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Stormwater Best Management Practices: Guidance Document

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1.0 SELECTION OF BMPS FOR AN URBAN ENVIRONMENT

1.1 PURPOSE

The purpose of this Stormwater Best Management Practices ("BMPs") Proposal and Guidance Document propose a suite of generic stormwater BMPs for potential application by the Boston Water and Sewer Commission ("BWSC") pursuant to Section VII, Part D, Paragraph 25 of the Consent Decree lodged in Conservation Law Foundation et al, v. Boston Water and Sewer Commission, U.S. District Court Civil Action No. 1:10-cv-10250-RGS. This document will identify a suite of proposed stormwater BMPS to address the range of known pollutant discharges, including general information, sizing requirements, critical design parameters and BMPs that are scalable as appropriate to match the discharge volumes, pollutant loads, sub-catchment areas served and anticipated site conditions within each sub-catchment area found within the BWSC's Municipal Separate Storm Water System (BWSC MS4). This proposal emphasizes structural BMPs incorporating both Green-Infrastructure ("GI") and Low-Impact Development ("LID") techniques. This BMP Proposal and Guidance Document will be used by BWSC during site plan review of development projects and when designing capital improvements to institute available BMPs (whether GI or LID) in both public and private development. This document contains discussion on selection of BMPs, fact sheets for a variety of BMPs, a BMP selection matrix, and a technical guidance section that focuses on Low Impact Development Techniques (LID), urban stormwater pollutants, current Massachusetts stormwater standards, and BMP design and sizing techniques. This document will also incorporate the standards found in Volume 2, Chapter 2 of the "Massachusetts Stormwater Handbook" (2008); as well as, the Stormwater Best Management Practices (BMP) Performance Analysis" (December 2008, revised March 2010) prepared by Tetra Tech for U.S. EPA Region 1. This document was originally prepared by Geosyntec in October 2011, but was revised and updated by the BWSC in January 2013. BWSC will continue to update this BMP Proposal and Guidance Document as appropriate as new technologies and applications are more widely employed and tested in the City of Boston and other urban areas.

1.2 General Considerations

An integral step in selecting suitable BMPs for a site within the BWSC MS4 is to assess the existing site conditions. This section focuses on a number of factors that should be considered in regards to the implementation of BMPs in an ultra-urban environment as the BWSC MS4.

Site Suitability

There are a wide range of BMPs available, from rain barrels that require little space to constructed stormwater wetlands that require a much larger footprint. The scale of the BMP is directly related to the size of the construction project. For example, it may be impractical for private landowners of a brownstone in Back Bay to be required to design and install a stormwater wetland for a redevelopment project. However, private landowners could install rain barrels or planter boxes, to capture roof runoff and use for on-site watering demands. Parks or grassed areas adjacent to roadways may be ideal location for the implementation of larger scale BMPs such as a water quality swales or bio-retention areas.

Physical constraints at a site may include soil conditions, watershed size, depth to water table, depth to bedrock and slope. For redevelopment projects, physical constraints may include already compacted soils or the location of underground utilities. Even with physical site constraints, BMPs can be modified and adapted to fit a site needs with site planning and design to meet the applicable stormwater standards.

The BMP selection matrix, found in Section 1.3, contains a column labeled "General Suitability" that designates whether specific BMPs are potentially suitable for private landowners, public property (i.e. parks, sidewalks, roadways, etc.) or both land uses.

Soils

Soils regulate the process of surface runoff, infiltration and percolation, and are a major controlling factor in evapotranspiration through the capacity of the soil to store and release water. Furthermore, soils play an important role in removing pollutants from the water column via sorption to soil particles. The characteristics of soils at any particular site should be carefully considered during site planning.

Soil types and subsequent infiltration rates in the BWSC MS4 Area vary widely and can include glacial till, a wide variety of fill types, possible contamination, organic material such as blue clay, and bedrock such as Roxbury Conglomerate. As a result, soils should be evaluated carefully at each site and BMPs that provide groundwater recharge (i.e., dry wells) should be selected only if the site is comprised of soils that meet the infiltration requirements stated in the Massachusetts (MA) Stormwater Handbook, attached and incorporated herein as Appendix C-1.

Groundwater

The depth of seasonal high groundwater is an important factor to consider when selecting BMPs, suitable for groundwater recharge requirements. Information such as distance between the ground surface and the groundwater table, depth and direction of groundwater flow, seasonal groundwater variation, regional geology, and the slope of the water table are important factors to consider. The groundwater table acts as an effective barrier to exfiltration through the BMP soil media and soils below and can prevent an infiltration BMP from draining properly.

The typical depth to groundwater in BWSC MS4 Area ranges from 8 to 20 feet; however, it can vary widely based on topography, soil types, and underlying bedrock.

Available Pervious Area

Pervious areas in the urban environment are critical to providing effective stormwater treatment. Several stormwater BMPs require pretreatment, which can consist of a vegetated buffer strip and all infiltration BMPs largely depend on pervious areas. For sites with high areas amounts of development, new pervious areas may be created by removing impervious surfaces. Similarly, for sites with poor permeability, a suitable BMP may be to over-excavate and backfill the area with a more permeable substrate to increase the capacity of the drainage system by increasing subsurface stormwater storage availability and the overall permeability.

Existing Infrastructure

One primary step is for the BWSC to perform a review of its existing infrastructure during the review of private site plan submissions and capital infrastructure design planning. BWSC should also evaluate other existing infrastructure (roadways, bridges, building foundations, retaining walls, etc) within close proximity to proposed or planned infiltration BMPs. The use of conveyance BMPs or structural proprietary devices in areas where existing infrastructure may not allow for other practices will be considered. BWSC should also consider other impacts caused by BMP placement; for example, trees or vegetation placed in filter boxes could obscure traffic signs or obstruct road visibility at corners.

Utilities such as gas lines, water and sewer lines, electricity, telephone, and optical cables are often located underground and can further complicate placement and selection of BMPs. Construction activities that involve excavation or the use of large construction equipment must be carefully planned and executed to avoid costly and potentially dangerous damage to overhead or underground utilities. Utility conflicts are particularly applicable to the Boston MS4 Area due to the vast number of utilities that exist in the City of Boston, its streets and sidewalks.

Cost Constraints

Cost is an important factor to consider for the implementation of stormwater BMPs. Cost estimation can be difficult due to the following:

- Project site variability;
- Unforeseen site conditions, particularly with retrofit situations, including subsurface conflicts, space constraints, site accessibility, safety and security;
- Differences and quality of planners, designers, and contractors;
- High cost of engineering, permitting and construction management; and
- Construction related issues such as change orders, accelerated constructions schedules, unsuitable designs, and the use of non-standard components.

The BWSC's BMP Selection Matrix and BMP Fact Sheets provide general construction cost estimate ranges for each discussed BMP. The estimated costs are general guidelines and BWSC should also consider the additional factors listed above that can influence the final cost for implementation of the various BMPs listed below. BWSC will also consider Whole Life Cycle (WLC) costs as a selection criterion for evaluating BMP alternatives. WLC costs take into account both capital, operations and maintenance costs over the long term. A study published by the Water Environment Research Federation (WERF) provides whole life cycle cost models for an array of stormwater BMPs. The WLC models are a set of spreadsheet tools that have been developed to facilitate automation of a WLC approach for stormwater BMPs. The models allow users to systematically combine capital costs and on-going maintenance expenditures in order to estimate costs (WERF 2009).

