New England Stormwater Retrofit Manual









DEVELOPED BY

VHB

The University of New Hampshire Stormwater Center

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Abbreviations

BATT	Best Management Practice Accounting and Tracking Tool
CSO	Combined Sewer Overflow
CTDEEP	Connecticut Department of Energy and Environmental Protection
D	Depth
DSV	Design Storage Volume
DWTR	Drinking Water Treatment Residuals
EPA	Environmental Protection Agency
HSG	Hydrologic Soil Group
I&M	Inspection and Maintenance
IA	Contributing Impervious Area
KSAT	Saturated Hydraulic Conductivity
L	Length
LID	Low Impact Development
MassDOT	Massachusetts Department of Transportation
MCM	Minimum Control Measure
MEDEP	Maine Department of Environmental Protection
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
MTD	Manufactured Treatment Device
NCHRP	National Cooperative Highway Research Program
NHDES	New Hampshire Department of Environmental Services
NPDES	National Pollutant Discharge Elimination System
PLERs	Pollutant Load Export Rates
PTAP	Pollutant Tracking and Accounting Project
QPA	Qualifying Pervious Area
RIDEM	Rhode Island Department of Environmental Management
RIDOT	Rhode Island Department of Transportation
Runoff Depth	Runoff Depth from Impervious Area
SCM	Stormwater Control Measure
SNEP	Southeast New England Program
SOP	Standard Operating Procedures
TMDL	Total Maximum Daily Loads
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
UOP	Unit Operations and Process
VPDES	Vermont Pollutant Discharge Elimination System
VTDEC	Vermont Department of Environmental Conservation
W	Width
WQDF	Water Quality Data Form

Acknowledgment

This manual was developed due to the forward thinking and commitment to water quality by the Southeast New England Program (SNEP) and Environmental Protection Agency (EPA) Region 1. The latest version of the manual may be accessed online at the following hyperlink, along with other supplementary documents:

https://snepnetwork.org/stormwater-retrofit-manual/#

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Introduction

This manual provides research-based guidance on planning, siting, and designing retrofit stormwater control measures (SCMs) to manage stormwater in existing or reconstructed development situations where regulatory requirements do not dictate prescribed specifications. It also presents an approach for crediting pollutant and runoff volume reductions associated with these measures. For the purposes of this manual, a retrofit is defined as the addition of stormwater controls on a currently developed site. Retrofits may include controls incorporated into planned construction work or controls implemented as a stand-alone stormwater improvement project. Retrofit SCMs are designed to minimize the impacts of existing development at sites that either lack stormwater controls or have insufficient controls in place.

Retrofit: the addition of stormwater controls on a currently developed site

Situations where retrofits are encouraged, and with which this manual will assist, include:

- ≈ Implementing stormwater controls as part of maintenance and planned construction
- ≈ Demonstrating stormwater treatment to the maximum extent practicable (MEP)
- ≈ Implementing stormwater controls to meet total maximum daily load (TMDL) targets
- ≈ Identifying and prioritizing stormwater management interventions to protect or improve a local water resource
- ≈ Enhancing existing structural SCMs for improved performance controls (e.g., increased pollutant load and runoff volume reductions)
- ≈ Understanding cost/benefit for various control measures and options

This manual does NOT replace existing federal, state, or local requirements for stormwater management. It should be used as a resource for supplemental guidance in making smart site design choices to mitigate stormwater impacts from existing developed areas.

This manual supports opportunities to make improvements on sites that do not fit within a current regulatory framework, with the understanding that achieving any water quality improvement is beneficial.

SNEP Network Mission

The mission of the SNEP Network is empowering communities to achieve healthy watersheds, sustainable financing, and long-term climate resilience through management of stormwater and restoration projects.

SNEP Context & Mission

The United States Environmental Protection Agency's (EPA) Southeast New England Program (SNEP) has a cooperative agreement with the New England Environmental Finance Center (New England EFC) based at the University of Southern Maine, serving EPA Region 1, to manage a network of technical assistance providers in Rhode Island and southeast Massachusetts—the SNEP Network. The mission of the SNEP Network is to empower communities to achieve healthy watersheds, sustainable financing and long-term climate resilience through local capacity building and management of stormwater and restoration projects. The SNEP Network partners collaborate and provide expert training and technical assistance to municipalities, organizations, and tribes to advance stormwater and watershed management, ecological restoration, and climate resilience in the SNEP region.

This Stormwater Retrofit Guidance Manual has been developed by the University of New Hampshire Stormwater Center and VHB with financial support from the SNEP Network and technical support from other SNEP Network partners, state agencies, and EPA Region 1. The SNEP Network and EPA Region 1 staff have embraced the opportunity to fund and support the development and implementation of this manual as a key tool for improving Southeast New England's water resources. The manual is intended to be relevant to all EPA Region 1 states.

Stormwater Regulatory Context

In the early 2000s stormwater practitioners began to focus on the impact of urban runoff from frequent smaller rain events on water resources. Many factors contributed to the shift in attention beyond simple peak flow or flood control. Among them was the Center for Watershed Protection's [1] "Impacts of Impervious Cover on Aquatic Systems" report that discussed how development and alteration of the land surface change the hydrologic response of the land, which in turn has physical, water quality, and biological impacts on receiving waters.

On a local level, a 2010 U.S. Geological Survey Scientific Investigations Report [2] and a 2009 National Research Council [3] book also showed the links of impervious area on streamflow alteration, habitat fragmentation, and water quality for Massachusetts stream basins.

The United States EPA and individual states have developed regulatory programs to address stormwater impacts on the nation's water resources. These regulatory requirements have been and continue to be shaped by legal actions to meet Clean Water Act mandates, and by research-based improvements in how stormwater is managed. This section reviews the New England state and federal stormwater water quality requirements for a better understanding of the current stormwater management regulatory context before discussing when these standards are relevant in retrofit designs.

Standards for Retrofit Scenarios

State redevelopment design standards have become entrenched in designers' approach to stormwater management and thus they are often applied unnecessarily as screening criteria in developing retrofit scenarios. When regulatory requirements do not govern, this manual can help guide standards for retrofit designs.

State Standards

State stormwater standards requiring stormwater mitigation for new development and redevelopment focus on water quality and flooding impacts at the point when they can most easily be addressed: during the construction or reconstruction of a site. State standards are usually triggered by development within certain natural resource areas and/or land disturbance area thresholds and focus on individual construction projects.

Table A-1 in Appendix A shows the stormwater water quality design and implementation requirements for the regulatory programs across New England. The typical new development standards for the New England states require that a particular volume (e.g., one inch over the contributing area) be treated with a discrete list of control measures. The state guidance manuals often provide prescribed required design criteria for those measures to achieve compliance. These criteria are often then used by designers to define the goals to be partially met in redevelopment scenarios.

Although some states have specific water quality goals (pollutant and runoff volume percent reductions), the means for meeting them are based on prescribed treatment volumes and set design standards. This approach is generally appropriate for new and redevelopment scenarios where site construction often necessitates more strict compliance and provides opportunities to manage stormwater on-site. In contrast, because these requirements have become entrenched in designers' approach to overall stormwater management, they are often unnecessarily applied to retrofit scenarios and limit the scope of potential opportunities to improve water resource health.

Federal NPDES Standards

The National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) programs cover the ongoing activities of stormwater discharges within the collective urbanized area (as defined by the latest U.S. Census [4]). The NPDES programs are overseen by EPA Region 1 in Massachusetts and New Hampshire and by the state environmental agencies in the other delegated New England states. The NPDES MS4 general permits contain requirements to address impaired waters, total maximum daily loads (TMDLs) and six minimum control measures (MCMs), including a post-construction measure (MCM 5) that addresses new and redevelopment activities.

Table A-2 in Appendix A summarizes the NPDES requirements for both post-construction stormwater management (MCM 5) and TMDLs/Impaired Waters. The table shows that the post-construction stormwater management requirements are typically high-level and either offer little detailed guidance or refer back to state guidance. In scenarios where limited MCM 5 guidance is provided, planners and designers often default back to known guidelines and criteria in the form of their state standards and manuals.

Recently, the Massachusetts and New Hampshire NPDES MS4 general permits, developed by EPA Region 1, have offered specific numeric requirements with companion guidance for demonstrating compliance. These approaches, which are generally mirrored in this retrofit guidance manual, provide a new, more flexible way of meeting water quality goals.

Default Mode

When EPA or state MS4 standards do not provide specific guidance for meeting impaired waters and TMDL requirements, regulators and designers often revert to known guidelines and criteria in the form of their state standards even though more flexible and cost-effective solutions are available.

Other Stormwater Regulatory Programs

In addition to the state and federal stormwater regulatory programs described above, stormwater discharges can also be regulated via:

- **Combined sewer overflow (CSO) permits and consent agreements:** On a regular basis, combined sewers collect and convey stormwater runoff and sewage in a single system to a treatment facility. When the collection system exceeds capacity, overflows discharge to local receiving waters. These overflows are permitted through state or federal NPDES individual permits and are sometimes addressed in enforcements, resulting in consent agreements, by state or federal agencies. Stormwater retrofits can reduce overall pollutants by separating sewer and stormwater systems and providing detention to alleviate significant volumes in the combined conveyance system during larger events.

Adaptive Management Plan

New Hampshire seacoast communities are working collaboratively to develop nitrogen control plans through an adaptive management planning process to implement structure stormwater treatment measures and other nonpoint source control measures to reduce nitrogen loading in the Great Bay watershed in lieu of more costly and extensive wastewater treatment upgrades. Collaboration occurs through the Municipal Alliance for Adaptive Management where municipal and stakeholder representatives meet to share ideas and approve cost-sharing proposals to develop a more holistic approach which address the requirements of EPA's Great Bay Total Nitrogen General Permit that was released in in November 2020. As part of this, the lead partnering communities have agreed to provide annual progress reports to provide updates of the various structural and non-structural measures that are being used or planned for nitrogen load reductions.

You can find more details at the following link: www.rochesternh.net/municipal-alliance-for-adaptive-management

- **Integrated (stormwater, wastewater, and CSO) water resources permits and adaptive management planning efforts:** Supported by EPA's 2012 *Integrated Municipal Stormwater and Wastewater Planning Approach Framework* [5], more municipalities are looking to integrate their stormwater and wastewater water quality permitting and planning efforts into one permit to streamline the identification and prioritization of the most cost-effective water quality measures. Often in these approaches, watershed-wide stormwater mitigation takes precedence as a cost-effective means to address water quality issues and meet other community objectives.
- **Local ordinances:** Local authorities can develop and implement their own stormwater management regulations in addition to state and federal programs to address local issues and goals. These may include municipality-wide requirements or overlay districts to focus on targeted areas of concern.
- **Stormwater utilities:** Stormwater utilities, also known as stormwater enterprises, are public utilities that operate much like an electric or water utility. They are established to collect fees to fund a municipal stormwater management program. The fee structure is typically based on total or impervious area contributing to the municipal drainage system and allows discounts and credits for mitigation practices [6].
- **Evolving stormwater permits:** In the New England area, agencies have recently implemented regional stormwater permitting via other mechanisms. For example, the use of EPA's "residual designation" authority has resulted in permits in Maine and Vermont and is being explored for portions of Massachusetts [7]. Massachusetts is utilizing watershed scale permits in Cape Cod as part of the Section 208 program [8] and New Hampshire communities are performing adaptive management planning and implementation processes to reduce nitrogen loading in the Great Bay watershed from several source types including stormwater [9].

These regulatory efforts have made great progress in moving the New England region's collective approach from simple flood control and drainage to stormwater management and mitigation. Unfortunately, many of New England water resources remain or continue to be degraded due to the water quality, hydrologic, and habitat impacts resulting from development, specifically, increased stormwater runoff from developed areas. To make progress towards reversing these impacts and improving water quality and hydrologic conditions, stormwater from developed areas must be managed in a more holistic manner that includes the installation of retrofit SCMs.

Introduction to Performance Curves

The SCM Water Quality Treatment Performance Curves (Performance Curves) are used as key tools to facilitate the flexible crediting approach for pollutant and runoff volume reductions. In short, the Performance Curves provide a quantification of water quality benefit (i.e., credit) for a range of sizes and types of SCMs. They are based on long-term cumulative performance modeling (versus storm event-based), and although they are normalized to a Runoff Depth from the contributing impervious area, they are based on the Design Storage Volume (instantaneous storage volume) versus what some programs and calculations call the "water quality volume."

This manual will provide detailed directions and examples of how to use these Performance Curves to support retrofit design and determine the water quality treatment measures that best meet a project's goals. The graphic on the next page offers an overview of the Performance Curves. Chapter 2 describes how the Performance Curves are used as a tool in the various retrofit approaches. Chapter 3 discusses how the Performance Curves are used as a means of evaluating SCMs. Chapter 4 provides a crosswalk outlining which specific SCM variations correspond to which Performance Curves.

Use the overview of the Performance Curves on the next page as a quick reference to what they are and how to use them. Take the page out of the manual for convenient use as a guide.

Performance Curves Overview

What Are The Curves?

The Stormwater Control Measure (SCM) Performance Curves were developed by EPA and serve as a tool that helps quantify water quality benefits of various structural stormwater controls. The curves relate the depth of runoff treated of various controls to pollutant reduction.

SCMs With Curves

The following SCMs have curves developed to date for Total Phosphorus, Total Nitrogen, Total Suspended Solids (TSS), Metals*, Bacteria, and Effective Impervious Cover:

* In developing the SCM Performance Curves, Zinc removal performance was modeled. The results from the Zinc models are used to represent removal performance for Metals in general. Accordingly, the manual uses the term "Metals" throughout.

- Infiltration Trench
- Infiltration Basin
- Bio-Filtration
- Bio-Filtration with ISR**
- Sand Filter
- Gravel Wetland
- Porous Pavement
- Wet Pond
- Extended Dry Detention
- Grass Swale
- Impervious Area Disconnection
- Impervious Area Disconnection Through Storage

** Internal Storage Reservoir

Curves have not been developed for all pollutants for each SCM. See Appendices B and C for more information. Infiltration controls have multiple curves to represent varying infiltration rates.

Curve Development

The curves were developed by EPA to represent long-term cumulative pollutant removal performance of several structural controls as a function of their size. The curves were generated using a long-term simulation model developed using EPA's Stormwater Management Model (SWMM) and a structural control analysis tool called Best Management Practice (BMP) Decision Support System in order to simulate the hydrology and pollutants during rain events in the New England area. Twenty-three years of rainfall data from Boston was used as the input rainfall timeseries and the models were calibrated and tested using performance data for in-situ controls collected by the University of New Hampshire Stormwater Center (UNHSC). EPA developed curves for five water quality constituents: Total Phosphorus, Total Nitrogen, Total Suspended Solids, Metals, and Bacteria.

Design Storage Volume (DSV) & Runoff Depth From Impervious Area (Runoff Depth)

The DSV of an SCM is the total volume of stormwater that a SCM is designed to effectively hold and treat. The Runoff Depth from Impervious Area (IA) may be calculated as:

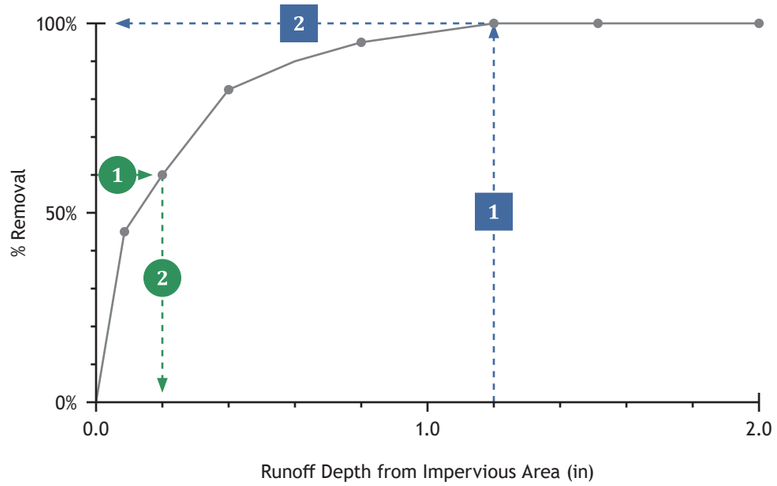
$$\text{Runoff Depth from Impervious Area (in)} = \frac{\text{DSV (ft}^3\text{)}}{\text{IA (ft}^2\text{)}} \times 12 \frac{\text{in}}{\text{ft}}$$



How to Use the Curves

The curves can be used to understand the relationship between DSV (as Runoff Depth from Impervious Area) of a given SCM and the percent pollutant reduction achieved by the SCM, using linear interpolation between values when needed. Generally, the greater the design storage volume, the higher the percent removal of the pollutant. The curves can be used to either determine the percent reduction based on a known DSV **(blue path below)** or the required DSV to achieve a desired percent reduction **(green path below)**.

The curves serve as a quick and simple tool to compare various SCMs for a site and allow a designer to readily choose which SCM is best for a site given both required treatment and sizing constraints. They also help designers understand when it may be less effective to continue to make a given SCM bigger by identifying the "knee" on the curve.



1. If a designer is working on a site where a pollutant reduction of 60% is desired...
2. ...the designer would use the curves to determine that a Runoff Depth from Impervious Area of approximately 0.2 inches achieves the desired reduction
1. If a designer determines that their SCM provides a DSV equivalent to 1.2 inches from the Impervious Area...
2. ...the designer would use the curves to determine a 98% pollutant reduction from this SCM

How to Use This Manual

This manual is not intended to support every stormwater project. It has a discrete focus on identifying, implementing, and quantifying the benefit of structural controls to address water quality and hydrologic water balance impacts within a retrofit context. By providing a flexible crediting approach for pollutant and runoff volume reductions associated with these measures, this manual encourages small local control measures. The range of sites and scale of where this guidance can be applied widely varies from watershed scale planning level designs to small-scale measures inserted into reconstruction or stand-alone retrofit projects. Essentially, this manual can support identification and implementation of controls for any site, project, or planning effort where prescribed regulatory design requirements do not apply.

Focus of This Manual

Identifying, implementing, and quantifying the benefit of structural controls to address water quality and hydrologic water balance impacts.

Audience

SCMs can be implemented during typical construction projects and through planned efforts, as discussed in more detail in Chapter 2. Given this range of possible SCM implementations, this manual is useful to a broad audience, including:

- Designers
- Municipal and agency public works and utility officials
- Municipal and community planners
- Project managers
- Local and state permitting authorities, including local conservation commissions
- Local and state permittees

In addition to capturing/treating contaminants, the SCMs discussed within this manual will provide many other co-benefits to local Southeast New England communities and water resources, which could include:

- Reducing peak discharge
- Recharging ground water
- Addressing water quality impairments
- Providing flood control and/or correcting past impacts from altered urban hydrology
- Incrementally counteracting impacts of climate change
- Mitigating temperature impacts
- Reducing erosion
- Providing habitat
- Improving aesthetics and quality of life

Manual Overview

The remainder of the manual is broken into the following chapters as described below with their intended use.

Chapter 2

Retrofit Approach

This chapter defines what a retrofit is and discusses the approaches to identifying and implementing SCMs in a retrofit situation. It reviews the opportunistic approach (including measures as part of other efforts) and the planning approach (proactive planning and prioritization).

Chapter 3

Credits

This chapter discusses credits, or the quantification of a SCM's stormwater benefits. It explains the need for credits and presents the SCM Water Quality Treatment Performance Curves, a crediting scheme that is becoming widely accepted in New England for quantifying benefits. The credits show that small-scale controls that do not necessarily meet widely implemented sizing standards can still provide significant benefit.

Chapter 4

Stormwater Control Measures Selection & Design

This chapter describes typical Unit Operations and Processes (UOPs) used by SCMs and how these relate to the Performance Curves. It also provides information on the SCM selection and design process and sizing guidance, as well as additional tools and resources for SCM selection and sizing.

Chapter 5

Stormwater Control Measure Guidance

This chapter steps through the functional components and treatment categories used to construct a SCM, providing relevant design guidance for the retrofit scenario. It also presents SCM variations within each treatment category along with design considerations and Inspection and Maintenance (I&M) activities for each variation.

Chapter 6

Stormwater Control Measures Selection & Design

This chapter introduces the importance of inspection and maintenance for long-term SCM health. It provides references where more detailed guidance and discussion can be found.

What This Manual Does NOT Cover

This manual has a targeted focus and is not intended to cover certain topics. The scope of this manual is intentionally limited to be most useful in filling a current gap in guidance on identification and implementation of retrofit stormwater control measures, and therefore does not include or address:

- Specific regulatory requirements and programs
- SCMs or best management practices implemented for construction site or new development post-construction stormwater runoff control
- Controls to specifically address flooding and climate change
- Non-structural and source controls
- Mitigation measures for non-stormwater pollutants
- Detailed inspection, operation, and maintenance procedures

Users of this manual are encouraged to seek out other resources as needed, including:

- Regulatory manuals and guidebooks
- Academic research materials
- Professional organization and agency design standards and guidance

2

Retrofit Approach

This chapter discusses the approaches used to identify and implement stormwater control measures (SCMs) in a retrofit situation, including overcoming commonly faced constraints and design limitations. Retrofits are, by definition, measures implemented after development has occurred. Therefore, it is often the case that options for the type, size, and site of SCMs are limited. However, as this chapter will discuss, cost-effective and creative solutions can be installed within even the most challenging site and situation.

Approaches to Implementing Controls

Stormwater retrofits can be implemented in a number of ways. This section describes the two primary approaches:

Opportunistic Approach

Incorporation of SCMs into already planned and needed construction projects

Planning Approach

Proactively planning retrofits and prioritizing sites where retrofits are possible and beneficial



OPPORTUNISTIC APPROACH EXAMPLE

Daisy Field

Boston, MA

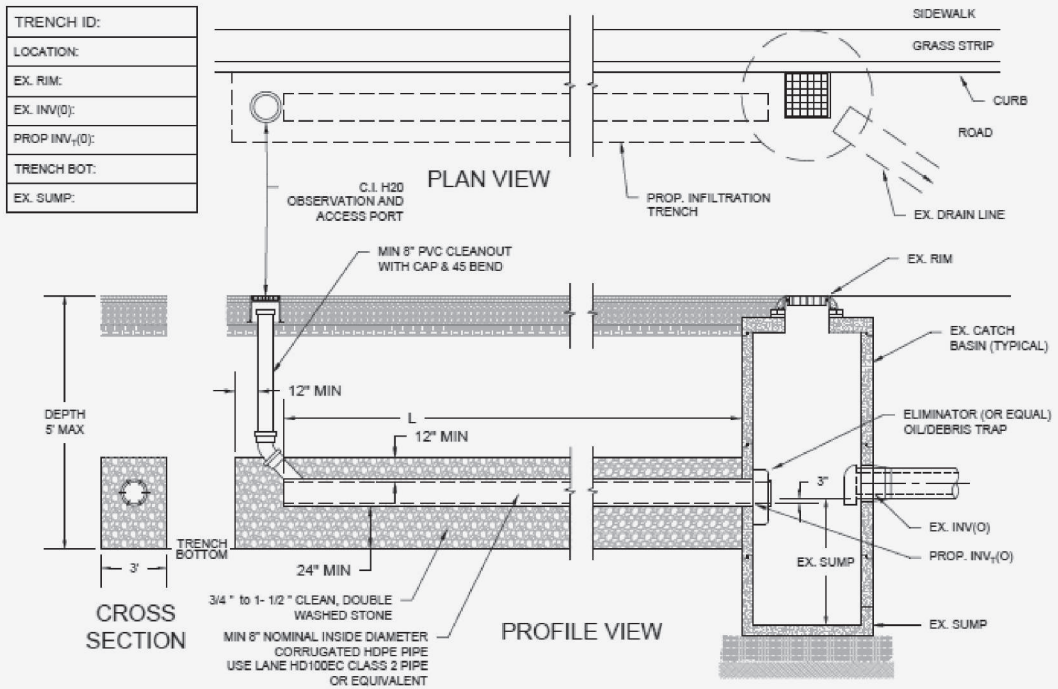
The Boston Water and Sewer Commission saw plans for an upcoming improvement to Daisy Field in Boston as the perfect opportunity for stormwater retrofits. A large pipe treating runoff from 75 urban acres runs underneath Daisy Field. Rather than install multiple upstream SCMs along the system, the Boston Water and Sewer Commission installed one large SCM to treat runoff from all 75 acres before it discharges to the Charles River [10].

Photo Source: www.boston.gov/parks/olmsted-park

Opportunistic Approach

The opportunistic approach to designing and implementing stormwater retrofits involves the incorporation of SCMs into already planned and needed construction projects. The opportunistic approach couples stormwater improvements with everyday infrastructure improvements to realize water resources objectives. One example is the inclusion of leaching basins into roadway reconstruction projects. This approach is best suited to owners, municipalities, and transportation agencies who are responsible for regular planned maintenance and construction projects. For this approach to be effective the project lead should:

- **Be proactive in identifying opportunities.** As project scoping, layout, and design are taking place, a goal of the project must be to incorporate stormwater controls.
- **Develop a suite of typical SCMs.** Identify typical SCMs and designs (details, specifications, and installation approaches) that work best for the organization.
- **Be willing to be flexible with the project specifications.** Allow for some changes, as necessary, to the base design to maximize stormwater treatment.
- **Plan for increases on project budgets to accommodate for these opportunities as a trade-off for more costly stand-alone retrofits in the future.**
- **Tailor the scale and type of SCMs to the project.** Projects that already impact grading and the drainage system likely provide additional opportunities to incorporate more sophisticated controls by allowing for changes to the existing stormwater system and taking advantage of mobilization of the required construction equipment. In addition, projects with larger overall construction costs may provide more opportunity to absorb relatively lower-cost SCMs.
- **Be creative.** Small tweaks to drainage patterns can have large impacts. For example, a simple curb cut can allow stormwater runoff from an impervious area to be treated over an adjoining pervious area (which can be credited using the Impervious Area Disconnection Performance Curves—see page 47).
- **Establish communication and shared goals between the various project members.** The project funder, designer, owner, installer, and maintainer all must agree on when and how to best take advantage of these opportunities and ensure their long-term effectiveness.

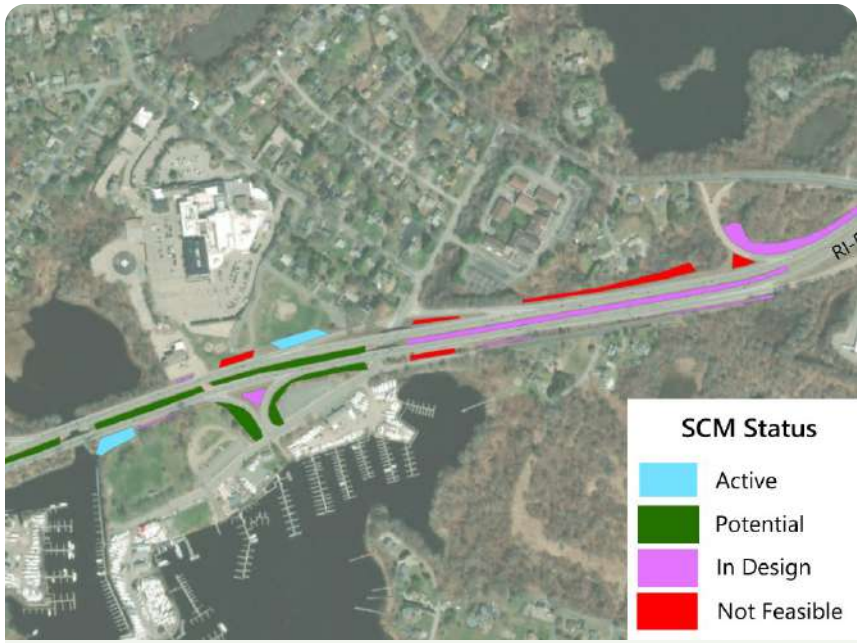


OPPORTUNISTIC APPROACH EXAMPLE

Installing Standardized Infiltration Trenches

Arlington, MA

The town of Arlington collaborated with EPA, the University of New Hampshire Stormwater Center, and the Mystic River Watershed Association to develop a standard design for an innovative infiltration trench retrofit. Since 2014, Arlington has installed 31 trenches and plans to install 20 more over the coming years [11], [12].



PLANNING APPROACH EXAMPLE

Rhode Island Department of Transportation Stormwater Control Plans

Rhode Island

The Rhode Island Department of Transportation (RIDOT) has used the planning approach to identify hundreds of potential SCM locations in impaired watersheds across the state. RIDOT uses the SCM Performance Curves to quantify water quality benefits of the potential SCMs and track progress towards meeting treatment goals [13].

Planning Approach

The planning approach to stormwater retrofits involves proactively planning retrofits and prioritizing sites where retrofits are possible and beneficial. Through prioritization, the planning approach aids in the selection of sites for retrofits that will have the greatest water quality benefits at the lowest cost. This approach is often used by municipalities and transportation agencies who must develop stormwater mitigation plans in response to total maximum daily load (TMDL) or other regulatory requirements. It is also well suited for those entities with sufficient resources to address specific water resource needs and to identify projects eligible for targeted funding or as part of capital infrastructure plans.

The planning approach can be broken down into the following steps as described in the following sections:

1. **Understand & Quantify Goals**
2. **Identify Potential Sites**
3. **Identify SCMs**
4. **Prioritize Sites & Controls**
5. **Implement SCMs**

1. Understand & Quantify Goals

Understand and quantify goals for the retrofit program. Goals may be developed to achieve short-term permit compliance, or they may be developed with long-term water quality benefits in mind.

Identify and consider project and program goals beyond stormwater management. In this way, municipalities or sites can realize significant efficiencies from a much broader breadth of planning than solely water quality/stormwater, if thoughtful consideration is given to this process. It is helpful to numerically quantify the goal(s), which allows for prioritizing work (see Step 4), measuring progress, and knowing when a goal has been met.

Example goals:

- Primary
  - 60 percent phosphorus reduction watershed-wide
  - Install 20 new SCMs
  - Spend $1M on stormwater controls over the next three years
- Ancillary
  - Increase greenspace on Main Street
  - Reduce flooding events in Mill Pond area

2. Identify Potential Sites

There are several factors to consider when identifying sites and assessing their feasibility. Use the checklists provided on page 19 to review considerations and potential constraints. In general, sites that likely produce higher stormwater load (concentration of impervious cover or known sources) and have available space are good candidate sites.

Example high-priority sites:

- Upcoming construction areas
- Public parcels with open space (e.g., schools, public works facilities, etc.)
- Large impervious areas (e.g., shopping centers and office parks)

Some Steps Are Iterative

Steps 2 and 3 can be done iteratively. SCM selection will depend, in part, on their prospective sites.

Non-Structural Controls

In the planning approach, non-structural controls should also be considered as they are often cost-effective means for the reduction of watershed pollutants. Factors such as cost, ease of implementation, required resources, and existing non-structural controls should be considered.

This step can be performed in phases, with the first phase done in a desktop setting analyzing available geospatial datasets (e.g., soils, land use, drainage system mapping, parcel maps, aerial imagery, etc.).

Follow-up field reviews of specific sites can further refine site evaluation. In some cases, it may be useful to conduct additional field survey and field tests (e.g., soils testing, utility research, etc.) to evaluate site feasibility at the planning stage Additional field survey and field tests will be necessary during SCM implementation (Step 5).

In addition to specific sites, small-scale SCMs implemented across a large footprint can be a cost-effective way to provide quantifiable benefits. For example, residential rain barrels used for enhanced IC disconnection or leaching basins may not individually provide much pollutant and runoff volume reduction, but if implemented widely across an entire municipality they would provide significant benefit.

3. Identify SCMs

Load Reductions

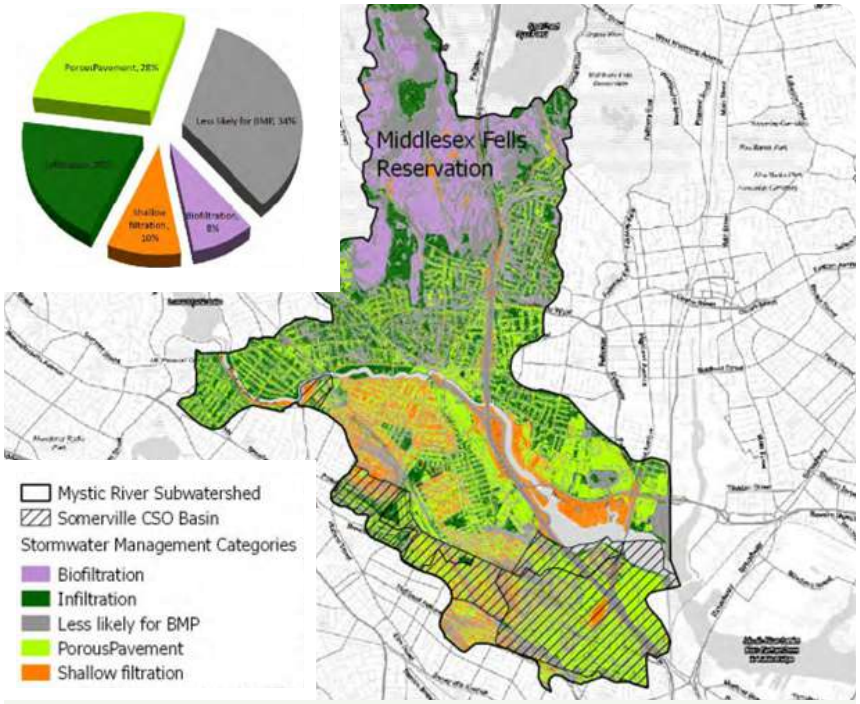
The Performance Curves provide cumulative relative (percent) reductions of pollutants and runoff volumes for infiltration SCMs. To estimate total load (mass) reduction and impervious cover (IC) runoff volume reduction, EPA Region 1 pollutant load export rates (PLERs) and IC runoff volume yields can be used to estimate the SCM's catchment load. See Appendix B, Appendix D, and page 42 for more information.

The Performance Curves can be used to select SCMs and optimize the chosen SCMs based on site-specific information such as pollutant loading rate, expected runoff volume, available space, soils information, etc. The Performance Curves for various SCMs with the same runoff depth from impervious area can easily be compared in order to choose and optimize the most effective structural control measure for a site. Existing controls can also be evaluated as part of the planning approach. It might be feasible and beneficial to upgrade existing controls so they perform more effectively (e.g., retrofit of an existing flood-control detention pond to also provide water quality treatment). See page 64 for more information on upgrading existing controls.

4. Prioritize Sites & SCMs

Once potential sites and SCMs have been identified, they can be prioritized to best understand which will contribute most towards achieving the retrofit program's goals. Prioritization may include criteria beyond simply progress toward the primary goal (pollutant and runoff volume reduction and water quality improvement), including:

- ≈ Estimated total cost
- ≈ Estimated cost per pollutant reduction



PLANNING APPROACH EXAMPLE

SCM Site Prioritization Using Planning-Level GIS Analysis

Stoneham, MA

Consideration of small-scale SCM substantially expands implementation opportunities across the developed landscape. A planning level GIS analysis can be done to develop a SCM opportunity map for the community. This approach was utilized in developing an Alternative TMDL for the Mystic River in Massachusetts [14].

- ≈ Proximity to resource area of interest
- ≈ Feasibility
  - ~ Ownership
  - ~ Ease of construction
  - ~ Access
  - ~ Likelihood for constraints encountered during design
- ≈ Progress towards other community, program, or site goals
- ≈ Opportunity to complement other planned improvements
- ≈ Inspection and maintenance needs/ability

Useful information to collect and consider when prioritizing sites includes land use, land cover (pervious or impervious area), soil type, existing SCMs, and future planned efforts. Chapter 3 will discuss how to use the Performance Curves as a credit system to quantify the benefits of various controls.

5. Implement SCMs

As funding and opportunities become available, SCMs can be implemented. They should be designed by trained professionals to work with existing drainage patterns and infrastructure and installed by contractors knowledgeable on the purpose of the facilities. It should be noted that the final SCMs will likely be different than initially planned due to the collection and analysis of more detailed site information. During the design process, site specific survey, soil analysis, and site evaluation can present factors that may change the size, type, or exact location of the SCMs. See page 18 for more discussion on site constraints and limitations and potential solutions to overcome them. The Performance Curves can be used to re-evaluate the final credit of the SCMs.

Using the Approaches Together

The two approaches described above do not have to be used independently. The planning approach can identify areas that are well suited for SCMs. Having these areas identified ahead of time can help to take advantage of upcoming construction projects in those areas identified under the opportunistic approach. An effective tool for doing this is a geospatial map of prioritized sites and data affecting SCM selection and implementation.

For both approaches, it is beneficial to choose a subset of SCMs that are generally accepted and preferred based on ease of installation and/or inspection and maintenance considerations, for example. Selecting SCMs on this basis can streamline designs and allow for design standardization. It will also support consistent installation and create standard inspection and maintenance procedures.

Overcoming Constraints & Limitations

Rethinking Limitations

Use the guidance in Chapters 4 and 5 to creatively consider solutions to constraints and limitations with the idea that achieving some site improvement is better than doing nothing.

Often stormwater retrofits are not installed or even considered because there is a perception that the site constraints cannot be overcome. Designers try to incorporate SCMs on existing developed sites using rigid design criteria and site specifications. With some creativity and better knowledge about how design and site parameters truly affect treatment performance, retrofit SCMs can be incorporated into almost every site.

Constraints are the limitations that put bounds on design ideas. For stormwater retrofit projects, a designer can misinterpret perceived constraints, resulting in lack of action and missed opportunities for progress toward restoration goals. This section discusses the considerations to be evaluated in making good retrofit decisions. This manual shows that these considerations typically can be accommodated to improve conditions.

The two primary questions to ask when considering stormwater retrofits are: "is this the **right situation** for a retrofit?" and "is this the **right site** for a retrofit?" See the lists on the following pages to help explore these questions.

Identifying the right situation for a retrofit includes identifying or creating the appropriate project, securing adequate funding and backing by the owner for continual inspection and maintenance, and making progress toward overarching goals. Identifying the right site for a retrofit includes an evaluation of site objectives, physical constraints, appropriate SCMs, and regulatory restrictions.

Is it the right situation for a retrofit?

Stand-alone retrofit...

- ◯ Will the project impact existing infrastructure or outfalls?
- ◯ Will the project need permitting for the work?

Existing project with "add-ons"...

- ◯ Is the project affecting existing infrastructure already?
- ◯ Will the retrofit require equipment already mobilized for other parts of the project or will additional equipment be needed?
- ◯ Will the retrofit fit within the project scale?

Project or program budget and funding...

- ◯ Do costs fit within the greater project or program budget?
- ◯ Does the project achieve significant treatment for its cost?

Inspection and Maintenance (I&M) requirements...

- ◯ Who will be performing the I&M for the measures?
- ◯ Is the owner aware of and willing to take responsibility for I&M costs?
- ◯ What is the required inspection and maintenance frequency?
- ◯ Are there special maintenance equipment needs?

Project or program goals...

- ◯ Will the project meet or make cost-effective progress towards goals?
- ◯ Will the retrofit accomplish other goals/benefits (as discussed on page 8)?
  - ≈ Reducing peak discharge
  - ≈ Recharging ground water
  - ≈ Addressing water quality impairments
  - ≈ Providing flood control and/or correcting past impacts from altered urban hydrology
  - ≈ Incrementally counteracting impacts of climate change
  - ≈ Mitigating temperature impacts
  - ≈ Reducing erosion
  - ≈ Providing habitat
  - ≈ Improving aesthetics and quality of life

Working With Existing Utilities

Existing utilities can provide significant challenges and constraints to retrofit SCMs. Consider the options in order of complexity.

Avoid: The easiest and most-cost effective option is to site the stormwater feature clear of any utility conflict or reduce the feature size to provide sufficient setback from the utility.

Coexist: Utility companies accept that the practice will coexist with the utility. Sufficient protection and/or clearance exists on the site. If the utility must be accessed, any damage to the stormwater practice will be repaired.

Modify: The entities agree that the feature and the utility can coexist, but alterations to the design of either could occur (e.g., planned elements of the stormwater feature such as inlets and outlets might need to be moved to avoid conflict).

Replace: To avoid conflicts, the utility is replaced or relocated. This process would incur the highest cost unless the entire project was planned as part of an infrastructure enhancement project.

Adapted from the Green Infrastructure Design Guide (San Mateo Countywide Water Pollution Prevention Program 2020)

www.flowstobay.org/wp-content/uploads/2020/03/GIDG-2nd-Edition-2020-03kh-RED.pdf

Is it the right site for a retrofit?

Are there other site uses and objectives to consider?

- ◯ Aesthetics
- ◯ Safety—Pedestrian, Cars, and Wildlife
- ◯ Flood control
- ◯ Public engagement

Will the SCM(s) have stakeholder support?

- ◯ Owner
- ◯ Neighborhood
- ◯ Local businesses
- ◯ Watershed groups
- ◯ Maintenance-responsible party

Are there existing SCMs that can be retrofitted? See Traditional Approaches in Chapter 5 for ideas of how to retrofit these SCMs to increase water quality performance.

- ◯ Wet Pond
- ◯ Extended Dry Detention
- ◯ Grass Swale

Are there physical constraints that cannot be overcome?

- ◯ Space
- ◯ Existing topography
- ◯ Soils (e.g., depth to Estimated Seasonal High Groundwater Table, ledge, poorly-drained)
- ◯ Setbacks to structures, property lines, travel way (e.g., Clear Zones)
- ◯ Existing drainage patterns and infrastructure
- ◯ Existing utilities (including private wells and on-site wastewater systems)
- ◯ Access
- ◯ Hazardous materials/soil contamination
- ◯ Established high quality vegetation

What will access to the site look like?

- ◯ Will the site be able to support access points for inspection maintenance?

Access can range from a small gate for an inspector to pass through to a large gate for maintenance vehicles to enter.

- ◯ Will access to the site be challenging due to steep slopes or narrow access roads?
- ◯ Will the site need to be fenced?
- ◯ Will there be adequate space for a material stockpile on (or near) the site (if needed)?

Can the designer work with permitting requirements or regulatory restrictions?

