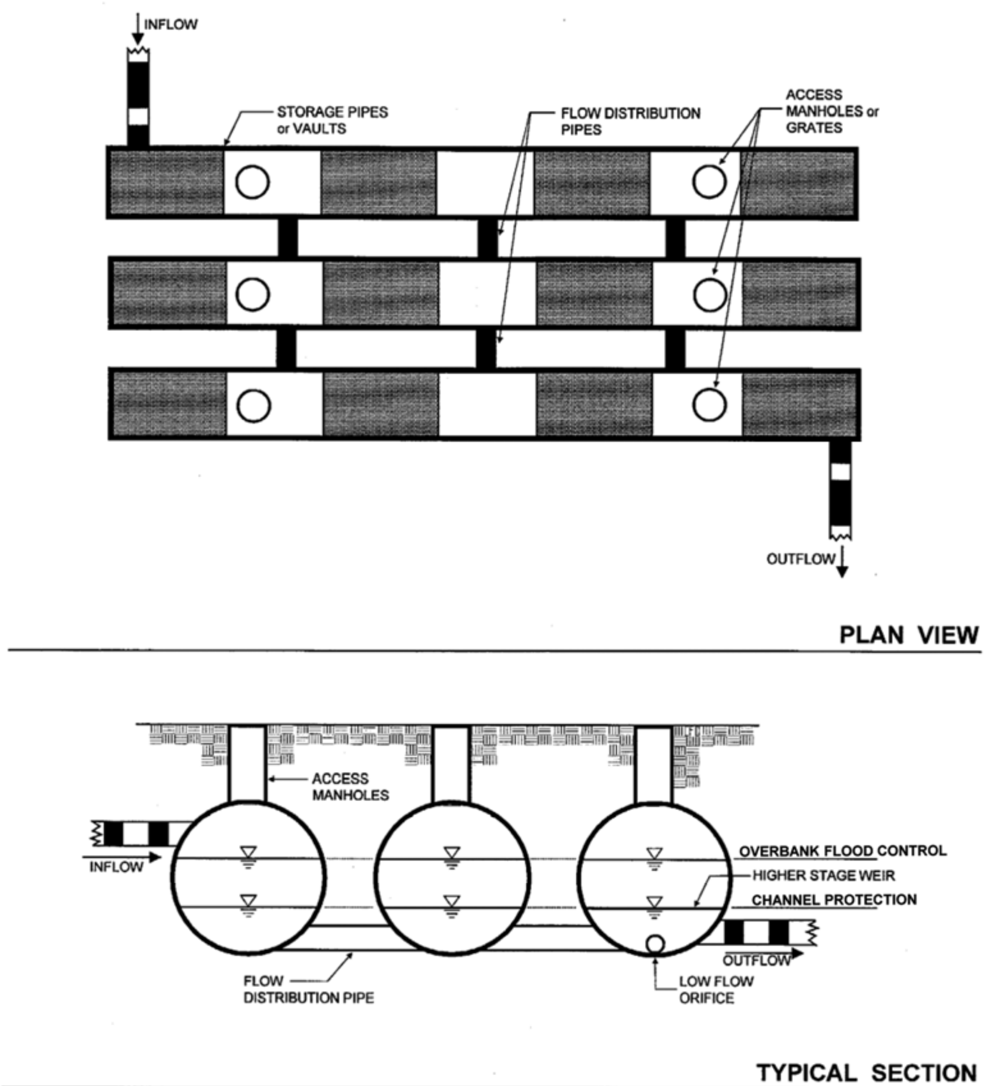
Figure 7-3 Underground Storage Vault



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.

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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). Extraordinary care should be taken to assure that long-term infiltration rates are achieved through the use of 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 two (2) feet vertically from the seasonal high groundwater table (SHGT) or bedrock layer, 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.
- 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 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 residential dry wells and infiltration facilities for private driveways (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	25	100
Surface Water Drinking Water Supply Impoundment* with Supply Intake	100	200

[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 residential dry wells and infiltration facilities for private driveways (ft)	From all other infiltration facilities (ft)
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	50	50
Down-gradient from Building Structures	10	25
Up-gradient from Building Structures	10	50
Onsite Wastewater Treatment Systems (OWTS)	25	25

*Refer to DEM Onsite Wastewater Treatment System Rules Figures 14-16 for maps of the drinking water impoundments.

Design Guidance

- 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

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.

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 ~~landscaping~~vegetation and soils to treat urban stormwater runoff by collecting it in shallow depressions, before filtering through ~~a fabricated~~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.

CENTER OF MASS METHOD - This is a method for determining detention time as necessary for meeting the CP_v requirement. This method evaluates the difference in time between the center of mass of the inflow and outflow hydrographs. Some TR-55 models calculate the detention time automatically, such as HydroCAD.

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 ~~(LUHPPL)~~ - 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.

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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 Rev 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, including infiltration trenches and infiltration basins.

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 ~~(LUHPPL)~~ - 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 modular concrete paving blocks, modular concrete or plastic lattice, cast-in-place concrete grids, and soil enhancement technologies. Stone, gravel, and other low-tech materials can also be used as alternatives for low traffic applications such as driveways, haul roads, and access roads

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.

<u>POINT SOURCE</u> - 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.

<u>PONDSCAPING</u> - ~~Landscaping~~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.

<u>PERMEABLE PAVEMENT</u> **–** Permeable pavement is similar to conventional asphalt or concrete but is formulated to have more void space for greater water passage through the material.

<u>PRETREATMENT</u> - Techniques employed in stormwater BMPs to provide storage or filtering to help trap coarse materials before they enter the system.

<u>PRINCIPAL SPILLWAY</u> - An open and/or closed channel designed to allow a normal range of stormwater flows to discharge from an impoundment.

<u>QUALIFYING PERVIOUS AREA</u> – 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 4.9.

<u>RAIN BARRELS</u> - 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 plan~~dscapt~~ing plan. The size of the rain barrel is a function of rooftop surface area and the design storm to be stored.

<u>RATIONAL EQUATION</u> – 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).

~~RECORD DRAWING - Drawing or certification of conditions as they were actually constructed.~~

<u>REDEVELOPMENT</u> – 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. 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 ~~(LUHPPL)~~ - 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.

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SEASONAL~~LY~~ HIGH GROUNDWATER TABLE – ~~The highest~~ the elevation of the groundwater table ~~typically observed~~ 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.

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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.

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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.

<u>ULTRA-URBAN</u> - Densely developed urban areas in which little pervious surface exists.

<u>UNDERGROUND DETENTION FACILITIES</u> - 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.

<u>UNDERGROUND INFILTRATION SYSTEMS</u> – 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.

<u>URBAN STORMWATER RUNOFF</u> - Stormwater runoff from developed areas.

<u>VELOCITY HEAD</u> - 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).

<u>WATER BALANCE</u> – Equation describing the input, output, and storage of water in a watershed or other hydrologic system.

<u>WATER QUALITY SWALES</u> - 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.

<u>WATER QUALITY VOLUME (WQ_v)</u> -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.

<u>WATERSHED INCHES</u> - 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.

<u>WATERSHED MANAGEMENT</u> **-** Integrated approach addressing all aspects of water quality and related natural resource management, including pollution prevention and source control.

<u>WET SWALE</u> - An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

<u>WET VEGETATED TREATMENT SYSTEMS (WVTS)</u> - Shallow, constructed pools that capture stormwater and allow for the growth of characteristic emergent vegetation.

XERISCAPING - ~~Landscaping~~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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