1.3 BMP Selection Matrix

The BWSC MS4 BMP Selection Matrix was developed to facilitate the site planning and capital design planning process whether by a developer, private landowner or BWSC. During the site planning process or capital design planning, a developer, private landowner or BWSC will review the proposed site and/or location conditions and suitability, including any site constraints and stormwater management goals. Upon completion of review, the developer, private landowner, public agency and/or BWSC will then apply the BMP Selection Matrix, to choose appropriate BMPs for the particular site of interest.

The BMP Selection Matrix, attached hereto and incorporated as Appendix A, includes the following categories:

- BMP Class - Massachusetts Department of Environmental Protection (Mass DEP) divides stormwater BMPs into several categories which include:
    - Pretreatment – designed to treat the entire water quality volume (on-line) or a specified discharge volume or rate (off-line), prior to a treatment, infiltration or other BMP.
    - Treatment – designed to provide peak rate attenuation, removal of pollutants through retention and settling or filtration through soil media.
    - Infiltration – designed to provide volume reduction through groundwater recharge.
    - Conveyance – designed to collect and transport stormwater to BMPs for treatment or infiltration and may provide temporary storage.
    - Other – BMPs that do not fit into the categories above.
- Construction Cost Range – provides an estimated typical range of construction cost for each BMP. This cost may vary depending on site hydrology, soils and location.
- Applicability – provides an estimate of the typical land use suitability, general space requirements, if BMP requires groundwater recharge and if the BMP requires pretreatment.
- Unit Processes – provides a summary of the unit processes the BMP is capable of including volume reduction, peak reduction, filtration and sorption and biological process, as designated in the Mass. Stormwater Handbook. These unit processes are ranked by H (high), M (medium) and L (low).
- Target Pollutants – provides a summary of the pollutant removal capabilities of a BMP for sediment, nutrients, bacteria and metals as designed in the MA Stormwater Handbook. The

target pollutants are ranked by H (high), M (medium) and L (low). More information on percent pollutant removal for each BMP is contained in the Fact Sheets.

2.0 BMP Fact Sheets

BMP Fact Sheets are attached hereto and incorporated as Appendix B to this Proposal and Guidance Document and include a fact sheet for each of the BMPs listed in Table 1**.** Each BMP Fact Sheet includes the following brief sections:

- BMP Description;
- Suitable Applications, Advantages and Limitations;
- Recommended Design, Construction and Maintenance Considerations;
- Applicability to Massachusetts Stormwater Standards
- Target Pollutants and typical removal efficiencies;
- Cost Considerations; and
- Illustrations of each BMP.

The BMPs chosen for inclusion in the fact sheets are versatile systems that can be easily adapted and/or used in conjunction with other BMPs for varying site characteristics (i.e. tributary area, soil permeability, slope, land availability, depth to seasonal high groundwater table) to best meet proposed objectives of the BWSC within its MS4.

3.0 TECHNICAL GUIDANCE

3.1 GREEN INFRASTRUCTURE AND LOW IMPACT DEVELOPMENT TECHNIQUES

Green Infrastructure (GI) and Low Impact Development (LID) are sustainable stormwater runoff management approaches. These approaches use distributed micro-scale stormwater runoff management principles and practices to mimic the natural hydrologic cycles to treat runoff through the processes of storage, infiltration (groundwater recharge), evapotranspiration, and filtration (MA EOEEA, 2011; Low Impact Development Center, 2007). Integrating these practices into new development and redevelopment begins at the site planning level with the BWSC Site Plan Review process. Careful site planning includes reducing the amount of directly-connected impervious areas, fitting the proposed improvements to the site terrain, preserving and using the natural drainage systems, and planning to replicate pre-development hydrology. BWSC will consider including infiltrating and treating stormwater runoff at the source, thereby reducing the demand on the BWSC MS4 infrastructure.

LID and GI approaches involve non-structural changes as well as structural controls. The non-structural practices take the form of broader planning and design approaches. Non-structural practices prevent stormwater generation, as opposed to structural practices which mitigate stormwater impacts once the issues arise. BWSC can prevent stormwater generation through encouraging developers and/or private landowners to implement land development practices such as:

- **Preserving site vegetation** which absorbs and reduces the amount of stormwater runoff;
- **Maintaining natural buffers and drainage ways** to slow and store water, promote infiltration and filter pollutants;
- Designing using **cluster and concentration** of development;
- Using **native vegetation** to reduce irrigation demand, fertilizers and pesticides;
- **Minimizing disturbance and maintenance**;
- **Disconnecting, distributing and decentralizing** practices;
- **Source control**;
- **Reduction of impervious area** by eliminating curbs and gutters, which promotes infiltration to grassy areas, decreasing driveway length and/or width. (MA Metropolitan Area Planning Council, 2010; MA Gov, 2011); and
- Providing **street and parking lot sweeping** to remove accumulated solids.

LID and GI structural approaches include:

- Planning location of structural BMPs which provide easy access for maintenance to reduce disturbance to existing areas;
- Using construction **erosion and sediment control practices**, to minimize migration of sediment during construction; and
- Choosing BMPs that promote infiltration, filtration, blend with natural terrain and reduce the disturbance footprint.

Some structural practices that provide these design and planning techniques are stormwater treatment trains. A treatment train is a series of BMPs to provide removal of coarse sediment (pretreatment BMP) followed by a treatment, filtration or infiltration BMP to provide peak attenuation, groundwater recharge or reduction of primary pollutants. An example of a treatment train is the drainage from a roadway and sidewalk being pretreated with a vegetated filter strip which discharges into a bio-retention area, which then provides filtration and or infiltration prior to discharging into the BWSC MS4 system.

BWSC will consider LID techniques and GI integrated into new developments or re-development projects in a manner that will meet Massachusetts stormwater management requirements. The integrated LID techniques and GI should provide additional site benefits such as maintaining and enhancing existing site vegetation, improving groundwater recharge, reducing stormwater volume, and providing improved site landscaping. In addition, BMPs, LID techniques and GI are best accomplished with written maintenance plans for both pre- and post-construction.

3.2 MASSACHUSETTS STORMWATER STANDARDS

In 1996, the Massachusetts Department of Environmental Protection (the "Department" or "MassDEP") issued the Stormwater Policy that established Stormwater Management Standards aimed at encouraging recharge and preventing stormwater discharges from causing or contributing to the pollution of the surface waters and ground waters of the Commonwealth. In 1997, MA DEP published the Massachusetts Stormwater Handbook as guidance on the Stormwater Policy. In 2008, MA DEP revised the Stormwater Management Standards and Massachusetts Stormwater Handbook to promote increased stormwater recharge, the treatment of more runoff from polluting land uses, low impact development (LID) techniques, pollution prevention, and the removal of illicit discharges to stormwater management systems, and improved operation and maintenance of stormwater best management practices (BMPs).

MA DEP applies the Stormwater Management Standards pursuant to its authority under the Wetlands Protection Act, M.G.L. c. 131, § 40, and the Massachusetts Clean Waters Act, M.G.L .c. 21, §§ 26-53. The revised Stormwater Management Standards have been incorporated in the Wetlands

Protection Act Regulations, 310 CMR 10.05(6)(k) and the Water Quality Certification Regulations, 314 CMR 9.06(6)(a).

The Stormwater Management Standards address water quality (pollutants) and water quantity (flooding, base flow and recharge) by establishing standards that require the implementation of a wide variety of stormwater management strategies. These strategies include environmentally sensitive site design and LID techniques to minimize impervious surface and land disturbance, source control, and the long-term operation and maintenance of stormwater management systems. The Massachusetts Stormwater Standards are attached and incorporated into this document for reference purposes.

Applicability

Stormwater runoff from all industrial, commercial institutional, office, residential and transportation projects including site preparation, construction and redevelopment, and all point source stormwater discharges from said projects shall be managed according to the Stormwater Management Standards.