- ◯ Wetlands
- ◯ Public water supplies
- ◯ Cold water fisheries
- ◯ Shellfish growing areas
- ◯ Bathing beaches
- ◯ Wildlife habitat
- ◯ Flood plains
- ◯ Conservation land
- ◯ Cultural/Historical resources
- ◯ Hazardous materials

3

Credits

In general, in order to be motivated or incentivized to take an action, it is important to understand the expected benefits. Good decision making in the world of stormwater retrofits involves weighing the benefits of a retrofit with the costs and impacts of performing that retrofit. In order to assess a retrofit's benefits fairly and systematically, it is important to quantify those benefits in the form of credits. For the purposes of this manual, "credits" are defined as the quantification of benefits.

Credits: the quantification of benefits

The benefits that stormwater retrofits provide are extensive and varied and can include:

- Reduction of pollutant discharge to receiving waters
- Groundwater recharge
- Habitat creation
- Improvement of aesthetics
- Peak flow reduction
- Runoff temperature decrease

It is difficult to measure all of the benefits of stormwater mitigation measures. As a simplified means to develop credits, designers can use one of the key benefits and often main driver of stormwater retrofits: pollutant and runoff volume reduction.

The Performance Curves (initially presented in Chapter 1) are incorporated into this manual as the crediting system for retrofit applications. They provide a quantified estimate of pollutant and runoff volume reduction in surface discharges for a wide range of stormwater control measure (SCM) sizes and types.

Credits via the Performance Curves can be used by:

- Planners to compare and prioritize
- Designers for evaluation, sizing, and optimization
- Project funders to confirm their investment is worthwhile
- Permittees to demonstrate progress and determine when they have met their regulatory (e.g., total maximum daily load (TMDL)) obligations
- Regulators to measure whether requirements are being met

Establishing concrete numeric goals and making measurements towards those goals removes subjectivity and supports the decision-making process. Establishing a consistent basis through which stormwater control measures are evaluated allows for comparison between measures and an accounting of all measures across a watershed or municipality.

Using the Curves for Retrofit Credit

The Performance Curves were introduced in Chapter 1. See the fact sheet on page 7 for an overview of what they are and how they were developed. Appendix B includes the full set of Performance Curves, including tables of their discrete values. Recall that there is a unique Performance Curve for Total Phosphorus (TP), Total Nitrogen (TN), Total Suspended Solids (TSS), Metals[1], Bacteria, and Runoff Volume reduction for twelve SCMs.

Although the Performance Curves were developed for a set list of SCMs, it is appropriate (with reasonable professional judgment) to use an available SCM Performance Curve for a SCM not listed when the listed SCM's treatment Unit Operation and Process (UOP) (e.g., Infiltration) is the same or similar to that of the SCM in question. Chapter 4 discusses this in more detail and provides a crosswalk of SCMs that can be aligned with the various Performance Curves. This crosswalk was developed for this manual specifically. Designers should defer to regulatory guidance when aligning SCMs with Performance Curves, as appropriate.

The Performance Curves in Appendix B also include percent reductions for Effective Impervious Area (IA). These values were developed by the Rhode Island Department of Transportation (RIDOT) as required for compliance with MS4 Permit provisions for impaired waters and bacteria total maximum daily loads (TMDLs). These values are based on the combination of annual pollutant, runoff, and flow-rate reductions and can serve as additional useful information for understanding the effectiveness of various SCMs.

This section discusses how to use the Performance Curves for assigning credit for retrofits. Chapter 4 and Chapter 5 present SCM selection and retrofit design guidance.

The Performance Curves ...

- ≈ Are highly flexible to accommodate SCM variations
- ≈ Encourage distribution of smaller SCMs
- ≈ Credit a range of sizes including smaller sizes
- ≈ Credit a range of pollutants to help connect performance with specific pollutant goals
- ≈ Credit runoff volume reduction
- ≈ Allow for crediting non-conforming designs
- ≈ Support optimization and cost-effective designs
- ≈ Are based on the most recent data and findings

[1] In developing the SCM Performance Curves, Zinc removal performance was modeled. The results from the Zinc models are used to represent removal performance for Metals in general. Accordingly, this manual uses the term "Metals" throughout.

Performance Curve Development

The Performance Curves were developed by simulating SCM response to continuous long-term precipitation and runoff inputs. Mass wash-off characteristics have been examined extensively for stormwater runoff across a range of storm events [15], [16], [17]. Findings of these studies show that nutrients (phosphorus and nitrogen) tend to possess more heavily weighted first flush characteristics with a predominance of mass in the beginning of the storm and approximate exponential decay of mass-transfer. Additionally, the distribution of precipitation events by depth in New England indicates event sizes are heavily weighted towards smaller depths such that relatively high percentages of average annual runoff volumes from impervious areas are delivered by relatively small runoff depths (e.g., Boston, 1992–2020: 31% by 0.2", 50% by 0.4", and 64% by 0.6") [18]. These characteristics are well represented in the continuous rainfall simulation used in the development of the Performance Curves. They better model empirical data collected on SCMs and more accurately characterize performance compared with event-based models.

Performance Curve Basics

The following key terms are essential to understand when using the Performance Curves:

- **Design Storage Volume (DSV):** the total volume of stormwater that a SCM is designed to be able to effectively hold. It includes permanent system treatment volume and does not include volumes associated with peak rate or flood control (i.e., volume above the primary outlet control). Each SCM will have a different method of calculating this volume, as presented in Appendix C.
- **Contributing Impervious Area (IA):** the impervious area that drains to the SCM
- **Runoff Depth from Impervious Area (Runoff Depth):** the depth of runoff the SCM is designed to instantaneously hold. Runoff Depth does NOT equate to a storm event depth and is not the same as the amount of precipitation that falls over the watershed during a given rain event. It is the amount of volume the SCM can store and hold normalized to the contributing impervious drainage area, calculated as follows:

$$Runoff\ Depth\ (in) = \frac{DSV\ (ft^3)}{IA\ (ft^2)} \times 12\ \frac{in}{ft}$$

- **Treatment Credit:** percent pollutant or runoff volume reduction for a given SCM based on DSV (as Runoff Depth from Impervious Area), and SCM type.

The Performance Curves can be used by having either a known Runoff Depth or a desired Treatment Credit to find the other value as shown in Figure 3-1.

A designer could use the Performance Curves to identify the Runoff Depth that is required to meet a certain pollutant or runoff volume reduction (green path in Figure 3-1), and then use that value to calculate the SCM Design Storage Volume. Alternatively, the designer could identify the percent reduction provided by a pre-determined Runoff Depth (blue path in Figure 3-1). When there is no discrete value provided, values can be interpolated linearly between provided values. The Performance Curves can also be used to understand size/treatment relationships, make comparisons between SCMs, and estimate load reduction, as described in the examples in the next sections. The tools presented on page 39 have been developed to easily work with the Performance Curve data.

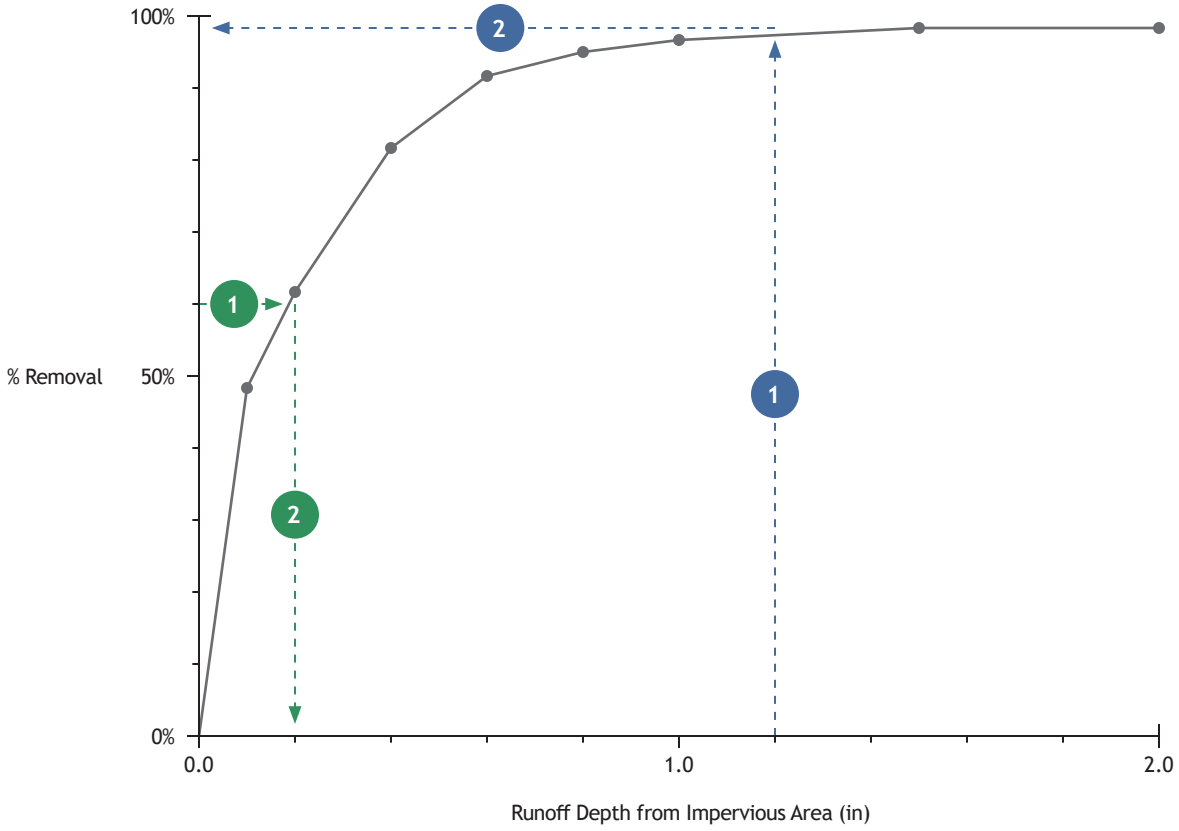
Figure 3-1: Demonstration of How to Use Performance Curves

1 If a designer is working on a site where a pollutant reduction of 60% is desired ...

2 ... the designer would use the curves to determine that a Runoff Depth from Impervious Area of approximately 0.2 inches achieves the desired reduction

1 If a designer determines that their SCM provides a DSV equivalent to 1.2 inches from the Impervious Area ...

2 ... the designer would use the curves to determine a 98% pollutant reduction from this SCM



Steps to calculate a SCM mass load reduction using the Performance Curves with the PLER

Delineate the catchment to the SCM

Identify land use and land cover types for catchment

Apply appropriate PLER for parameter of interest to each individual portion of the catchment

Sum loads contributing to the SCM

Calculate the SCM Design Storage Volume and Runoff Depth

Use the Performance Curves to obtain the pollutant/runoff reduction percentage of the SCM

Multiply the SCM's pollutant/parameter percent reduction with the total load calculated

For retrofit SCM load calculations, general practice is to solely consider the impervious area contributing to the SCM since pervious area contributes relatively little runoff and load.

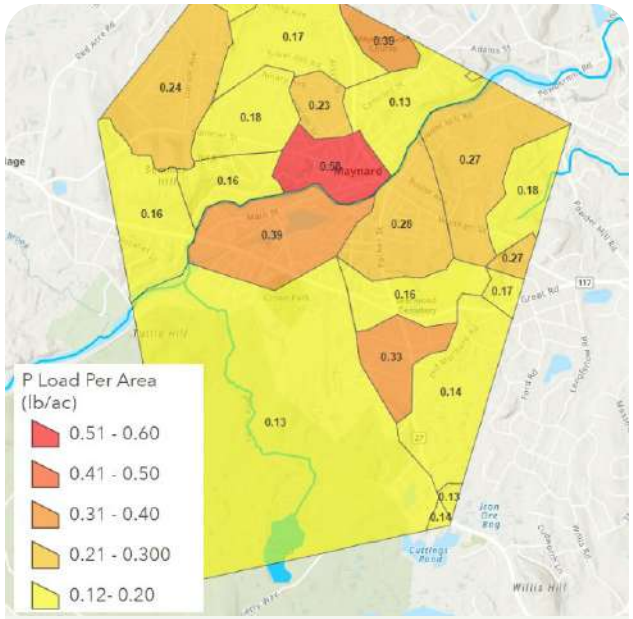
Using the Performance Curves to Calculate Pollutant Load/ Runoff Volume Reduction

SCMs are credited on an individual basis. The load reduction provided by each SCM can be summed up on a site or watershed scale to understand the cumulative impact of the controls. The steps for calculating the estimated pollutant load reduction for a given SCM are detailed to the left. Appendix E details the steps for an example site.

EPA Region 1 has developed stormwater runoff pollutant load export rates (PLERs) for pervious and impervious areas that are annual pollutant mass per unit area load or volume per area load estimates [18], [19], [20], [21], [22]. The PLERs include the same parameters represented in the Performance Curves (Total Phosphorus, Total Nitrogen, TSS, Metals, Bacteria, and Runoff) and include unique values for pervious and impervious area for the following land use categories:

- Commercial/Industrial
- Residential (low [rural], medium, and high/multi-family density)
- Highway
- Forest
- Agriculture
- Open land
- Developed land pervious (based on hydrologic soils group)

The PLER values for each parameter and land use can be found in Appendix D. For the purposes of retrofit SCM load estimates, it is generally appropriate to solely consider the impervious area contributing to the SCM because pervious areas contribute very little runoff [19] for storm events less than two inches, and therefore very little pollutant load or runoff volume during those the smaller rainfall events used for sizing these retrofits.



EXAMPLE OF USING POLLUTANT LOADS IN THE PLANNING APPROACH

Pollutant Load Calculations for MS4 Permit Compliance

Maynard, MA

The town of Maynard, Massachusetts, used GIS analysis and the PLERs to calculate pollutant load for watersheds draining to impaired waters and wetlands throughout the town. This analysis helped the town prioritize areas where retrofit SCMs would be the most impactful [23].

Examples of Using the Curves

The Performance Curves can support both the opportunistic and the planning approach to retrofits (Chapter 2). For both approaches, the Performance Curves can be used to:

- **Size SCMs to accommodate site conditions.** For retrofits to be incentivized and valued, designers need to be able to credit all of them, including ones that cannot be sized to prescribed treatment volumes due to site constraints. The Performance Curves can be used to quantify performance at a range of SCM sizes. When used with SCM cost information, the Performance Curves can be used to identify when a SCM is not cost effective because it either does not reduce significant pollutant/runoff volumes or it does not produce considerable increases in pollutant/runoff volume reduction proportionate to increases in size.
- **Take credit for what is already installed.** Existing SCMs can often be credited with a little investigation to estimate the parameters necessary to use the Performance Curves (i.e., the contributing SCM catchment area and SCM DSV).
- **Decide if and how to make upgrades to existing SCMs.** Using the existing SCM treatment credit while reviewing its respective Performance Curve, as well as those of other SCMs, can help determine whether a larger or different type of SCM would be beneficial.
- **Compare and prioritize SCM types and site applications.** In addition, the Performance Curves can be used in conjunction with the PLERs to compare SCM total load reduction.
- **Select the best SCMs for incorporation into standard designs.** Reviewing and comparing the Performance Curves across both size and SCM type can support the selection of certain SCMs to work within a project or program constraints and make the most progress toward goals.
- **Size SCMs to meet specific numeric pollutant or runoff volume reduction targets.** For regulatory compliance, or to meet other objectives, a retrofit may need to be sized to achieve a specific pollutant or runoff volume reduction. In this case, the Performance Curves can be used to understand what size is needed to meet that objective for each SCM type.

4

Stormwater Control Measure Selection & Design

This chapter discusses how to choose stormwater control measures (SCMs) and their components and the key design elements focused on the retrofit setting. See Chapter 2 for more information on approaches to implementing SCMs and guidance for overcoming potential site constraints. Chapter 5 discusses retrofit design guidance for SCM components.

Selection Drivers

Several factors or drivers are used to guide the SCM selection and design process. Selecting a SCM for a retrofit application is more challenging than simply picking a design from a list. It is a process that involves aligning the SCM components with the goals, needs, and constraints of the site and watershed.

First, retrofit SCMs should address development's impact on receiving waters. The receiving water's designated uses and impairments (if any) can be used to further inform the water quality needs of the watershed, and thereby, the pollutant load or runoff volume reductions needed. In addition to reducing specific pollutant loads or runoff volume, incrementally restoring the hydrologic imbalance due to development and impervious cover can be a goal for all retrofits. Stormwater retrofits provide numerous co-benefits that may additionally drive the SCM selection and design. See Chapter 2 for more discussion on SCM planning.

Second, the site conditions, owner preferences and limitations, and project scope will pose challenges or establish constraints in selecting and installing retrofit SCMs. It is possible that the site conditions or limitations will evolve and change throughout the design process. These changes, when known, should, to the degree possible, be considered in the design. See the checklists on pages 19 and 20 for suggested considerations and potential constraints that will help drive SCM selection. SCM selection will also be influenced by whether the retrofit is following the opportunistic approach (as defined on page 12) where SCMs must fit within the context of a given construction project, or the planning approach where SCMs can be more deliberate and selective (as defined on page 14).

Treatment Unit Operations & Processes

For the purposes of this manual, SCM selection is based on the primary goal of reducing pollutants in surface stormwater discharges (a.k.a. "treatment"). Treatment within SCMs happens through a range of Unit Operations and Processes (UOPs) that reduce the amount of pollutants in the SCM surface outflow.

Those UOPs can be categorized as:



Hydrologic **Physical** **Biological** **Chemical**

Table 4-1 lists the various UOPs typically found in stormwater treatment, the primary pollutant that each targets, and examples of SCMs that use these UOPs. Hydrologic UOPs contribute to restoring the pre-development hydrologic response of the contributing catchment and can provide significant pollutant reduction.[2] Exceptions include scenarios involving dissolved and highly conservative pollutants such as chlorides. Because these pollutants are not generally treated effectively through native soils, further consideration is needed with respect to selecting SCMs that use Hydrologic UOPs if these conservative pollutants are the target pollutants.



UOPs: Unit Operations & Processes

Operations: Methods of treatment in which application of *Physical* and *Hydrologic* forces dominate.

Processes: Methods of treatment in which *Chemical* or *Biological* activities are involved.

[2]Where runoff volume is the target parameter to be addressed by the SCM, hydrologic UOPs should be chosen as they provide significant runoff volume reduction. This manual focuses on scenarios where pollutant reductions are the target parameters to be addressed.

Table 4-1: Unit Operation and Processes (UOPs) Summaries and Example Measures

Operation/Process Mechanism & Definition	Primary Pollutant Targeted	Example
HYDROLOGIC		
Evaporation and Transpiration: Water returning to the atmosphere from water surfaces and water returning to the atmosphere through plant metabolism	Runoff volume	Planted basins
Infiltration and Runoff Reduction: Water flowing into soils that does not become stormwater runoff	Runoff volume and associated pollutants	Infiltration systems
Attenuation: Temporary detention of water for the purpose of controlling the rate of outflow	Peak flow	Detention basin
PHYSICAL		
Flotation: Separation of oil/grease and litter upward through the water column through buoyancy	Oil/grease, litter, vegetation	Catch basins with hoods
Screening: Separation of gross pollutants from water by straining through large openings	Gross pollutants, vegetation	Grates
Filtration: Sedimentation and physical retention of smaller particles passing through media	Suspended solids, bacteria	Bio-Filtration
Sedimentation: Process by which solids are removed from the water column by settling	Suspended solids	Wet Pond
Enhanced Sedimentation and Swirl Concentration: Movement of water to the center of a hydraulic vortex and of particles to the outer edges of the vortex via inertia and gravitational force	Heavy solids	Hydrodynamic Separator
BIOLOGICAL		
Plant Metabolism: Uptake of nutrients from water by plants for the purpose of metabolism	Dissolved nutrients	Bio-Filtration
Nitrification/Denitrification: Process of nitrogen removal by bacteria that results in nitrogen release to the atmosphere as a gas	Nitrogen	Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)
CHEMICAL		
Adsorption: Attachment of a pollutant to the surfaces of a media	Dissolved nutrients	Enhanced Bio-Filtration with ISR
Precipitation: Joining of two inorganic dissolved pollutants into a heavier particle that can be settled or filtered	Dissolved inorganic pollutants	Alum addition to filter media
Coagulation: Joining of small particles of one pollutant into a heavier particle that can be settled or filtered	Colloidal solids	Chemical treatment
Ion Exchange: Capture of a dissolved pollutant, typically heavy metals or phosphorus, in a media through the exchange of ions between the media and the pollutant	Heavy metals and phosphorus	Chemical treatment
OTHER		
Thermal/Temperature Control: Cooling of water that has been heated through contact with pavements and other surfaces	Temperature	Gravel Wetland

Adapted from the Minnesota Stormwater Manual
www.stormwater.pca.state.mn.us/index.php?title=Processes_for_removing_pollutants_from_stormwater_runoff

Multiple UOPs

Systems often operate using multiple UOPs with some more dominant than others. When selecting the appropriate Performance Curve to evaluate pollutant removal, the designer should prioritize and weight dominant UOPs. For instance, a Bio-Filtration system in Hydrologic Soils Group (HSG) A or B soils could be represented using the Infiltration Basin Performance Curve, provided the underdrains are elevated to maximize infiltration in the system.

Some UOPs that conflict with others' performance can be placed in series. For example, Denitrification that requires an anoxic zone achieved through a permanent pool of water cannot be directly combined in the same basin designed to infiltrate.

The UOPs are the basis for water quality treatment performance of a SCM, and therefore offer the basis for SCM selection that will best meet treatment goals. Keep in mind that the UOPs provide other co-benefits that can improve the environment and serve to meet additional retrofit goals beyond water quality improvement, such as groundwater recharge, temperature regulation, and flood mitigation, as discussed on page 30.

The Performance Curves provide pollutant reduction estimates for various SCMs that include a pre-determined UOP or set of UOPs. The Performance Curves do not represent an exhaustive list of SCMs and UOPs. However, some SCM types do correspond directly to a Performance Curve. The UOP(s) of these SCMs can be aligned with the Performance Curve, which then supports the use of the Performance Curve for a broader range of SCM variations that utilize the same UOP(s). Table 4-2 lists the primary UOP(s) represented by each of the Performance Curves and lists the Treatment Category for each Performance Curve. Treatment Categories are discussed further on page 46. Figure 4-1 shows the relationship between SCM components, the UOPs, and the Performance Curves. Functional components bring runoff to and discharge from the treatment components. The treatment components are where the primary UOP functions occur. These relate to the Performance Curves to evaluate SCM treatment credit.

Figure 4-1: Relationship of SCM Components and Unit Operations and Processes

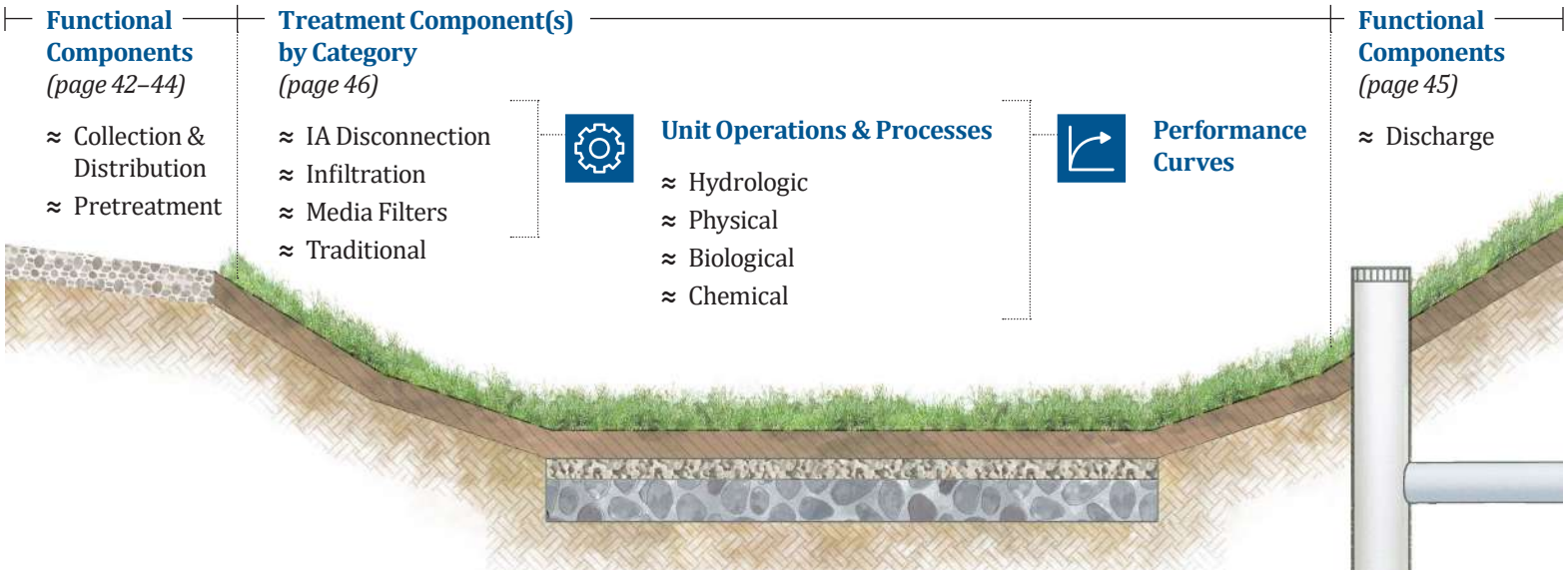


Table 4-2: Unit Operations and Processes (UOPs) Represented by the Performance Curves

Primary UOP	Performance Curve Category	SCMs Represented
IMPERVIOUS AREA DISCONNECTION SCMS		
Hydrologic: Infiltration	Impervious Area Disconnection	• Impervious Cover Disconnection • Vegetated Filter Strip • Vegetated Buffer • Qualifying Pervious Area (QPA)
Hydrologic: Infiltration	Impervious Area Disconnection through Storage	• Rain barrels • Cisterns
INFILTRATION SCMS		
Hydrologic: Infiltration	Infiltration Basin (by HSG of underlying soil)	• Infiltration Basin • Infiltration Swale • Permeable Pavement (no or elevated underdrain) • Bio-Filtration Basin (no or elevated underdrain) • Bio-Filtration Curb Inlet Planter (no or elevated underdrain) • Rain Garden (no or elevated underdrain) • Underground Infiltration Chamber
Hydrologic: Infiltration	Infiltration Trench (by HSG of underlying soil)	• Infiltration Trench • Leaching Basin • Dry Well • Leaching Galley
MEDIA FILTER SCMS		
Physical: Filtration	Bio-Filtration	• Bio-Filtration Basin (with underdrain) • Bio-Filtration Curb Inlet Planter (with underdrain) • Rain Garden (with underdrain)
Physical: Filtration	Sand Filter	• Sand Filter • Media Filter
Physical: Filtration **Biological: Nitrification/Denitrification** **Chemical: Adsorption of Dissolved P and Bacteria**	Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)	• Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)
Biological: Nitrification/Denitrification	Gravel Wetland	• Gravel Wetland • Gravel Wet Vegetated Treatment System • Wet Vegetated Treatment System • Shallow Wetland
Physical: Filtration	Permeable Pavement (with underdrain)	• Permeable Pavement (with underdrain)

Table 4-2: Unit Operations and Processes (UOPs) Represented by the Performance Curves (continued)

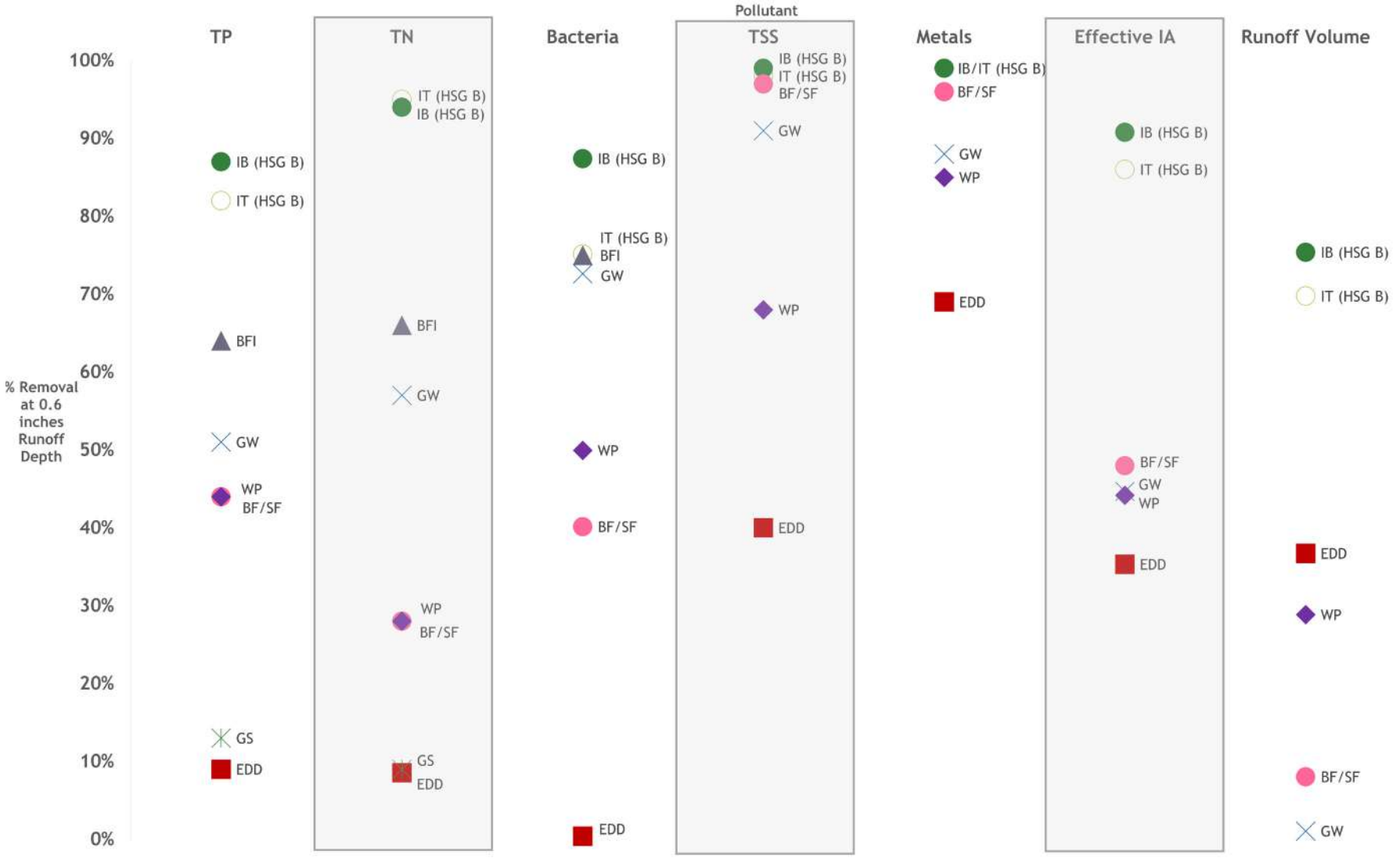
Primary UOP	Performance Curve Category	SCMs Represented
TRADITIONAL APPROACHES		
Physical: Settling	Wet Pond	• Wet Pond • Wet Swale
Physical: Settling	Extended Dry Detention	• Dry Pond • Dry Swale • Extended Detention Wetland • Extended Dry Detention Basin
Physical: Settling	Grass Swale	• Grass Swale • Water Quality Swale • Water Quality Grass Swale with Detention

Figure 4-2 compares how these specific SCMs perform for the various stormwater pollutants. The figure uses 0.6 inch runoff depth from impervious area as an example baseline for comparison. This graph visually shows several key trends to keep in mind while beginning the UOP and SCM selection process:

- ≈ Infiltration SCMs are high performers across the pollutant types and also provide the additional benefit of runoff reduction.
- ≈ While Infiltration may not directly deal with immobilization of a specific pollutant, often Filtration through the system or the native soils will.
- ≈ Restoration of the hydrology also eases the burden on downstream infrastructure and receiving waters, reducing erosion, flooding, and other harmful impacts associated with stormwater and also positively contributing to baseflow. Baseflow contribution can be particularly beneficial during periods of drought and can contribute to restoring a waterbody's pollutant assimilative capacity.

The design of a retrofit SCM can include one or more UOPs to remove pollutants and address targeted need. The following narrative is a discussion of how to select the treatment UOP(s) that best suits the given application. The next sections also discuss SCM design, including the combination of treatment UOPs with Functional Components that make a system perform within a site's parameters.

Figure 4-2: SCM Pollutant Removal Performances at a Glance



IB	Infiltration Basin HSG B	**GW**	Gravel Wetland
IT	Infiltration Trench HSG B	**WP**	Wet Pond
BFI	Enhanced Bio-Filtration with ISR	**GS**	Grass Swale
SF/BF	Sand Filter/Biofiltration	**EDD**	Extended Dry Detention

Selection & Design Process

The remainder of this chapter focuses specifically on selecting SCMs. For more information on assessing a situation and site for a retrofit, see page 18.

The goal of retrofit selection and design is to find a SCM design that will work within the context and constraints of the site and maximize treatment for the given receiving water. Therefore, the selection of SCM UOPs and the design of the full SCM system are more complex than simply inserting a prescribed SCM design into a site. The ability to be flexible and creative is what produces the best retrofit designs that will help achieve results that go beyond stormwater management.

To allow for the most creativity and flexibility in retrofit design, each SCM can be designed on a component-by-component basis to create the unique design best suited to the retrofit application.

In general, the treatment UOP(s) are selected to align with project goals, and then Functional Components are added to the design to ensure it will operate within the site. Functional Components are the portions of the SCM that regulate flow, facilitate access and maintenance, and support aesthetics. The Functional Components and Treatment Categories can be adapted and modified to suit long-term operation and performance criteria of the individual site. **Be creative in considering the following options so that the retrofit works for the site:**

- **Size and scale**
- **Shape (basin vs. linear)**
- **Inline vs. offline**
- **Above vs. below ground**
- **Desired materials**
- **Inspection and O&M needs/ability**
- **Aesthetics**
- **Co-Benefits (e.g., temperature impacts, groundwater recharge)**

Use the design guidance in Chapter 5 to consider retrofit design criteria for Functional Components and Treatment Categories and potential SCM variations.

Site Design for Stormwater Management: Low Impact Development (LID)

Prior to considering structural controls, consider implementing LID. Review the design of the site and identify opportunities to preserve and enhance features that promote stormwater infiltration, extend flow paths, and provide filtering and settling opportunities. Treatment in these ways may reduce or eliminate the need for structural controls.

Look for opportunities to:

- Preserve and enhance vegetation and trees
- Provide micro topography to capture and slow runoff
- Minimize and reduce pavement and impervious surfaces
- Disconnect runoff from impervious cover

Designing SCMs Considering Inspection and Maintenance

The ability to access, inspect, and maintain SCMs is another consideration that must be taken into account. Research shows that unmaintained SCMs function anywhere between three to eight years before ceasing to provide the treatment they were designed for [24]. Therefore, not only is selection of appropriate UOPs important but the resulting system has to lend itself to the type of maintenance the owner/operator is comfortable with and able to perform. The designer should consider the following maintenance-related items when selecting UOPs for a SCM:

- Will the owner/operator have ready access to the materials necessary for maintenance (e.g., vegetation, soils, filter materials)?
- Will the owner/operator have other SCMs they are responsible for maintaining?
- Will the owner/operator have the appropriate equipment needed for maintenance? (e.g., vac trucks, mowers)?
- Will the owner/operator have the appropriate skills and training for appropriately maintaining the SCM?
- Who will perform inspections? How frequently will inspections be performed?
- Will maintenance be performed on an annual basis or on an as-needed basis? Or both?

It is important to have in place an I&M program for the SCM before it has been built to ensure that the appropriate resources are available.

Once an owner/operator has found a design or approach that best satisfies selection drivers, system details can be standardized for more efficient implementation in areas with similar site conditions (e.g., underlying soils, surface topography, sizing constraints, treatment requirements). This will streamline up-front design efforts for similar retrofits and facilitate streamlined but effective Inspection and Maintenance (I&M) procedures by utilizing the same components.

Sizing Guidance

In the retrofit setting, SCMs are sized to maximize treatment performance given the site and project constraints. The Performance Curves can be used for optimizing sizing and supporting cost/benefit review of the size and types of SCMs.[3] Chapter 3 introduces the use of the Performance Curves for pollutant reduction credit evaluation. The Performance Curves can also be used to support one of the key design factors for SCMs: how much stormwater a SCM can retain, recharge, and/or treat.

Optimization: Small Is (Beautiful) Good

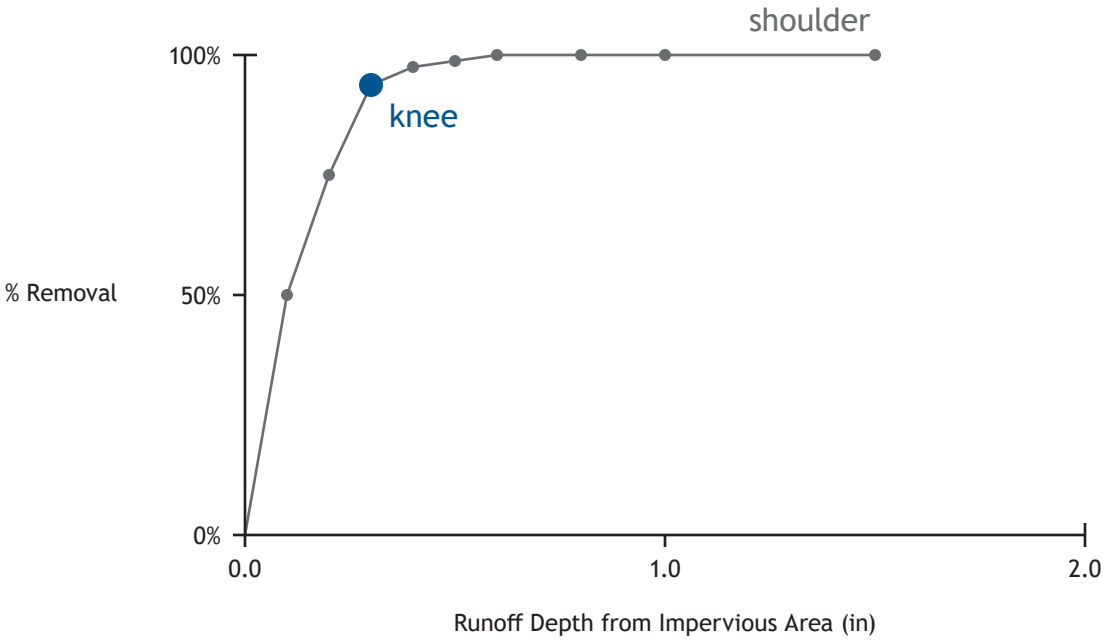
The Performance Curves show significant pollutant reduction for Runoff Depth (as defined on page 23) in the smaller range (0.1 to 0.5 inch over the contributing impervious area). Although the standard regulatory sizing guidelines of 0.5 or one inch may be appropriate and more feasible for new and redevelopment scenarios, the Performance Curves show that retrofit goals can be maximized by designing incremental, smaller improvements.

Larger SCMs are often more costly due to the need for more land, construction labor, and materials. Therefore, SCMs built smaller can be nearly as effective in pollutant reductions, plus provide cost efficiencies.

[3] Although most SCM types can be sized using the SCM Design Storage Volume (DSV) and the Performance Curves, high-rate flow-through devices are not typically sized using the Performance Curves. These units are typically sized using a design treatment flow rate rather than DSV and Runoff Depth. High-rate flow-through devices are discussed further in page 78.

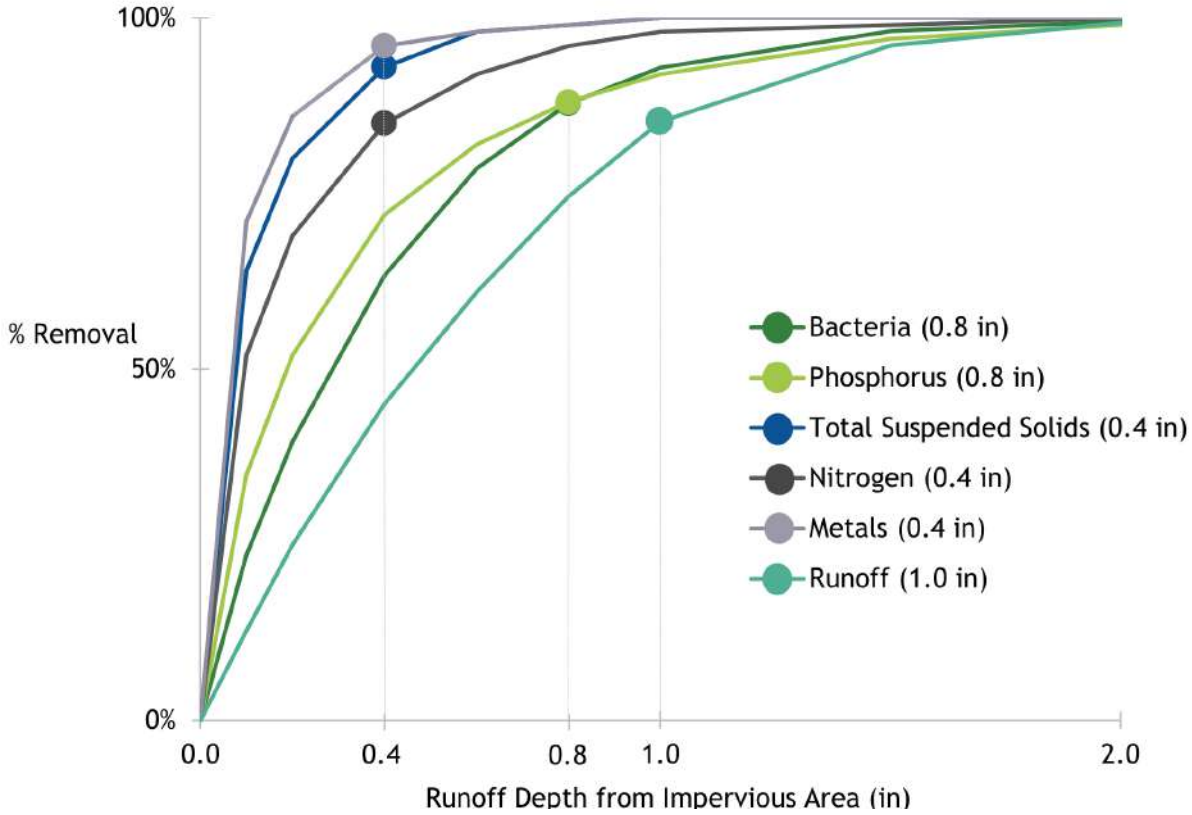
The Performance Curves can be used to optimize SCM size in retrofit conditions because larger SCM size does not necessarily result in equally proportionate larger pollutant reduction performance. The “knee” of any Performance Curve is the point at which the Performance Curve starts to level out and the increase in pollutant reduction per increase in Runoff Depth starts to decrease. This point of diminishing returns, or "shoulder", is where the slope of the Performance Curve starts to become more level, as shown in Figure 4-3. The cost-optimal size will occur where the knee becomes the shoulder.