The Stormwater Management Standards do not apply to:

(1) A single-family house;

(2) Housing development and redevelopment projects comprised of detached single-family dwellings on four or fewer lots provided that there are no stormwater discharges that may potentially affect a critical area;

(3) Multi-family housing development and redevelopment projects with four or fewer units, including condominiums, cooperatives, apartment buildings and townhouses, provided that there are no stormwater discharges that may potentially affect a critical area; and

(4) Emergency repairs to roads or their drainage systems.

The Stormwater Management Standards apply to the maximum extent practicable to:

(1) Housing development and redevelopment projects comprised of detached single-family dwellings on four or fewer lots that have a stormwater discharge that may potentially affect a critical area;

(2) Multi-family housing development and redevelopment projects, with four or fewer units, including condominiums, cooperatives, apartment buildings, and townhouses, that have a stormwater discharge that may potentially affect a critical area;

(3) Housing development and redevelopment projects comprised of detached single-family dwellings on five to nine lots, provided there is no stormwater discharge that may potentially affect a critical area;

(4) Multi-family housing development and redevelopment projects with five to nine units, including condominiums, cooperatives, apartment buildings, and townhouses, provided there is no stormwater discharge that may potentially affect a critical area;

(5) Marinas and boat yards provided that the hull maintenance, painting and service areas are protected from exposure to rain, snow, snow melt, and stormwater runoff; and

(6) Footpaths, bike paths and other paths for pedestrian and/or non-motorized vehicle access.

There are fewer options for stormwater BMPs for heavily urbanized areas like the City of Boston and the BWSC MS4. The primary barrier to BMP implementation is a lack of physical space. This limitation eliminates many space-intensive options (i.e., extended dry-detention basins, wet ponds) and makes BMPs that could be used on a micro-scale level more feasible. When proposing BMPs for redevelopment BWSC will consider potential engineering concerns such as the redevelopment's connection to existing storm drain infrastructure, ensure available head, hydraulic grade lines and will review the impacts of possible pipeline bottlenecks that may increase flooding potential. The presence of underground utilities, including gas and water mains, sewer pipes and electric cable conduits in the City of Boston, will also reduce the available space or land suitable for BMPs. Given the many constraints an ultra-urban environment like the City of Boston presents; managing stormwater with redevelopment BMPs is the most feasible option for BWSC. Therefore, this BMP Proposal and Guidance Document focuses on the BMPs suitable for Redevelopment Projects, as discussed in the BMP Fact Sheets and in the BMP Matrix.

Stormwater Management Standards and Documenting Compliance

Standard 1: Untreated Discharges

No new stormwater conveyances (e.g. outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

This standard allows the direct discharge of stormwater to waters and wetlands provided the discharge is adequately treated. The term "treated" refers to the implementation of stormwater management systems that are specifically designed to achieve sediment and contaminant removal rates that adequately protect ground water, surface waters and wetlands.

To ensure stormwater discharges do not "cause erosion in a wetlands or waters of the Commonwealth", BMPs and associated pipes and other conveyances must be properly designed and installed to minimize erosion.

To meet the requirement of Standard 1, the applicant shall demonstrate that there are no new untreated discharges. To demonstrate compliance the applicant shall, at a minimum:

1) Determine the 2-year, 24-hour maximum velocity at each discharge location; and

2) Provide calculations to estimate the sizing/weight of stone or bioengineered material to resist the force of water or compare the permissible velocity of a material to the discharge

velocity at each discharge location (examples can be found in the MA Stormwater Handbook).

Standard 2: Peak Control and Flood Prevention

Stormwater management systems shall be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates.

For new development sites, development that involves the creation of impervious surfaces will have particularly significant effects on runoff. The Stormwater Policy recommends the control of post-development peak rates to meet the following criteria:

- Post-development peak rates for the 2-year and 10-year design storm events must be controlled to be less than or equal to the pre-development condition. The discharges shall be evaluated at the point of discharge or at the down-gradient property line.

- Evaluate the 100-year design storm event to demonstrate that there will be no increased flooding impacts off-site.

To meet these requirements, sites shall be designed to minimize impervious areas, minimize steep slopes, maximize opportunities for infiltration and maximize overland flow paths. Temporary storage shall be provided for runoff from all portions of the site and the release of water shall be regulated from the storage facilities by an outlet structure or infiltration into groundwater.

This Standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

Standard 3: Recharge to Groundwater

Loss of annual recharge to ground water shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

To demonstrate compliance with Standard 3, the applicant shall calculate the proposed site impervious area, required recharge volume and bottom sizing area for infiltration practices. To evaluate the potential for recharge at a specific site, a soil evaluation shall be conducted to determine site soils and hydrologic soil groups. In locations where infiltration best management practices are proposed, the depth to season high groundwater and the saturated hydraulic conductivity shall be estimated (in accordance with the methods outlined in the MA Stormwater Handbook).

The recharge volume equals the depth of runoff corresponding to the soil type times the impervious areas covering that soil type at post-development condition, and is calculated as:

Rv = F * ImpArea

where Rv is the recharge volume; F is the target depth factor (as defined in the MA Stormwater Handbook) and ImpArea is the impervious area in the associated soil hydrologic group (examples are presented in the MA Stormwater Handbook).

Use the recharge volume to size the infiltration BMP to allow for recharge to groundwater or use the other acceptable methods as specified in the MA Stormwater Handbook.

Standard 4: Water Quality and 80% TSS Removal

Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). This Standard is met when:

a. Suitable practices for source control and pollution prevention are identified in a long-term pollution prevention plan, and thereafter are implemented and maintained;

b. Structural stormwater best management practices are sized to capture the required water quality volume determined in accordance with the Massachusetts Stormwater Handbook; and

c. Pretreatment is provided in accordance with the Massachusetts Stormwater Handbook.

To meet the Standard 4, determine the required water quality volume, which is defined as the volume of water requiring TSS treatment and is calculated as:

WQv = D * ImpArea

where D is the water quality depth in inches (use 1.0 for land uses with a higher pollutant load potential, within an area of rapid infiltration (> 2.4 in/hour), within Zone II or the interim wellhead protection area or discharging to a critical area or 0.50 for all other land uses) and ImpArea is the post construction impervious area.

Prepare TSS removal computations, which are provided by MassDEP in an automated Excel spreadsheet, to meet the TSS requirements (80%) or to the maximum extent practicable for redevelopment. Calculations must be completed for each proposed stormwater outlet and shall demonstrate that 44% TSS removal has been achieved prior to discharging to infiltration BMPs.

Develop a Long Term Pollution Prevention Plan (LTPPP) to include guidance on Site practices for:

- Good housekeeping
- Storing materials and waste products inside or under cover

- Vehicle washing
- Routine inspection and maintenance of stormwater BMPs
- Spill prevention and response
- Maintenance of lawn, gardens and other landscaped areas
- Storage and use of herbicides, fertilizers and pesticides
- Pet waste management
- Operation and maintenance of septic systems (if applicable)
- Proper management of deicing chemicals and snow

Standard 5: Land Uses with Higher Potential Pollutant Loads (LUHPPLs)

For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable. If through source control and/or pollution prevention all land uses with higher potential pollutant loads cannot be completely protected from exposure to rain, snow, snow melt, and stormwater runoff, the proponent shall use the specific structural stormwater BMPs determined by the Department to be suitable for such uses as provided in the Massachusetts Stormwater Handbook.

To meet this requirement, the applicant shall:

- Address all source control and pollutant prevention measures in the LTPPP;
- Select BMPs which are suitable for design and construction in LUHPPLs. A water quality depth of 1.0 inch shall be used to design these BMPs;
- Pretreatment requirement of 44% shall be achieved prior to discharging to an infiltration structure; and
- If there is potential for runoff with high concentrations of oil and grease, a pretreatment device suitable for removal of oil and grease (oil grit separator, sand filter or filtering bioretention area, or equivalent) shall be designed and installed.

Standard 6: Critical Areas

Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply and stormwater discharges near or to any other critical area require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined to be suitable for managing discharges to such areas as provided in the Massachusetts Stormwater Handbook.

To demonstrate compliance with this requirement, the Applicant shall at a minimum:

- Include source controls and pollution prevention measures in the LTPPP;
- Choose BMPs that are suitable for critical areas;
- Size BMPs using a recharge depth of 1.0 inch; and
- Pretreatment requirement of 44% shall be achieved prior to discharging to an infiltration structure.

<u>Standard 7: Redevelopment</u>

A redevelopment project is required to meet Standards 2, Standard 3, the pre-treatment and structural best management practice requirements of Standard 4, 5, and 6 to the “maximum extent practicable.” Existing storm water discharges shall comply with Standard 1, only to the “maximum extent practicable.”

The “maximum extent practicable” is defined as:

(1) Proponents of redevelopment projects have made all reasonable efforts to meet the applicable Standard;
(2) Made a complete evaluation of possible stormwater management measures including environmentally sensitive site design that minimizes land disturbance and impervious surfaces, low impact development techniques, and stormwater BMPs; and,
(3) If not in full compliance with the applicable Standards, they are implementing the highest practicable level of stormwater management.

To demonstrate compliance with this Standard, at a minimum the Applicant shall develop:

- Long Term Pollution Prevention Plan (as required under Standard 4);
- Erosion and Sediment Control Plan (as required under Standard 8);
- Operation and Maintenance Plan (as required under Standard 9);
- Illicit Discharge Compliance Statement (as required under Standard 10);
- Demonstrate that there are no new discharges that cause or contribute to erosion of wetlands or waters of the Commonwealth (as required under Standard 1);
- Demonstrate that the designed measures proposed improve the existing conditions; and

- Complete necessary computations to determine proposed structural BMPs meet the requirements of Standards 2, 3 and the structural BMP requirements of Standards 4 and if applicable, 5 and 6 to the maximum extent practicable.

Standard 8: Erosion and Sediment Controls

Development and implementation of a plan to control construction related impacts including erosion, sedimentation and other pollutant sources during construction and land disturbance activities (construction period erosion, sedimentation, and pollution prevention plan).

To demonstrate compliance with this Standard, the Applicant shall:

- Provide computations for the area to be disturbed; and

- Provide a Construction Erosion and Sediment Control Plan (CESCP) to show construction period controls that shall be implemented to prevent erosion during construction. The CESCP shall include computations showing that all proposed erosion and sediment control structures are properly sized and a map indicating the locations of these practices.

The Applicant will also be required to submit a SWPPP plan and comply with NPDES requirements related to construction sites exceeding one (1) acre or common development plans affecting more than one (1) acre, consistent with the BWSC Construction Site Inspection and Enforcement Program.

Standard 9: Operation and Maintenance

A Long-Term Operation and Maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed.

To demonstrate compliance with this Standard the Applicant shall create a Long-Term Operation and Maintenance Plan (O&M Plan), which shall include:

- Stormwater Management Owners;

- Party or parties responsible for operation and maintenance;

- Routine and non-routine maintenance tasks to be undertaken after construction is complete and a schedule for implementing those tasks;

- Plan including locations of all stormwater BMPs along with their discharge location;

- Description and delineation of public safety features; and

- An estimated operation and maintenance budget.

Standard 10: Prohibition of Illicit Discharges

All illicit discharges to the stormwater management system are prohibited.

To demonstration compliance with this Standard, the Applicant shall submit a written and signed statement indicating that no illicit discharges to the stormwater management system are being proposed as part of the Project.

3.3 Priority Pollutants

BWSC conducted a Stormwater Quality Evaluation Program in the Summer and Fall of 2010. The purpose of the program was to:

1) Assess the current concentrations of pollutants in stormwater discharged from three representative drainage areas (high-density residential, open space, and mixed use) within the Boston Water and Sewer Commission's (Commission) drainage system; and
2) Evaluate the impact of wet weather discharges on the water quality of three receiving water bodies.

The high-density residential area located in Charlestown included approximately 2.1 acres of attached brick row houses at a density of about 32 housing units per acre. The area is representative of multi-family housing throughout Charlestown and other areas of the City.

The open space area, Wesley G. Ross Playground, located in Hyde Park consisted of approximately 12-acres of baseball fields, tennis and basketball courts, a children's playground, and small paved areas for vehicles (parking lot and access road). There are no buildings or sewers located within the playground.

The mixed-use area located in Hyde Park included 19 acres of residential (57%), commercial (11%), institutional (21%), and transportation related (11%) land uses. The residential land use is primarily made up of single-family residences with grassed areas in the front and back yards, the institutional use comprised of a church, school, funeral home, and 2 additional buildings, the River Street MBTA station and parking areas constitute the transportation land use, and the commercial land use consists of a bank, laundromat, day care center, variety stores, and restaurants.

Some of the key findings and conclusions of the Program included:

- Bacterial levels in stormwater exceeded applicable water quality standards, particularly those based on fecal coliform concentration, even in areas known to have no illegal sanitary connections, such as open spaces.

- Levels of copper and zinc in runoff from the Boston area exceeded applicable water quality criteria, particularly in dissolved form.

- Drainage areas with more pavement and associated automobile traffic (e.g. high-density residential and mixed use areas) generally had higher levels of solids, heavy metals, oil & grease, and/or TPH.
- Sources other than the BWSC's storm drains are the primary cause of metals and bacterial pollution in the brooks. Chandler Pond does not have many other sources of pollution and is generally cleaner than the brooks.

As a result, the quality of stormwater in the BWSC MS4 is typical of run-off in highly urbanized areas across the nation. Sediment, nutrients, metals, and bacteria are common pollutants in urban runoff discharged to receiving waters.

BWSC also recently completed monitoring related to calibration of its newly created Stormwater Model developed by CDM Smith, submitted for review and approval to EPA on December 28, 2012. BWSC will also evaluate the findings and pollutant loading estimates generated in its model to evaluate potential BMP implementation within the sub-catchment areas delineated within the BWSC MS4.

In the following sections, relevant water quality standards, removal mechanisms, and typical BMPs that are employed for each pollutant are discussed.

Suspended Solids/Sediment

Suspended solids/sediment consists of soils or other surficial materials that are eroded and deposited by wind, water, or gravity. Excessive sediment can increase turbidity, settle out in conveyance systems decreasing the capacity of the conveyance, damage pump facilities, and increase maintenance requirement frequencies. The largest source of suspended sediment is typically erosion from disturbed soils. Consequently, sediment in urban runoff often contains a variety of pollutants that are solid particulates or have a high affinity for binding to organic materials. Suspended sediment is primarily removed through infiltration and sedimentation (reduction in runoff velocities below settling velocities of the particles). Common BMPs designed to increase sedimentation include vegetated filter strips, bioretention areas, baffle boxes, infiltration basins, and hydrodynamic separators.

Nutrients

This category commonly consist of nitrogen and phosphorous. Nutrients commonly exist in the form of mineral salts dissolved or suspended in water and as a particulate organic matter transported by stormwater. Excessive discharge of nutrients to water bodies and streams can cause eutrophication and release of toxins in sediment. Primary sources of nutrients in urban runoff are fertilizers, trash and debris, and eroded soils. Particulate bound nutrients are removed through sedimentation, while dissolved nutrients can be removed through biological processes such as denitrification, and filtration and sorption within engineered soils. Common BMPs designed to remove nutrients are bioretention areas, constructed stormwater wetlands, sand filters, and water quality swales.