Figure 4-3: Example of a Knee on a Performance Curve



Some SCM and pollutant specific Performance Curves are steeper and have a more obvious point of diminishing returns while some are flatter and show more gradual increases in performance. The knees of the SCM Performance Curves typically occur in the range of 0.35 to 0.5 inches of Runoff Depth for all pollutants and SCM types. Figure 4-4 shows an example of the cost optimal size by Runoff Depth for multiple pollutants for an infiltration trench.

Figure 4-4: Infiltration Basin (HSG C) Performance Curve with Cost Optimal Runoff Depths



For some SCM types, the optimal SCM size may be on the "smaller" end of the typical Runoff Depth for water quality treatment, depending on how dramatic the "knee" is and the constraints and considerations for the site.

This is not to say that larger SCMs would not provide benefit if the space is available to size a larger SCM. In general, the knees of the Performance Curves for most SCMs for TSS and Metals removal are seen within the smaller Runoff Depths, whereas the Performance Curves for the other pollutants show more gradual performance increases. Figure 4-2, which shows all SCM and pollutant Performance Curves together, demonstrates this variability.

The Performance Curves provide flexibility to select and size controls cost effectively and should not be used to minimize treatment but to maximize and optimize what can be done for site-specific performance objectives in a given space. The Performance Curves provide guidance and justification for including controls in retrofit situations, even when the SCM may be smaller in size as compared to those specified in state regulatory guidelines. Sizing using the Performance Curves does not replace sizing criteria from applicable regulatory requirements. Appendix F provides more information and supporting documentation concerning this retrofit sizing guidance.

In addition to the use of the Performance Curves, other ways to optimize SCM sizing for volume and pollutant reductions while considering cost and maintenance include:

- Optimizing site-specific characteristics that might influence the quantity and timing of runoff (e.g., LID and environmentally sensitive site design practices)
- Pairing structural controls with source control practices
- Calibrating typical designs to the site-specific conditions, which can be especially beneficial for practices that can be implemented across a municipality or organization
- Implementing targeted UOPs for the pollutant of concern, especially for dissolved constituents that are not represented currently in the Performance Curves

Available Tools

The Performance Curves have been included in various tools to support their use in analyzing design scenarios and tracking and accounting, as outlined in Table 4-4.

Table 4-4: Available Tools That Use the Performance Curves

Tool	Description	Source
Stormwater Management Optimization Tool (Opti-Tool)	Provides output information to be used in cost-benefit analysis for constructing stormwater management plans at both the watershed and site-specific level	Environmental Protection Agency (EPA), 2016 www.epa.gov/tmdl/opti-tool-epa-region-1s-stormwater-management-optimization-tool
Best Management Practice Accounting and Tracking Tool (BATT)	Provides accounting, tracking, and reporting for pollutant load reduction from stormwater best management practices (BMPs) and non-point source controls	EPA, 2021 www.epa.gov/npdes-permits/stormwater-tools-new-england
New Hampshire Department of Environmental Services (NHDES) Pollutant Tracking and Accounting Project (PTAP)	Provides a general database of tracking and accounting systems for pollutant load reduction in the Great Bay estuary region (NH) to be used to encourage regional consistency	University of New Hampshire (UNH) https://www.unh.edu/unhsc/ptapp
Rhode Island Department of Transportation (RIDOT) Stormwater Control Plan Calculator	Provides pollutant load reduction estimates for various SCM types to be used for stormwater management plans at the watershed level	RIDOT, 2019 www.dot.ri.gov/about/stormwater.php
Massachusetts Department of Transportation (MassDOT) Water Quality Data Form (WQDF)	Provides pollutant load reduction estimates for various SCM types to be used at the site-specific level	MassDOT, 2022 www.mass.gov/lists/forms-documents-massdot-environmental-services#stormwater-management
UNH Stormwater Center (UNHSC) Calculator	Aids in selection, design, and planning level performance and cost assessment of SCMs	UNHSC 2022 www.unh.edu/unhsc/ms4-resources

5

Stormwater Control Measure Guidance

Appendix F provides more detail on select design guidance included in this manual for retrofit scenarios. It also provides rationale for the proposed retrofit guidance along with supporting resources.

This chapter provides descriptions and design considerations for stormwater control measures (SCMs). This manual focuses on the most critical considerations and design approaches for the retrofit scenario. Therefore, this manual, and this chapter in particular, is not exhaustive and should be used only as supplemental guidance to standard engineering practices and state stormwater guidance manuals or other relevant guidance documents when those requirements apply. Regulatory requirements may require other approaches to selection, sizing, and component designs and specifications.

Functional Components *(page 42–44)*

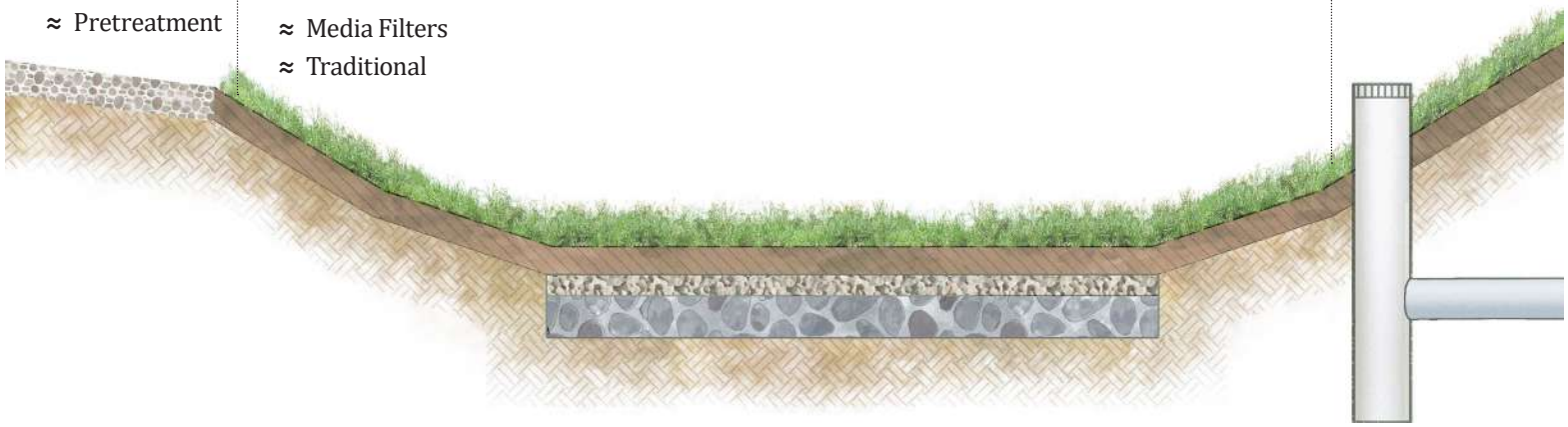
- ≈ Collection & Distribution
- ≈ Pretreatment

Treatment Component(s) by Category *(page 46)*

- ≈ IA Disconnection
- ≈ Infiltration
- ≈ Media Filters
- ≈ Traditional

Functional Components *(page 45)*

- ≈ Discharge



Functional Components

All SCMs are composed of a combination of different Functional Components, which determine the form and configuration of a SCM. The Functional Components of a SCM are chosen and designed to control flow rates and volumes and ensure the treatment category and UOPs function as designed. The Functional Components of SCMs can be grouped as:



In a retrofit scenario, choosing and designing the Functional Components is critical for making the SCM work under the various site constraints and needs. The chosen configuration of Functional Components will affect SCM footprint, SCM pollutant removal performance, and I&M needs. This section provides an overview of the three Functional Components and how they may be configured for the retrofit scenario to support various SCMs. Examples of I&M considerations for certain Functional Components are included throughout. Each section includes a description, typical components and retrofit-specific design consideration.

Consider Inspection & Maintenance

When selecting Functional Components, think about how to best facilitate Inspection and Maintenance (I&M) of these components. Consider including sediment gauges or other markers on structures to facilitate inspection and markers for locating key components that could be lost in dense vegetation.

Collection & Distribution

Collection and distribution Functional Components consist of all the components that collect (e.g., catch basins, drop inlets), convey (e.g., pipes, swales, ditches), and discharge (e.g., outfalls, curb cuts) runoff to the SCM and all structures in between (e.g., drainage manholes). Depending on the SCM design, the collection and distribution Functional Component(s) may be complex and consist of various collection structures, pipes, and outfalls, or it may be simple and consist of a sole pipe or ditched area guiding runoff into the SCM.

Regardless of their complexity, collection and distribution Functional Components are crucial for ensuring that runoff reaches the receiving SCM as intended. Decisions around collection and distribution options should have I&M expectations that are consistent with the long-term owner/operator serviceability.

Typical Components

- Catch basin
- Drop inlet
- Drainage manhole
- Curb cut
- Paved waterway
- Swale/Ditch
- Pipe
- Level spreader
- Perforated pipe
- Riser
- Berm
- Check dam
- Weir
- Flow splitter
- Backflow preventer

Design Considerations

Inline vs. Offline

- Consider if the collection system is creating an inline or offline treatment system. In inline systems, all flows are conveyed to the treatment system and once treatment has occurred, the treatment system outlets. Therefore, overflows must be included in order to accommodate flows larger than those the system is sized for. Offline systems only receive design flows and excess flows/volumes are bypassed or conveyed by an upstream diversion structure. In an offline system, a backflow preventer may be included to prevent flow from discharging from the SCM back to the collection and distribution components before it is treated.

Sizing

- Design collection and distribution systems to convey, at a minimum, the desired volumes to and through the treatment components of the SCM.
- For inline systems, design collection and distribution systems to accommodate design storm events without erosion or damage to the SCM or downstream features based on desired risk and/or regulatory requirements.
- Flow splitters used in conjunction with offline systems should be designed to bypass flows in excess of the design volume of the SCM.
- Review impacts to upstream and downstream hydrology.

Placement

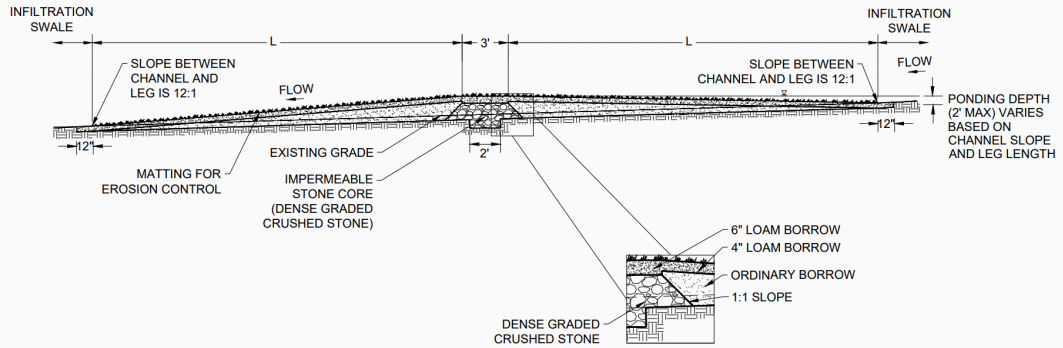
- Inlets often need to be placed at low points, but also may be required incrementally along slopes.
- Proper grading of collection and distribution components is crucial to prevent undesired ponding and prevent concentrated flow, which can lead to riffle and gully erosion.
- Consider potential impacts of collection and distribution features adjacent to critical infrastructure.
- Consider potential for collecting debris and snow/ice, and clogging.
- Consider the available head difference and make sure it is adequate for the SCM to function as designed.

Erosion Control and Energy Dissipation

≈ Incorporate erosion control features as necessary to minimize erosion, including flared-end sections, rip rap aprons, plunge pools, and other velocity dissipaters.

Ancillary Structures

≈ When using check dams to promote retention within the SCM (usually with linear SCM configurations), design them with an impermeable core to ensure ponding of water upstream, forcing runoff to either infiltrate or filter through the SCM.



EXAMPLE OF ADAPTING STORMWATER FUNCTIONAL COMPONENTS TO SAFETY NEEDS

Check Dams in the Clear Zone

Check dams are crucial collection/distribution functions in linear SCMs and allow designers to readily retrofit Infiltration into existing ditches. However, when placed in the unobstructed right-of-way needed for roadway safety or "clear zone" of a roadway, they can present potential hazards for stray vehicles. The Massachusetts Department of Transportation (MassDOT) developed specifications for a transversible check dam which involves minimizing the size and slope of the feature so as to minimize risk to stray vehicles [25]. This approach allows the incorporation of a high-performing UOP while also protecting motorists. These check dams also may be constructed of vegetated, mowable materials so that they may be mowed as part of the overall SCM, easing the maintenance burden.

Pretreatment

Pretreatment Functional Components help support the I&M of the overall system and thereby extend the life of the primary treatment component. They provide a discrete and accessible location for larger materials (e.g., coarse sediment, debris, trash) to be captured and isolated within the system, facilitating their removal and preventing more rapid degradation of the primary treatment area.

Pretreatment should be provided whenever possible. However, for retrofit scenarios, pretreatment may not always be incorporated due to constraints, and therefore other components of the system may require more frequent inspections and maintenance. In scenarios where space is a constraint, the designer should consider simple measures such as deep sump catch basins and/or vegetated buffers, even if they do not meet standard requirements. These simple pretreatment measures will, at a minimum, ease the maintenance burden on the primary Treatment Component.

Typical Components

- Sediment forebay
- Filter strips
- Pretreatment swale
- Deep-Sump catch basin
- Hoods on catch basins, manholes, or other structures
- Proprietary structure
- Trash racks and grates
- Pea gravel/ stone diaphragm for filtering

Design Considerations

- Choose pretreatment Unit Operations and Processes (UOPs) based on expected site pollutant types, for example, if coarse materials and debris are expected to be present in runoff, include grates, racks, sumps, and detention features to support the Physical UOPs of Separation and Settling. Whereas if oils or floatable trash are expected, include baffles or hoods to isolate those materials.
- Include discrete and easy-to-access locations for I&M. Consider the use of sediment gauges or other markers to facilitate inspections.
- Design to support the I&M of the feature by knowing what equipment and methods will be used to remove accumulated sediment.
- Pretreatment features can sometimes be combined with the collection features. For example, flow splitting structures can also serve as a means of pretreatment by providing sumps and weirs to separate floatables and heavier materials that settle. Alternatively, components of or smaller versions of SCMs can be placed upstream of other SCMs to serve as pretreatment especially if they offer different UOPs than the primary SCM.
- For SCMs that receive sheet flow from adjacent surfaces (e.g., linear configuration systems receiving adjacent roadway runoff), consider including a vegetated buffer to act as a filter strip or creating a smaller upstream cell to act as a “forebay” where larger material will be captured.

Source Controls

Source Controls can play an important role in the management of pollutants on site. Through source controls such as sweeping, leaf collection, reduced winter sanding, and trash/litter pickup, significant pollutant removal can occur before runoff enters the SCM. This can reduce the frequency and effort of maintenance activities at the SCM by reducing coarse sediment, trash, vegetation debris, and other gross solids in the runoff. Managing fertilizer use in adjacent areas can also reduce nutrient loads. Employing spill prevention and control measures, especially to protect critical downstream resources, can also contribute to overall stormwater management measures.

Discharge

Discharge Functional Components consist of features designed to convey runoff out of the SCM in a controlled and intentional manner. Discharge components are required in inline systems and offline systems where the design volume cannot be fully retained within the SCM. This component category includes overflow features that are used in inline systems to safely convey runoff out of a SCM for larger storm events and prevent uncontrolled discharge that results in erosion and flooding of nearby areas.

Typical Components

- Underdrain systems
- Weir
- Orifice
- Outlet control structure (combines several discharge components in a designed structure)
- Outfalls
  - Flared end section
  - Plunge pool
  - Riprap apron
  - Headwall
- Spillways
- Level spreader

Design Considerations

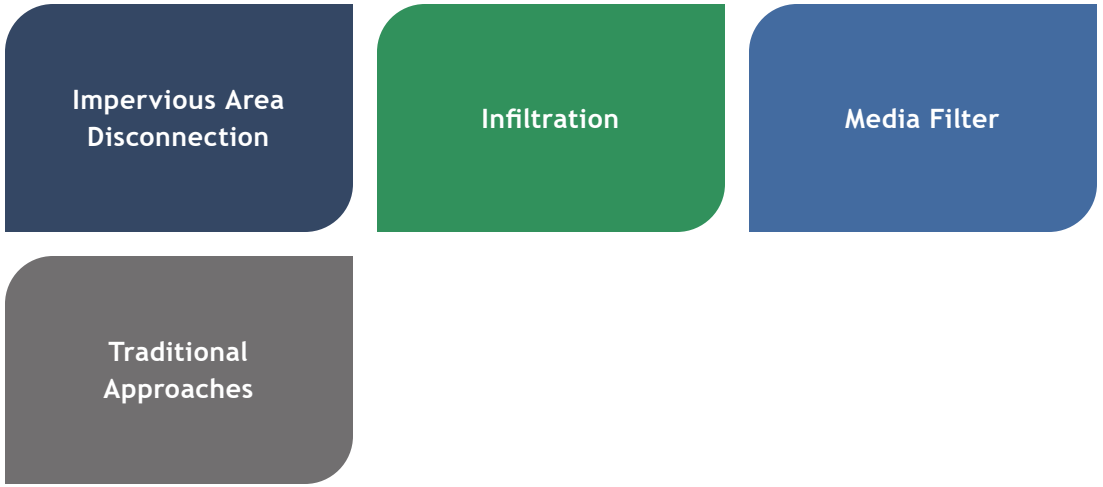
- Be clear about whether the SCM is designed as an inline or an offline system to guide the sizing and design of discharge features.
- Elevate failsafe features, such as underdrains set in a stone layer, to enhance primary treatment such as infiltration.
- Size inline systems size for safe conveyance under design storm events.
- Ensure safe conveyance paths to the downstream drainage system or receiving water.
- Incorporate devices (e.g., clay trench dams, anti-seep collars, impervious cores) to prevent "piping" of water around discharge components.



Rhode Island Department of Transportation Bio-Filtration Basin featuring curb-cut inlets with rip-rap, an outfall with a rip-rap apron, and an outlet control structure.

Treatment Categories

Treatment in the SCM can be divided into four categories roughly based on the primary UOPs they provide. For the purposes of this manual, the four categories are discussed in the context of the full SCM(s) that incorporate them. The treatment categories are:



For each category, the following sections present:

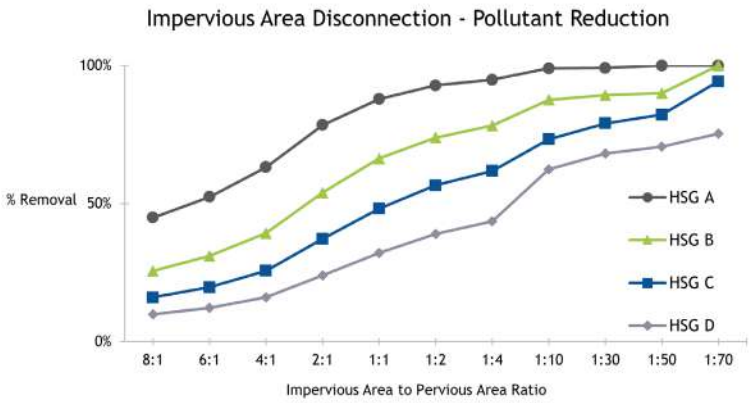
- Overview of each category
- Critical and optional system components and treatment UOPs
- Primary design guidance for the retrofit scenario
- One-page design reference sheets for SCM variations that represent the category

Remaining mindful that retrofits can (and need to be) flexible and creative, use this information as guidance to help design the right SCM(s) for the site. Mix and match the different Functional Components and Treatment Categories as needed to make a unique SCM best suited to site needs and constraints.

Treatment Category Inspection and Maintenance (I&M)

Each Treatment Category will have its own unique I&M considerations and requirements that a designer should think about when selecting treatment categories to incorporate. If a SCM is not maintained, it will require replacement much more quickly than if it is maintained. Both annual and as-needed maintenance will help to increase the service life of the SCM.

IA Disconnection SCMs are a key retrofit measure since they often do not involve the design and build of an entire structural measure. IA Disconnection could be as simple as re-grading an existing impervious surface to direct runoff to a receiving pervious parcel or removing curbing where it is not necessary. As discussed in Appendix F, IA Disconnection should be provided whenever possible.



Impervious Area Disconnection Stormwater Control Measures

Impervious Area (IA) Disconnection stormwater control measures (SCMs) provide pollutant reduction primarily through Hydrologic UOPs. IA Disconnection SCMs involve changing flow patterns so that runoff that would otherwise discharge directly to a receiving water (directly connected) will have the opportunity for treatment and infiltration by flowing over pervious areas (disconnected). This can happen by removing excess impervious surfaces, directing runoff from impervious surfaces to flow over pervious surfaces, or storing runoff from impervious surfaces and then slowly releasing it to pervious surfaces.

Keep in mind that IA Disconnection SCMs only intercept a portion of the runoff to them since the infiltration capacity of the receiving parcel may be exceeded during large runoff events, resulting in discharges from the pervious receiving area.

The removal and/or disconnection of impervious surfaces leads to a reduction in the surface discharge volume, and therefore pollutants, of runoff via the Hydrologic—Infiltration UOP. IA Disconnection SCMs can also achieve pollutant reduction through Physical UOPs. As runoff travels through vegetation and soils along the receiving pervious area, it may also be naturally treated by the Physical—Filtration UOP. In configurations where IA Disconnection happens via storage, some treatment may also occur via the Physical—Settling UOP as the runoff is held in the storage component.

Biological UOPs (discussed on page 28) can also be incorporated into IA Disconnection in the form of specialized soil media and/or plantings in the receiving pervious area to treat a broad range of pollutants.

Pollutant reduction for IA Disconnection SCMs can be quantified using the SCM Performance Curves. The Impervious Area Disconnection through Storage or Impervious Area Disconnection Performance Curves are used, depending on the configuration of the SCM. The Performance Curves are based on the ratio of the disconnected impervious area to the receiving pervious area or the available storage volume for disconnection through storage. Performance also varies based on the Hydrologic Soils Group (HSG) of the underlying soils of the receiving pervious area, or the release rate for disconnection through storage. The SCM Performance Curves assume Hydrologic UOPs as the only treatment mechanism.

System Components

Essential Treatment UOPs

- **Hydrologic—Infiltration:** A portion of the impervious cover runoff is captured and infiltrated within a pervious area. The quality of underlying soil health will affect the ability for runoff to infiltrate. The healthier the underlying soils, the more runoff will infiltrate and the more recharge will be provided. IA Disconnection Measures are not well suited for sites with contaminated underlying soils.
- **Physical—Filtering:** Filtering by the vegetation and soils within the pervious receiving areas provides additional pollutant removal. Although such filtering is not an "essential" UOP, it occurs because of the very nature of how this SCM works.

Optional Treatment UOPs

- **Hydrologic—Infiltration:** Runoff capture, evapotranspiration, and infiltration rates can be increased by amending existing soils and vegetation in the receiving pervious area.
- **Biological—Plant Metabolism:** Specialized soil media and/or plantings in the receiving pervious area can provide additional Biological treatment.
- **Physical—Settling:** Impervious Area Disconnection through Storage may provide Physical treatment via settling if the residence time in the storage container is long enough.

Essential Functional Components

- **Collection:** The runoff from the impervious area must be appropriately routed to the receiving pervious area. For Impervious Area Disconnection directly to a pervious area, grading and level spreaders may be required to create sheet flow. For Impervious Area Disconnection through Storage, storage containers and flow controls are required.

Optional Functional Components

- **Distribution:** Level spreaders and careful grading can be used for pavement disconnection to pervious areas where sheet flow must be maintained to ensure that runoff evenly distributes and infiltrates. Gravel strips may also be included at the impervious/pervious area interface to prevent scour as runoff first reaches the pervious surface.

Primary UOP	Performance Curve Category	SCMs Represented
IMPERVIOUS AREA DISCONNECTION SCMS		
Hydrologic: Infiltration	Impervious Area Disconnection	• Impervious Cover Disconnection • Vegetated Filter Strip • Vegetated Buffer • Qualifying Pervious Area (QPA)
Hydrologic: Infiltration	Impervious Area Disconnection through Storage	• Rain barrels • Cisterns

Primary Design Guidance[4]

≈ **Ensure sheet flow to and through the pervious area:** The pervious treatment area must support dispersion, capture, and infiltration of runoff and, when necessary, possible outflow control to protect downgradient properties. Use grading, level spreaders, and erosion controls as necessary to promote sheet flow, not only as runoff transitions to the pervious area but throughout the pervious area. Sites with flatter slopes (<5%) will typically be able to maintain dispersed flow better, although steeper slope sites (>5%) may still function if sheet flow can be maintained via dense vegetation and/or micro depressions in the topography. In general, sheet flow cannot be maintained for flow lengths greater than 300 feet [26]. Utilizing existing sites that already contain established vegetation can be advantageous. Ensure that flows for larger events exit the pervious area in a controlled manner.

≈ **Maintain pervious area:** The treatment area for IA Disconnection measures is the pervious area. The entirety of the pervious area should be inventoried, inspected, and maintained as any other SCM. Often the receiving area can be neglected since this measure is not as visibly obvious as other SCMs. When designing this measure (or crediting existing instances of disconnection), be sure to identify the limits of the receiving area, including the spatial limits, ownership, vegetated cover, and soil types, and add it to an existing SCM inventory to ensure it gets inspected and maintained along with other SCMs.

Hydrologic Soils Group (HSG):

Common soils classification system with groups that are based on estimates of runoff potential.

Soils are assigned a classification of A through D, with A producing the least amount of runoff and D producing the most runoff. Appendix G provides a crosswalk between the HSG classifications and the Natural Resources Conservation Service (NRCS) soil texture classifications and assumed infiltration rates.

[4]See Appendix F for supporting documentation for portions of this design guidance.

- **Understand infiltration capacity of pervious area:** Understand soil infiltration capacity and groundwater conditions of the pervious receiving area. Although the Performance Curves provide credit estimates for receiving areas of Hydrologic Soils Group (HSG) D soils, the receiving pervious area should not contain standing water or wetlands. For existing areas, consider amending soils and plantings to improve treatment performance.

Inspection and Maintenance Activities

- Inspect receiving pervious receiving area to ensure no channelization has taken place, infiltration rates are maintained, and there is adequate vegetative coverage.
- Inspect and maintain flow controls to ensure runoff is transferred as sheet flow to the receiving area and excess runoff is safely exiting the receiving pervious area.
- Confirm there are no alterations within the receiving area that may affect flow pattern and infiltration capacity.
- Inspect storage containers and flow controls and remove any settled solids and ensure proper inflow/outflow.
- Inspect and maintain additional equipment (e.g., pumps) for larger storage systems.

Variation-Specific Design Considerations

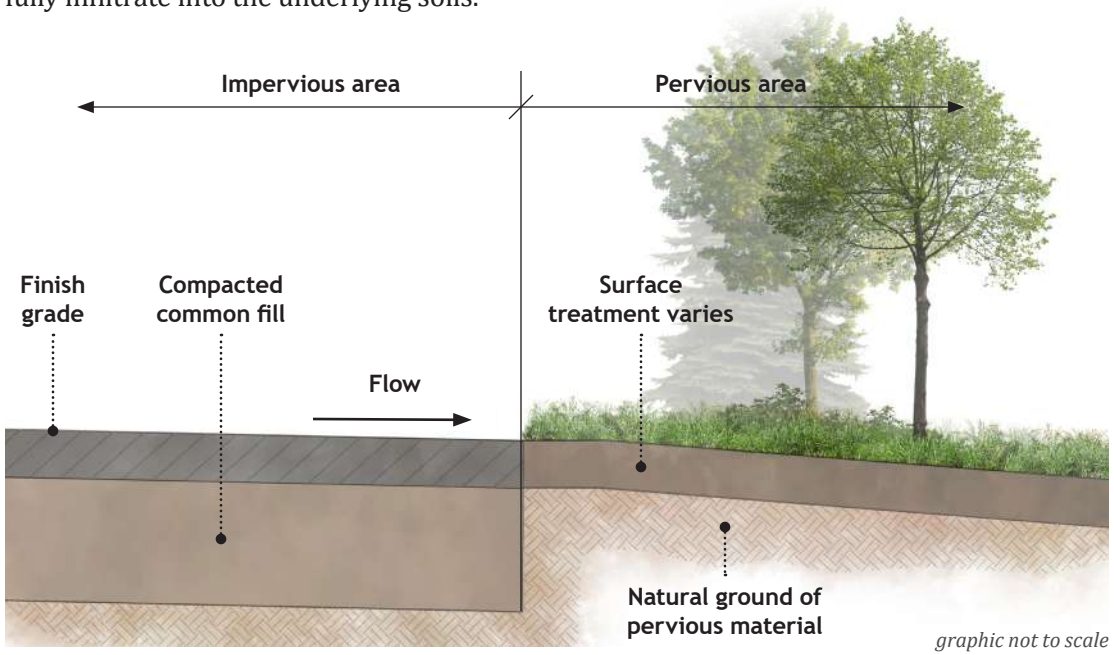
Placement of IA Disconnection to Pervious Area SCMs can vary based on site needs. IA Disconnection to Pervious Areas can be designed as a stand alone SCM or can be placed upstream of other SCMs for pretreatment or downstream of an SCM that discharges sheet flow (e.g., gravel infiltration trench).

Sizing for IA Disconnection to Pervious Areas can be flexible. The recieving pervious area can be larger or smaller than the contributing impervious area. Greater runoff and pollutant reduction will occur with larger pervious areas with good vegetated cover and well-draining soils.

IA Disconnection to Pervious Area

(also known as vegetated filter strips, vegetated buffers, and areas deemed as "Qualifying Pervious Areas" in some regulatory guidance)

Impervious Area (IA) Disconnection is routing runoff from impervious cover to a pervious receiving area. Examples include installing a curb cut to allow runoff from a roadway to travel to an adjacent vegetated median or grading an uncurbed parking lot towards a vegetated island. As the runoff travels over the pervious/vegetated area, it will partially or fully infiltrate into the underlying soils.



graphic not to scale

Well suited for sites with ...

- ≈ Distributed sheet flow
- ≈ Available pervious space adjacent to impervious areas

Not well suited for sites with ...

- ≈ Large concentrated flow
- ≈ Steep slopes
- ≈ Wetland or standing water

Variation-Specific Design Considerations

Storage containers can be small and simple, such as residential rain barrels, or larger and more complex, such as cisterns for an industrial facility. Include screens or filters to serve as pretreatment.

Sizing of storage containers can vary. Design for a retention time of one to three days to allow receiving pervious area time to dry after a storm, and prior to the next potential storm.

Discharge should be done in a controlled and intentional manner. Plan for additional equipment such as pumps when locating storage containers underground or discharging stored runoff to non-adjacent areas. Storage containers that are located above ground can often use gravity to discharge runoff to adjacent areas.

Overflow mechanisms should be included. Include an overflow mechanism for bypassing large events and draining between storms to the pervious area.

Cisterns and Rain Barrels

Cisterns and Rain Barrels collect runoff routed from impervious cover, storing it, and slowly releasing it over a defined period of time. The stored runoff may be re-used for irrigation purposes or released to a receiving pervious area. As the runoff travels over the pervious/vegetated area, it will partially or fully infiltrate into the underlying soils.



Photo Source: www.epa.gov/soakuptherain/soak-rain-rain-barrels

Well suited for sites with...

- ≈ Relatively clean runoff source (e.g., rooftop)
- ≈ Available pervious space for discharge

Not well suited for sites with...

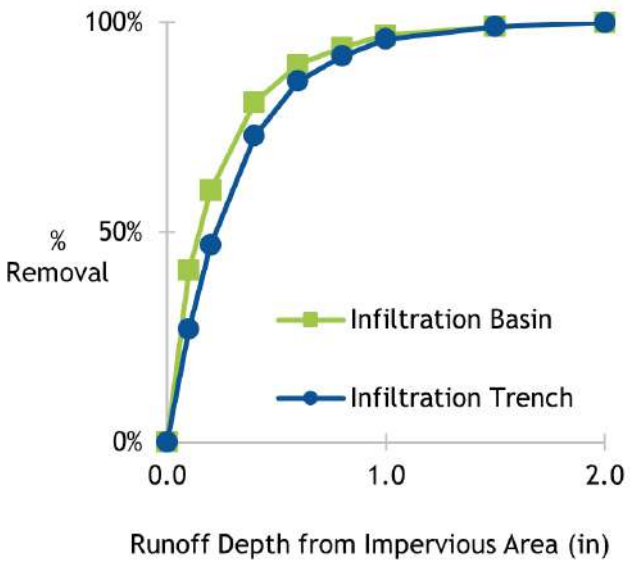
- ≈ Large concentrated flow
- ≈ Steep slopes
- ≈ Wetland or standing water

Infiltration Stormwater Control Measures

Infiltration stormwater control measures (SCMs) provide pollutant and runoff volume reduction primarily through Hydrologic UOPs. Infiltration SCMs provide the proper conditions for stormwater runoff to infiltrate into native soils. This runoff is therefore not discharged directly to surface receiving waters. Pollutant and runoff volume reductions to the receiving waters are achieved by reducing the amount of pollutant-containing runoff that is discharged. This not only reduces volume and associated pollutant mass, but also decreases geomorphic stream instability and the concentration of pollutants associated with stream channel degradation.

Infiltration SCMs can also achieve pollutant reduction through Physical UOPs. As water percolates through the underlying soils, many common stormwater pollutants that are hydrophobic in nature (e.g., phosphorus, total suspended solids, and metals) and thus bound or associated with sediments are largely removed in the soil media, providing a cleaner discharge to groundwater systems. Some settling of non-dissolved pollutants may also take place in SCMs that include a storage component as the runoff is temporarily detained before it percolates into the underlying soils. Biological UOPs to treat dissolved pollutants such nitrate can also be incorporated into Infiltration SCMs as added design features including specialized soil media and/or plantings.

Pollutant and runoff volume reduction for SCMs where infiltration is the dominant UOP can be quantified using the SCM Performance Curves. Either the Infiltration Basin or Infiltration Trench Performance Curve is used depending on the design and configuration of the infiltration SCM. Table 4-2 and Appendix C contains a crosswalk outlining which Infiltration SCM variations correspond to each Infiltration SCM Performance Curve. Infiltration SCM performance also varies based on the infiltration rate of the native underlying soils. For the purposes of this manual, the Performance Curves have been aligned with the NRCS Hydrologic Soils Group (HSG) classifications, which is a common system for characterizing soil classifications.[5]



Consolidated Total Phosphorus (TP) Performance Curves for Infiltration Measures in HSG B soils. See Appendix B for full set of Performance Curves.

[5]The original EPA Performance Curves include values for six different infiltration rates. These six Performance Curves were simplified to three Performance Curves by aligning the infiltration rates with HSG A, B, and C classifications using the Rawls Rate Table. See Appendix G for the Rawls Rate Table and a listing of which Performance Curve was used for each HSG. This manual also presents SCM Performance Curves for Infiltration SCMs in HSG D based on new EPA modeling. See Appendix B for more information about the HSG D Performance Curve development and use in this manual.

Ideally, systems would infiltrate stormwater runoff in the same quantities and patterns as the pre-development watershed they are treating, essentially mitigating the hydrologic and water quality effects of developing that watershed. For retrofit systems, the emphasis is to maximize infiltration on an annual average basis. Because the majority of storms in the New England area are less than 0.5 inches, infiltration systems do not need to be very large to show significant performance in mitigating hydrologic and water quality impacts.

System Components

Essential Treatment UOPs

- **Hydrologic—Infiltration:** Infiltration is the primary UOP for infiltration measures. Once runoff is routed to the SCM, it is directed to a treatment area, where it slowly infiltrates into the native soils. Infiltration provides both runoff volume reduction as the runoff infiltrates and treatment as pollutants are filtered out as the runoff travels through the native soils.

Optional Treatment UOPs

- **Biological—Plantings:** Specialized plantings may be included in surface infiltration measures to provide Biological treatment by providing nutrient uptake. Their root systems also keep soils loose, which helps maintain the permeability of the upper layers. Targeted plantings may be included if Biological treatment and enhanced Nitrogen/Phosphorus reduction are a priority for the site or for aesthetic purposes.
- **Physical—Filtering:** Filter media may be included within the infiltration pathway to provide enhanced treatment beyond infiltration alone. This may be of special interest with pollutants such as dissolved phosphorus where amendments like drinking water treatment residuals (DWTR) or ionic metal additions can be added, and/or in areas with reduced separation to groundwater. Nitrogen treatment can be enhanced through the creation of internal storage reservoirs (see basin variations on page 59) and/or the inclusion of additional carbon sources (<10%) such as wood chips in the reservoir.

Essential Functional Components

- **Collection:** Runoff collection mechanisms can include inlets, pipes, and manholes in addition to less-structural measures, including grading for sheet flow and curb cuts that transport runoff to the Infiltration SCM.

- **Treatment:** Infiltration SCMs must include a designated area where runoff can infiltrate. Runoff storage areas hold runoff within the SCM so that it can be infiltrated. This storage volume provides the basis for Runoff Depth (the x-axis on the Performance Curves).
- **Discharge:** Discharge components for smaller storm events are not required but overflow discharge mechanisms are generally provided to allow runoff that is beyond the process capacity of the SCM to be safely discharged. For inline systems, all runoff passes through the SCM, and high flows may be discharged from the SCM via spillways or outlet control structures. For offline systems, bypass is controlled upstream of the SCM such that only design flows are delivered.

Optional Functional Components

- **Pretreatment:** Pretreatment measures that remove coarse materials, trash, and separate oils and greases will help extend the maintenance cycle required for Infiltration SCMs. Underground Infiltration SCMs will especially benefit from having contained and accessible locations for materials that may clog underground components that are hard to inspect and access.
- **Distribution:** Depending on the design of the SCM, distribution functional components may be required to distribute and evenly disperse runoff throughout the SCM. Distribution functional components such as header pipes are most common in underground infiltration measures. For planted surface systems, stone wicks or other mechanisms may be necessary to connect the storage area to the underlying soils.
- **Discharge:** Optional underdrains may be desired to ensure drawdown between storm events. To enhance infiltration, underdrains should be elevated to create maximum storage in the reservoir course below the underdrain invert. If additional Design Storage Volume (DSV) is desired and there is sufficient separation between the estimated seasonal high groundwater table (ESHGWT) and/or bedrock, then a stone layer serving as a reservoir course can be included.

Primary UOP	Performance Curve Category	SCMs Represented
INFILTRATION SCMS		
Hydrologic: Infiltration	Infiltration Basin (by HSG of underlying soil)	• Infiltration Basin • Infiltration Swale • Permeable Pavement (no or elevated underdrain) • Bio-Filtration Basin (no or elevated underdrain) • Bio-Filtration Curb Inlet Planter (no or elevated underdrain) • Rain Garden (no or elevated underdrain) • Underground Infiltration Chamber
Hydrologic: Infiltration	Infiltration Trench (by HSG of underlying soil)	• Infiltration Trench • Leaching Basin • Dry Well • Leaching Galley

Primary Design Guidance[6]

1. Understand In-Situ Conditions of the Native Soil

In-situ conditions of the native soil will affect how much runoff is able to infiltrate. Current research demonstrates that horizontal exfiltration paths dominate recharge in infiltration systems, even in soils traditionally considered to have limited infiltration capacity [27]. As these findings suggest, infiltration practices can be used for a range of soil infiltration rates, which is reflected in the Performance Curves.

In-situ infiltration testing will give the designer a better understanding of the infiltration capacity of the native soils, including effects of site-specific conditions such as compaction that would not be known based on NRCS soil mapping. The key is to characterize the underlying soils properly so that the design can reflect those conditions. Avoid topping the system with more constrictive soils for the purposes of planting.

In-Situ Testing Alternative

Install a capped underdrain or elevated underdrain within the system when it is not possible to perform in-situ infiltration testing or there is concern that the system may not infiltrate as desired. After monitoring the installed system through a range of storm events, if the system functions and infiltrates as expected then the underdrain can be left capped. If it does not infiltrate as expected, then the underdrain can be uncapped and the system can function more as a Media Filter system.

[6] See Appendix F for supporting documentation for portions of this design guidance.

2. Understand Distance to Bedrock or Groundwater and Hydraulic Gradient

The distance to bedrock or groundwater can influence the ability for infiltration to successfully take place. A competent soil professional can determine groundwater depths based on visual review of soil strata. Infiltration systems that include a filtering layer, such as bio-filtration systems, should have one foot or more of separation from the bottom of the filter course to the ESHGWT.

In areas with pollutant sources and sensitive resources related to dissolved constituents (e.g., chlorides and nitrogen), greater separation should be considered and some form of assessment of consequences should be performed [28], [29], [30].[7]

3. Understand Proximity to Critical Resource Areas and Infrastructure

Once runoff infiltrates, it may reach critical resource areas via subsurface flow. This may introduce a pollutant source to the resources area or water to underground structures such as foundations and footings. Careful consideration of the hydraulic gradient and protection of downgradient infrastructure is important. Many older urban areas may preclude infiltration due to the concern for water intrusion into abandoned pipes, basements, private potable water wells, and other urban infrastructure connected to adjacent properties.

Use flexible sizing approaches to control stormwater and adhere to regulatory setbacks. Attempt to install more dispersed, smaller-scale shallow controls in lieu of larger centralized controls.

Note that in some scenarios, governing regulatory authorities may require that infiltration SCMs obtain permits for underground discharge [31].

[7] A groundwater mounding analysis is suggested for practices designed to infiltrate more than the one-year, 24-hour storm event and when the ESHGWT separation from the bottom of the filtering SCM is less than one foot.

4. Support Long-Term I&M

Long-term I&M of an infiltration measure will support the Infiltration Treatment Category and extend the lifespan of the measure. To support long-term I&M of the Infiltration SCM:

- **Consider pretreatment:** Pretreatment measures for infiltration systems will help prevent material from entering the system that may clog the system and therefore slow infiltration rates and reduce performance. Pretreatment measures can be especially beneficial when installed upstream of an infiltration measure with a particularly high infiltration capacity. Runoff may infiltrate quickly and reach groundwater before significant treatment can take place if the infiltration capacity is high. See page 44 for more information on pretreatment.
- **Include access points for underground measures:** Inspection and maintenance access points aid in performing maintenance on otherwise difficult to maintain/access infiltration measures, and include structures like inspection ports, observation wells, and access structures.

Inspection and Maintenance Activities

- Inspect/restore enhanced filter media (if applicable) to maintain enhanced treatment.
- Visually observe systems after rain events or use a high-efficiency infiltration rate testing device to ensure that infiltration rates are maintained.
- Surface SCMs
  - Remove sediment from the storage area as it accumulates to maintain the soil's infiltration capacity.
  - Maintain vegetation and plantings.
- Subsurface SCMs
  - Designate discrete, easy-to-access inspection and maintenance points within the system.
  - Monitor underlying and surrounding soils or perform periodic infiltration testing to ensure that infiltration rates are maintained.
  - Fully replace storage media, if necessary.

Variation-Specific Design Considerations

Sizing for these relatively basic features can range in size from small (0.1-inch Runoff Depth) to large (>2-inch Runoff Depth) if flood control is also desired.

Topsoil should be more hydraulically efficient than the native soil to ensure the basin infiltrates as expected and to decrease maintenance burdens.

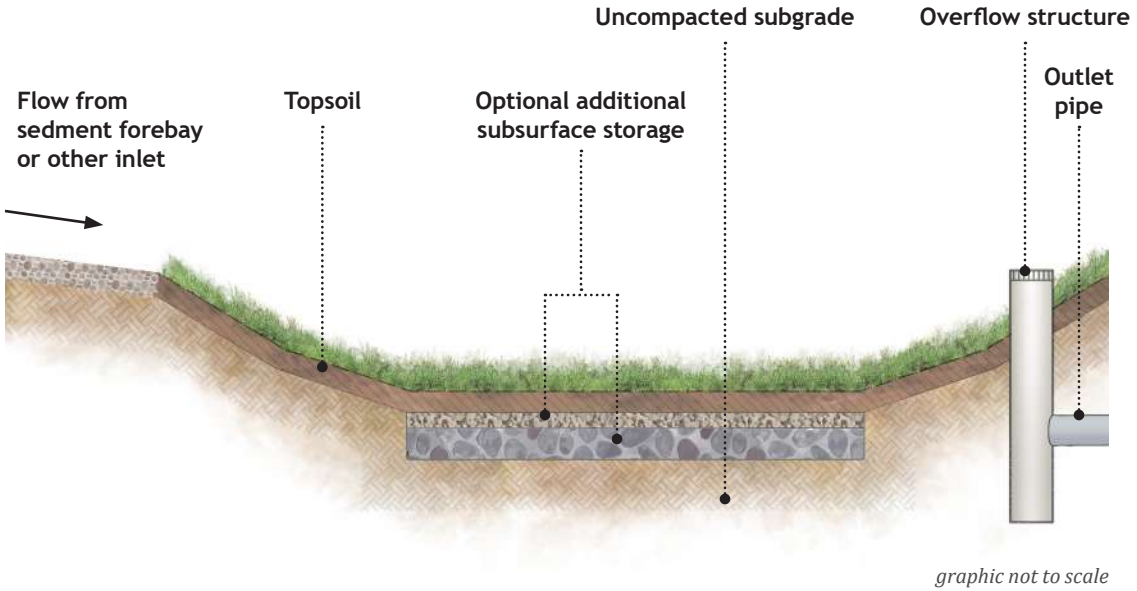
Plantings must be able to tolerate frequent inundation when the basin fills with runoff.

Grading within the basin must be done appropriately to ensure there are no short-circuiting flow paths.

Subsurface composition may be enhanced to increase runoff treatment by providing biological uptake or washed stone reservoir to increase capture volume.

Basins

Basins are above-ground, vegetated depressions designed to collect, temporarily store, and infiltrate runoff into the underlying soils.



graphic not to scale

Well suited for sites with...

- ≈ Available above-ground space
- ≈ Separation to estimated seasonal high groundwater table

Not well suited for sites with...

- ≈ Contaminated underlying soils
- ≈ Limited available above-ground space

Variation-Specific Design Considerations

Outlet controls should be considered as a means to retain runoff through mechanisms such as impermeable check dams and raised outlet control structures. In addition, maximum depths for design events should be evaluated to ensure no flooding of adjacent infrastructure.

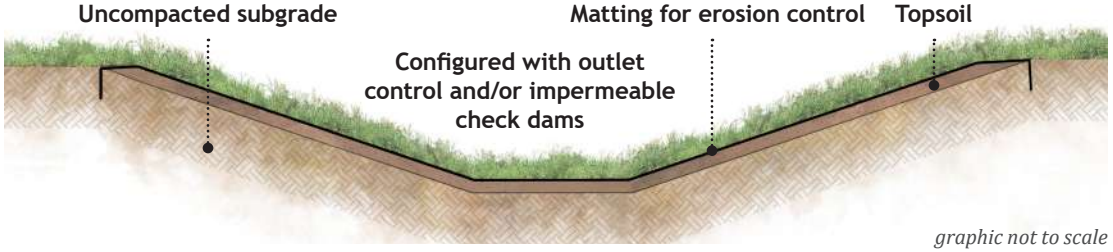
Flow velocity should be zero for the DSV of the SCM; there should be no flow in the system, and therefore all captured runoff will be stored and infiltrated. Flow velocities for larger design events should be evaluated to avoid erosion and resuspension.

Check dams are often included to isolate cells within the linear basin. Check dams should have an impermeable core to force retention and vertical infiltration. Surface treatments of the check dam can vary to support maintenance needs. See example of check dams in the clear zone on page 43.

Linear Configuration

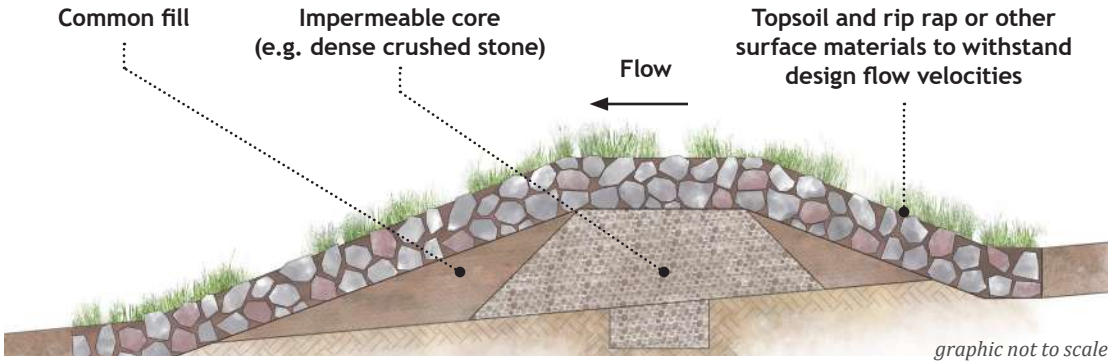
Linear Configuration SCMs are basins configured within more linear areas. They contain one or more cells designed to store and infiltrate stormwater into the underlying soils. Overflows are commonly conveyed from one cell to the next downstream cell in the linear system like a swale.

Infiltration Linear Configuration



graphic not to scale

Check Dam



graphic not to scale

Well suited for sites with...

- A linear stretch of above-ground space (such as a roadway shoulder, a roadway median, or dividing areas within large parking lots)

Not well suited for sites with...

- Contaminated underlying soils
- Steep slopes

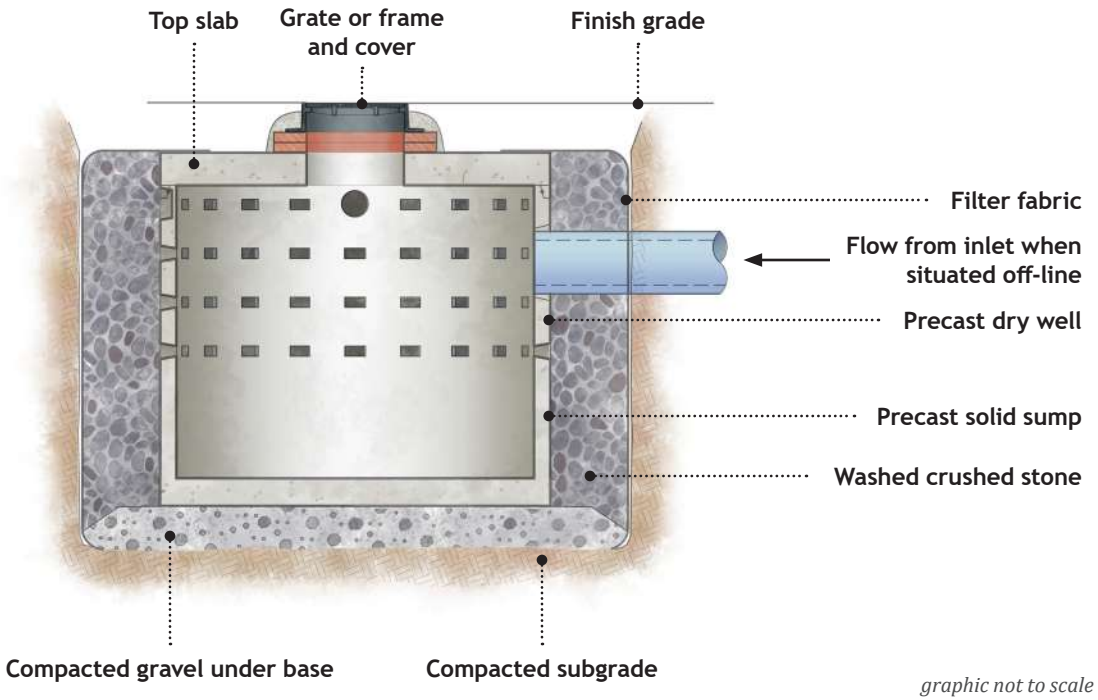
Variation-Specific Design Considerations

Offline is the preferred configuration for leaching basins so that the leaching basin is not the collection structure. Pair a leaching basin with a deep-sump catch basin with a hood to serve as the collection structure for sediment and floatables. If configured online, consider including a deep sump in the structure to serve as an area for settlement and targeted maintenance.

The structure is often pre-cast concrete perforated barrel of specified dimensions made by a manufacturer. Include a solid sump to capture particles and facilitate long-term I&M.

Leaching Basin/Dry Well

A Leaching Basin, also known as Dry Well, is a subsurface perforated structure surrounded by washed crushed stone designed to temporarily store and infiltrate runoff into the surrounding and underlying subsurface soils.



graphic not to scale

Well suited for sites with...

- ≈ Minimal surface footprint
- ≈ Separation to estimated seasonal high groundwater table

Not well suited for sites with...

- ≈ Contaminated underlying soils
- ≈ Underground utility conflicts

Variation-Specific Design Considerations

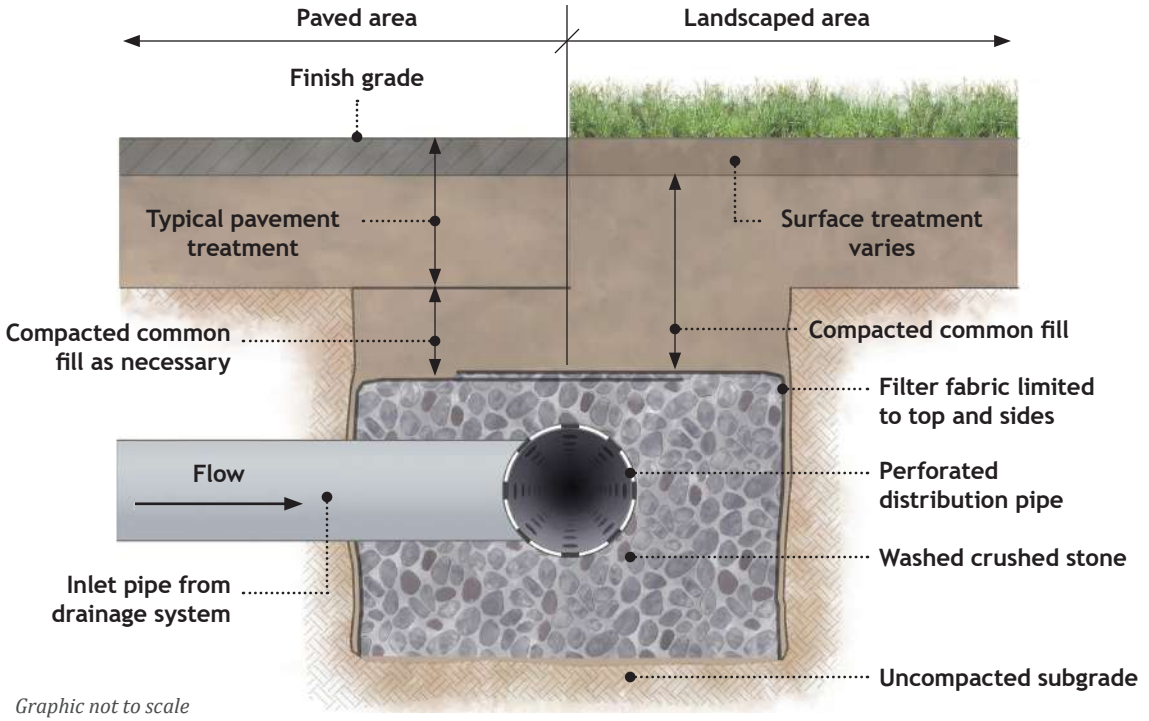
Distribution pipe is often used to distribute runoff evenly throughout a trench, especially if runoff does not enter the trench via distributed sheet flow.

Inspection ports/observation wells are highly encouraged for inspection and maintenance purposes.

System bottom should be flat to encourage equal distribution and infiltration across the footprint. If the surface topography is sloped, create stepped cells within the SCM, separated to prevent flow through them and avoid unusable storage.

Trench

An Infiltration Trench is a subsurface, linear trench filled with washed crushed stone designed to temporarily store and infiltrate runoff into the surrounding and underlying soils.



Graphic not to scale

Well suited for sites with...

- ≈ Minimal surface footprint
- ≈ A linear stretch of subsurface area
- ≈ Separation to estimated seasonal high groundwater table from bottom of stone reservoir

Not well suited for sites with...

- ≈ Contaminated underlying soils
- ≈ Underground utility conflicts
- ≈ Steep slopes

Variation-Specific Design Considerations

Storage chambers can be hollow to increase capacity and can be aligned in varied configurations to suit site needs.

Distribution piping conveys collected runoff throughout the system to storage chambers.

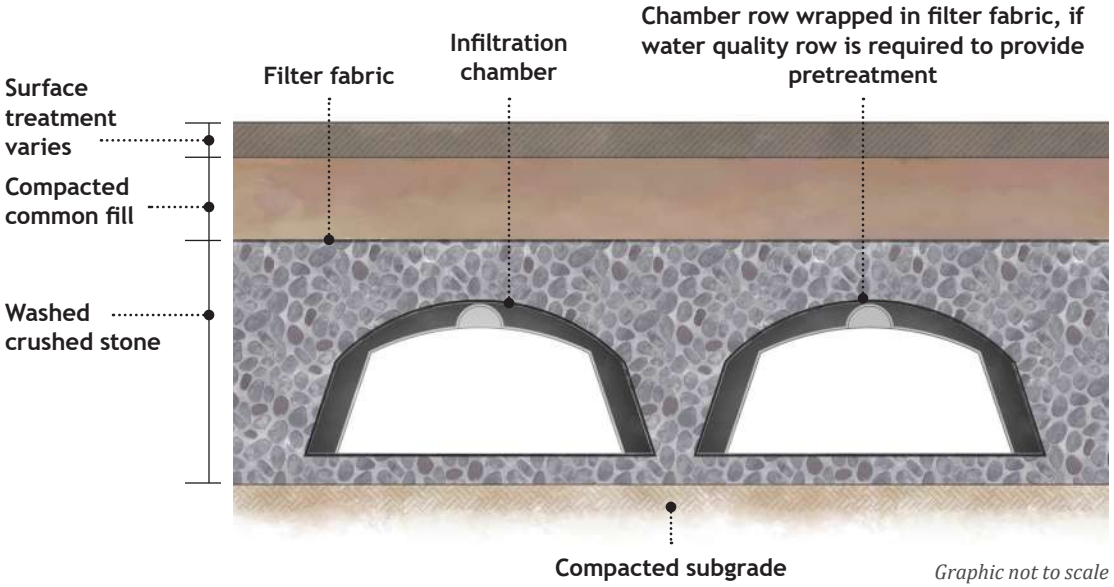
Water quality isolator row is a row upstream in the system that is wrapped in filter fabric and used for system pretreatment.

Inspection ports/access structures are highly encouraged for inspection and maintenance purposes.

Infiltration rates may be altered if subgrade is compacted to support surface loads. Confirm infiltration rates upon construction completion to ensure system is functioning as designed.

Galley

Infiltration Galleys are subsurface systems featuring multiple storage chambers operating in parallel. They are surrounded by washed crushed stone and designed to temporarily store and infiltrate runoff into the underlying soils. Proprietary vendors can help guide design based on their specific materials and products.



Graphic not to scale

Well suited for sites with...

- ≈ Minimal surface footprint but underlying soils with a high infiltration rate
- ≈ Separation to estimated seasonal high groundwater table
- ≈ Areas with larger amounts of water to infiltrate

Not well suited for sites with...

- ≈ Contaminated underlying soils
- ≈ Many underground utilities
- ≈ Significant anticipated surface loading

Variation-Specific Design Considerations

Surface materials include paving blocks or grids, pervious asphalt, or pervious concrete. The latest asphalt designs can withstand frequent travel and turning [32].

Surface slopes can follow the existing gradient to an extent (<10%), as long as there are mechanisms such as a stepped system or internal check dams to stop concentrated flow at the confining layer, typically the native, compacted subgrade.

Contributing drainage area is typically the surface pavement itself. The system can be designed to receive adjacent runoff, although that design increases the maintenance burden and can cause construction challenges when joining the standard and permeable pavement cross sections.

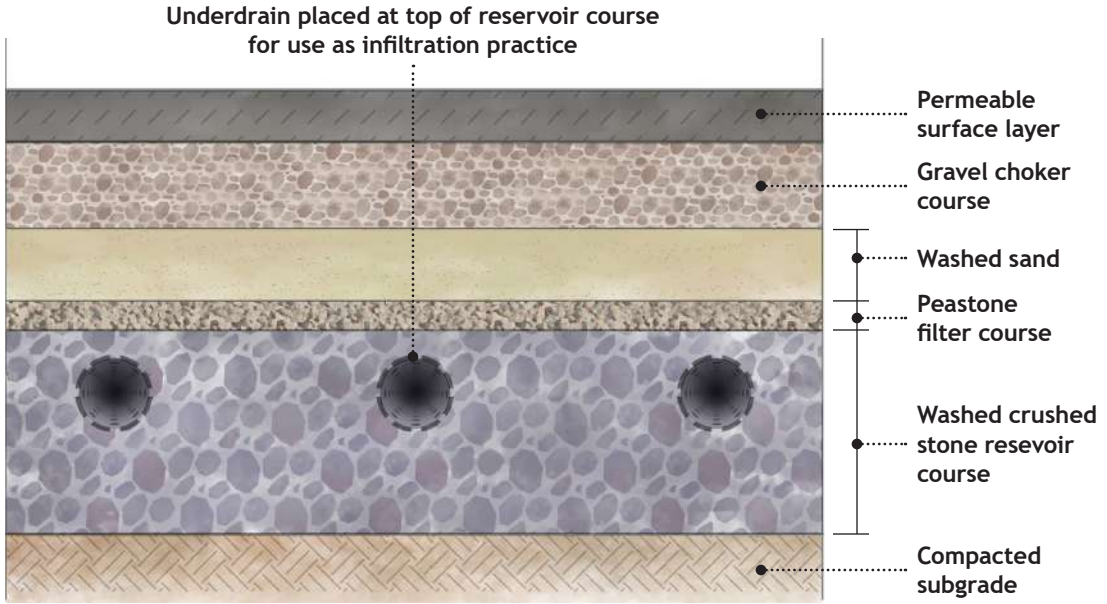
Sanding should not take place on or near permeable pavement. Sediment must be removed from the pavement course via regular vacuuming with specialized equipment. Permeable pavements often require less sanding and salting due to the lack of surface ponding.

Pretreatment is provided by the filter course[8] before runoff is infiltrated.

[8]Sample permeable pavement specifications: www.unh.edu/unhsc/sites/default/files/media/unhsc_pa_spec_-_feb-2014_-rev_9-16.pdf

Permeable Pavement

Permeable Pavement is a paved surface that captures runoff in voids where it is temporarily stored, and from which it ultimately infiltrates into the underlying and surrounding soils. Permeable Pavement is only considered an infiltration measure when there is either no underdrain or an elevated underdrain and no impermeable liner included.



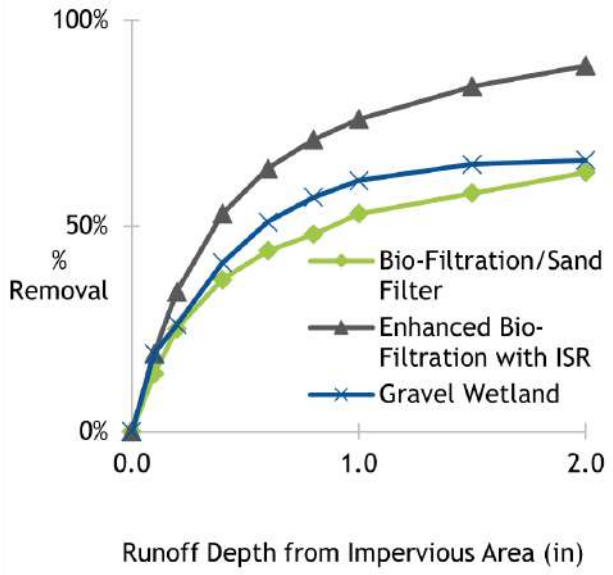
Graphic not to scale

Well suited for sites with...

- Low-traffic pavement (e.g., overflow parking, sidewalks)
- Areas that will not receive winter sanding
- Separation to estimated seasonal high groundwater table

Not well suited for sites with...

- Contaminated underlying soils
- Many underground utilities
- Significant anticipated surface loading
- Significant anticipated sanding
- Steep surface slopes



Total Phosphorus (TP) Performance Curves for Media Filter Measures. See Appendix B for full set of Performance Curves

Media Filter Stormwater Control Measures

Media Filter stormwater control measures (SCMs) provide pollutant reduction primarily through the Physical—Filtering and Biological UOPs. Variations in this category of SCMs are designed specifically to take advantage of different Filtering, Biological, and Chemical processes. Certain variations of Media Filters may also provide Chemical treatment via specialized soil media to treat dissolved pollutants such as nutrients. High flow rate filters are not included in this category, and are discussed further on in Manufactured Devices.

Media Filter SCMs are often configured with underdrains at the bottom of the system. If infiltration is the desired primary UOP, the underdrain can be elevated or removed entirely to enhance the infiltration capabilities of the system through Hydrologic - Infiltration UOPs. Alternatively, if infiltration is not desired or acceptable for the site due to constraints such as high potential pollutant loading or contaminated soils, impermeable liners can be installed to prevent infiltration entirely. Media Filter SCMs are therefore flexible and can be designed and configured to address the pollutants of concern and site constraints. Variations in Media Filter SCMs design depend on several factors, including:

- Materials
- Above- versus below-ground components
- Flow direction (horizontal versus vertical)
- Configuration
  - Basin versus swale
  - Number of cells
- Discharge location (infiltration versus downstream surface discharge)
- Plantings

Design decisions for each of these factors will affect the UOPs performing the treatment, and will affect how the SCM operates and what the SCM will look like. Pollutant reduction for Media Filter SCMs can be quantified using the SCM Performance Curves. The Bio-Filtration, Enhanced Bio-Filtration with Internal Storage Reservoir (ISR), Gravel Wetland, or Sand Filter Performance Curves can be used, depending on the design and configuration of the SCM. If Infiltration is incorporated into the design, then the Infiltration Trench or Infiltration Basin Performance Curves may be used to quantify pollutant reduction, if it is the primary UOP.



EXAMPLE LINEAR RETROFIT SCM

Bio-Filtration Swale in Construction on Route 290 in Massachusetts

The Massachusetts Department of Transportation (MassDOT) retrofitted bio-filtration swales into the roadway median along Route 290 in Auburn, Massachusetts to help meet their water quality goals. MassDOT elected to install an underdrain at the bottom of the Bio-Filtration Swale surrounded by a crushed stone layer (as seen above). The swale was filled with a bioretention soil mix [33].

System Components

Essential Treatment UOPs

- **Physical—Filtration:** Filter media physically removes pollutants from runoff as it travels through the SCM. Suspended sediments and sediment-associated constituents are physically captured or screened through the filter media.
- **Biological—Plant Metabolism:** Plantings can be selected to provide Biological treatment and enhance nutrient uptake. Their root systems also keep macropores open, which helps maintain the long-term permeability of the upper layers.
- **Biological—Nitrification/Denitrification:** Through the process of nitrification, the organic compounds are converted to ammonia and nitrate by microbial respiration in the presence of oxygen. Denitrification, the conversion of nitrate to nitrogen gas, occurs only in the absence of oxygen. The subsurface gravel wetland provides these functions in the open, aerated forebay, the surface of each treatment cell, and the fully saturated subsurface gravel layer.
- **Chemical—Adsorption:** This is the process of attracting and chemically attaching dissolved pollutants onto adsorbent surfaces in the filter media. Chemical adsorption can be enhanced by media amendments, most commonly, positively charged ionic compounds (aluminum and iron) that elevate cation exchange capacity.

Optional Treatment UOPs

- **Hydrologic—Infiltration:** Based on the functional component configuration and provided residence time, infiltration into the surrounding soils may also occur. Hydrologic UOPs may be of particular interest where runoff reduction and recharge are also priorities.

Essential Functional Components

- **Collection:** Runoff collection mechanisms can include inlets, pipes, and manholes in addition to less-structural measures, including grading for sheet flow and curb cuts that transport runoff to the Media Filter measure.
- **Treatment:** The treatment media that the runoff flows through is the essential component that allows for the treatment UOPs to occur. This media is selected and designed based on the desired processes and can include sand (Sand Filter) or a prescribed soil (Bio-Filtration).

- **Discharge:** Outlets can discharge filtered runoff that is not retained for infiltration. Overflow mechanisms allow runoff that is beyond the process capacity of the SCM to be safely discharged downstream. For inline systems, all runoff is passed through the SCM, and overflows may be spillways or outlet control structures providing discharge pathways from the SCM. For offline systems, bypass is controlled upstream of the SCM.

Optional Functional Components

- **Pretreatment:** Pretreatment may be included, if the anticipated sediment load to the Media Filter SCM is particularly high, in order to ease the maintenance burden.
- **Distribution—Impermeable Liner:** An impermeable liner may be included to prevent infiltration and maintain a saturated zone or to prevent groundwater from entering the system.
- **Discharge—Underdrain:** Underdrains are often included to collect and discharge runoff after it has filtered through the media layer. When possible, underdrains should be elevated within the system toward the top of the reservoir course to enhance infiltration into the native soils.
- **Distribution:** Depending on the design of the SCM, distribution features (pipes, risers) may be required to disperse runoff throughout the SCM's internal distribution piping.

Primary UOP	Performance Curve Category	SCMs Represented
MEDIA FILTER SCMS		
Physical: Filtration	Bio-Filtration	• Bio-Filtration Basin (with underdrain) • Bio-Filtration Curb Inlet Planter (with underdrain) • Rain Garden (with underdrain)
Physical: Filtration	Sand Filter	• Sand Filter • Media Filter
Physical: Filtration **Biological: Nitrification/Denitrification** **Chemical: Adsorption of dissolved P and Bacteria**	Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)	• Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)
Biological: Nitrification/Denitrification	Gravel Wetland	• Gravel Wetland • Gravel Wet Vegetated Treatment System • Wet Vegetated Treatment System • Shallow Wetland
Physical: Filtration	Permeable Pavement (with underdrain)	• Permeable Pavement (with underdrain)

Primary Design Guidance[9]

1. Choose Filter Media to Target Pollutant of Concern

Each filter media SCM performs differently for treating various pollutants. Use the Performance Curves to choose which measure and UOP work best for the target pollutant(s). The table below presents media, and associated SCM(s) which provide the greatest pollutant removal at an example Runoff Depth of 0.6 inches.

Pollutant	Media	SCM
Total Suspended Solids	Sand or Soil	Bio-Filtration or Sand Filter
Total Nitrogen	Soil/Saturated Gravel	Enhanced Bio-Filtration with ISR
Total Phosphorus	Soil/Saturated Gravel	Enhanced Bio-Filtration with ISR
Metals	Sand or Soil	Bio-Filtration or Sand Filter
Bacteria	Soil/Saturated Gravel	Enhanced Bio-Filtration with ISR

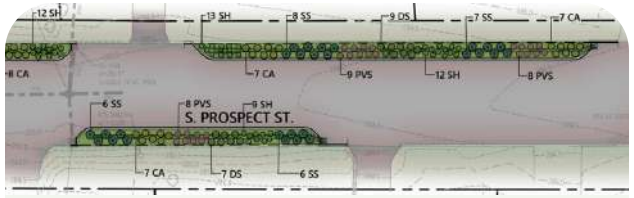
2. Align Design with I&M Capabilities

Some variations require more landscape and operational attention than others. Design the system such that inspections and regular maintenance can fit within existing or desired programs. Consider developing a standard design that works for the organization/long-term owner operator and employing it consistently to create a collection of measures that require the same inspection, operation, and maintenance needs, which will streamline work.

3. Design Flow Controls to Ensure Proper Flow Throughout the System

Because treatment occurs by passing water through the filter system, the design of flow controls must encourage water distribution vertically throughout the system and evenly through the filter media to maximize treatment and support the designed flow rates for treatment and overflow conditions.

[9] See Appendix F for supporting documentation for portions of this design guidance.



EXAMPLE OF USING MULTIPLE SMALL SCALE MEDIA FILTERS

Right-of-Way Bio-Filtration Cells

Burlington, VT

The city of Burlington, Vermont recently installed 15 small-scale Bio-Filtration cells along the right-of-way in a residential neighborhood. By installing multiple small-scale SCMs rather than one large structure, Burlington was able to successfully work with spatial constraints and still provide significant pollutant reduction [35].

4. Include Opportunity for Infiltration

Although Media Filter SCMs are often chosen when Infiltration SCMs are less viable, they can be configured to still support infiltration that may occur for smaller, more sporadic events and/or during lower groundwater periods. With the exception of Gravel Wetlands and Bio-Filtration with ISR SCMs that require a saturated zone, media filters may be designed with elevated outlets or underdrains and/or storage layers (e.g., gravel) to encourage infiltration even if soils do not warrant a standard infiltration system. Small amounts of infiltration over the bulk of small storms that occur can have a significant impact on long-term groundwater recharge. Existing literature reviews regarding the pollution risks associated with choosing infiltration identify the often-greater pollution risks of not choosing infiltration [34].

Inspection and Maintenance Activities

- ≈ Remove sediment from filter media to ensure filtration is not impeded.
- ≈ Remove sediment from distribution piping to ensure proper flow throughout system.
- ≈ Maintain surrounding vegetation and inspect for erosion. Consider cutting back and removal of plantings every three years after die-off to reduce additional nutrient source.
- ≈ Inspect impermeable liner and replace if damaged (if applicable).
- ≈ Inspect saturated zone to ensure water retention (if applicable).

Variation-Specific Design Considerations

- ≈ **Filter media specification** should be low in nutrients so as to not introduce unwanted nutrient sources[10] (e.g., media high in compost content).
- ≈ **Drinking water residuals** have shown promising results in targeting dissolved phosphorus precipitation, based on recent research [36], [37]. Existing Bio-Filtration systems can be retrofitted to include this additive and increase performance without new construction.
- ≈ **Plantings** of the surface basin can be simple or intricate. Large woody vegetation should be avoided to better support maintenance and replacement of the soil media.
- ≈ **Impermeable liners** may be necessary if groundwater intrusion is an issue or if the surrounding soils are contaminated.
- ≈ **Pretreatment** can be used to extend the serviceable life since the top of the filter bed is typically not accessible without deconstructing the entire practice.
- ≈ **Underdrain or outlet pipe** should be elevated whenever possible to provide infiltration.

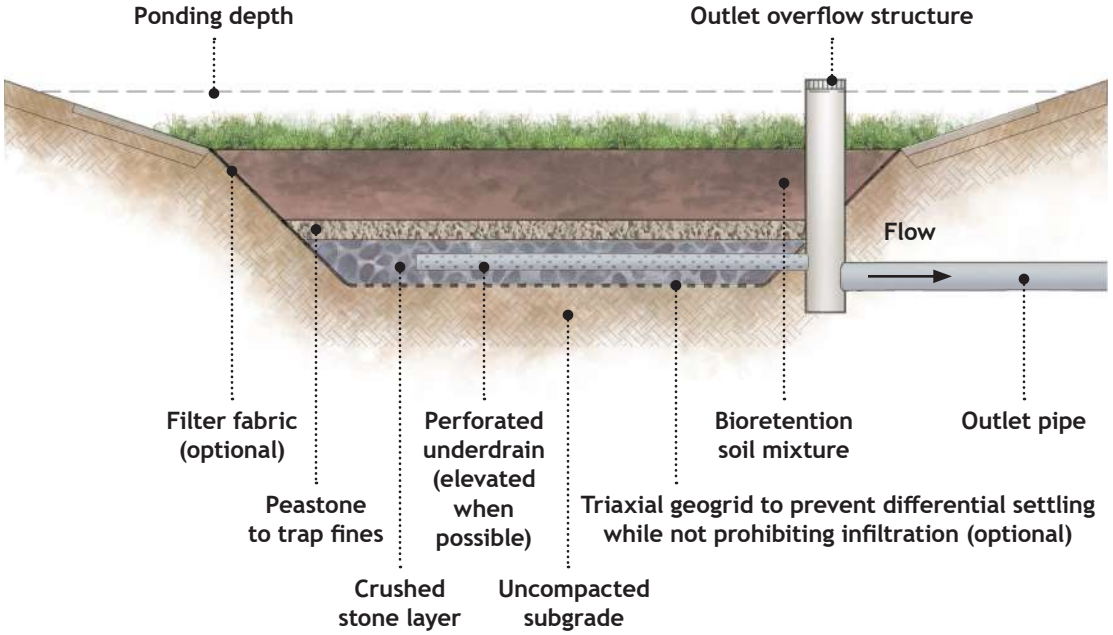
[10] Soil specifications samples:

www.unh.edu/unhsc/sites/default/files/media/unhsc_bsm_spec_9-2021.pdf

www.fremont.gov/DocumentCenter/View/886/BASMAA-Soil-Specification

Bio-Filtration Basin

Bio-Filtration basins are vegetated basins that capture, temporarily store, and filter stormwater runoff through an engineered soil media. Depending on the configuration, infiltration may or may not be provided. These basins can also be configured in a linear shape. See variation-specific design considerations for the linear configuration under Infiltration SCMs in the Linear Configuration section.



Graphic not to scale

Well suited for sites with...

- ≈ Above ground available space
- ≈ Infiltration is limited or not possible
- ≈ Interest in plantings

Not well suited for sites with...

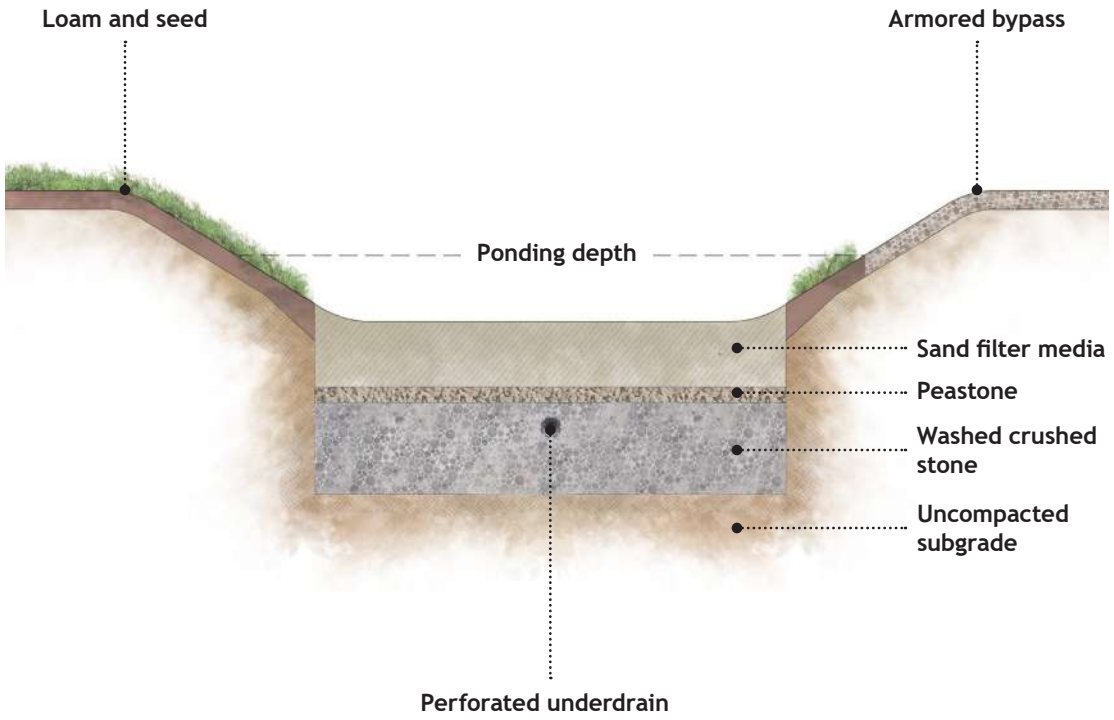
- ≈ Limited ability to establish and maintain vegetation

Variation-Specific Design Considerations

- **Surface configuration** involves a surface treatment using the sand itself or washed crushed stone or peastone to provide some protection. The sand layer can be topped with soil and plantings, provided it is separated with filter fabric, but doing so risks breakthrough and clogging of the sand media.
- **Subsurface configuration** involves using underground chambers as the storage component [38]. I&M challenges for subsurface Sand Filters are greater than those for surface Sand Filters.
- **Underdrains** can be elevated if infiltration is possible at the location, and this measure can be credited as an Infiltration Basin with Infiltration as the primary UOP.

Sand Media Filter

A Sand Filter is a basin or trench designed to filter runoff through a sand layer.



Well suited for sites with...

- Inability to infiltrate or need to provide treatment prior to infiltration

Not well suited for sites with...

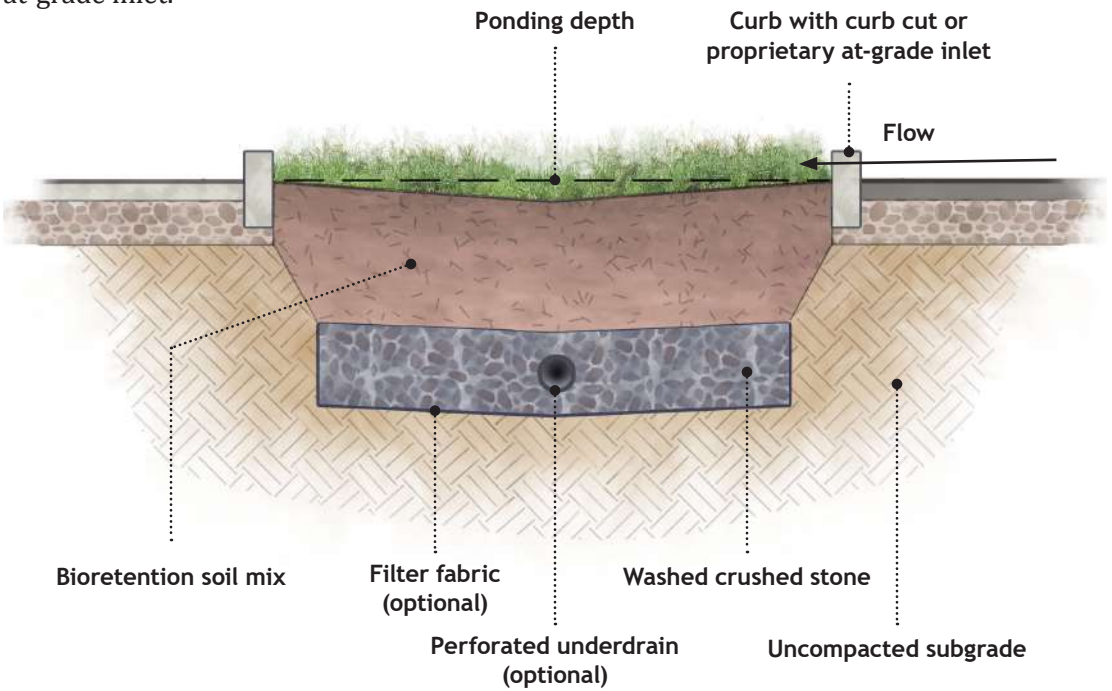
- Underground utility conflicts
- Steep slopes
- Limited I&M capabilities

Variation-Specific Design Considerations

- **Inlets** must be at or near grade and not introduce safety hazards for vehicles or pedestrians. Grates or small sumps on these inlets can provide some pretreatment of gross solids. There are many creative manufactured inlets that are capable of sitting at-grade on the market to accommodate these issues. Make sure inlets have the capacity to capture flow rates and volumes desired for the system.
- **Sizing** often presents a challenge as these systems are highly constrained and can only be sized according to available space. Use the Performance Curves to understand and optimize sizing and treatment.
- **High-traffic areas** where Bio-Filtration Curb Inlet Planters are frequently installed are often accessible to the public and receive direct runoff from urban streets and sidewalks require more frequent sediment and trash removal. Consider partnering with local neighborhood groups to help with plantings and trash.

Bio-Filtration Curb Inlet Planter

A Bio-Filtration Curb Inlet Planter is a Bio-Filtration measure located within a roadway right-of-way, immediately adjacent to the curb, containing engineered soil media and plantings. Runoff often enters the measure at the surface via a curb cut or proprietary at-grade inlet.