Metals

The main metals of concern include cadmium, chromium, copper, lead, mercury, and zinc. They are commonly found in commercial paints, fuels, and automotive products. The primary source of metals in urban stormwater is typically commercially available metal products and automobiles. The common unit processes associated with removing metals from stormwater runoff include: sedimentation, sorption, filtration, as well as chemical and biological processes. Common BMPs designed to remove metals are bioretention areas, infiltration basins, planter boxes, porous pavement, and constructed stormwater wetlands.

Bacteria

Bacteria are microorganisms that thrive under a range of environmental conditions. Water containing excessive pathogenic bacteria can create a harmful environment for humans and aquatic life. The source of pathogenic bacteria in urban runoff is typically associated with the transport of animal or human fecal wastes from the watershed and particularly from sanitary sewer overflows, or illicit connection of sanitary waste disposal lines to stormdrain piping, but pathogenic organisms do occur in the natural environment. Bacteria are commonly removed from urban runoff through volume reduction and controlling the source (i.e. animal waste). Low impact development (LID) techniques, such as bioinfiltration areas, porous pavement, and proprietary tree box filters can potentially reduce bacteria loads conveyed to receiving waters. In addition, the BWSC is actively seeking out and eliminating illicit connections and working to prevent sanitary sewer overflows.

3.4 EVALUATION METHODS FOR BMPS

BMP performance is often evaluated based upon effluent quality. The effluent quality of a BMP describes the concentrations of various pollutants in the flows discharged from the BMP. Other methods of quantifying the efficiency of a BMP include percent removals of pollutant loads. Traditionally, the efficiency of BMPs have often been described and compared based on percent removal of pollutants. However, BMPs do not typically function with a uniform percent removal across a range of influent quality concentrations. BMPs demonstrate high percent removals under high loadings and poor percent removal where pollutant concentrations are low. In highly developed, urbanized tributary areas such as industrial or commercial areas in Boston, with potentially high pollutant concentrations in stormwater runoff, the designed BMP may achieve the desired pollutants removal efficiency; however, the system may still discharge at concentrations detrimental to the receiving watershed. In under-developed or residential areas with low inflow pollutant concentrations, the designed BMP may not achieve the desired pollutant removal efficiency because the inflow concentrations are relatively low; however, the system may discharge at concentrations below levels that impair the receiving watershed. At some sites, there is a minimum concentration achievable through implementation of BMPs for many constituents (Schueler, 1996 and Minton, 1998). Percent removal alone, even where the results are statistically significant does not provide a useful assessment of BMP performance.

The MA DEP 2008 Stormwater Handbook requires BMPs to be sized according to the 10 standards previously discussed in Section 3.2 of this report based upon site location. According to Standard 7, redevelopment projects are required to meet Standards 2 (Peak Control and Flood Prevention), Standard 3 (Recharge to Groundwater), the pre-treatment and structural BMP requirement of Standard 4 (Water Quality and 80% TSS Removal), Standard 5 (Higher Potential Pollutant Loads), and Standard 6 (Critical Areas) to the "maximum extent practical", which has been previously defined.

Stormwater BMPs considered for implementation need to be scalable to account for larger flows and higher pollutant loads from different land use types. For example, proprietary devices are most often completely scalable by simply increasing their size, flow capacity, or surface area of treatment. Underground systems that use cartridges for filtration can be configured to include more surface area of treatment within the device. Practices that require stormwater detention can be increased in size in drainage areas where flows are concentrated and occur in volumes larger than anticipated. If filtering BMPs are used, proper design for flow is required to account for overflows or bypass during extreme precipitation events. In urban areas the filter media may require more frequent maintenance to prevent clogging and to account for higher pollutant loading. The key is to properly size the selected BMPs based upon a hydrologic assessment of the drainage area.

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APPENDICES

APPENDIX A:

BMP Selection Matrix

Table 1. BMP Selection Matrix

BMP Class [1]	BMP Type	Target Pollutants [4]				Construction Cost Range [2]	Applicability					Unit Processes [3]			
		Sediment	Nutrients	Bacteria	Metals		General Suitability	Suitable for Redevelopment	Provides Groundwater Recharge	General Space Requirements	Requires Pretreatment	Volume Reduction	Peak Flow Reduction	Filtration & Sorption	Biological Processes
Pretreatment	Vegetated Filter Strips	M	L	L	L	$50 to $100 per linear feet	Public	√		H		M	M	M	L
Pretreatment	Hydrodynamic Separators	M	L	L	M	$8,000 to $15,000 each	Public	√		L		L	L	L	L
Pretreatment	Baffle Box	H	L	L	L	$20,000 to $30,000 each	Both	√		M		L	L	L	L
Treatment	Bioretention	H	M	H	H	$5 - $30 per square foot	Both	√	√	M	√	M	L	H	H
Treatment	Planter Box	H	M	H	H	$24 to $32 per square foot	Both	√		L	√	M	L	H	M
Treatment	Tree Box Filter	H	M	L	M	$10,000 to $18,000 each	Both	√		L		L	L	M	L
Treatment	Filterra® Tree Box Filter	H	M	L	M	$10,000 to $18,000 each	Both	√		L		L	L	M	L
Treatment	TREEPOD® Tree Box Filter	H	M	L	M	$10,000 to $18,000 each	Both	√		L		L	L	M	L
Treatment	Constructed Stormwater Wetland	H	M	L	H	$50,000 to $250,000	Public			H	√	L	H	M	H
Treatment	Sand Filters	H	M	M	H	$10,000 to $50,000 per Impervious Acre	Public	√		H	√	L	L	H	L
Infiltration	Gravel Trench	H	H	H	H	$50 to $80 per linear foot	Public	√	√	H	√	H	H	H	L
Infiltration	Dry Wells	H	L	L	L	$500 to $1,000 each	Private	√	√	L		H	M	M	L
Infiltration	Infiltration Basin	H	H	H	H	Varies	Both	√	√	M		H	M	H	M
Infiltration	Proprietary Infiltration Device (CULTECH)	H	L	L	L	Varies	Both	√	√	M	√	H	M	M	L
Infiltration	Subsurface Infiltration Systems	H	L	L	L	Varies	Both	√	√	M	√	H	M	M	L
Conveyance	Dry Water Quality Swale	H	L	L	M	$8 - $10 per linear foot	Public	√		H	√	L	L	L	M
Other	Porous Pavement	H	M	M	M	$8 - $15 per square foot	Both	√	√	M		H	M	M	L
Other	Disconnect Impervious Surfaces	H	H	L	L	Varies	Private	√		L		L	M	L	L
Other	Rain Barrels / Cisterns	NA	NA	NA	NA	Cistern - $1 to $4 per gallon Rain Barrel $60 to $100 each	Private	√		L		M	M	L	L
Other	Green Roofs	L	L	L	L	$20 to $30 per square foot	Private	√		M		H	M	L	L

Notes:

1. BMP Class as designated in the Massachusetts Stormwater Handbook (2008)
2. Construction Cost Ranges are based on construction installation cost and do not include costs associated with permitting, design or maintenance.
3. Unit Processes based on designation in the Massachusetts Stormater Handbook (2008).
4. Target Pollutant based on pollutant removal efficiencies as stated in the Massachusetts Stormwater Handbook (2008).