Well suited for sites with...

- Limited available above-ground space
- Urban areas
- Infiltration is limited or not possible
- Interest in plantings

Not well suited for sites with...

- Large Design Storage Volumes
- Limited ability to establish and maintain vegetation

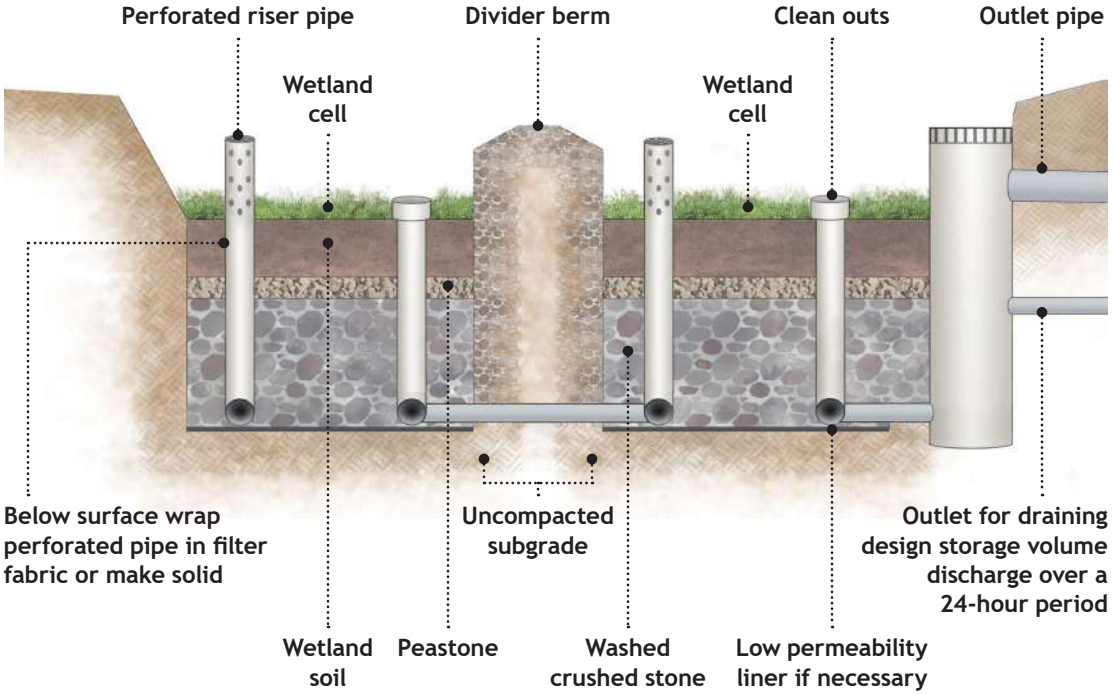
Variation-Specific Design Considerations

- **Maintaining the anoxic zone** necessary to support the denitrification process requires that portion of the SCM to be saturated at all times. Therefore, the design must either require that water is maintained within the system via low-conductivity soils or liners or that the system intercept groundwater to provide a source of constant saturation.
- **Maximize residence time to** increase Biological treatment using multiple treatment cells and outlet control for at least a 24 hour residence time. Overflows should be included for larger events.[11]
- **Risers or other piping** may be included to ensure water flows from surface storage basins to the anoxic zone and between cells.
- **The ratio of internal storage reservoir volume to design storage volume** is typically 0.25, with more recent retrofit designs using smaller ratios (around 0.1) [39], [40].
- **Inspection ports** can be included to support inspection and maintenance activities.

[11] For more information about outlet configuration for gravel wetland, see the University of New Hampshire Stormwater Center's subsurface gravel wetland report: www.unh.edu/unhsc/sites/unh.edu.unhsc/files/NHDOT%20SGW%2002-06-15%20Final%20Report_w%20Attchmts.pdf

Gravel Wetland

Gravel Wetlands are one or more flow-through Created Wetland cells containing gravel media and soils and typically planted with wetland vegetation. Water flows horizontally through the gravel media, allowing microbial treatment via the roots and microbes present in that saturated zone.



Well suited for sites with...

- Available above-ground space
- No ability to infiltrate (e.g., contaminated soils, high groundwater)

Not well suited for sites with...

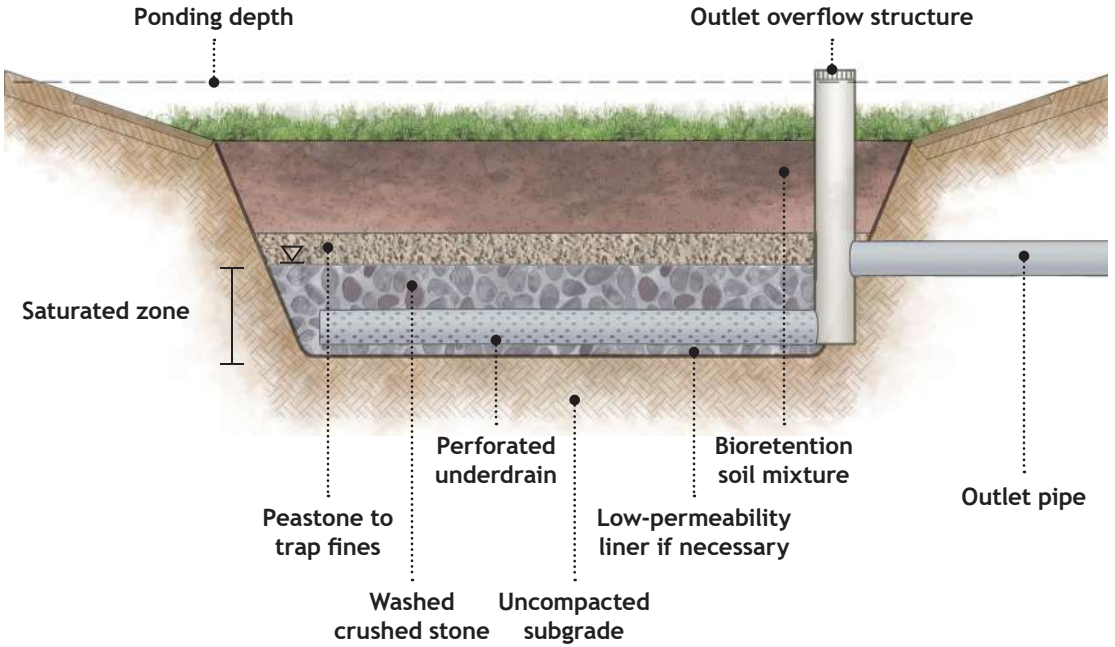
- Limited available above-ground space

Variation-Specific Design Considerations

- **Internal Storage Reservoir** may be created by using an elevated outlet pipe discharging from the outlet overflow structure or a pipe upturned 90 degrees to force an elevated outlet from underdrain pipes.
- **To avoid short circuiting** and maximize residence time, run the liner or low permeable layer at an adverse slope away from the outlet structure back to within 10 feet of the inlet.

Enhanced Bio-Filtration With Internal Storage Reservoir

Enhanced Bio-Filtration with Internal Storage Reservoir (ISR) is a basin that provides filtering through an engineered soil media similar to Bio-Filtration SCM, but designed to also include a gravel storage reservoir that remains saturated and creates an anoxic zone for Denitrification.

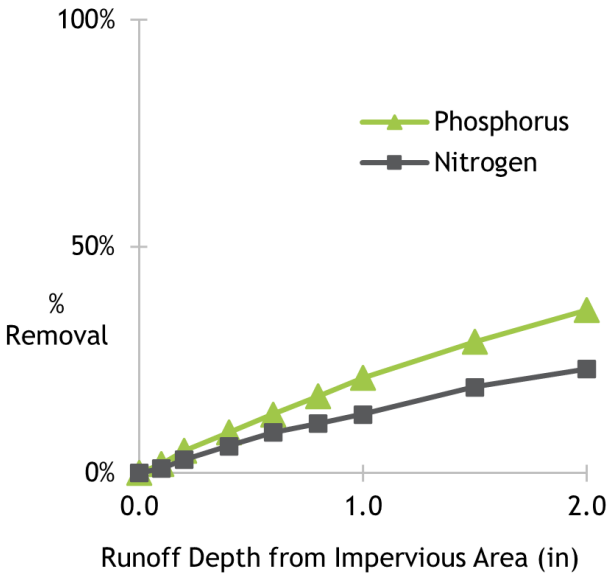


Well suited for sites with...

- Available above-ground space
- No ability to infiltrate (e.g., contaminated soils, high groundwater)
- Need to target phosphorus and nitrogen treatment

Not well suited for sites with...

- Limited ability to maintain saturated zone



Grass Swale Performance Curve. See Appendix B for full set of Performance Curves

Traditional Approaches

Traditional approaches to stormwater management are focused primarily on water quantity management and/or treatment of larger particles within stormwater runoff through the Physical—Sedimentation UOPs. They include variations of Wet Ponds, Extended Dry Detention Ponds, and Grass Swales and are often seen in stormwater designs that do not have water quality treatment as the primary goal. Extended Dry Detention Ponds have historically been a staple of stormwater design because they can attenuate peak flow rates while also providing some water quality treatment.

As presented in previous sections, stormwater management designs have evolved to include SCMs that provide more pollutant removal while requiring the same or even less space and fewer components as compared to traditional approaches. Given these advances, this manual does not encourage traditional approaches in retrofit design applications and does not provide design guidance for them. Instead, the presence of traditional SCMs on a site provides an opportunity to retrofit them to include higher-performing UOPs. Use the guidance presented in the previous sections, this chapter, and Appendix F to support retrofitting these traditional approaches to include higher-performing UOPs.

This section will give a brief explanation of each of the traditional approaches and provide examples of how they could be enhanced or retrofitted to improve water quality treatment performance.

Primary UOP	Performance Curve Category	SCMs Represented
TRADITIONAL APPROACHES		
Physical: Settling	Wet Pond	• Wet Pond • Wet Swale
Physical: Settling	Extended Dry Detention	• Dry Pond • Dry Swale • Extended Detention Wetland • Extended Dry Detention Basin
Physical: Settling	Grass Swale	• Grass Swale • Water Quality Swale • Water Quality Grass Swale with Detention



MassDOT Wet Pond and Forebay

Wet Pond/Swale

A Wet Pond/Swale is a surface pond or swale with a permanent pool of water with limited plantings or internal grading. Treatment occurs as material settles out through the water column and is dependent on residence time within the system.

Retrofit possibilities include conversion to a Gravel Wetland, which also requires a permanent pool of water, by creating an anoxic layer within gravel cells.

Created Wetland

A Created Wetland is a surface pond with wetland vegetation and internal grading. Created wetlands can be designed as online or offline systems and can be used in series. Treatment occurs primarily via Nitrification/Denitrification in the treatment cells and nutrient uptake by the wetland vegetation. They can be complex to design and have been shown to be sources of nutrients during certain parts of the seasonal cycle [41].

Retrofit possibilities include conversion to a gravel wetland, which involves one or more flow-through Created Wetland cells and also requires a permanent pool of water to create the anoxic layer within the gravel cells.

Extended Dry Detention Pond

An Extended Dry Detention Pond is a surface pond with an outlet or outlets set at the bottom of pond elevations, designed to temporarily store runoff and slowly release through surface outlets over a prescribed time. Treatment occurs as material settles out through the temporary water column created during runoff detention.

Retrofit possibilities include:

- ≈ Conversion to an Infiltration Basin (with potential additional gravel reservoir if more storage is needed) by raising or blocking lower-level outlets.
- ≈ Conversion to a Bio-Filtration system by adding soil media, plantings, and an optional underdrain for discharge.
- ≈ Conversion to a Gravel Wetland by adding a saturated reservoir.

If additional space is available downgradient, use the settling process of the Extended Dry Detention Pond as pretreatment and incorporate an additional SCM focusing on more effective UOPs (e.g., Infiltration or Media Filter SCM) downstream for additional treatment.

Grass Swale

A Grass Swale is a grass-lined open conveyance that provides Settling, Filtration, and Infiltration as runoff flows through.

Retrofit possibilities include:

- ≈ Conversion to an Infiltration Swale by retaining the DSV by providing outlet control at the terminus of the swale and/or throughout the swale via impermeable check dams or weirs.
- ≈ Conversion to a Bio-Filtration Swale by adding soil media, plantings, and optional underdrains for discharge.

If additional space is available downgradient, use the sedimentation process of the Grass Swale as pretreatment and incorporate an additional SCM focusing on more effective UOPs (e.g., Infiltration or Media Filter SCM) downstream for additional treatment.

Manufactured Devices

Manufactured devices are structures or systems that have been pre-engineered to support UOPs, including Enhanced Sedimentation/Swirl Concentration, Filtering, Adsorption, and Plant Metabolism. They are often configured to require significantly less space than traditional SCMs and be placed underground, and are therefore appealing for retrofit scenarios where available footprint may be limited.

Currently there are no Performance Curves for these manufactured devices. In general, these devices have been known to work well at removing gross solids and coarse sediment and pollutants bound to those particles, although their removal performance varies widely across each device since each is engineered with specific hydraulic configurations and enhanced UOP features. Their performance also relies on their size, which is often characterized by the flow rate they can accommodate. Third-party testing is recommended as the best way to evaluate their effectiveness. If available, that testing should include:

- ≈ Testing based on typical stormwater inflows (i.e., volumes, flow rates, pollutant concentrations).
- ≈ Field testing in addition to controlled laboratory testing.
- ≈ Analysis of removal performance of varying particles sizes.
- ≈ Analysis of removal performance of specific pollutants of interest (e.g., phosphorus, nitrogen, various metals, bacteria).

Because of their gross particle and pollutant removal performance and their typically small footprint, these devices can be useful in ultra-urban or constrained settings to provide some level of treatment. They can also serve as pretreatment for many of the other SCMs discussed in this manual.

Types of Manufactured Devices

Hydrodynamic separators: These devices are flow-through systems that use chambers and/or swirl concentrators to separate particulate matter from stormwater. Various proprietary systems have their own engineered configurations and devices designed to separate particulate matter and to isolate that material to prevent resuspension. Hydrodynamic separators are typically used for removing sediment and/or other non-dissolved pollutants since they do not contain any treatment media. Accumulated particulate matter is removed through periodic cleaning.

Filtering systems: These devices are flow-through systems that pass runoff through filter media that is designed to capture specific particulate sizes and/or pollutants through Physical—Filtering and/or Chemical processes. Often the filter media is configured in cartridges that can be more easily maintained through backwash or replacement. Some systems use Biological treatment through custom plantings.

Tree Filters

Tree Filters are a type of flow-through filtering manufactured device with open-bottoms and one or more trees filled with filter media. These systems are appealing in urban areas where street trees provide co-benefits for the site. The Providence Stormwater Innovation Center provides a wide range of variations and considerations for these systems.

www.stormwaterinnovation.org/surface-tree-trench-options-guide

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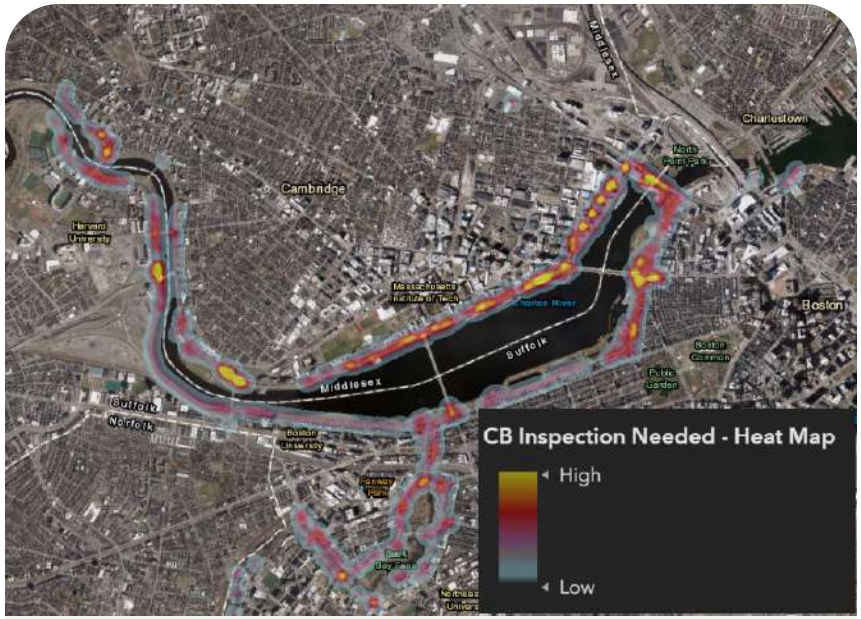
Inspection & Maintenance

The long-term success of any SCM system relies on attention and maintenance. A successful SCM will function at or close to the original design standard years after installation. In order to support a successful SCM, components of the system will need to be inspected and evaluated for their ability to perform as designed, and then maintained as necessary to restore any loss function.

SCM inspection and maintenance (I&M) is an extensive topic on its own. Accordingly, for its purposes, this manual only touches upon the SCM planning (Chapter 2) and design (Chapter 4 and Chapter 5) considerations related to inspection and maintenance. It does not cover the numerous other aspects of SCM inspection and maintenance (e.g., protocols, best practices, and planning, tracking, and reporting).

Given the importance of planning for and performing SCM inspection and maintenance, the designer is encouraged to review these available resources:

- EPA Region 1 compiled guidance, standard operating procedures (SOPs) and templates—www.epa.gov/npdes-permits/stormwater-tools-new-england#gh
- TRB's National Cooperative Highway Research Program (NCHRP) Report 792: Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices—www.trb.org/Publications/Blurbs/171471.aspx
- Minnesota Stormwater Manual: Operation and maintenance of green stormwater infrastructure best management practices—state.mn.us
- Implementing a Stormwater BMP Inspection & Maintenance Program A Guidance Manual for New Hampshire Municipalities—https://www4.des.state.nh.us/nh-ms4/wp-content/uploads/2022/01/SSC_IM_-Guidance_Manual_Final.pdf



EXAMPLE OF I&M MANAGEMENT

Catch Basin Cleaning Optimization in Massachusetts by the Department of Conservation and Recreation (DCR)

The Massachusetts Department of Conservation and Recreation (DCR) performed a geospatial analysis to rank and prioritize catch basins for inspection and maintenance across their properties in the entire state of Massachusetts. The priority ranking considered a variety of factors including previous inspection frequency, flood priority, and last measured catch basin sediment level. This analysis allowed DCR to concentrate their I&M resources in critical areas [42].

- Philadelphia, Green City, Clean Waters Green Infrastructure Maintenance Manual—https://water.phila.gov/pool/files/gsi-maintenance-manual.pdf
- UNH Stormwater Center Operation and Maintenance checklists—www.unh.edu/unhsc/maintenance
- New York City Stormwater Manual—www.nyc.gov/assets/dep/downloads/pdf/water/stormwater/unified-stormwater-rule/uswr_nyc_stormwater_manual.pdf

Appendices

Appendix A—New England Stormwater Regulatory Requirement

*Table A-1 State Regulatory Programs Addressing Stormwater Mitigation Across New England**

	State					
Regulatory Component	**Connecticut**	**Maine**	**Massachusetts**	**New Hampshire**	**Rhode Island**	**Vermont**
New/Redevelopment Permit Program (Regulatory Agency)	General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities (Connecticut Department of Energy and Environmental Protection [CTDEEP])	Chapter 500: Stormwater Management (Maine Department of Environmental Protection [MEDEP])	310 CMR 10.00 Wetlands Protection Act (Massachusetts Department of Environmental Protection [MassDEP])	Chapter Env-Wq 1500 Alteration of Terrain (New Hampshire Department of Environmental Services [NHDES])	250-RICR-150-10-8 Stormwater Management, Design, and Installation Rules (Rhode Island Department of Environmental Management [RIDEM])	Vermont Water Pollution Control statute, 10 V.S.A. Chapter 47, specifically §§ 1258 and 1264 and the Vermont Stormwater Permitting Rule (Environmental Protection Rules, Chapter 22 (Vermont Department of Environmental Conservation [VTDEC])
Guidance Document Referenced	2004 Connecticut Stormwater Quality Manual	Maine Stormwater Best Practices Manual	Massachusetts Stormwater Handbook	New Hampshire Stormwater Manual	Rhode Island Stormwater Design and Installation Standards Manual	2017 Vermont Stormwater Management Manual Rule
Pollutant Percent Reductions Required	80% Total Suspended Solids (TSS) (guidance, not required)	None	80% TSS	None	80% TSS 60% Pathogens 30% Total Phosphorus (TP) (freshwater discharge) 30% Total Nitrogen (salt/tidal discharge)	Tiered approach. Practices achieving 80% TP and 98% TSS must be evaluated first. Only once these have been deemed infeasible may a designer move to "lower tiers", which provide less TP/TSS reduction.
New Development Prescribed Volume to Treat**	1.0 inch	1.0 inch for impervious area 0.4 inch for pervious area	0.5 to 1.0 inch depending on discharge source and receiving water	1.0 inch	1.0 inch for impervious area and 0.2 inch for pervious area in certain large-scale projects	1.0 inch
Redevelopment Prescribed Volume to Treat	0.5 inch or 1.0 inch to the Maximum Extent Practicable (MEP) depending on original impervious area	Varies based on land use	Maximum Extent Practicable	1.0 inch	1 inch from 50% redevelopment area with credit for reduction in impervious area	50% of water quality volume (WQV) from redeveloped impervious area OR less if impervious area is reduced
SCM Percent Reductions Provided	No	No	Yes	No	Yes	Yes
Prescribed BMP Design Standards/ Criteria	Yes	Yes	Yes	Yes	Yes	Yes
TMDL Requirements Included	Yes	Requirements for phosphorus impaired watersheds and urban impaired streams	Yes (Numeric)	Yes (Numeric)	Yes	Yes

* Note: This table reflects state guidance as of April 2022. This table will be republished periodically with updated requirements, but for the most recent requirements, please refer to the Permit Program for the respective state.

** State guidance often refers to this as "Water Quality Volume." Because each state defines this differently, this manual specifically avoids use of this term.

*Table A-2 National Pollutant Discharge Elimination System (NPDES) MS4 Regulatory Programs Addressing Stormwater Mitigation Across New England**

Minimum Control Measure (MCM) 5 Post-Construction Requirements

Regulatory Component	State					
	Connecticut	Maine	Massachusetts	New Hampshire	Rhode Island	Vermont
Permit Program	General Permit for the Discharge of Stormwater from Small Municipal Separate Storm Sewer Systems	General Permit for the Discharge of Stormwater from Small Municipal Separate Storm Sewer Systems	General Permits for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems in Massachusetts	General Permits for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems	Rhode Island Pollutant Discharge Elimination System Storm Water Discharge from Small Municipal Separate Storm Sewer Systems and from Industrial Activity at Eligible Facilities Operated by Regulated Small MS4s	Vermont Pollutant Discharge Elimination System (VPDES) General Permit 3-9014 (2018) for Stormwater Discharges from Regulated Small Municipal Separate Storm Sewer Systems (MS4s) and Certain Developed Lands
Permit Author	State (CTDEEP)	State (MEDEP)	EPA Region 1	EPA Region1	State (RIDEM)	State (VTDEC)
Water Quality Requirements	Reduce pollutants to MEP	Reduce pollutants to MEP	See next row	See next row	Reduce pollutants to MEP	Reduce pollutants to MEP
Pollutant Percent Reductions Required	None	None	Remove 90% TSS AND 60% TP (New Development) OR Remove 80% TSS AND 50% TP (Redevelopment) or volume as below	Remove 90% TSS AND 60% TP (New Development) OR Remove 80% TSS AND 50% TP (Redevelopment) or volume as below	None	None
New Development Prescribed Volume to Treat	1.0 inch to MEP	None	1.0 inch or pollutant reductions as above	1.0 inch or pollutant reductions as above	None	None
Redevelopment Prescribed Volume to Treat	1.0 inch to MEP or 0.5 inch to MEP if < 40% IC	None	0.8 inch or pollutant reductions as above	1.0 inch or pollutant reductions as above	None	None
Prescribed SCM Design Standards/Criteria	Yes (reference state guidance manual)	None	Yes (reference state guidance manual)	Yes (reference state guidance manual)	Yes (reference state guidance manual)	None

* Note: This table reflects state guidance as of April 2022. This table will be republished periodically with updated requirements, but for the most recent requirements, please refer to the Permit Program for the respective state.

Table A-2 National Pollutant Discharge Elimination System (NPDES) MS4 Regulatory Programs Addressing Stormwater Mitigation Across New England (continued)*

TMDL/Impaired Waters Requirements

Regulatory Component	State					
	Connecticut	Maine	Massachusetts	New Hampshire	Rhode Island	Vermont
TMDL Retrofit Structural Controls Required	Yes	Yes	Yes	Yes	Yes	Yes
Impaired Waters Retrofit Structural Controls Required	Yes	Yes	Yes	Yes	Yes	Potential
Numeric Targets	Yes, for select TMDLs	Yes, for select TMDLs	Yes, for select TMDLs	Yes, for select TMDLs	Permittee-defined "Measurable Goals"	Yes, for select TMDLs
Prescribed SCM Design Standards/ Criteria	Yes (in accordance with MS4 MCMs)	None	Yes (reference MassDEP SW Handbook)	Yes (reference NHDES Manual)	Yes (in accordance with MS4 MCMs)	None
Treatment Credit System Used	None	None	Performance Curves	Performance Curves	None	Performance Curves

* Note: This table reflects state guidance as of April 2022. This table will be republished periodically with updated requirements, but for the most recent requirements, please refer to the Permit Program for the respective state.

Appendix B—Performance Curves

This manual presents the EPA Stormwater Control Measure (SCM) Performance Curves as a means of estimating pollutant reduction performance for various SCMs. This manual presents the SCM Performance Curves included in the 2016 Massachusetts and New Hampshire Municipal Separate Storm Sewer System (MS4) Permits, which are administered by EPA. The Massachusetts and New Hampshire MS4 Permits currently include pollutant reduction performance values for Total Phosphorus (TP) and Total Nitrogen (TN). EPA has also developed curves for Zinc (Metals), and Total Suspended Solids (TSS), and Bacteria for various SCMs. EPA is currently in the process of updating the SCM Performance Curves with updated pollutant reduction performance values and creating new Performance Curves for additional SCMs. These updated and new Performance Curves are anticipated to be released some time in 2023/2024. However, since these updated SCM Performance Curves are not publicly available at this time, they have not been included in this manual.

The Massachusetts and New Hampshire MS4 Permits present Infiltration SCM Performance Curves based on the infiltration rate of the underlying soils. This manual presents infiltration SCM Performance Curves based on Hydrologic Soils Group (HSG) as opposed to infiltration rate, since HSG is a more commonly used and accessible soils classification system. Table B-1 below presents the infiltration rate assumed for each HSG for the Infiltration SCM Performance Curves presented in this manual. The full set of Infiltration Performance Curves can be found in Attachment 3 to Appendix F of the Massachusetts MS4 Permit [46].

Table B-1: HSG and Corresponding Infiltration Rate assumed in this manual (in/hr)

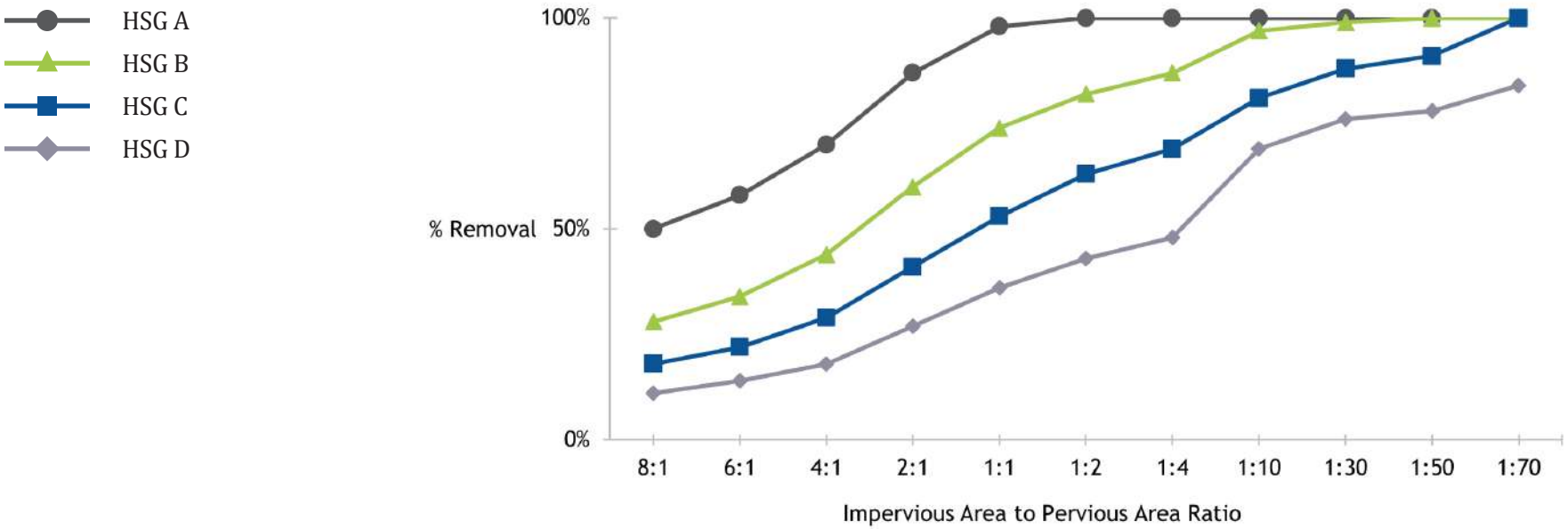
HSG	Corresponding Infiltration Rate (in/hr)
A	8.27
B	1.02
C	0.17
D	0.10

Additionally, this manual includes some new SCM Performance Curves, specifically for infiltration in HSG D. The SCM Performance Curves currently included in the Massachusetts and New Hampshire MS4 do not currently include reduction values for infiltration in HSG D soils (infiltration rate of 0.10 in/hr or less). However, new modeling performed by EPA and additional research performed by non-EPA entities [47], [48] suggest that significant infiltration can still take place in these soils with low infiltration rates and significant pollutant reduction can be achieved. Since these reduction values are planned to be included in the Massachusetts and New Hampshire MS4 permits moving forward and are entirely new, they have been included in this manual since this manual aims to support designers in installing retrofit SCMs wherever possible based on site constraints.

This manual also presents pollutant reduction values for Bacteria, which are not included in the Massachusetts and/or New Hampshire MS4 Permits. However, these reduction values have been developed and approved by EPA Region 1 for select SCMs and as such are worthwhile for inclusion in this manual since Bacteria may be a pollutant of concern in retrofit scenarios.

Similarly, this manual presents pollutant reduction values for Effective Impervious Area reduction, which are also not included in the Massachusetts and/or New Hampshire MS4 Permits. These Effective Impervious Area reduction values were developed by VHB for the Rhode Island Department of Transportation (RIDOT) based on similar modeling and techniques used to develop the EPA SCM Performance Curves. These Effective Impervious Area reduction values have been reviewed and approved by EPA and the Rhode Island Department of Environmental Management (RIDEM) and as such are worthwhile for inclusion in this manual since Effective Impervious Area reduction may be a pollutant of concern in retrofit scenarios.

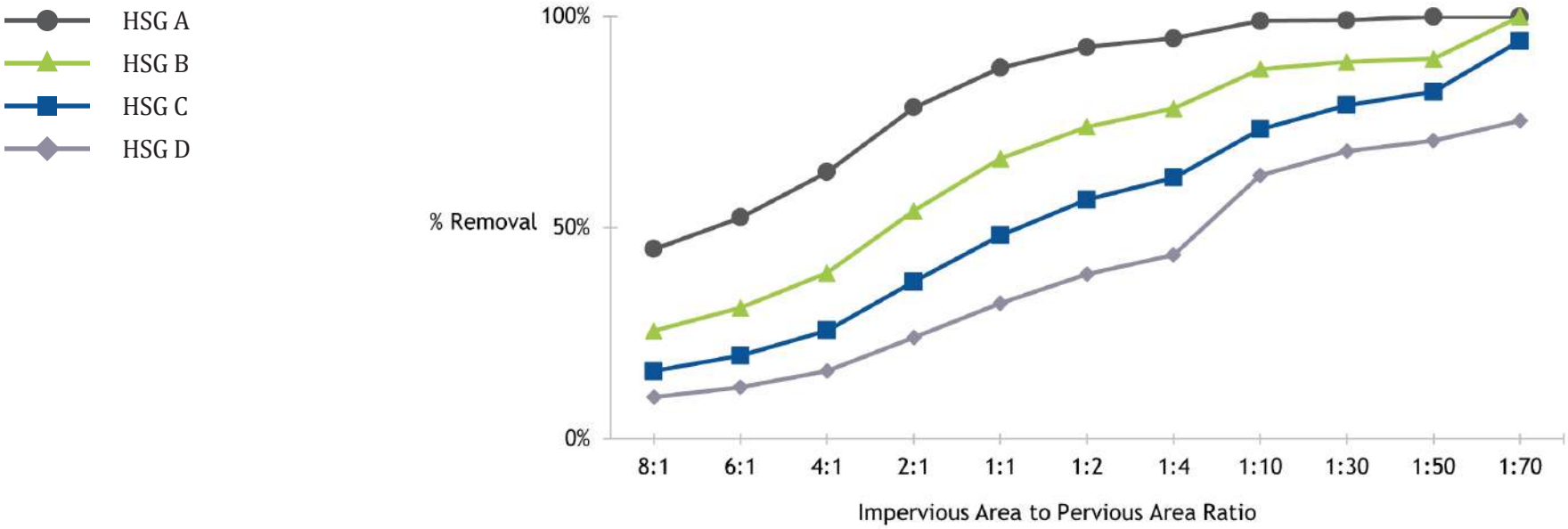
Impervious Area Disconnection—Effective IA Reduction



Effective IC Reduction

HSG	Impervious Area to Pervious Area Ratio										
	8:1	6:1	4:1	2:1	1:1	1:2	1:4	1:10	1:30	1:50	1:70
HSG A	50%	58%	70%	87%	98%	100%	100%	100%	100%	100%	100%
HSG B	28%	34%	44%	60%	74%	82%	87%	97%	99%	100%	100%
HSG C	18%	22%	29%	41%	53%	63%	69%	81%	88%	91%	100%
HSG D	11%	14%	18%	27%	36%	43%	48%	69%	76%	78%	84%

Impervious Area Disconnection—Pollutant Reduction[12]

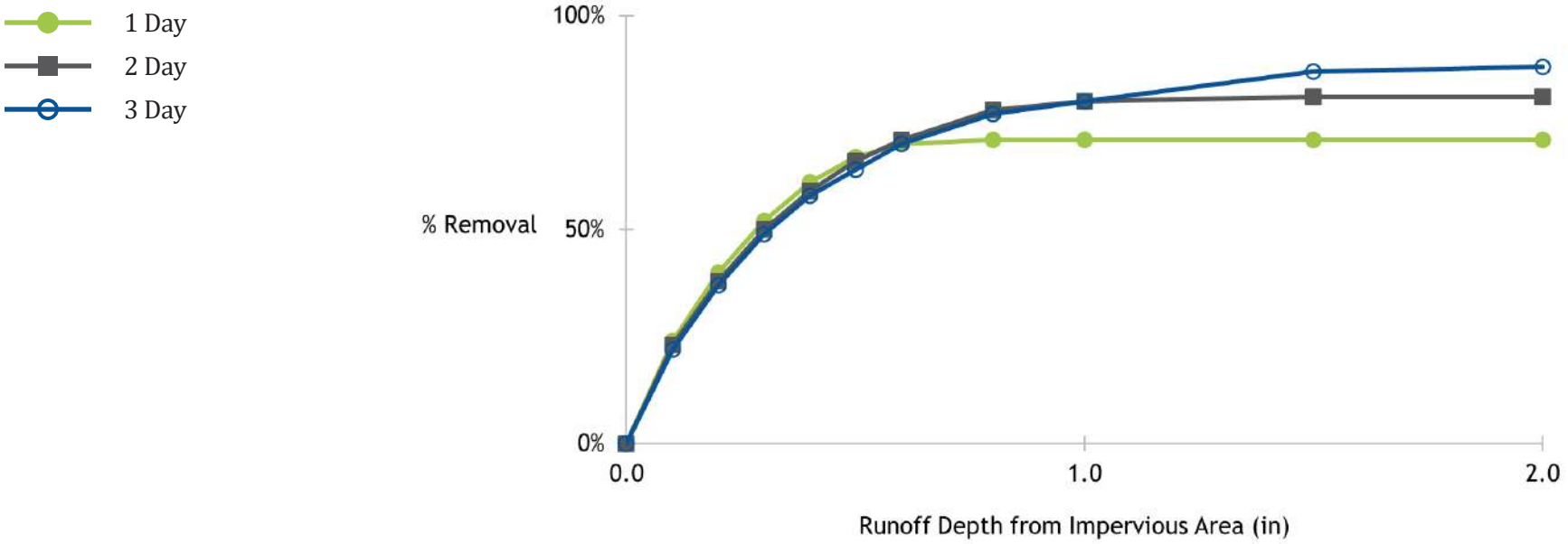


Pollutant Reduction

HSG	Impervious Area to Pervious Area Ratio										
	8:1	6:1	4:1	2:1	1:1	1:2	1:4	1:10	1:30	1:50	1:70
HSG A	45%	52%	63%	78%	88%	93%	95%	99%	99%	100%	100%
HSG B	26%	31%	39%	54%	66%	74%	78%	88%	89%	90%	100%
HSG C	16%	20%	26%	37%	48%	57%	62%	73%	79%	82%	94%
HSG D	10%	12%	16%	24%	32%	39%	44%	62%	68%	71%	75%

[12]% Removal for this measure represents runoff reduction, but may be used as a surrogate for all other pollutants.

Impervious Area Disconnection through Storage (HSG A)—Impervious to Pervious Ratio 4:1[13]

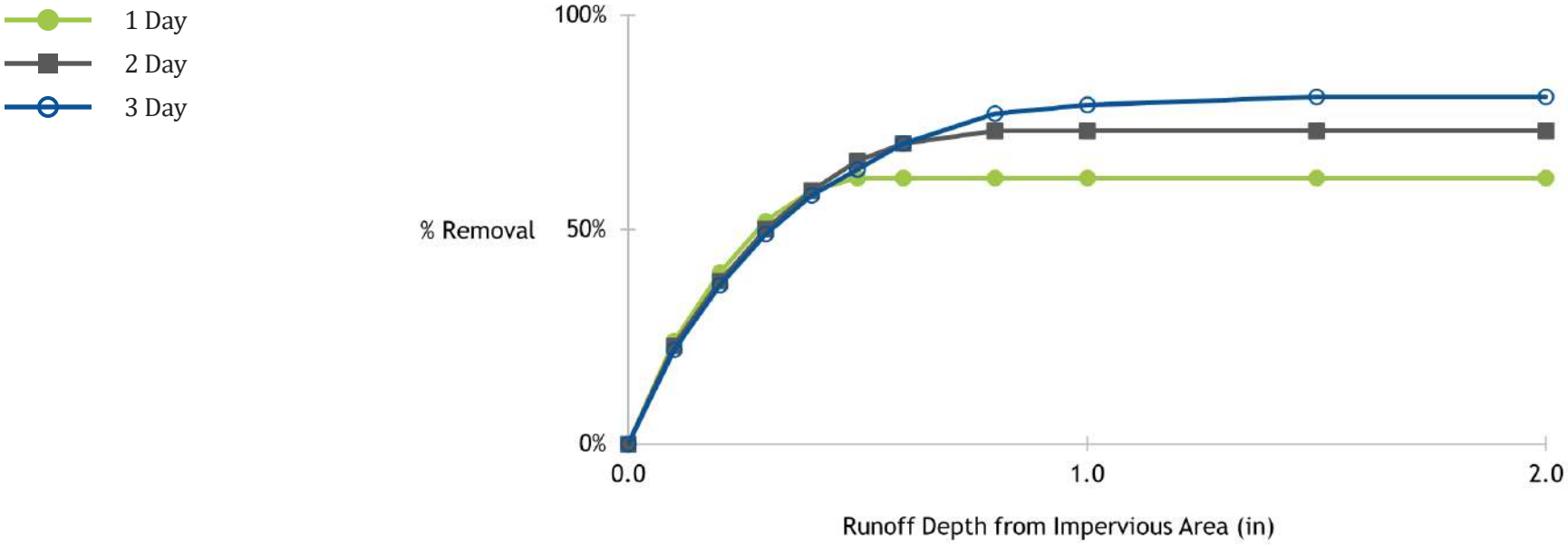


Release Rate	Design Storage Volume: Runoff Depth from Impervious Area (in)										
	0	0.1	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00
1-day	0%	24%	40%	52%	61%	67%	70%	71%	71%	71%	71%
2-day	0%	23%	38%	50%	59%	66%	71%	78%	80%	81%	81%
3-day	0%	22%	37%	49%	58%	64%	70%	77%	80%	87%	88%

[13] Performance curves for multiple Impervious to Pervious Area Ratios have been developed for this measure. This manual includes only the 4:1 ratio curves as an example. See Attachment 3 to Appendix F of the Massachusetts MS4 permit [19] for the complete set of IA Disconnection through Storage Performance Curves.

% Removal for this measure represents runoff reduction, but may be used as a surrogate for all other pollutants.

Impervious Area Disconnection through Storage (HSG B)—Impervious to Pervious Ratio 4:1[14]

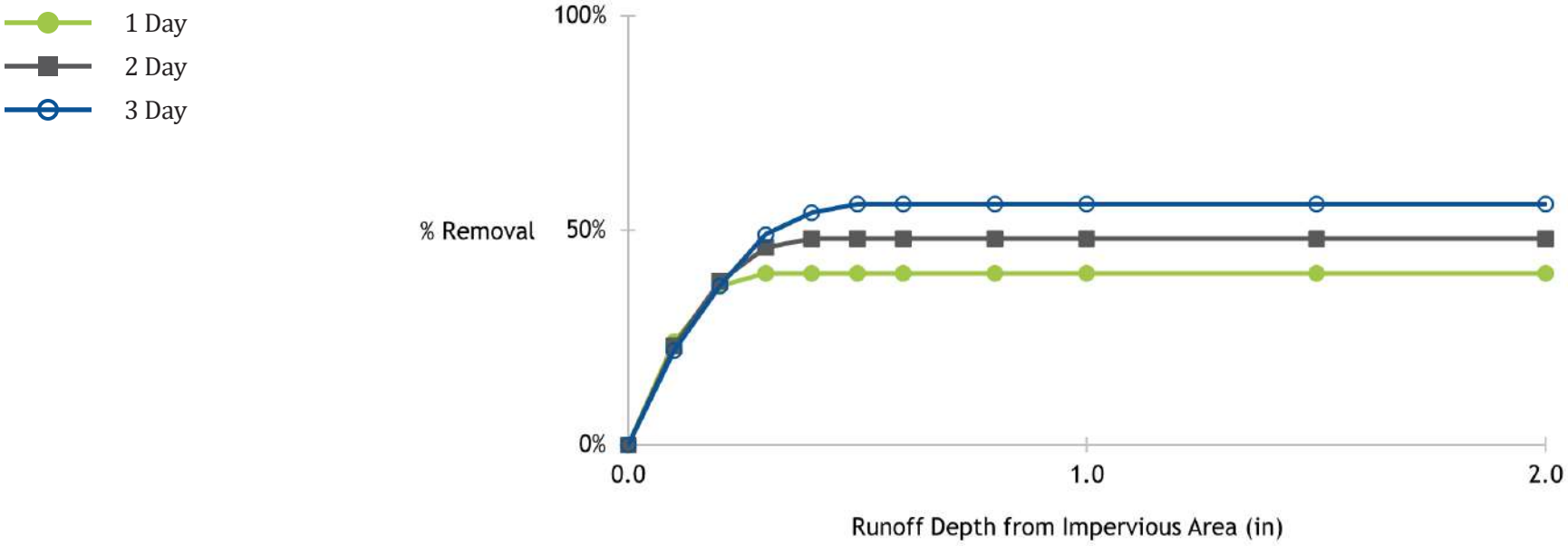


Release Rate	Design Storage Volume: Runoff Depth from Impervious Area (in)										
	0	0.1	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00
1-day	0%	24%	40%	52%	59%	62%	62%	62%	62%	62%	62%
2-day	0%	23%	38%	50%	59%	66%	70%	73%	73%	73%	73%
3-day	0%	22%	37%	49%	58%	64%	70%	77%	79%	81%	81%

[14]Performance curves for multiple Impervious to Pervious Area Ratios have been developed for this measure. This manual includes only the 4:1 ratio curves as an example. See Attachment 3 to Appendix F of the Massachusetts MS4 permit [19] for the complete set of IA Disconnection through Storage Performance Curves.

% Removal for this measure represents runoff reduction, but may be used as a surrogate for all other pollutants.

Impervious Area Disconnection through Storage (HSG C)—Impervious to Pervious Ratio 4:1[15]

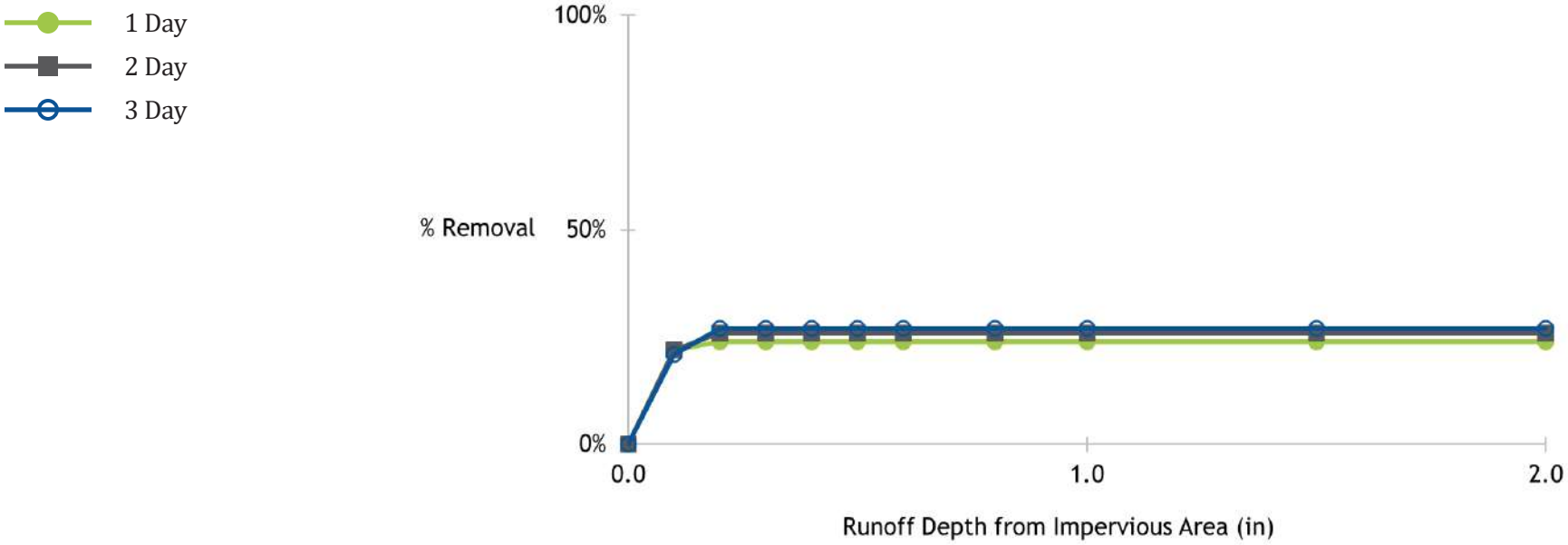


Release Rate	Design Storage Volume: Runoff Depth from Impervious Area (in)										
	0	0.1	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00
1-day	0%	24%	37%	40%	40%	40%	40%	40%	40%	40%	40%
2-day	0%	23%	38%	46%	48%	48%	48%	48%	48%	48%	48%
3-day	0%	22%	37%	49%	54%	56%	56%	56%	56%	56%	56%

[15]Performance curves for multiple Impervious to Pervious Area Ratios have been developed for this measure. This manual includes only the 4:1 ratio curves as an example. See Attachment 3 to Appendix F of the Massachusetts MS4 permit [19] for the complete set of IA Disconnection through Storage Performance Curves.

% Removal for this measure represents runoff reduction, but may be used as a surrogate for all other pollutants.

Impervious Area Disconnection through Storage (HSG D)—Impervious to Pervious Ratio 4:1[16]



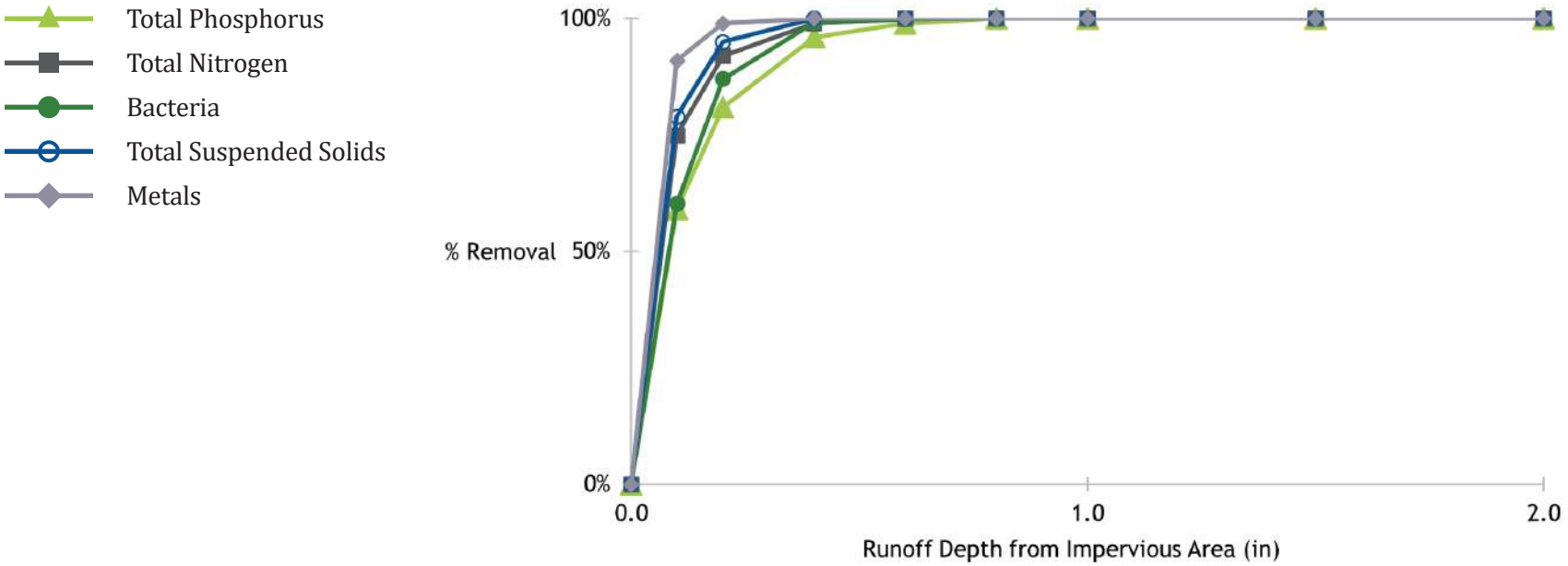
Release Rate	Design Storage Volume: Runoff Depth from Impervious Area (in)										
	0	0.1	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00
1-day	0%	22%	24%	24%	24%	24%	24%	24%	24%	24%	24%
2-day	0%	22%	26%	26%	26%	26%	26%	26%	26%	26%	26%
3-day	0%	21%	27%	27%	27%	27%	27%	27%	27%	27%	27%

[16]Performance curves for multiple Impervious to Pervious Area Ratios have been developed for this measure. This manual includes only the 4:1 ratio curves as an example. See Attachment 3 to Appendix F of the Massachusetts MS4 permit [19] for the complete set of IA Disconnection through Storage Performance Curves.

% Removal for this measure represents runoff reduction, but may be used as a surrogate for all other pollutants.

Infiltration Basin (HSG A)

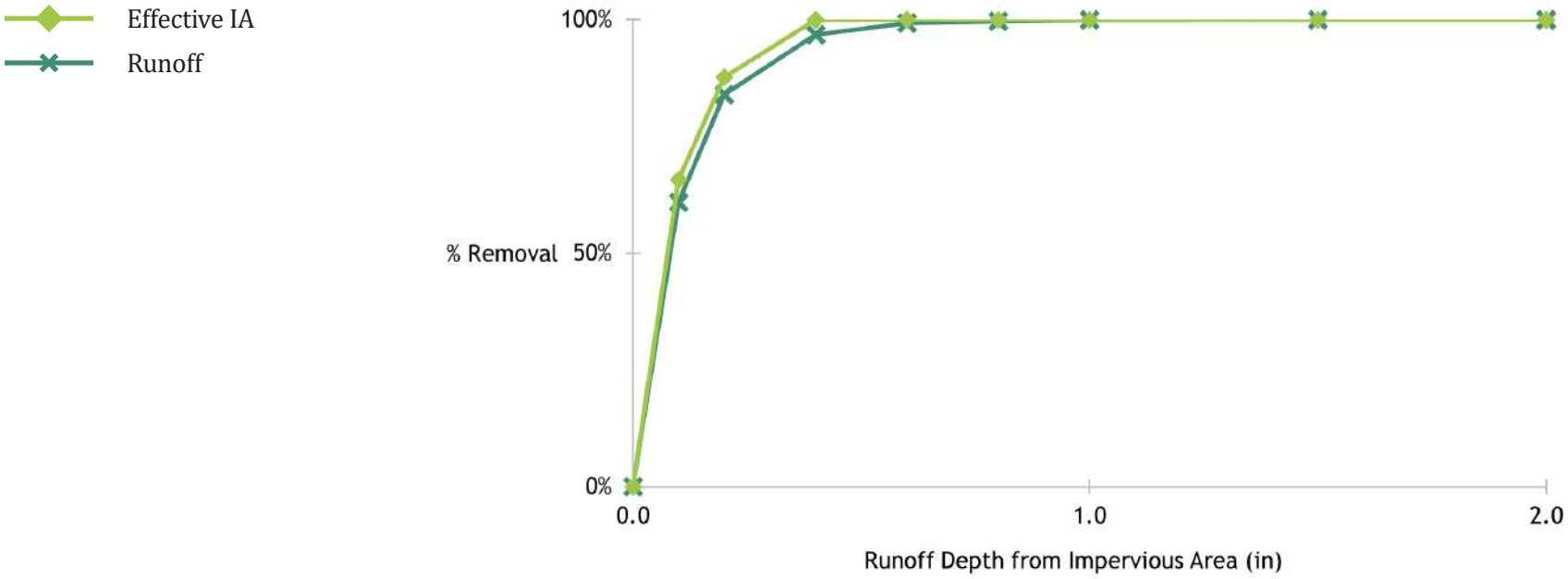
(Infiltration Rate = 8.27 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	59%	81%	96%	99%	100%	100%	100%	100%
TN	0%	75%	92%	99%	100%	100%	100%	100%	100%
Bacteria	0%	60%	87%	99%	100%	100%	100%	100%	100%
TSS	0%	79%	95%	100%	100%	100%	100%	100%	100%
Metals	0%	91%	99%	100%	100%	100%	100%	100%	100%

Infiltration Basin (HSG A)

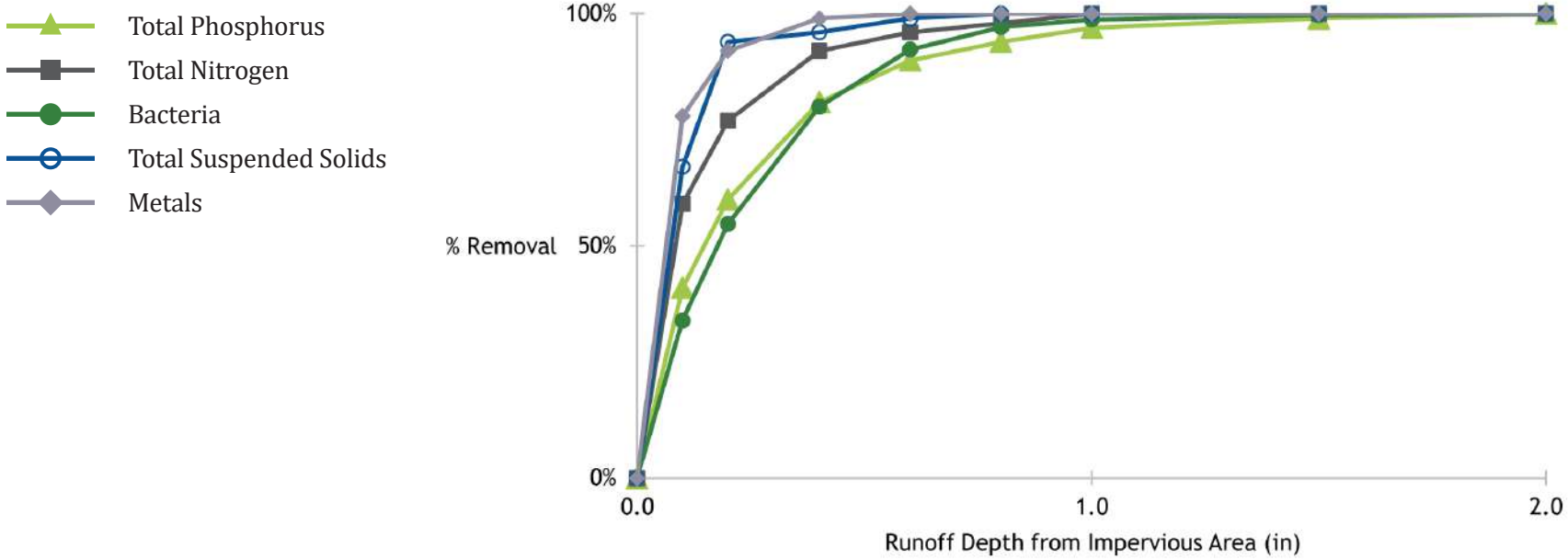
(Infiltration Rate = 8.27 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	66%	88%	100%	100%	100%	100%	100%	100%
Runoff	0%	61%	84%	97%	99%	100%	100%	100%	100%

Infiltration Basin (HSG B)

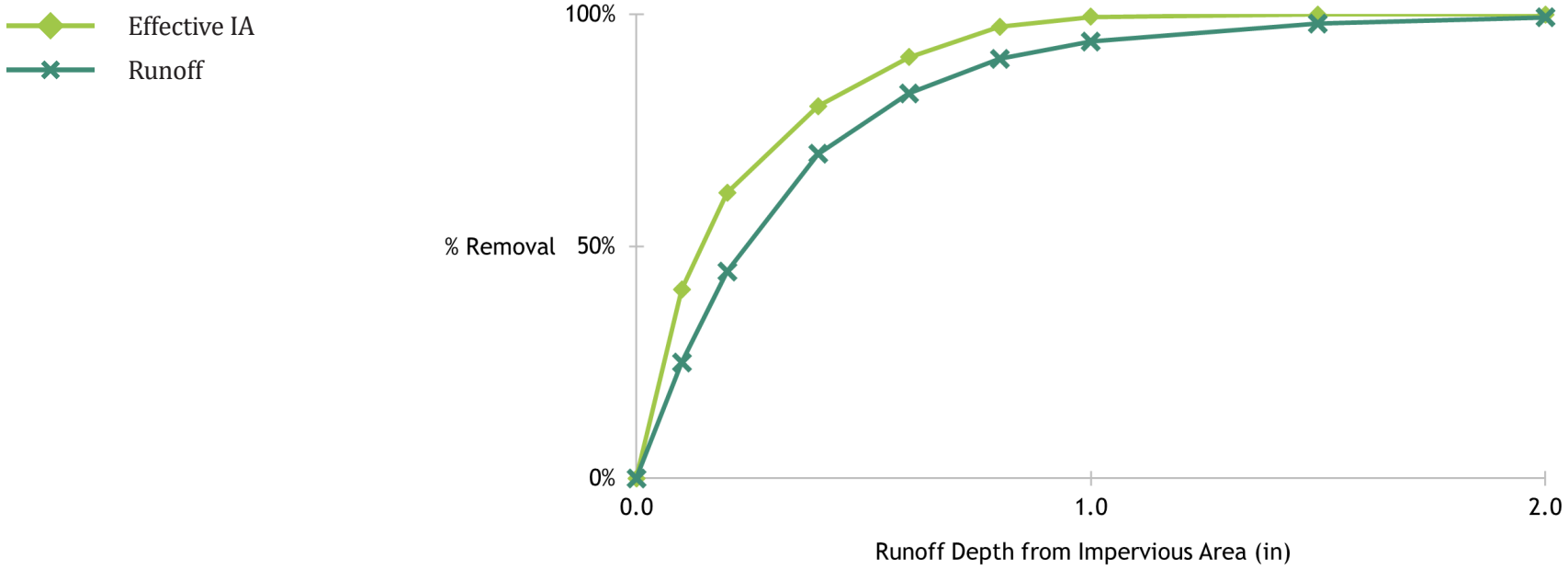
(Infiltration Rate = 1.02 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	41%	60%	81%	90%	94%	97%	99%	100%
TN	0%	59%	77%	92%	96%	98%	100%	100%	100%
Bacteria	0%	34%	55%	80%	92%	97%	99%	100%	100%
TSS	0%	67%	94%	96%	99%	100%	100%	100%	100%
Metals	0%	78%	92%	99%	100%	100%	100%	100%	100%

Infiltration Basin (HSG B)

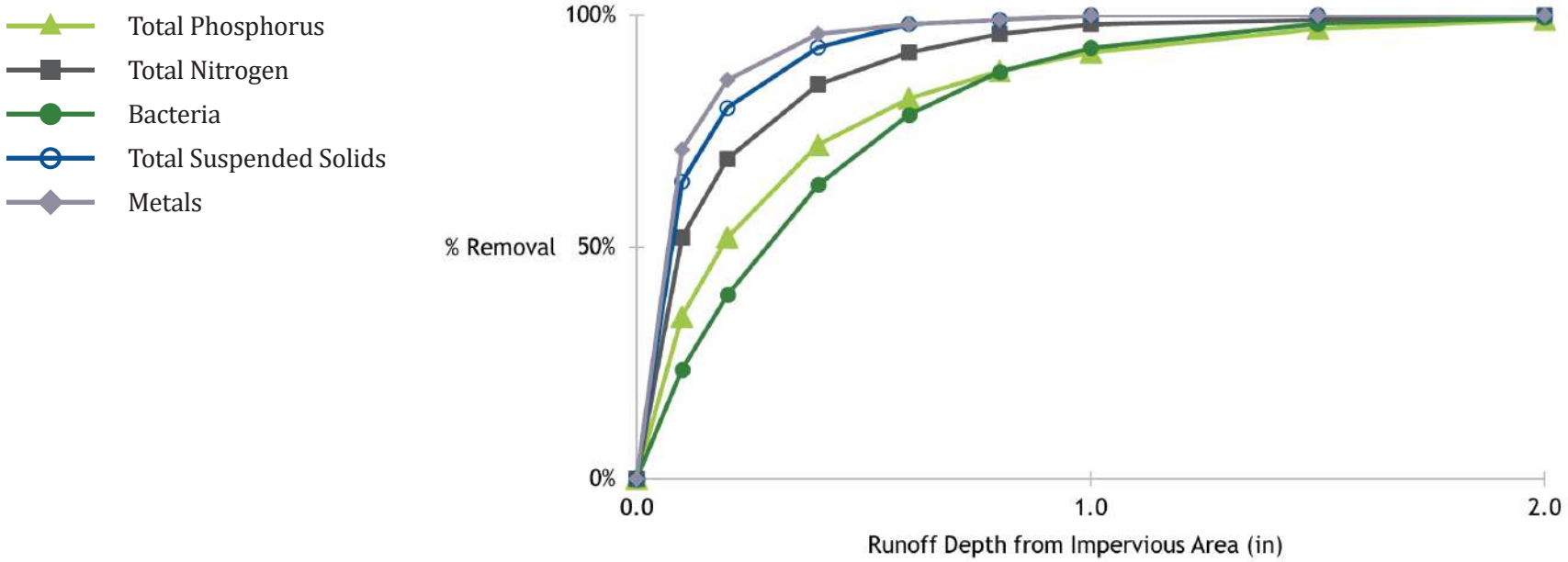
(Infiltration Rate = 1.02 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	41%	62%	80%	91%	97%	99%	100%	100%
Runoff	0%	25%	45%	70%	83%	90%	94%	98%	99%

Infiltration Basin (HSG C)

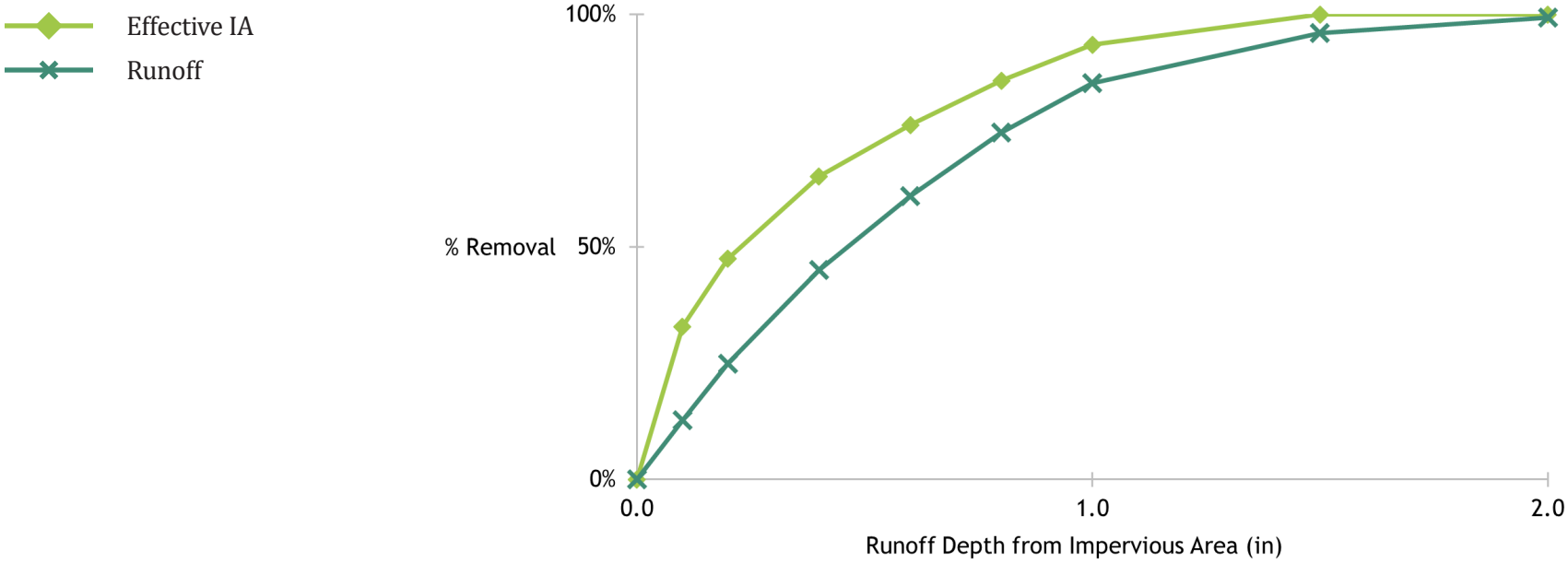
(Infiltration Rate = 0.17 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	35%	52%	72%	82%	88%	92%	97%	99%
TN	0%	52%	69%	85%	92%	96%	98%	99%	100%
Bacteria	0%	24%	40%	63%	79%	88%	93%	98%	99%
TSS	0%	64%	80%	93%	98%	99%	100%	100%	100%
Metals	0%	71%	86%	96%	98%	99%	100%	100%	100%

Infiltration Basin (HSG C)

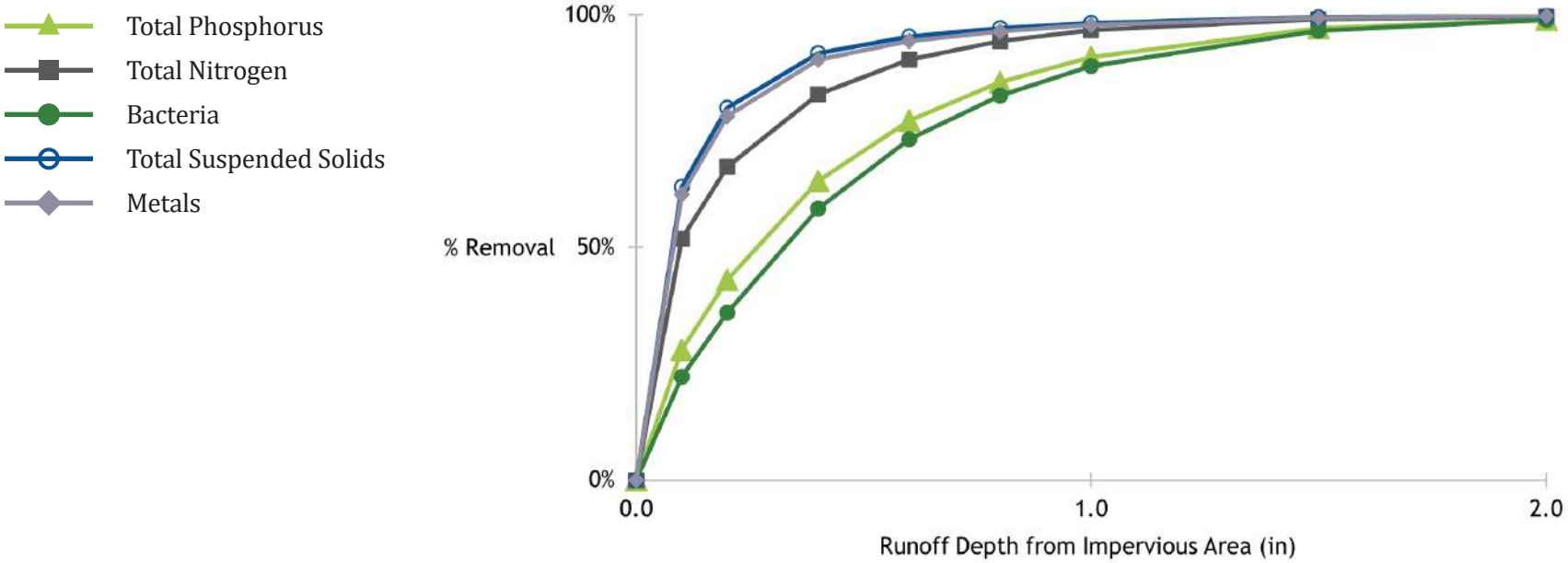
(Infiltration Rate = 0.17 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	33%	48%	65%	76%	86%	93%	100%	100%
Runoff	0%	13%	25%	45%	61%	75%	85%	96%	99%

Infiltration Basin (HSG D)[17]

(Infiltration Rate = 0.10 in/hr)

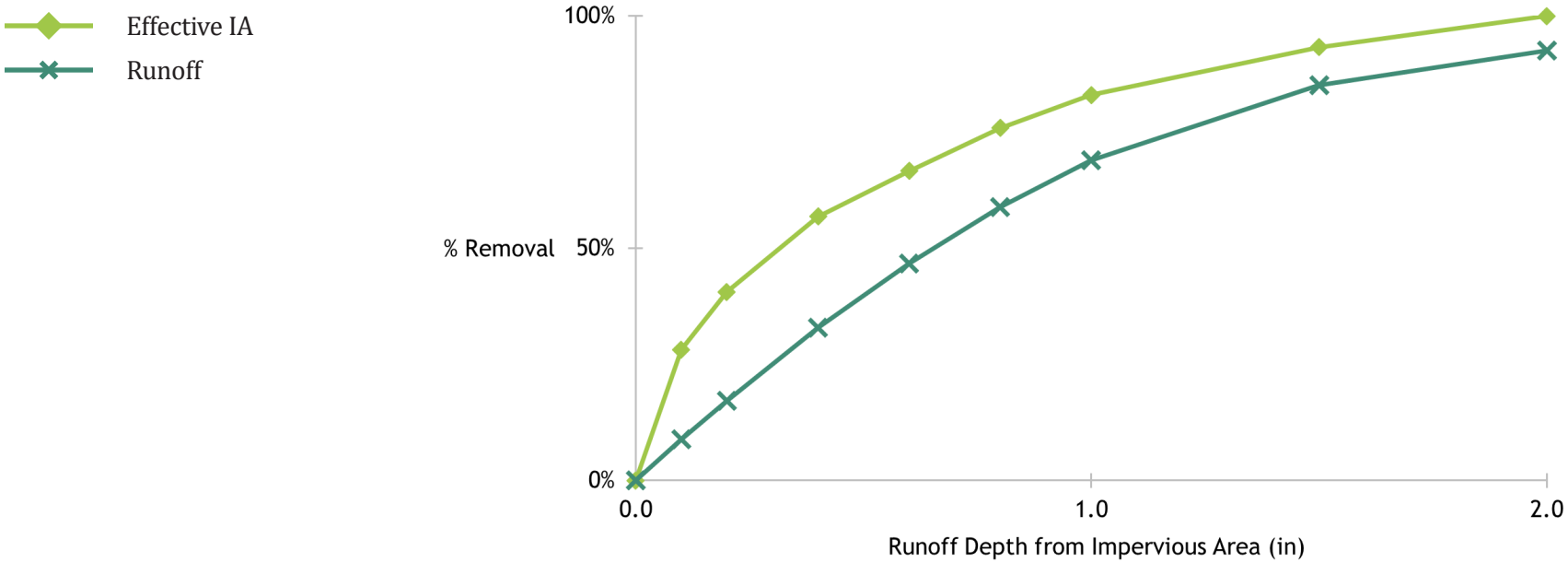


Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	28%	43%	64%	77%	86%	91%	97%	99%
TN	0%	52%	67%	83%	90%	94%	97%	99%	100%
Bacteria	0%	22%	36%	58%	73%	83%	89%	97%	99%
TSS	0%	63%	80%	92%	95%	97%	98%	99%	100%
Metals	0%	61%	78%	90%	94%	96%	98%	99%	100%

[17] HSG D Performance Curves come from new modeling performed by EPA and will be included in subsequent MS4 permits/supporting documentation.

Infiltration Basin (HSG D)[18]

(Infiltration Rate = 0.10 in/hr)

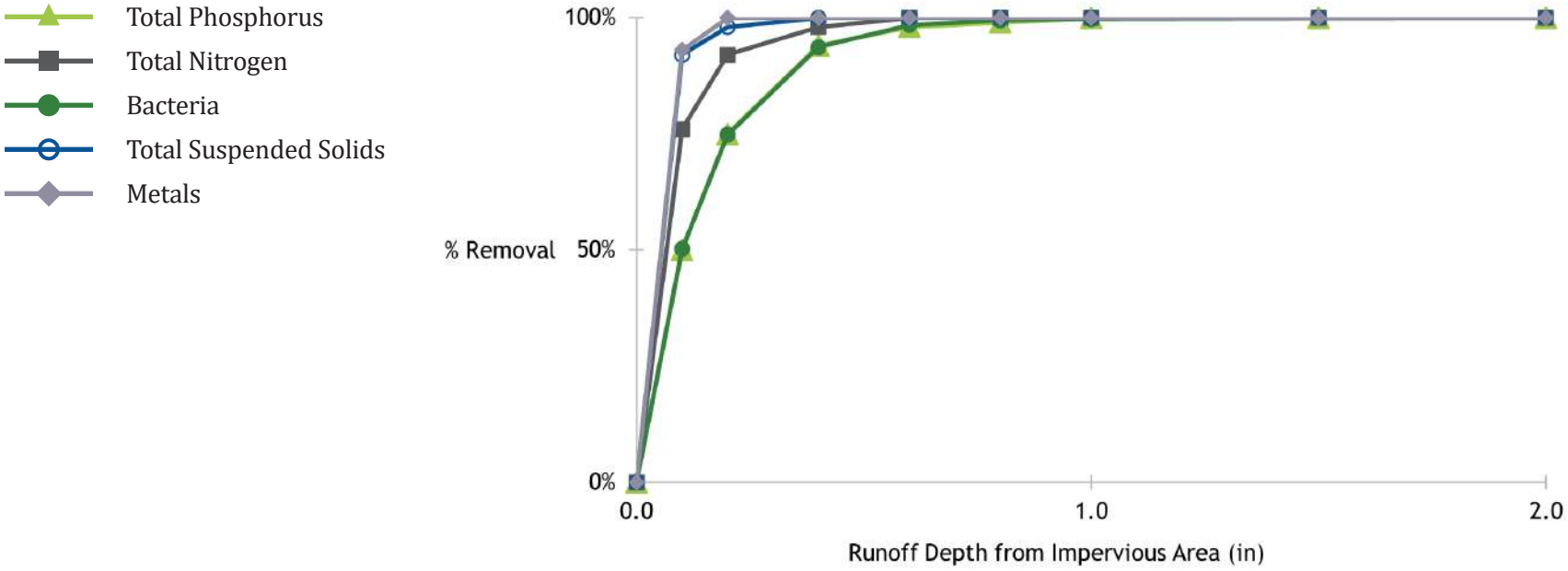


Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	28%	41%	57%	67%	76%	83%	93%	100%
Runoff	0%	9%	17%	33%	47%	59%	69%	85%	93%

[18]HSG D Performance Curves come from new modeling performed by EPA and will be included in subsequent MS4 permits/supporting documentation.

Infiltration Trench (HSG A)

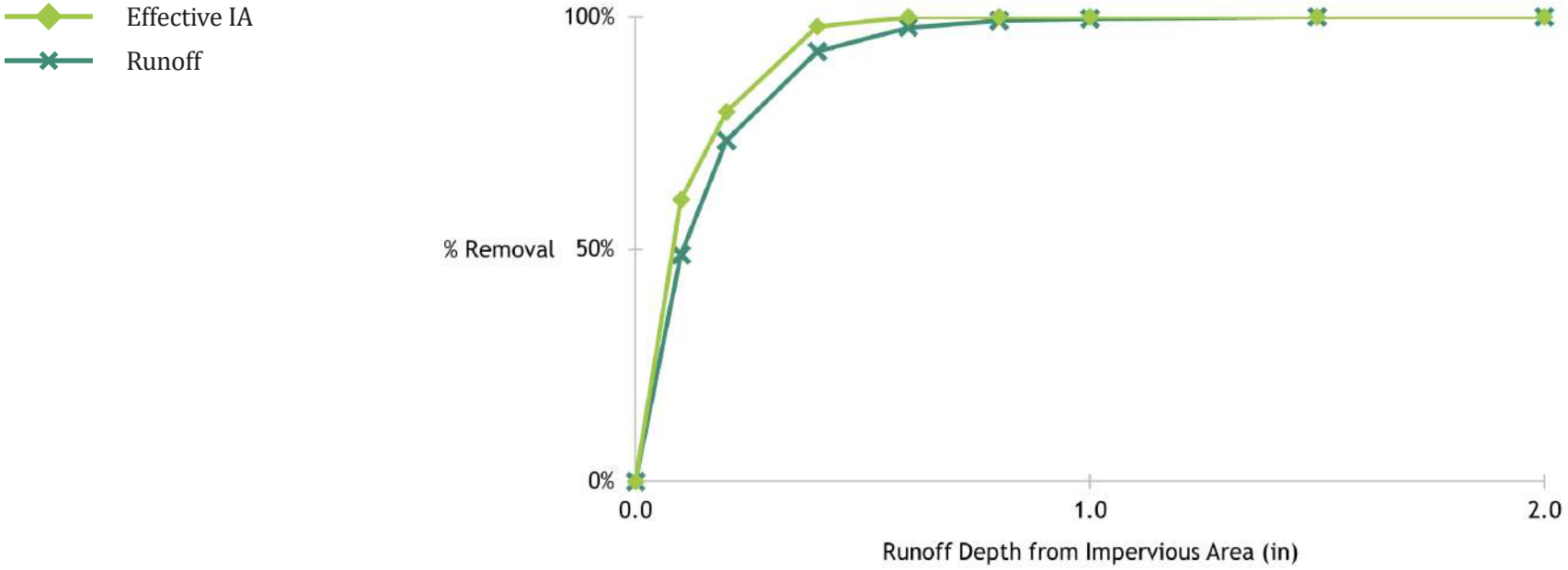
(Infiltration Rate = 8.27 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	50%	75%	94%	98%	99%	100%	100%	100%
TN	0%	76%	92%	98%	100%	100%	100%	100%	100%
Bacteria	0%	50%	75%	94%	98%	99%	100%	100%	100%
TSS	0%	92%	98%	100%	100%	100%	100%	100%	100%
Metals	0%	93%	100%	100%	100%	100%	100%	100%	100%

Infiltration Trench (HSG A)

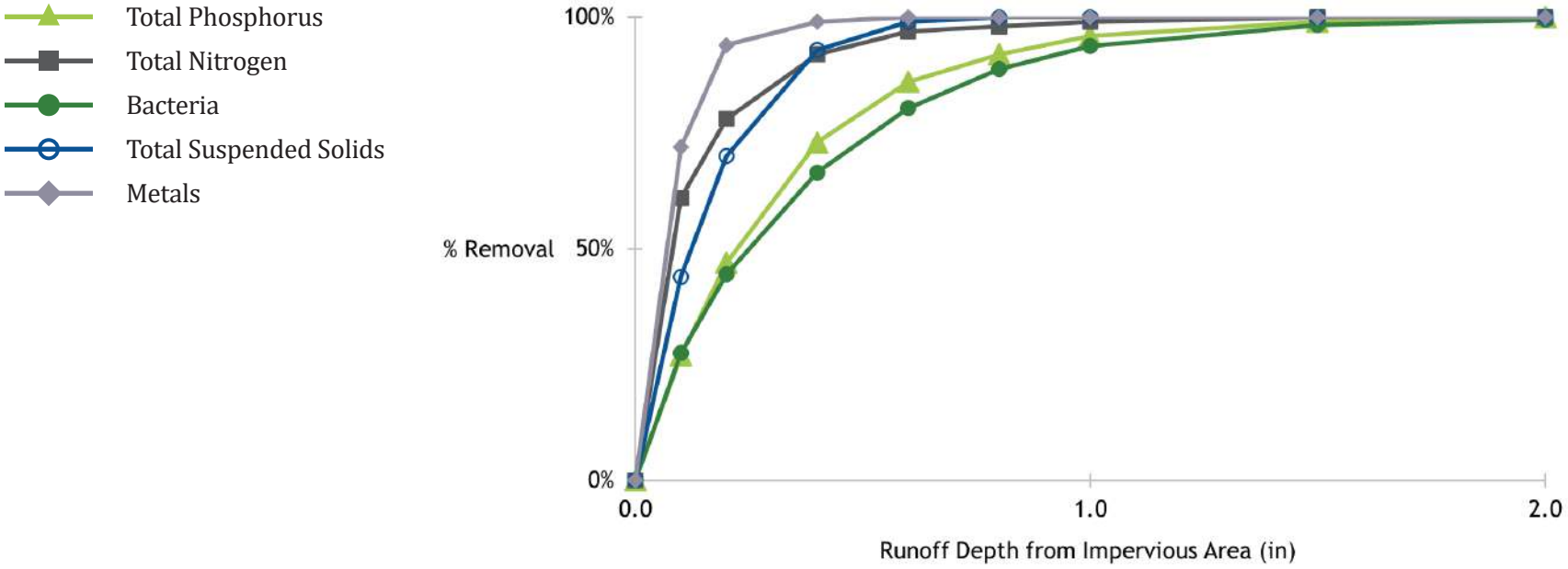
(Infiltration Rate = 8.27 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	61%	80%	98%	100%	100%	100%	100%	100%
Runoff	0%	49%	73%	93%	98%	99%	100%	100%	100%

Infiltration Trench (HSG B)