Designation categories include:

- H (high) > 80% pollutant reduction
- M (moderate) between 30% and 80% pollutant reduction
- L (low) < 25% pollutant reduction
- NA - not applicable (no pollutant reduction provided)

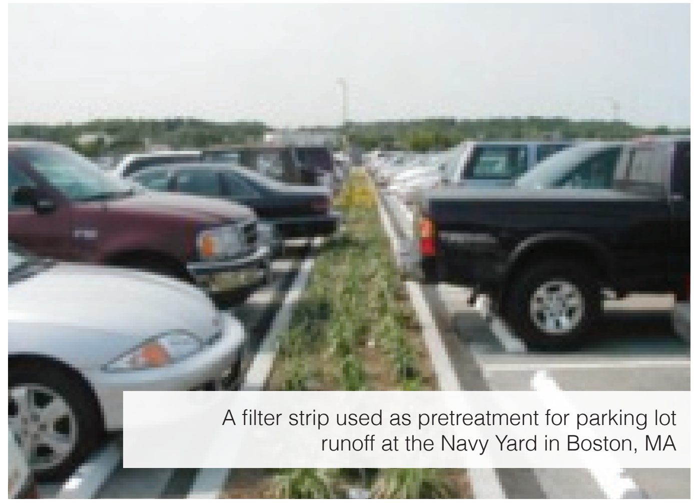
APPENDIX B:

BMP Fact Sheets

Vegetated Filter Strip

DESCRIPTION

Vegetated filter strips are uniformly graded, vegetated, pretreatment practices designed to treat low volume concentrated flows or sheet flow from adjacent roads, highways, small parking lots, and residential driveways. Vegetated filter strips are designed to decrease runoff velocities, capture sediment, and decrease runoff volumes. Filter strips provide effective treatment when combined with bioretention areas and stream buffers.



A filter strip used as pretreatment for parking lot runoff at the Navy Yard in Boston, MA

Applications

- Pretreat sheet flow from roads, highways, and small parking lots.
- Pretreat runoff from residential driveways
- Retrofit options in urban settings
- Side slopes of grass channels or water quality swales to enhance infiltration and remove sediment runoff from small parking lots and roads.

Advantages

- Volume & peak flow reduction
- Reduces runoff velocity
- Effective pretreatment for bioretention cells
- Can mimic natural hydrology
- Used as part of runoff conveyance system with other BMPs

Limitations

- Design dictates pollutant removal efficiency
- Effective on drainage areas with less than 6% slopes
- Improper grading can diminish removal efficiency

UNIT PROCESSES	
M	Volume reduction
M	Peak flow reduction
M	Sedimentation
M	Filtration & sorption
L	Biological processes

TARGET CONSTITUENTS	
L	Nutrients
L	Metals
L	Bacteria
M	Sediment
M	Oil and grease
M	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

Some peak flow attenuation

TSS removal (dependant on width)

Can be constructed in:

Higher pollutant land use areas as pretreatment if lined

Critical Areas as pretreatment is lined

Pretreatment device or stand alone device for redevelopment

LEGEND

H = High

M = Medium

L = Low

NOTES

These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Estimated cost range of filter strip is between $50 and $100 per linear foot (assuming 25 feet wide strip)

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Contributing drainage area is limited to one acre or less
- Filter strip typically consists of a level spreader, topsoil, and vegetation (grass)
- Shall drain within 24 hours and design flow depth shall be ≤ 0.5 inches
- Design filter strip at a minimum of 25 feet in length and as wide as the area draining to the strip
- Plant filter strip with salt-tolerant grasses which are also resistant to high velocities
- Use level spreader (level trenches or curbing and concrete weirs) at head of filter strip to evenly distribute runoff across entire length
- Design head and toe of filter strip as flat as possible to prevent erosion.

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail under Removal Efficiencies

Total Suspended Solids (TSS): 10% (If filter strip is 25 ft wide)

Total Suspended Solids (TSS): 45% (If filter strip is 50 ft wide)

Nutrients and Metals: (Dependent on site and design characteristics)

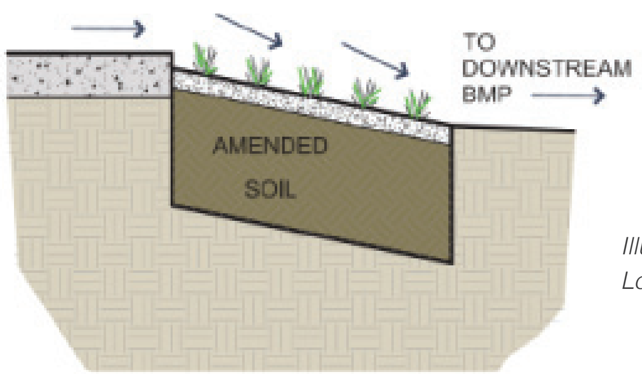


Illustration of a filter strip from the Los Angeles LID Handbook.

CONSTRUCTION CONSIDERATIONS

- Proper grading of filter strip and level spreader is necessary to establish sheet flow
- Use upstream sediment traps to protect area being used by filter strip
- Stabilize soil until vegetation has established to prevent erosion
- Use existing topsoil on site to enhance plant growth

MAINTENANCE

- Inspect level spreader for sediment buildup and vegetation for signs of erosion
- Mow grass regularly
- Reseed eroded and bare vegetated areas to restore surface permeability, increase sedimentation, and prevent creation of concentrated flow
- Remove trash and debris to prevent creation of concentrated flow
- Remove accumulated sediment at top of filter strip to maintain appropriate slope and prevent formation of berm

Hydrodynamic Separators

DESCRIPTION

Hydrodynamic separator devices are proprietary stormwater BMPs that remove trash, debris, and coarse sediment from incoming flows using screening, gravity settling, and centrifugal forces generated by forcing the influent into a circular motion. By having the water move in a circular fashion, rather than a straight line, it is possible to obtain significant removal of coarse sediments and attached pollutants with less space as compared to other traditional gravity settling devices. Several types of hydrodynamic separation devices are also designed to remove floating oils and grease using sorbent media and baffles and trash racks can be added to reduce trash and debris. Hydrodynamic separators are designed and manufactured by private businesses, and come in different sizes to accommodate different design storms and flow conditions. The effectiveness of proprietary separator varies greatly by design and size, so units must be correctly sized for specific soil conditions and flow profiles.

Hydrodynamic separator during testing
(Photo courtesy of the UNH stormwater center)

Applications

- Pretreatment only
- Sites with space constraints
- Ultra-urban areas
- Spill control

Advantages

- Can be custom-designed to fit specific needs of a specific site
- Smaller footprint required
- Pretreatment device
- Decentralized stormwater treatment
- Ideal for redevelopment or in ultra-urban setting

Limitations

- Must be purchased from private sector firm
- May require more maintenance
- Performance must be verified by third party
- No groundwater recharge
- No control of runoff volume

UNIT PROCESSES	
L	Volume reduction
L	Peak flow reduction
M	Sedimentation
L	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
L	Nutrients
M	Metals
L	Bacteria
M	Sediment
L	Oil and grease
H	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
TSS removal if used as pretreatment
Can be constructed in:
Higher pollutant loading land use areas as a pretreatment device
Critical Areas as pretreatment
Redevelopment or retrofit situations

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Estimated average cost range for hydrodynamic devices is $8,000 to $15,000.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Design, construct, and maintain in accordance with manufacturer's specifications
- Typically sized based on flow rate
- Primarily used for pretreatment and placed at beginning of stormwater treatment train
- May have baffles or other devices to direct incoming water into and through a series of chambers and/or skirts or weirs to keep trapped sediments from re-suspending during larger flows
- Design to include safe inspection and access ports for maintenance