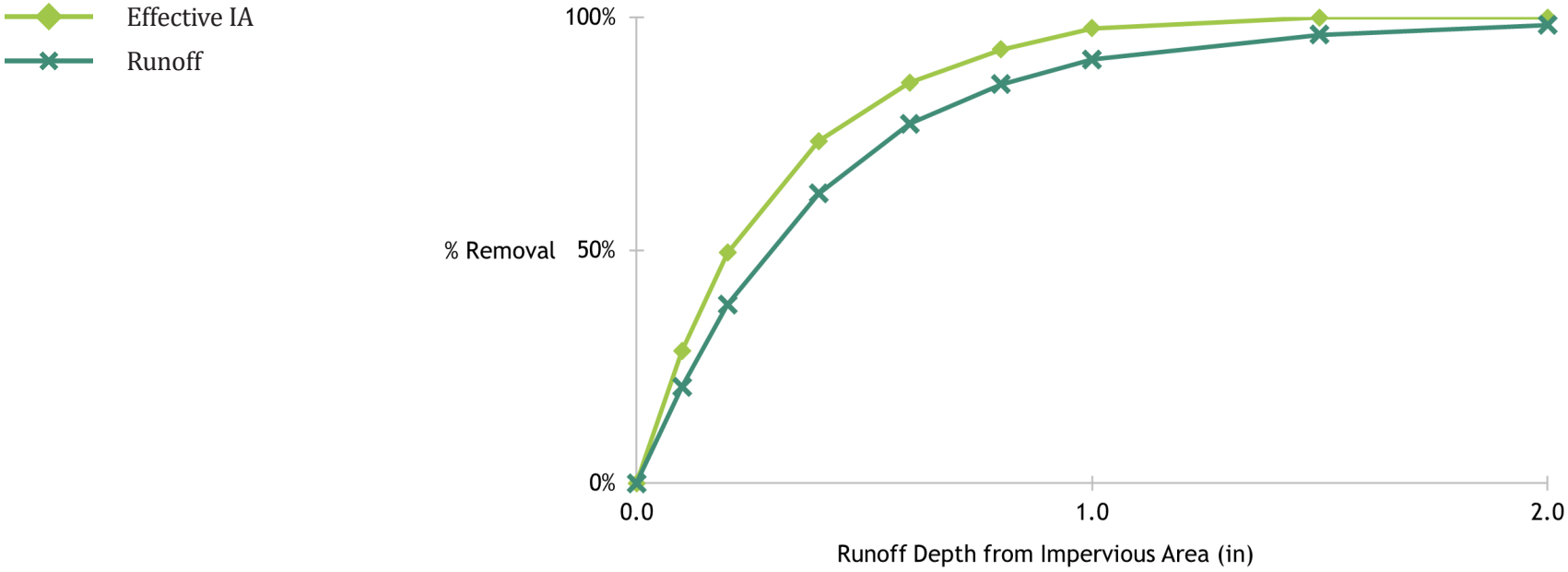
(Infiltration Rate = 1.02 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	27%	47%	73%	86%	92%	96%	99%	100%
TN	0%	61%	78%	92%	97%	98%	99%	100%	100%
Bacteria	0%	27%	45%	67%	80%	89%	94%	98%	99%
TSS	0%	44%	70%	93%	99%	100%	100%	100%	100%
Metals	0%	72%	94%	99%	100%	100%	100%	100%	100%

Infiltration Trench (HSG B)

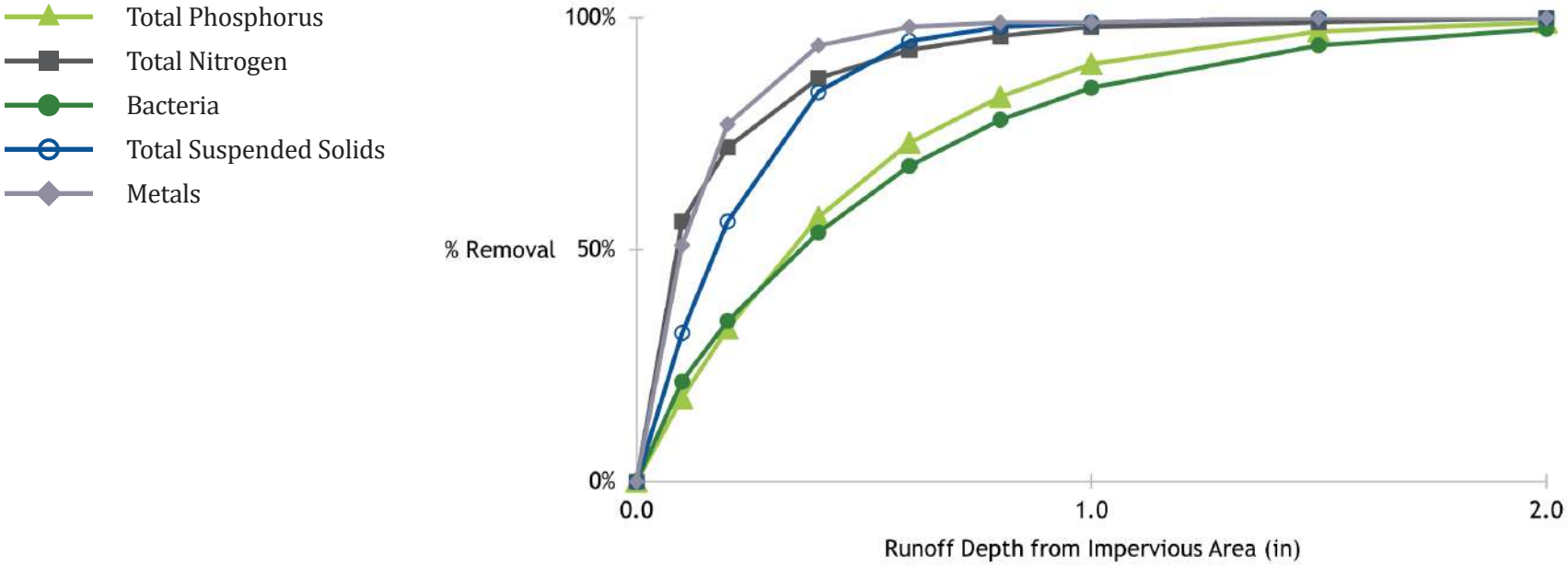
(Infiltration Rate = 1.02 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	29%	49%	73%	86%	93%	98%	100%	100%
Runoff	0%	21%	38%	62%	77%	86%	91%	96%	98%

Infiltration Trench (HSG C)

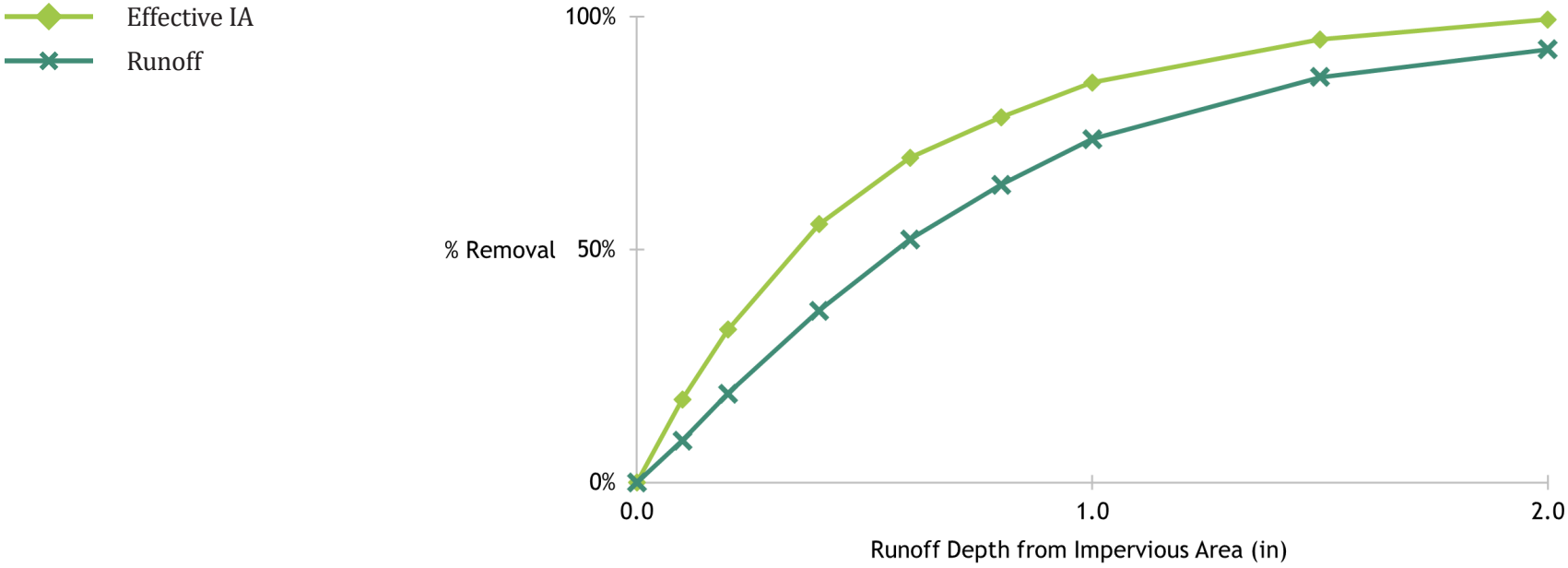
(Infiltration Rate = 0.17 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	18%	33%	57%	73%	83%	90%	97%	99%
TN	0%	56%	72%	87%	93%	96%	98%	99%	100%
Bacteria	0%	22%	35%	54%	68%	78%	85%	94%	98%
TSS	0%	32%	56%	84%	95%	98%	99%	100%	100%
Metals	0%	51%	77%	94%	98%	99%	99%	100%	100%

Infiltration Trench (HSG C)

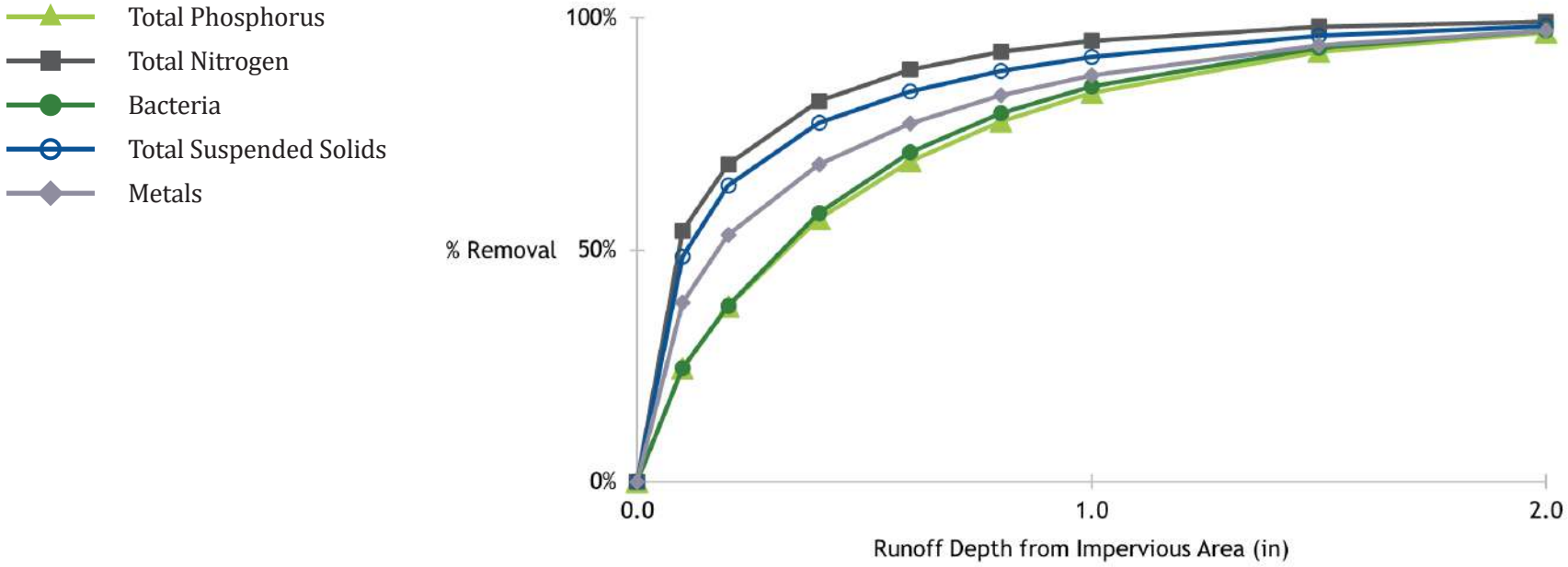
(Infiltration Rate = 0.17 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	18%	33%	55%	70%	78%	86%	95%	99%
Runoff	0%	9%	19%	37%	52%	64%	74%	87%	93%

Infiltration Trench (HSG D)[19]

(Infiltration Rate = 0.10 in/hr)

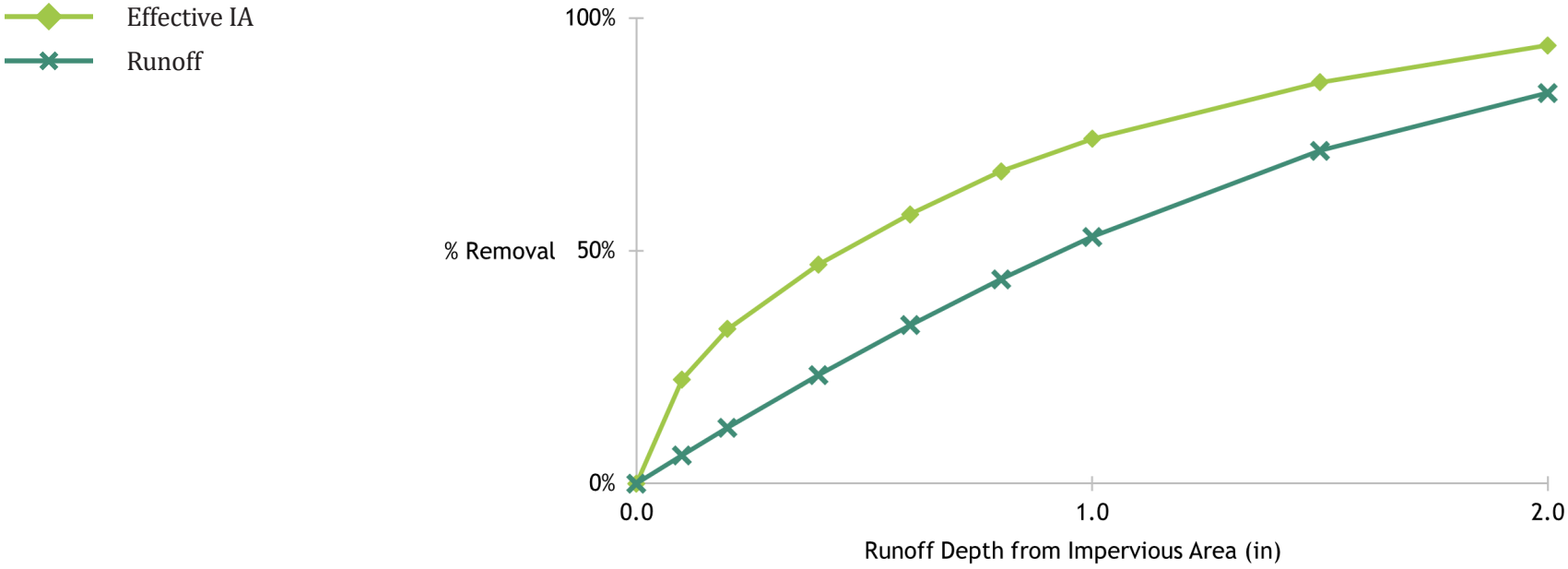


Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	24%	38%	57%	69%	78%	84%	93%	97%
TN	0%	54%	68%	82%	89%	93%	95%	98%	99%
Bacteria	0%	25%	38%	58%	71%	80%	85%	94%	97%
TSS	0%	49%	64%	77%	84%	89%	92%	96%	98%
Metals	0%	39%	53%	68%	77%	83%	88%	94%	97%

[19]HSG D Performance Curves come from new modeling performed by EPA and will be included in subsequent MS4 permits/supporting documentation.

Infiltration Trench (HSG D)[20]

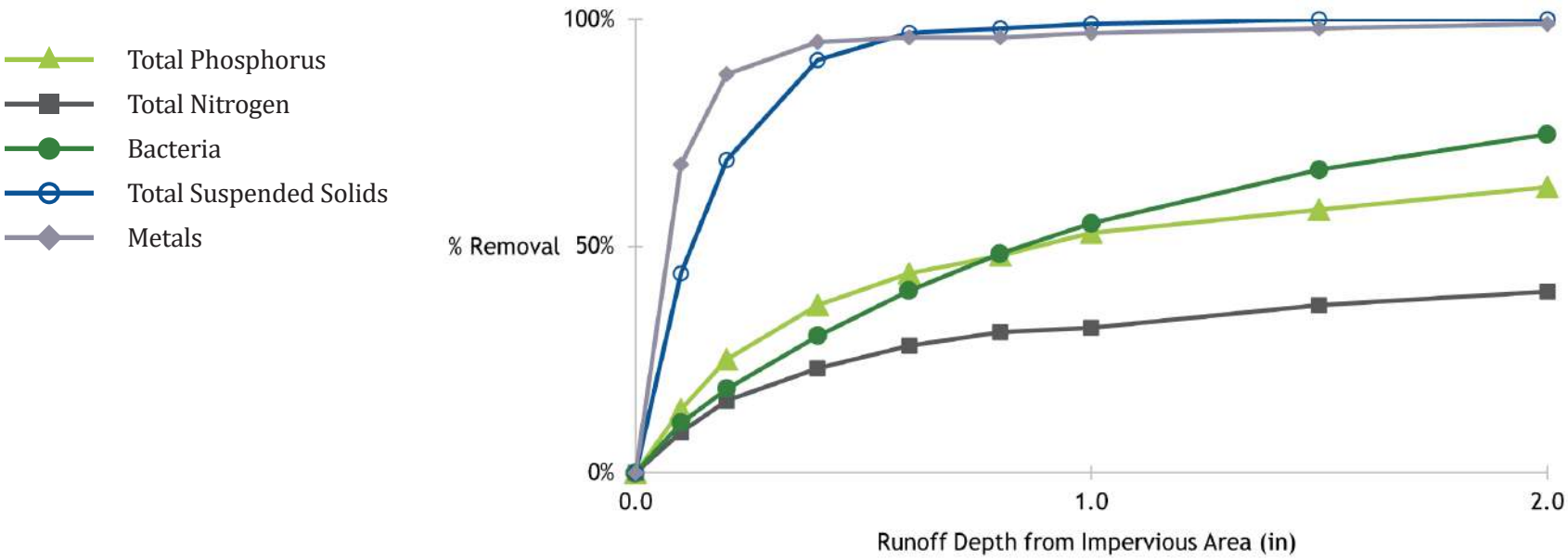
(Infiltration Rate = 0.10 in/hr)



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	22%	33%	47%	58%	67%	74%	86%	94%
Runoff	0%	6%	12%	23%	34%	44%	53%	72%	84%

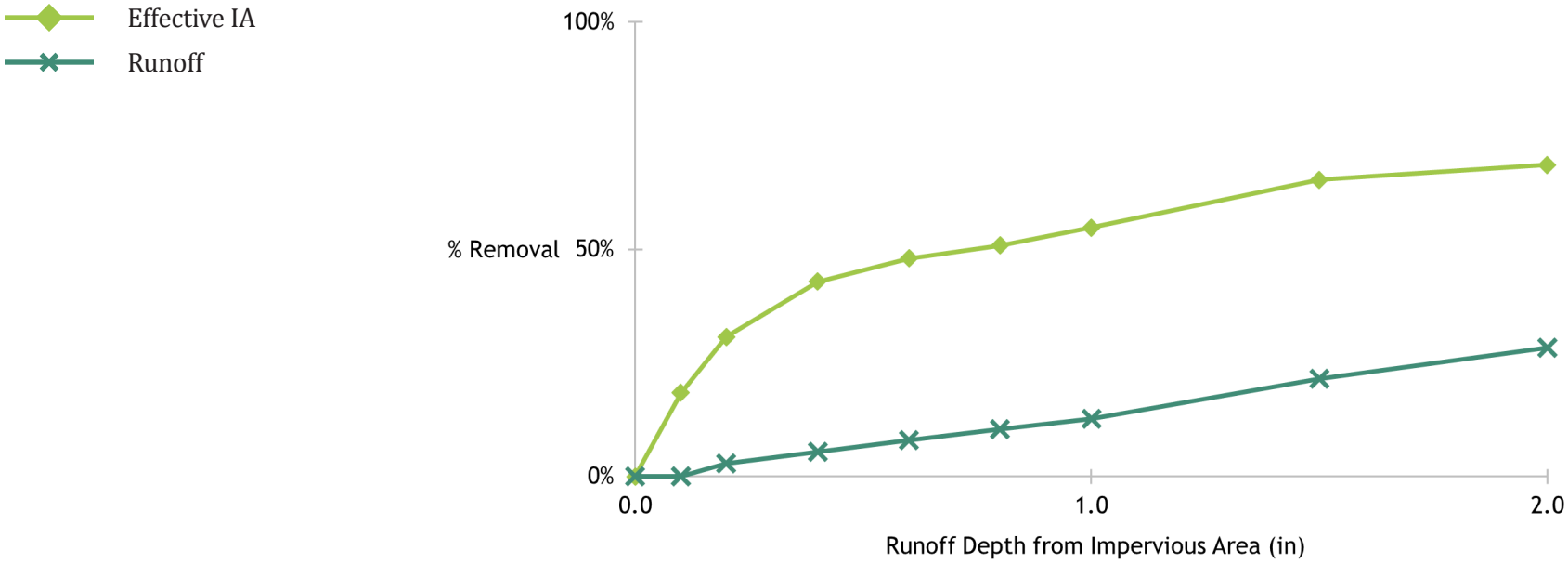
[20] HSG D Performance Curves come from new modeling performed by EPA and will be included in subsequent MS4 permits/supporting documentation.

Bio-Filtration



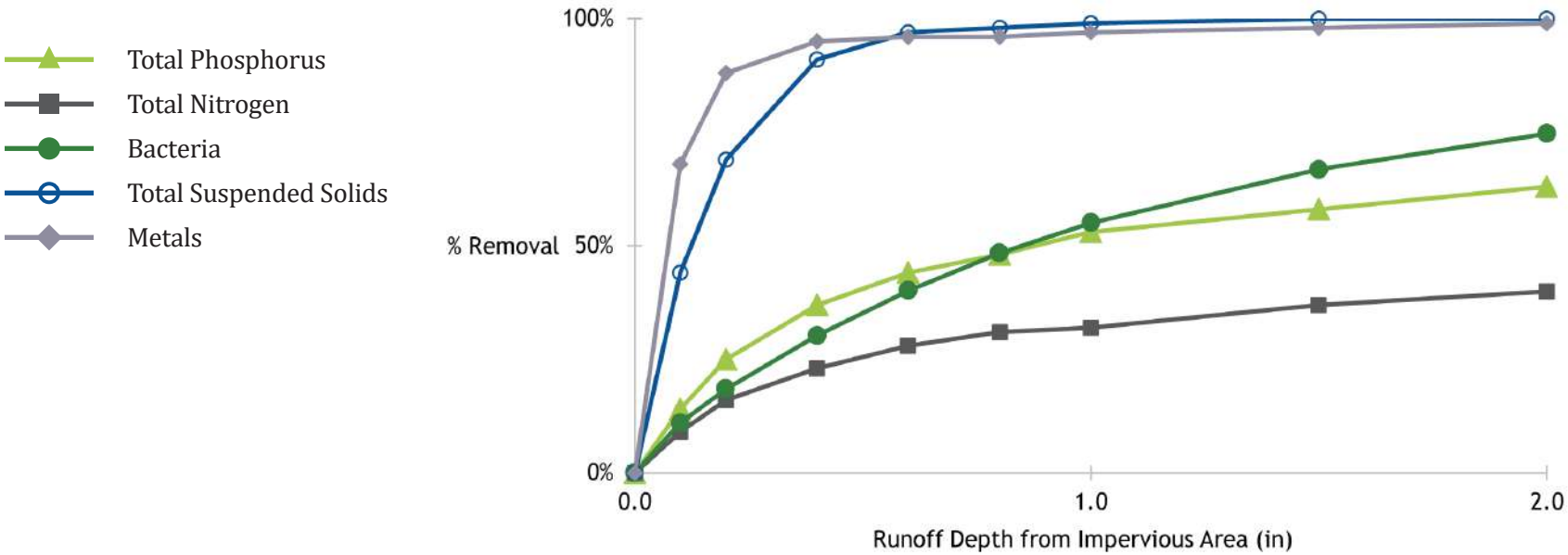
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	14%	25%	37%	44%	48%	53%	58%	63%
TN	0%	9%	16%	23%	28%	31%	32%	37%	40%
Bacteria	0%	11%	19%	30%	40%	48%	55%	67%	75%
TSS	0%	44%	69%	91%	97%	98%	99%	100%	100%
Metals	0%	68%	88%	95%	96%	96%	97%	98%	99%

Bio-Filtration



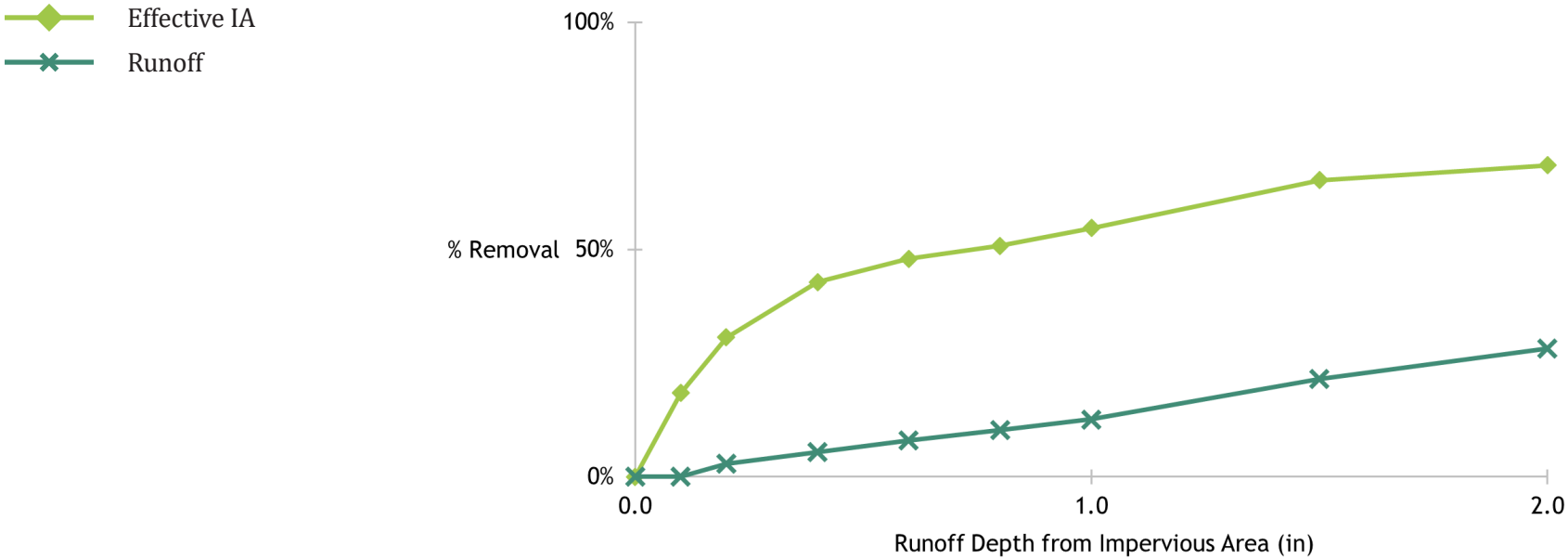
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	18%	31%	43%	48%	51%	55%	65%	69%
Runoff	0%	0%	3%	5%	8%	10%	13%	22%	28%

Sand Filter



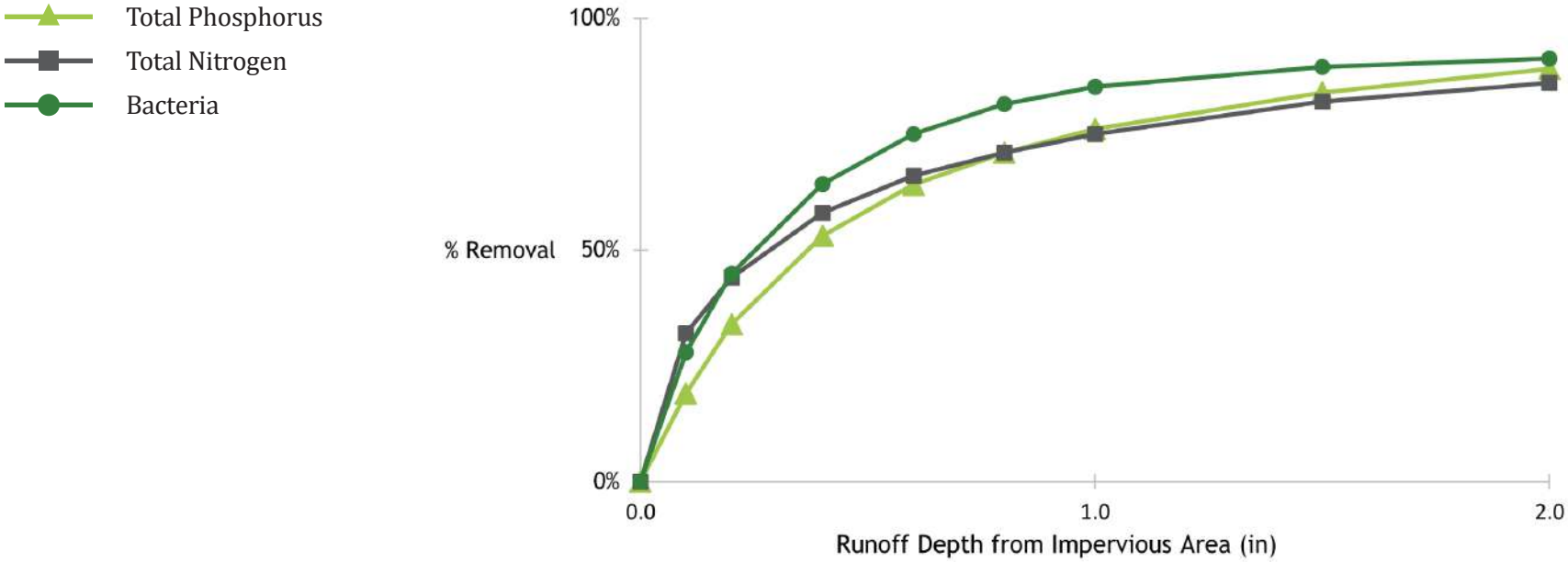
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	14%	25%	37%	44%	48%	53%	58%	63%
TN	0%	9%	16%	23%	28%	31%	32%	37%	40%
Bacteria	0%	11%	19%	30%	40%	48%	55%	67%	75%
TSS	0%	44%	69%	91%	97%	98%	99%	100%	100%
Metals	0%	68%	88%	95%	96%	96%	97%	98%	99%

Sand Filter



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	18%	31%	43%	48%	51%	55%	65%	69%
Runoff	0%	0%	3%	5%	8%	10%	13%	22%	28%

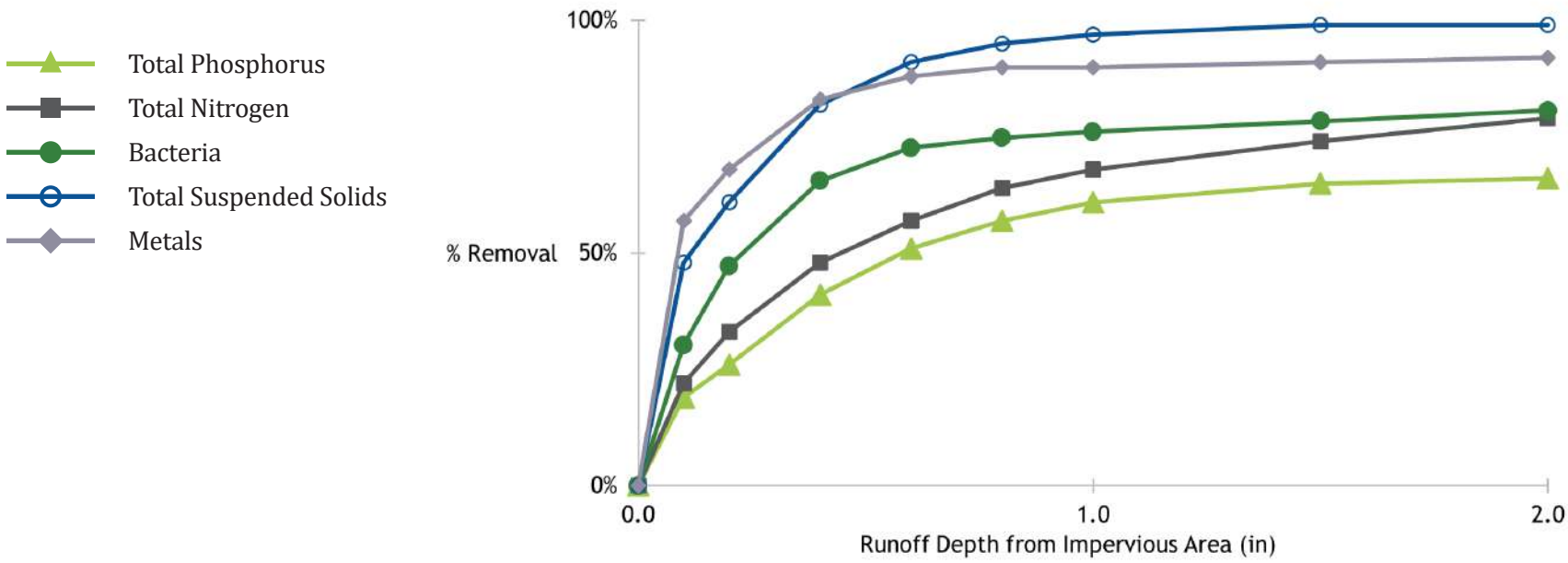
Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)[21]



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	19%	34%	53%	64%	71%	76%	84%	89%
TN	0%	32%	44%	58%	66%	71%	75%	82%	86%
Bacteria	0%	28%	45%	64%	75%	81%	85%	89%	91%

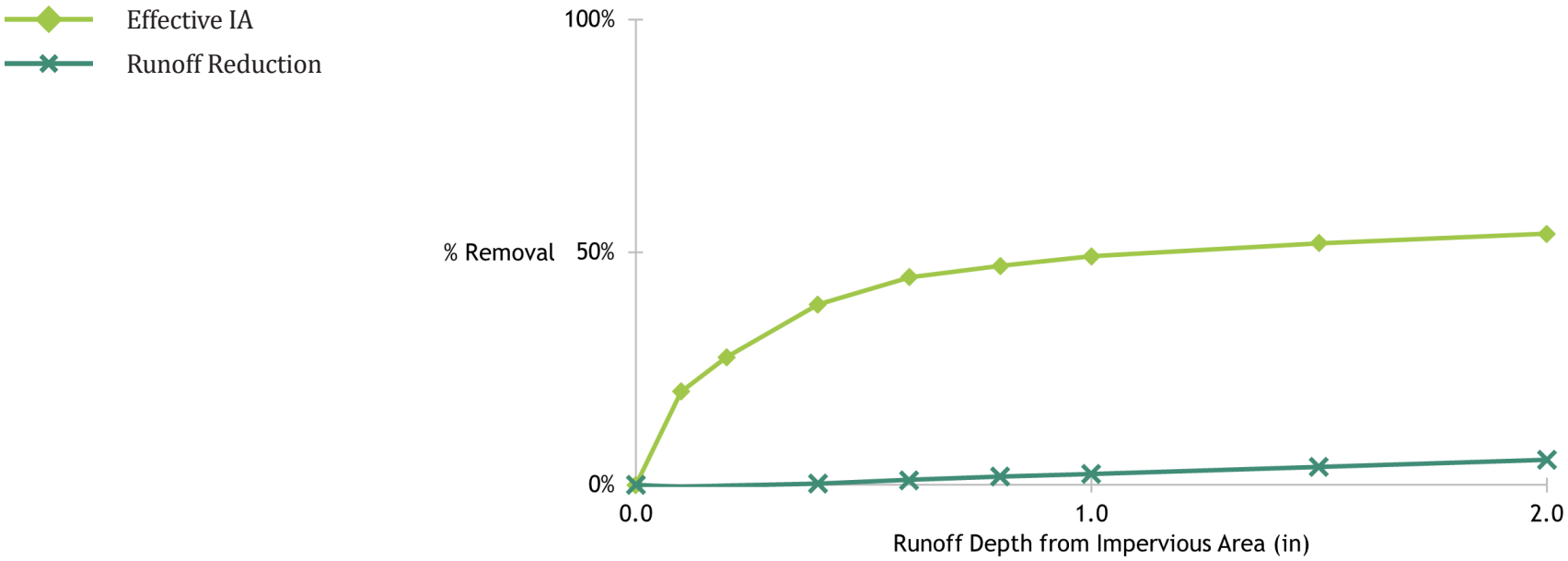
[21] SCM Performance values not currently available for TSS, Metals, Effective IA, and Runoff.

Gravel Wetland



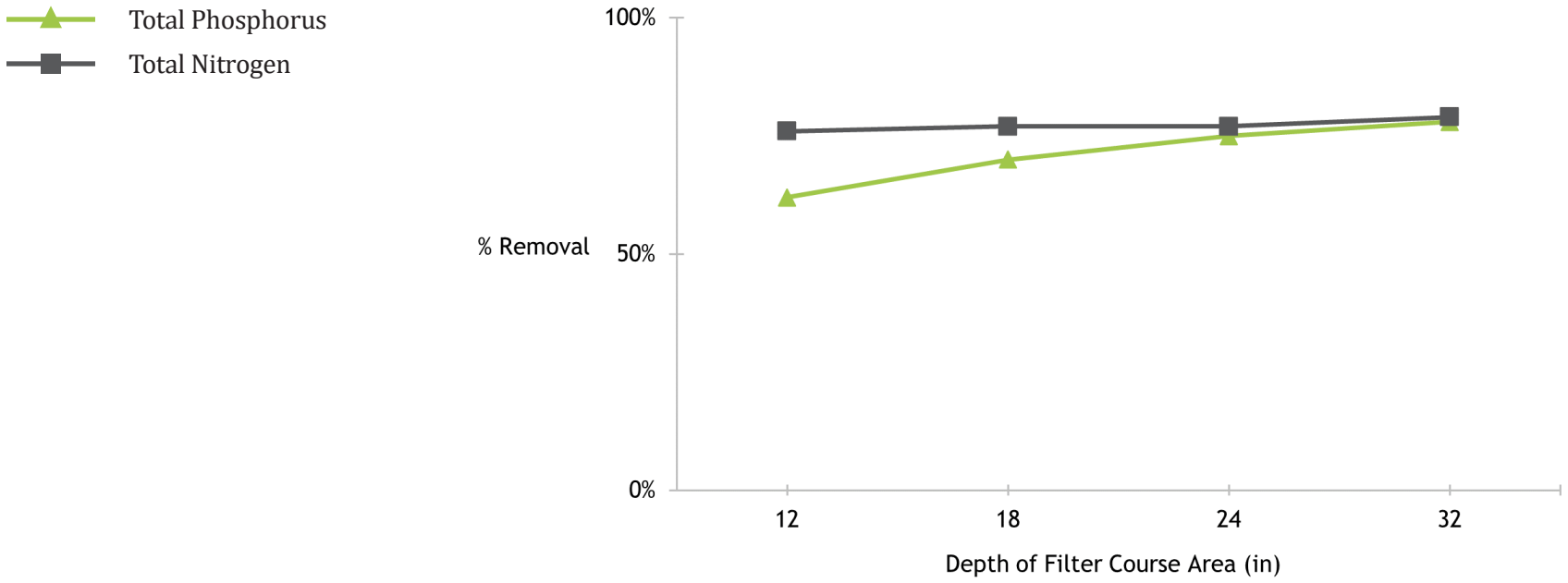
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	19%	26%	41%	51%	57%	61%	65%	66%
TN	0%	22%	33%	48%	57%	64%	68%	74%	79%
Bacteria	0%	30%	47%	66%	73%	75%	76%	78%	81%
TSS	0%	48%	61%	82%	91%	95%	97%	99%	99%
Metals	0%	57%	68%	83%	88%	90%	90%	91%	92%

Gravel Wetland



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	20%	27%	39%	45%	47%	49%	52%	54%
Runoff	0%	0%	0%	0%	1%	2%	2%	4%	5%

Permeable Pavement (with underdrain)[22]

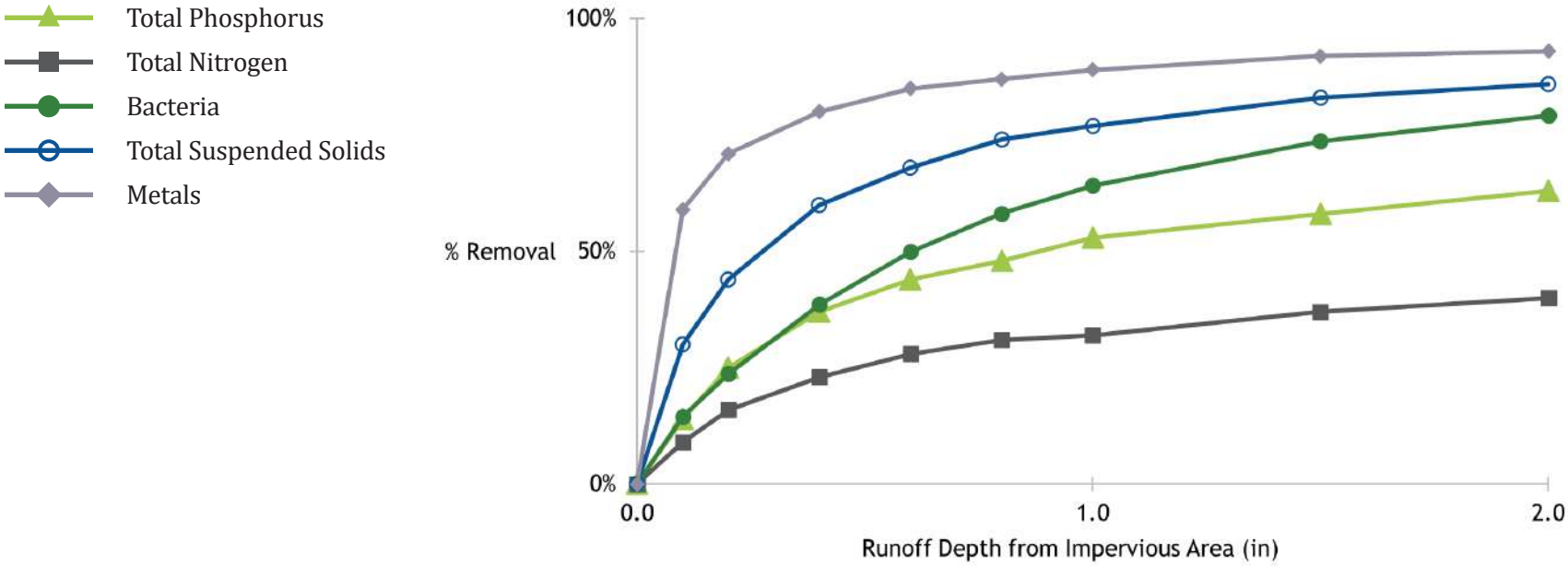


Pollutant	Depth of Filter Course Area (in)			
	12	18	24	32
TP	62%	70%	75%	78%
TN	76%	77%	77%	79%

[22] SCM Performance values not currently available for Bacteria, TSS, Metals, Effective IA, and Runoff.

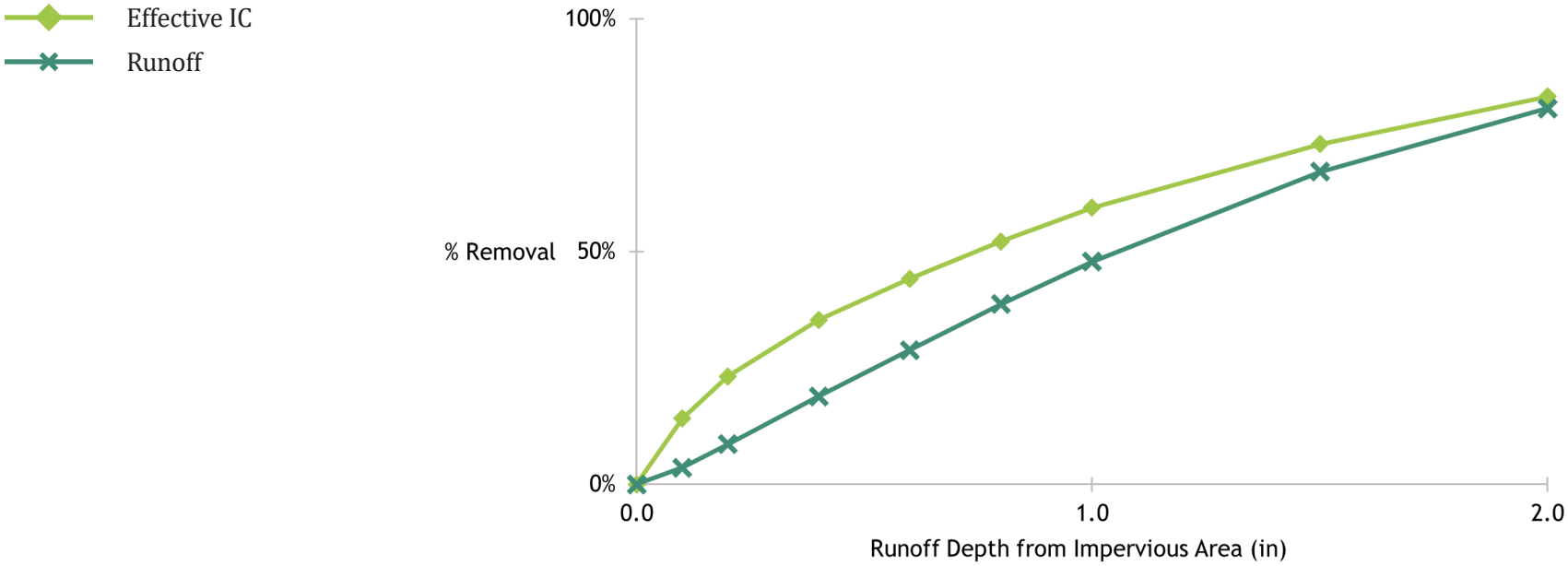
If Permeable Pavement does not have an underdrain or the underdrain is set higher than the outlet, the primary UOP for the SCM is infiltration and the appropriate infiltration SCM Performance Curve (based on underlying soil type) should be used for estimating SCM performance.

Wet Pond



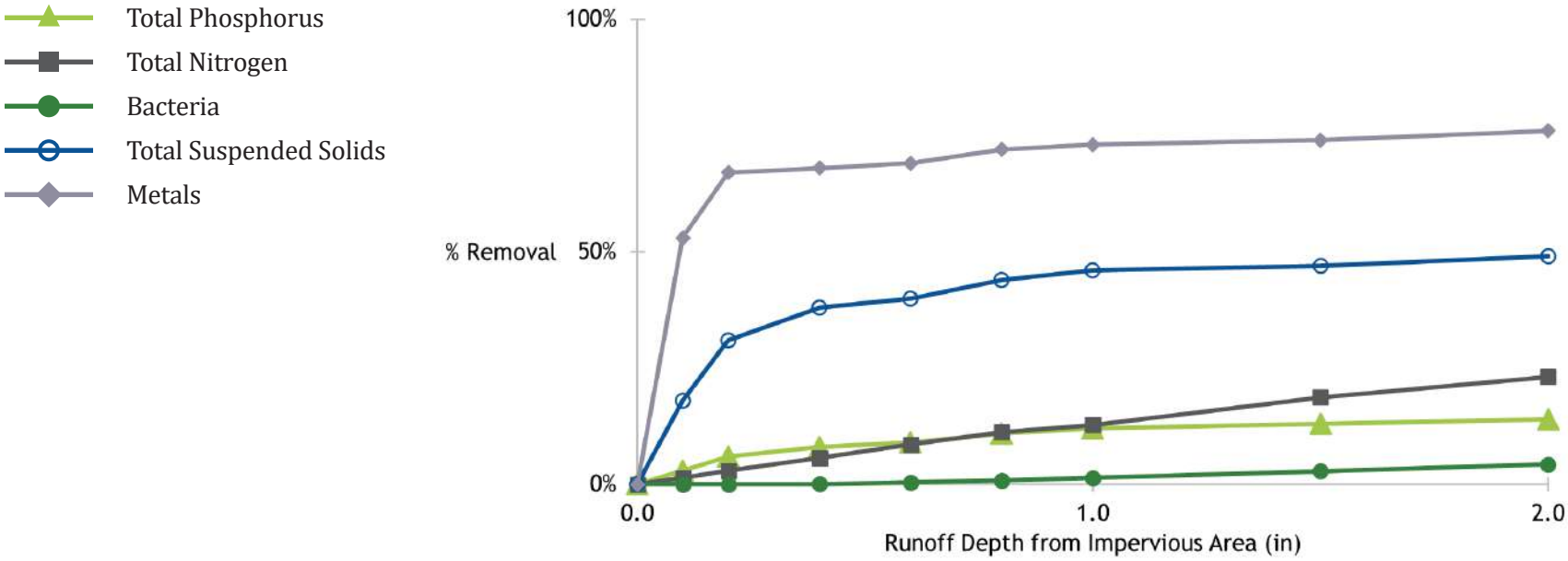
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	14%	25%	37%	44%	48%	53%	58%	63%
TN	0%	9%	16%	23%	28%	31%	32%	37%	40%
Bacteria	0%	15%	24%	39%	50%	58%	64%	74%	79%
TSS	0%	30%	44%	60%	68%	74%	77%	83%	86%
Metals	0%	59%	71%	80%	85%	87%	89%	92%	93%

Wet Pond



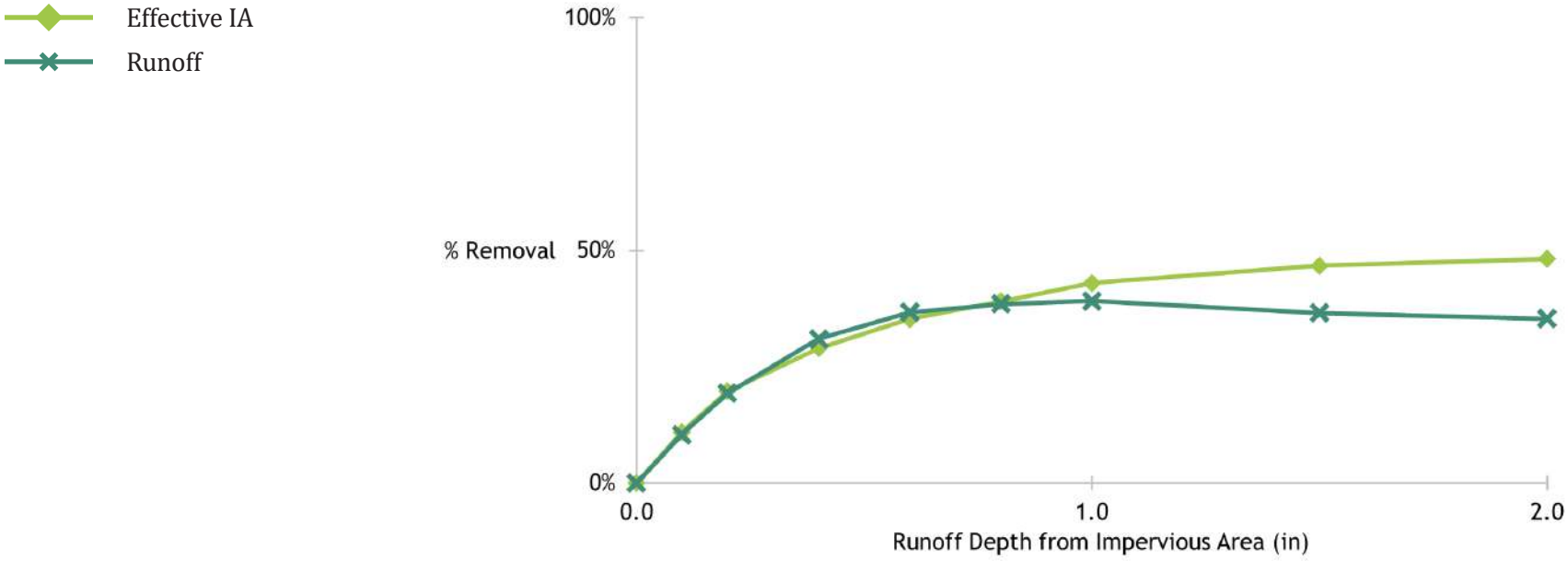
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	14%	23%	35%	44%	52%	59%	73%	83%
Runoff	0%	4%	9%	19%	29%	39%	48%	67%	81%

Extended Dry Detention



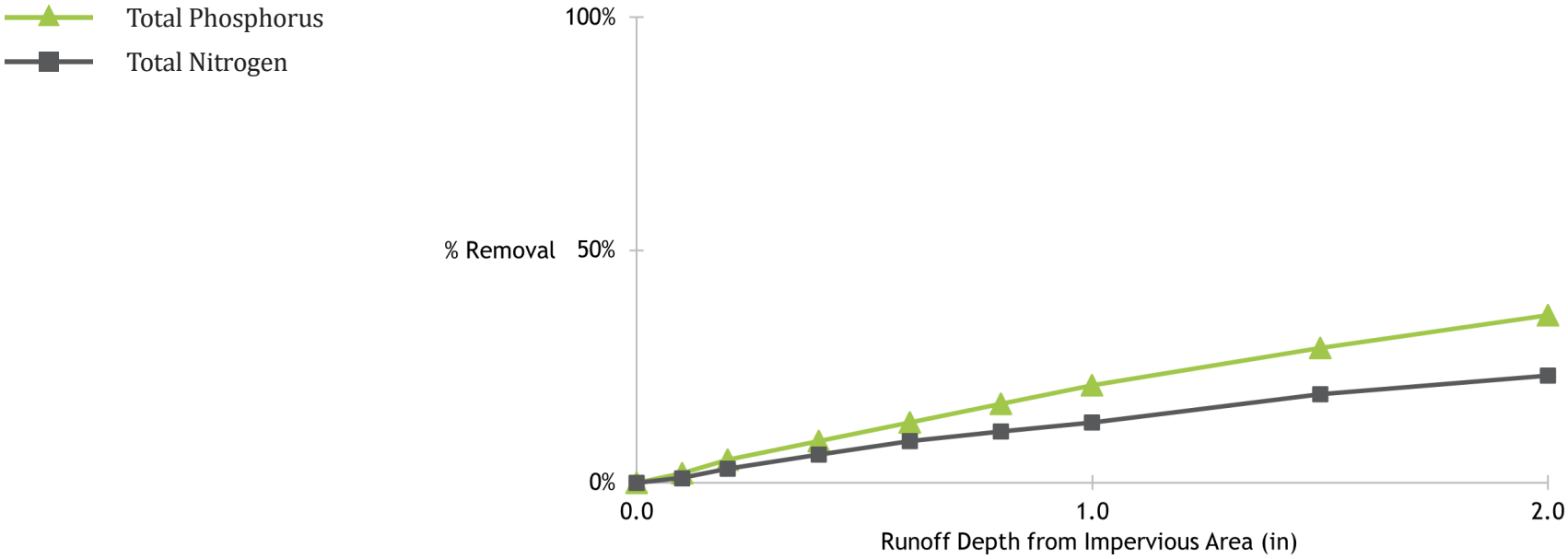
Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	3%	6%	8%	9%	11%	12%	13%	14%
TN	0%	1%	3%	6%	9%	11%	13%	19%	23%
Bacteria	0%	0%	0%	0%	0%	1%	1%	3%	4%
TSS	0%	18%	31%	38%	40%	44%	46%	47%	49%
Metals	0%	53%	67%	68%	69%	72%	73%	74%	76%

Extended Dry Detention



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
Effective IA	0%	11%	20%	29%	35%	39%	43%	47%	48%
Runoff	0%	10%	19%	31%	37%	39%	39%	37%	35%

Grass Swale[23]



Pollutant	Design Storage Volume: Runoff Depth from Impervious Area (in)								
	0	0.10	0.20	0.40	0.60	0.80	1.00	1.50	2.00
TP	0%	2%	5%	9%	13%	17%	21%	29%	36%
TN	0%	1%	3%	6%	9%	11%	13%	19%	23%

[23] SCM Performance values not currently available for Bacteria, TSS, Metals, Effective IA, and Runoff.

Appendix C—Stormwater Control Measure Crosswalk & Design Storage Volume Calculation Methods

L = length
W = width
D = depth at design capacity before bypass
n = porosity fill material
A = average surface area for calculating volume
Infiltration rate = saturated soil hydraulic conductivity

This crosswalk was assembled specifically for the purposes of this manual and retrofit scenarios. Designers should defer to crosswalks and assigned Performance Curves assembled by regulators for compliance and coordination with regulatory standards.

Performance Curve Category	Stormwater Control Measure (SCM) Type	Design Storage Volume (DSV)
IMPERVIOUS AREA DISCONNECTION SCMS		
Impervious Area Disconnection	• Impervious Cover Disconnection • Vegetated Filter Strip • Vegetated Buffer • Qualifying Pervious Area (QPA)	Instead of DSV, the relative area of impervious area to pervious area is measured for using the Performance Curve.
Impervious Area Disconnection through Storage	• Rain Barrels • Cisterns	Instead of DSV, the relative area of impervious area to pervious area is measured for using the Performance Curve.
INFILTRATION SCMS		
Infiltration Basin *(by HSG of underlying soil)*	• Infiltration Basin • Infiltration Swale • Permeable Pavement (no or elevated underdrain) • Bio-Filtration Basin (no or elevated underdrain) • Bio-Filtration Curb Inlet Planter (no or elevated underdrain) • Rain Garden (no or elevated underdrain) • Underground Infiltration Chamber	DSV = Water volume of storage structure before bypass **Example for linear trapezoidal vegetated swale:** $DSV = (L \times ((W_{bottom} + W_{top@Dmax})/2) \times D)$
Infiltration Trench *(by HSG of underlying soil)*	• Infiltration Trench • Leaching Basin • Dry Well • Leaching Galley	DSV=Water storage volume of storage components and void space volumes of backfill materials **Example for subsurface galleys backfilled with washed stone:** $DSV = (L \times W \times D)_{galley} + (A_{backfill} \times D_{stone} \times n_{stone})$

Performance Curve Category	Stormwater Control Measure (SCM) Type	Design Storage Volume (DSV)
MEDIA FILTER SCMS		
Bio-Filtration	• Bio-Filtration Basin (with underdrain) • Bio-Filtration Curb Inlet Planter (with underdrain) • Rain Garden (with underdrain)	DSV = pretreatment volume + ponding volume + void space volume of sand and washed stone layers $DSV = (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{soil} \times n_{soil})$
Sand Filter	• Sand Filter • Media Filter	DSV = pretreatment volume + ponding volume + void space volume of sand and washed stone layers $DSV = (A_{pretreatment} \times D_{pretreatment}) + (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{sand} \times n_{sand}) + (A_{bed} \times D_{stone} \times n_{stone})$
Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)	• Enhanced Bio-Filtration with Internal Storage Reservoir (ISR)	DSV = Ponding water storage volume and void space volume of soil filter media + gravel void space volume of ISR $DSV = (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{soil} \times n_{soil}) + (A_{ISR} \times D_{gravel} \times n_{gravel})$
Gravel Wetland	• Gravel Wetland • Gravel Wet Vegetated Treatment System • Wet Vegetated Treatment System • Shallow Wetland	DSV = pretreatment volume + ponding volume + void space volume of gravel ISR $DSV = (A_{pretreatment} \times D_{pretreatment}) + (A_{wetland} \times D_{ponding}) + (A_{ISR} \times D_{gravel} \times n_{gravel})$
Permeable Pavement (with underdrain)	• Permeable Pavement (with underdrain)	DSV = void space volume of choker, filter media and stone layers $DSV = (A_{choker} \times D_{choker}) + (A_{filter} \times D_{filter} \times n_{filter}) + (A_{bed} \times D_{stone} \times n_{stone})$
TRADITIONAL APPROACHES		
Wet Pond	• Wet Pond • Wet Swale	DSV = Permanent pool volume prior to high flow bypass $DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume)
Extended Dry Detention	• Dry Pond • Dry Swale • Extended Detention Wetland • Extended Dry Detention Basin	DSV = Ponding volume prior to high-flow bypass $DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume)
Grass Swale	• Grass Swale • Water Quality Swale • Water Quality Grass Swale with Detention	DSV = Volume of swale at full design flow $DSV = L_{swale} \times A_{X\text{-sect. swale}}$

Appendix D—Pollutant Load Export Rates (PLERs) [18], [19], [20], [21], [22]

Land Use Category	Land Surface Cover	TP Load (lb/ac/yr)	TN Load (lb/ac/yr)	TSS Load (lb/ac/yr)	Metals Load (lb/ac/yr)	Bacteria Load (# col/100 mL)	Runoff Volume (in/ac/yr)
Commercial	Directly Connected Impervious	1.78	15.0	377	1.4	3.8–9.0	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
Industrial	Directly Connected Impervious	1.78	15.0	377	1.4	3.8–9.0	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
Low-Density Residential	Directly Connected Impervious	1.52	14.1	439	0.7	3.8–9.0	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
Medium-Density Residential	Directly Connected Impervious	1.96	14.1	439	0.7	3.8–9.0	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
High-Density Residential/ Multi-Family Residential	Directly Connected Impervious	2.32	14.1	439	0.7	190–478	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
Highway	Directly Connected Impervious	1.34	10.5	1,477	1.2	14–60	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
Forest	Directly Connected Impervious	1.52	11.3	650	0.7	14–60	40.75
	Pervious	0.13	0.5	29	0.02	-	2.81
Open Land	Directly Connected Impervious	1.52	11.3	650	1.0	14–60	40.75
	Pervious	See DevPerv	See DevPerv	See DevPerv	See DevPerv	-	See DevPerv
Agriculture	Directly Connected Impervious	1.52	11.3	649	0.07	14–60	40.75
	Pervious	0.45	2.6	29	0.02	-	1.81

Land Use Category	Land Surface Cover	TP Load (lb/ac/yr)	TN Load (lb/ac/yr)	TSS Load (lb/ac/yr)	Metals Load (lb/ac/yr)	Bacteria Load (# col/100 mL)	Runoff Volume (in/ac/yr)
Developed Land Pervious—HSG A (DevPerv)	Pervious	0.03	0.3	7	0.01	-	0.51
Developed Land Pervious—HSG B (DevPerv)	Pervious	0.12	1.2	29	0.02	-	2.81
Developed Land Pervious—HSG C (DevPerv)	Pervious	0.21	2.4	60	0.05	-	6.19
Developed Land Pervious—HSG C/D (DevPerv)	Pervious	0.29	3.1	76	0.06	-	8.15
Developed Land Pervious—HSG D(DevPerv)	Pervious	0.37	3.6	91	0.07	-	11.01

Note 1: For pervious areas, if the HSG is known, use the appropriate DevPerv value as applicable. If the HSG is unknown, assume HSG C.

Note 2: No PLERs have been developed for bacteria for pervious land cover. In-situ testing may be performed to estimate site-specific bacteria PLERs, if desired.

Note 3: Attachment 1 to Appendix F of the The Massachusetts [46] MS4 Permit and a supplemental document [49] and Attachment 1 to Appendix F of the New Hampshire MS4 Permit [50] all contain crosswalks for mapping typical land use descriptions to the PLER land use categories.

Appendix E—Using the Performance Curves to Calculate Pollutant Load Reduction for a Fictious Site

Step

Example

1. Delineate the catchment to the SCM

Assume a catchment draining to an infiltration trench in a commercial new development project with the following design data:

- Total Catchment Area = 20,000 ft²
- SCM Type = Infiltration Trench (HSG B)

2. Identify land use and land cover types for catchment

Land Use	Land Cover	Area (ft²)
Commercial	Impervious	10,000
Medium-Density Residential	Impervious	5,000
Medium-Density Residential	Pervious	5,000

3. Apply appropriate PLER for pollutant of interest to each individual *impervious* portion of the catchment.

Note: The pervious area, which would have added 0.01 lb/yr or 1.5% more load, was omitted as standard practice

*Annual Load for Specific Land Use = Specific Impervious Land Use Area * PLER*

Land Use	Phosphorus PLER (lb/ac/year)	Area (ft²)
Commercial	1.78	10,000
Medium-Density Residential Impervious	1.96	5,000

$$Commercial\ Load = \frac{1\ acre}{43{,}560\ ft^2} * 10{,}000\ ft^2 * 1.78\ \frac{lb}{acre * year} = \mathbf{0.41}\ \frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

$$Medium - Density\ Residential\ Impervious\ Load = \\ = \frac{1\ acre}{43{,}560\ ft^2} * 5{,}000\ ft^2 * 1.96\ \frac{lb}{acre * year} = \mathbf{0.23}\ \frac{\boldsymbol{lb}}{\boldsymbol{year}}$$

Step	Example
4. Sum loads contributing to the SCM	**Land Use** / **Load (lb/year)** Commercial: 0.41 Medium-Density Residential: 0.23 **Total Load: 0.64**
5. Calculate the Runoff Depth of the SCM using equations in Appendix C *For an Infiltration Trench:* $DSV = (L \times W \times D) \times n_{stone}$ $Depth\ of\ Runoff\ from\ Impervious\ Area\ (in) = \frac{DSV\ (ft^3)}{IA\ (ft^2)} * 12\frac{in}{ft}$	Assume the following design data for the proposed Infiltration Trench: • Length (L) = 200 ft • Width (W) = 5 ft • Depth before bypass (D) = 2 ft • Fill Stone Porosity (n_{stone}) = 0.4 $DSV = (200\ ft * 5\ ft * 2\ ft) * 0.4 = \mathbf{800\ ft^3}$ $Depth\ of\ Runoff\ From\ Impervious\ Area\ (in) = \frac{800\ ft^3}{15{,}000\ ft^2} * \left(12\ \frac{in}{ft}\right) = \mathbf{0.64\ in}$

Step

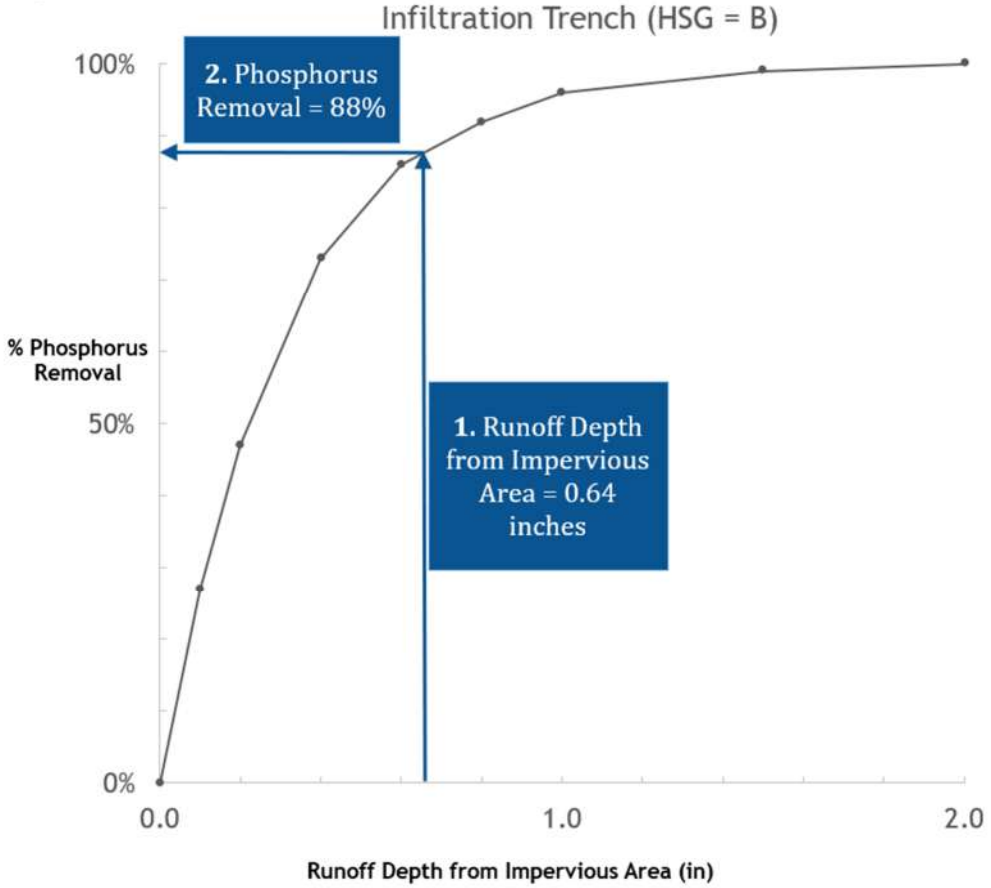
6. Use the Performance Curves to obtain the pollutant reduction percentage of the SCM

Example

Assume a proposed SCM with the following design data:

- Infiltration Trench
- Hydrologic Soils Group at location of SCM: B
- Design Runoff Depth = 0.64 inches

Use the appropriate Performance Curve for this design data to determine an annual Phosphorus Removal of 88%



Step	Example
7. Multiply the SCM's pollutant percent reduction with the total load calculated in Step 4 $SCM\ Pollutant\ Mass\ Load\ Reduction = Total\ Load\ (\frac{mass}{year}) * SCM\ Pollutant\ Reduction\ \%$	$SCM\ Pollutant\ Mass\ Load\ Reduction = 0.64\ \frac{lb}{year} * 88\% = \mathbf{0.56}\ \boldsymbol{\frac{lb}{year}}$

Appendix F—Basis for Retrofit Guidance

Every potential retrofit site has characteristics that drive the stormwater management design. Sometimes site characteristics are optimal for stormwater management such as ample open space, permeable soils, no conflicting underground utilities, etc. but often, developed sites have characteristics that limit or influence potential for maximum stormwater management. The designer must take these characteristics into account and create a design that optimizes treatment rather than solely focusing on volume or peak flow reduction. These challenges are to be expected and research demonstrates that implementing small scale controls is far better than doing nothing.

Requirements by state regulatory authorities create design limitations that may reduce the potential for stormwater treatment. While not the intent, sometimes requirements eliminate the opportunity for stormwater treatment entirely because the requirements could not be met fully. As discussed previously, these design standards and requirements have become the accepted practices and are often applied even in retrofit situations. In contrast, flexible standards embodied in this manual are promoted and follow existing research.

In order to help designers understand how to be more flexible with these design parameters, this section provides a summary of parameters that often appear in design criteria that require flexibility for retrofit applications and optimization of water quality improvements. For each design parameter this Appendix describes:

- The current typical requirement
- Why the requirement exists
- Impact of the requirement on retrofit design and implementation
- Proposed guidance for the retrofit application
- Reason for retrofit guidance

Chapters 4 and 5 discuss further overall SCM siting and design considerations.

Sizing Requirements

Current Typical Requirement: SCMs are sized to hold the water quality volume which is typically calculated as 1-inch over the impervious catchment area. SCMs often are sized to also provide volume reduction and peak flow attenuation.

Reason for Current Requirement: Water quality requirements are intended to protect downstream receiving waters from stormwater pollutants. Most state programs (see **Table A-1**) establish a design requirement to provide 1-inch of water quality volume. This standard is typically supported with the argument that the majority of daily storms depths (on the order of 90%) in a given year are 1-inch in depth or smaller. In addition, most pollutants wash off watersheds within the first inch of precipitation (the first flush) and as such the design standard around the 1-inch storm manages the majority of polluted runoff. Therefore, if SCMs are sized for the runoff from 1-inch of precipitation they will capture,hold, and treat the major portion of runoff and attendant pollution.

Impacts of the Requirement on Retrofits: Many regulatory approaches only credit pollutant removal efficiencies and subsequent pollutant load reduction for full sized systems meeting the water quality volume standard. This approach unfortunately assumes that there is no value in a SCM that does not sized for the full water quality volume, and leads to sites with potential space limitations being completely ignored for retrofit opportunities.

Proposed Retrofit Guidance: New site developments should fully size SCMs. Size retrofit SCMs within existing developed landscapes using the Performance Curves to optimize cost-effective pollutant reduction and encourage the installation of SCMs distributed across the landscape where runoff is generated.

Reasoning for Retrofit Guidance: Achieving any water quality improvement, however small, is an improvement to the existing condition and the receiving waters. Sizing for retrofits should be flexible to allow for the maximum treatment that site conditions allow. This retrofit manual adopts the sizing approach using the Performance Curves included in Appendix F of the recent EPA Massachusetts and New Hampshire NDPES MS4 permits. As the Performance Curves show, SCMs sized smaller than 1-inch and as low as 0.1-inch can achieve substantial pollutant reductions. In addition, the curves also show that some SCMs achieve diminishing increases in pollutant reduction after a certain design storage volume. Using this information in the retrofit approach allows for optimization based on incremental cost per incremental pollutant reduction achieved.

Sizing SCMs larger for peak flow attenuation, while important for protecting downstream infrastructure and properties in new and redevelopment scenarios, are not as relevant in retrofit scenarios. Retrofits represent an improvement over existing conditions where no stormwater management presently exist other than drainage. Recent studies have shown that increases in impervious cover in a watershed has a more dramatic effect on runoff than the increase in rainfall expected from climate change [43]. The difference between a watershed with effective impervious cover managed by SCMs under future climate change conditions and the traditionally managed watershed under current day conditions was minimal, implying SCM implementation will keep flooding from getting any worse as the climate shifts [44].

Additionally, if a system sized for the water quality volume cannot be sited because of site space limitation, the site is also too small for peak flow control: smaller-sized systems can dramatically improve water quality but yield minimal impact on peak flow reduction.

Bedrock and Groundwater Separation for Infiltration SCMs

Current Typical Requirement: Typical standards require that the bottom of an Infiltration SCM must have one to three feet of separation to the estimated seasonal high ground water table (ESHGWT) or bedrock. Groundwater, as do streams, rises and falls over the year; some years are wetter than others. Most commonly at sites, groundwater monitoring wells do not exist or there is no long-term local groundwater elevation data to define the ESHGWT. In these cases, estimates of the average annual highest groundwater level are made from soil characteristics (redoximorphic features). However, just because the groundwater table may exist right up to the bottom of a SCM, the system can still successfully function to infiltrate stormwater: ponded water in the system still drives water downward and horizontal infiltration, although not recognized in a regulatory or design sense, occurs. There is a clear distinction between hydraulic and water quality expectations of Infiltration SCMs.

Reason for Current Requirement: Removal of many pollutants can occur in the vadose zone that underlies the SCM. Shallow groundwater, or impervious layers, may reduce the depth of unsaturated native soils that are available for treatment of infiltrated stormwater. With shallow unsaturated soils there is concern of localized groundwater contamination from stormwater infiltration especially in areas with private wells. Often the same vertical separation requirements for ESHGWT are applied to depth to bedrock as there are often fractures that hydrologically connect through bedrock to the water table.

More importantly, often bedrock has little to no permeability compared to the soils surrounding the SCM. As such, bedrock acts as a physical boundary to infiltration. Its presence also limits saturated thickness of groundwater flow: the smaller the saturated thickness, the larger the groundwater mound from infiltrated stormwater.

The vertical separation requirements for SCMs are likely attributable to septic system design standards. Lacking stormwater specific criterion, it is understandable that septic system design standards could have been seen as a suitable proxy for SCMs. However, given the significant differences in pollutant source strength and hydraulic loading characteristics, this criteria results in a highly conservative standard for siting stormwater systems.

At this writing, some jurisdictions allow relaxing the depth to ESHGWT if groundwater mounding modeling demonstrates that under design conditions, the mound does not grow into the SCM itself.

Impacts of the Requirement on Retrofits: This strict vertical separation often precludes the installation of Infiltration SCMs. Designers have come to believe that infiltration is not possible without meeting these separation requirements because these requirements are so ubiquitous.

Proposed Retrofit Guidance: Infiltration systems that include a filtering layer, such as Bio-Filtration systems, must have one foot or more of separation from the bottom of the filter course to the ESHGWT at all times. The filter layer may be included in the groundwater separation (rather than starting the calculation at or below the bottom of SCM excavation) calculation since treatment is being provided in this layer. In areas with pollutant sources and sensitive resources related to dissolved constituents (e.g. chlorides and nitrogen) stricter separation requirements should be upheld, and some form of technical assessment of consequences should be performed [28], [29], [30]. As with the siting of any infiltration system, careful consideration of the hydraulic gradient and protection of down gradient infrastructure is important. Many older urban areas may preclude infiltration due to the concern for water intrusion into abandoned pipes, basements, and other urban infrastructure that may be connected to adjacent properties.

A groundwater mounding analysis is required for practices designed to infiltrate more than the 1-year, 24-hour storm event; and when the ESHGWT separation from the bottom of the Filter Media SCM is less than 1 foot.

This analysis should be performed under more conservative conditions (high groundwater table). Mounding may grow into the SCM, but not back up stormwater runoff flowing into the SCM. It is recommended that SCM design and its mounding analysis accommodate and take advantage of horizontal infiltration. This recommendation should be framed in the context that it is for retrofit SCMs, and that the alternative is doing nothing, in which case there is no water quality improvement and stormwater flows unabated into receiving waters.

Reasoning for Retrofit Guidance: The use of infiltration systems for stormwater control is a legitimate concern for groundwater contamination and for down gradient water intrusion, however it is unclear the foundation upon which the current separation guidance is derived and may be more important for particular pollutants over others (i.e. dissolved constituents like chloride or nitrate) or in areas where the hydraulic gradient threatens public infrastructure. The literature has some information on guidance for restrictions for Infiltration SCMS however the appropriate information regarding the pollution risks associated with choosing infiltration—and the often greater pollution risks of not choosing infiltration—must be available to optimize and execute appropriate water resources management decisions.

Soils for Infiltration SCMs

Current Typical Requirement: Typical standards require soils with infiltration rates within a given range to be suitable for infiltration. Infiltration is not allowed in areas with too low or too high infiltration rates.

Reason for Current Requirement: The reasoning for these requirements is likely based on the assumption that if infiltration rates are too low, substantial infiltration will not occur and/or SCMs will not drain between storm events or they will need to be extremely large in order to drain the water quality volume within a specified time, and this defeats the fundamental thrust of retrofit SCMs in which space is often a major constraint. Restrictions for high infiltration rate soils are presumably to protect groundwater with the assumption that high infiltration rate soils do not effectively remove stormwater pollutants and that infiltrating water quickly flows to groundwater. As with separation to groundwater or bedrock, presumably this requirement was derived from onsite wastewater leach field design practices in which the soil was expected to perform significant improvement to the infiltrated wastewater quality.

Impacts of the Requirement on Retrofits: These prescribed soil requirements often preclude Infiltration SCMs from being installed without additional design constraints that eliminate infiltration benefits, such as inclusion of liners.

Proposed Retrofit Guidance: Consider Infiltration SCMs for all soil hydraulic conductivities where infiltration is appropriate. The Performance Curves include pollutant reduction results based on a large range of conductivities. For the sake of this manual, the Performance Curves for infiltration have been simplified and are presented by Hydrologic Soils Group (HSG) rather than infiltration rate.

The simplified SCM Performance Curves for Infiltration by HSG are presented in Appendix B. Appendix G contains a crosswalk mapping the NRCS soil texture and infiltration rate to HSG.

Reasoning for Retrofit Guidance: Research has shown that substantial infiltration can still occur in lower infiltration rate soils. Ultimately providing some infiltration is better than none.

Horizontal Setbacks for SCMs

Current Requirement: Horizontal setbacks are required between SCMs and other structures, resources, or property boundaries. Often setbacks from Infiltration SCMs may be even more stringent. Typical setbacks include offsets from the following features:

- Septic system
- Building foundation
- Private groundwater well
- Public groundwater drinking supply well
- Surface drinking water supply
- Surface waters
- Property line
- Certified vernal pools
- Wetlands

The setback requirements for Infiltration SCMs conservatively assume groundwater paths are in the direction from the SCM to the structure or resource of concern and do not account for the level of dispersion and/or treatment capable of the in-situ soils.

Reason for Current Requirement: Setbacks protect the integrity of the adjacent structures and resources.

Impacts of the Requirement on Retrofits: Historically, setback requirements can limit viable areas for SCMs resulting in small SCMs, locating SCMs on other parts of the property, installing fewer SCMs or completely prohibiting Infiltration SCMs altogether.

Proposed Retrofit Guidance: Use flexible sizing approaches to control stormwater and adhere to setbacks. For Infiltration SCMs, attempt to install smaller-scale shallow controls in lieu of larger centralized controls.

Reasoning for Retrofit Guidance: Although, retrofits often are small systems and not designed to hold and/or infiltrate large volumes of water during any given storm event, setbacks are often regulatory in nature and designed for protection. Studies of stormwater infiltration systems have shown that for most constituents concentrations approach background conditions within 1 foot (0.3 m) in the vertical (depth) and horizontal surrounding soil profiles [43] for non-dissolved pollutants such as TSS, TP, and TN. More conservative, dissolved pollutants such as chloride and nitrate may not necessarily approach background conditions within the 1-foot distance. The Performance Curves provide flexibility needed to size infiltration systems smaller or change the SCM type to a non-infiltration system that still provides good pollutant reduction.

Pretreatment

Current Requirement: Prescribed pretreatment measure types and sizing criteria.

Reason for Current Requirement: Pretreatment is known to extend the life and function of downstream SCMs. It also provides a targeted location for more regular maintenance and cleaning.

Impacts of the Requirement on Retrofits: When pretreatment sizing requirements are paired with SCM sizing requirements, viable retrofit SCM locations may not be possible or have adequate space.

Proposed Retrofit Guidance: Provide pretreatment whenever possible. When overcoming space constraints, consider simple measures such as deep sump catch basins and vegetated buffers even if they do not meet standard requirements. The goal is a viable and accessible pretreatment access point. Be prepared to increase inspection and maintenance operations when pretreatment is not able to be implemented fully.

Reasoning for Retrofit Guidance: Pretreatment is intended to enhance operation and maintenance. The risk of not including substantial pretreatment is that the SCM may need more frequent maintenance. For retrofit applications, the installation of some treatment is better than none.

Monitoring of SCMs with any pretreatment access point results in longer lifespan of the primary treatment component (UNHSC unpublished results). Often referenced performance criteria for pretreatment indicate a 10% reduction of sediment is a standard target. Multiple studies demonstrate that any easily maintained access point (volumetrically sized or not) offers such performance and provides the needed accessibility for long term pretreatment functionality [45].

Criteria for Impervious Area Disconnection Measures

Current Requirement: Impervious Area (IA) Disconnection in general is the practice of directing stormwater runoff from impervious areas to vegetated treatment areas. In current state guidance manuals, the included IA Disconnection measures (e.g., vegetated filter strips and qualifying pervious areas) typically need to meet slope, length and width, contributing area, soils, vegetation, setback, and ownership criteria to be credited.

Reason for Current Requirement: These criteria will presumably ensure that the benefits of IA Disconnection are realized.

Impacts of the Requirement on Retrofits: Existing or proposed IA Disconnection that does not meet the prescribed criteria is not valued as a stormwater mitigation feature and therefore not incentivized to incorporate into site layout design or maintained as a stormwater feature.

Proposed Retrofit Guidance: Provide IA Disconnection whenever possible and use the Performance Curves to estimate treatment for a range of pervious to impervious ratios and receiving area soil types. Ensure that disconnection scenarios do not result in erosion or channelized flow and that the receiving pervious area is well-vegetated. Add to the inventory, along with other SCMs for regular inspections and maintenance.

Reasoning for Retrofit Guidance: IA Disconnection is a low-cost measure that helps pavement runoff mimic natural site hydrology. It should be widely encouraged and implemented and valued as a SCM.

Appendix G—Hydrologic Soils Group Crosswalk with Rawls Rate Table

Approximate HSG	Soil Texture Class	Infiltration Rate (in/hr)
A	Sand*	8.27
A	Loamy Sand	2.41
B	Sandy Loam*	1.02
B	Loam	0.52
C	Silt Loam	0.27
C	Sandy Clay Loam*	0.17
D	Clay Loam*	0.10
D	Silty Clay Loam	0.06
D	Sandy Clay	0.05
D	Silty Clay	0.04
D	Clay	0.02

*Denotes soil texture class used as representative for SCM Performance Curves

Source for Soil Texture Class and Infiltration rates: Rawls, W.J. et al., (1983). J. Hyd. Engr., 109:1316. Approximate HSGs are assigned based on Soil Texture Class descriptions.

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