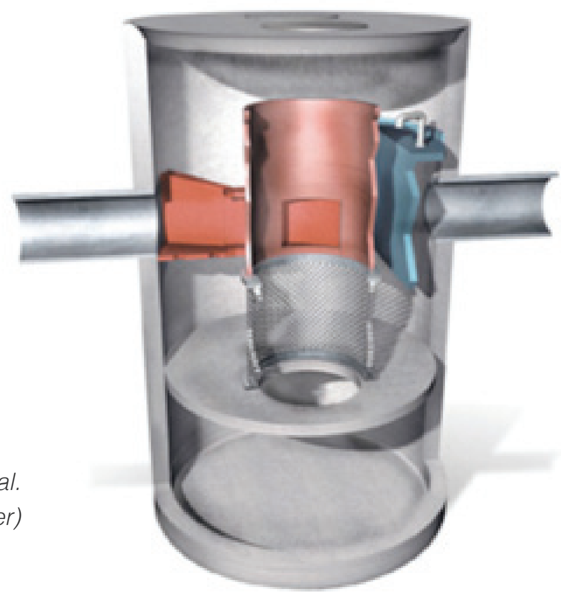
Pollutant Removal Efficiencies

Total Suspended Solids (TSS): Varies by unit (consult manufacturer)

Nutrients and Metals: Varies by unit (consult manufacturer)

LIST OF PROPRIETARY MANUFACTURERS

- **BaySaver:** www.baysaver.com;
- **Aquashield, Inc:** www.aquashieldinc.com;
- **Contech Stormwater Solutions:** www.contech-cpi.com/stormwater/products/14;
- **CrystalStream Technologies:** www.crystalstream.com



Cross-section of hydrodynamic separator, typical. (Image courtesy of the UNH Stormwater Center)

CONSTRUCTION CONSIDERATIONS

- Install construction barriers around excavation to prevent pedestrian access
- Use diversions and other soil erosion practices to prevent runoff from entering site before construction is completed
- Stabilize soil of surrounding area and established outlets
- Remove any temporary structures after vegetation is established

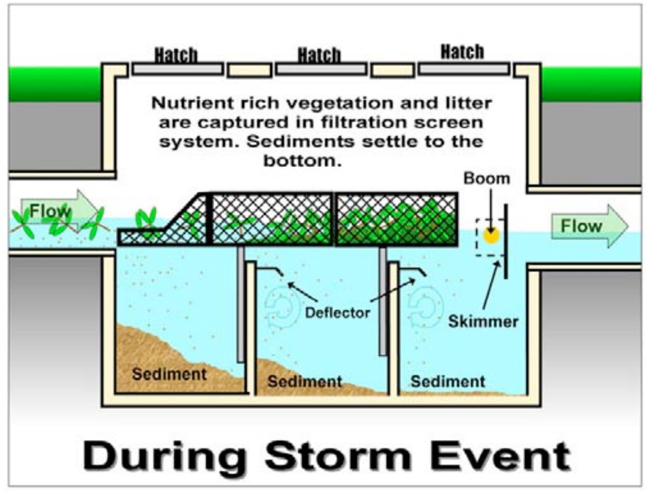
MAINTENANCE

- Inspect and clean in accordance with manufacturer requirements, but no less than twice a year following installation, and no less than once a year thereafter.
- Vactor trucks or manual removal of sediment are typical means used for cleaning these devices

Baffle Box

DESCRIPTION

Baffle boxes are proprietary concrete or fiberglass structures containing a series of sediment settling chambers separated by baffles. The stormwater runoff enters the box and begins to fill the first chamber, as the runoff encounters the first baffle, the velocity decreases allowing sediment and pollutants to drop out into internal storage zones. When the first chamber is full, flow is directed to the second chamber where additional settling of sediment occurs. Larger particles typically settle in the first chamber while smaller particles accumulate in the subsequent chambers. To provide additional removal of trash, oil, and grease trash racks, screens, or skimmers may be used. Baffle boxes may be used as pretreatment devices and typically discharge to other treatment or infiltration BMPs.



Schematic of Nutrient Separating Baffle Box
(Source: BIOCLEAN Environmental Services, Inc.)

Applications

- Ideal for retrofits in existing pipes

Advantages

- Good retrofit capability
- Simple and inexpensive
- Good for densely populated urban areas or parking lots
- Relatively small area footprint

Limitations

- Require significant maintenance
- Can re-suspend settled sediment in subsequent storms
- Not designed for nutrient removal
- Not effective at removing finer sediment

UNIT PROCESSES	
L	Volume reduction
L	Peak flow reduction
H	Sedimentation
L	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
L	Nutrients
L	Metals
L	Bacteria
H	Sediment
M	Oil and grease
M	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

25% TSS Removal when used for pretreatment

Can be constructed as a pretreatment device in:

Higher Pollutant Load Land Use Areas
Critical Areas
Redevelopment Areas

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

The cost of a baffle box will depend on the site characteristics and desired goal, with a typical cost range between $20,000 and $30,000.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Consult manufacturer for specific design considerations for their product
- Typical baffle boxes consist of a inlet pipe, concrete or fiberglass structure, baffles, trash screens or other treatment devices, and an outlet pipe
- Typical baffle boxes are: 10 - 15 feet long, 2 feet wider than the inflow pipe, and 6 - 8 feet high. Baffle (weir) heights are usually 3 ft high
- Set baffle height level with the pipe invert to minimize hydraulic losses
- For pipe diameters up to 48 inches the baffle box can be precast, for pipe diameters up to 60 inches, the baffle box shall be cast in-place
- Manholes are set over each chamber for ease of inspection and maintenance

Pollutant Removal Efficiencies

Refer to Section 3.4 of the Guidance Document for more detail under Removal Efficiencies

Removal efficiencies vary by manufacturer (provided by USEPA, 2001)

55 to 90% TSS reduction

40 to 85% Total Phosphorus reduction

MANUFACTURERS

Directly consult manufacturer for design requirements, site considerations, removal efficiencies, and costs. Some baffle box manufacturing companies are:

- **Suntree Technologies Inc**.: http://www.suntreetech.com
- **ACF Environmental**: http://www.acfenvironmental.com/nsbb.html
- **BIOCLEAN Environmental Services, Inc**.: http://www.biocleanenvironmental.com

CONSTRUCTION CONSIDERATIONS

- Consult manufacturer for specific construction considerations for their product
- During construction, redirect water from entering system and pipes
- Stabilize surrounding areas to prevent accumulated sediment within the box

MAINTENANCE

- Inspect and clean every 2 to 3 months to dispose of accumulated sediment. If not properly maintained, sediment can re-suspend with subsequent storms. Use vactor trucks to remove sediment
- Remove stagnant water every 2 to 3 months to prevent odors and mosquito breeding
- Consult manufacturer for specific maintenance requirements for their product

Bioretention

DESCRIPTION

Bioretention areas (sometimes referred to as rain gardens) use soil, plants, and microbes to treat stormwater, prior to infiltrating or discharging to a stormwater conveyance system or best management practice. Bioretention areas are shallow depressions filled with soil media (referred to as bioretention soil), topped with mulch, and planted with dense native vegetation. These devices, if designed and installed properly, are capable of removing nitrogen, phosphorous, metals, hydrocarbons, and pathogens through filtration, sedimentation, plant uptake, and biological processes.

There are two types of bioretention: Filtering and Exfiltrating. Filtering are designed with an impermeable liner and underdrain to prevent infiltration and recharge. Exfiltrating allow infiltration and recharge to groundwater.

A bioretention area installed on a residential property (Long Pond Watershed, Littleton, MA).

Applications

- Bioretention areas provide "first-flush" pollutant removal
- Well suited for ultra-urban environments
- Can be integrated into parking lot islands, median strips and traffic islands to treat urban runoff and promote infilltration.
- Can be distributed around a property to enhance aesthetics.

Advantages

- Used in Areas with Space Constraints
- Can Provide Groundwater Recharge
- Improve Aesthetics
- Removal of Multiple Pollutants
- Provides Shade, Windbreaks, and Absorb Noise
- Can Modify Existing Landscape – Retrofit
- Reduce Urban Heat Island Effect

Limitations

- Requires Careful Landscaping/ Maintenance
- Not Suitable for Areas with Slope > 20%
- Not Suitable for Large Drainage Areas
- Requires Pretreatment
- Not Suitable where Groundwater is within 6 Feet of Ground Surface

UNIT PROCESSES	
M	Volume reduction
H	Filtration & Sorption
H	Sedimentation
H	Biological Processes
L	Peak Flow Reduction
L	Plant Uptake

TARGET CONSTITUENTS	
M	Nutrients
H	Metals
H	Bacteria
H	Sediment
H	Trash and debris
H	Hydrocarbons

STORMWATER STANDARD APPLICABILITY

Provides:

Groundwater Recharge (if unlined)

TSS Removal (with pretreatment)

Can be constructed in:

Higher Pollutant Load Land Use Areas

Critical Areas

LEGEND

H = High
M = Medium
L = Low

NOTES

These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Estimated cost range of a bioretention is between $5 and $30 per square foot.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Evaluate underlying soil to determine infiltration capacity and depth to groundwater.
- Design, at a minimum, to capture and treat required water quality volume for water quality treatment or the recharge volume for groundwater recharge requirements (or the larger of the two volumes)
- **Bioretention Areas are typically designed in layers as follows (from bottom to top):**
  - * **Impermeable liner and underdrain (optional)**
  - * **Cover bottom of excavation area with coarse gravel, over pea stone, over sand**
  - * **Between 2 to 4 feet of bioretention soil media (see specification below)**
  - * **Cover soil with 2 to 3 inches of fine-shredded hardwood mulch**
  - * **Provide at a minimum 6 to 9 inches of ponding depth (varies with site conditions)**
  - * **Planting plan shall include herbaceous perennials and shrubs which can tolerant frequent ponding, saline conditions, and extended dry periods**
- Design to drain within 72 hours (to prevent breeding of mosquitoes design to drain within 24 hours)
- To achieve 90% TSS removal credit, pretreatment is required and may include:
  - * For sheet flow: a vegetated filter strip, grass channel or water quality swale, gravel strip
  - * Direct pipe flow: sediment forebay

Pollutant Removal Efficiencies

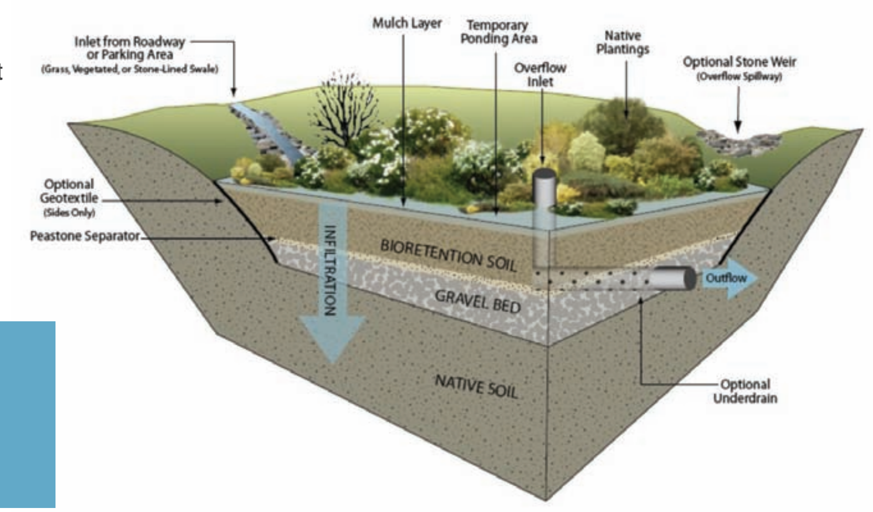
Refer to Appendix 3.4 for more detail on Removal Efficiencies

90% TSS Reduction with pretreatment

30 to 50% Total Nitrogen Reduction

30 to 90% Total Phosphorus Reduction

40 to 90% Metals Reduction



Soil Media Specification

- **40% sand**
- **20-30% topsoil**
- **30-40% compost**

CONSTRUCTION CONSIDERATIONS

- Avoid compacting soils to maintain underlying soil infiltration capacity
- During construction, direct only runoff from stabilized areas to bioretention. Direct construction runoff elsewhere to prevent accumulating silt and sediment within area, causing clogging.
- Place soil media in 1 to 2 foot lifts to avoid compaction
- Plant one tree or shrub per 50 square feet and at least 3 species of herbaceous perennials and shrubs to prevent a monoculture

MAINTENANCE

- Inspect pretreatment devices and bioretention areas regularly for sediment build-up, structural damage and standing water
- Inspect for erosion and re-mulch void areas on a monthly basis (or as necessary)
- Remove and replace dead vegetation in spring and fall
- Remove invasive species to prevent from spreading within bioretention area
- Do not store snow in bioretention areas
- Periodically observe function under wet weather conditions

Planter Box

DESCRIPTION

Planter boxes are bioretention treatment control measures that are completely contained within an impermeable structure with an underdrain (they do not infiltrate). The boxes can be comprised of a variety of materials, such as brick or concrete, (usually chosen to be the same material as the adjacent building or sidewalk) and are filled with gravel on the bottom (to house an underdrain system), planting soil media, and vegetation. As stormwater passes down through the planting soil, pollutants are filtered, adsorbed, and biodegraded by the soil and plants.

Infiltrating planter box designed to capture and treat rooftop runoff (Plymouth, MA).

Applications

- Most commonly used in urban areas adjacent to buildings

Advantages

- Small footprint and simple design and construction
- Aesthetically pleasing
- Combines stormwater treatment with runoff conveyance
- Volume & peak flow reduction

Limitations

- Vegetative maintenance required
- Treats small volumes and contributing area
- Must be constructed with underdrain system to convey excess water

UNIT PROCESSES	
L	Volume reduction
M	Peak flow reduction
M	Sedimentation
H	Filtration & Sorption
M	Biological processes

TARGET CONSTITUENTS	
M	Nutrients
H	Metals
H	Bacteria
H	Sediment
H	Oil and grease
H	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

90% TSS removal with adequate pretreatment

Can be constructed in:

Higher Pollutant Loading Land Uses if used as pretreatment device

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Estimated cost range for planter boxes is $24 to $32 per square foot.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Design at a minimum to capture and treat the required water quality volume
- **Planter boxes are typically designed in layers as follows (bottom to top):**
  - **Concrete or brick planter box, lined with impermeable geomembrane to prevent infiltration near the building foundation**
  - **Minimum 12 inch gravel layer with underdrain, which shall be slotted, polyvinyl chloride (PVC) pipe**
  - **Minimum depth of 2 to 3 feet of soil media (see specification) to provide sufficient root zone for plant palette**
  - **2 to 3 inches of mulch**
  - **Maximum of 6 inches of ponding above the mulch**
  - **Overflow riser shall be plumbed to underdrain**

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail in Removal Efficiencies

90% TSS Reduction with pretreatment

30 to 50% Total Nitrogen Reduction

30 to 90% Total Phosphorus Reduction

40 to 90% Metals Reduction

Soil Media Specification

- **40% sand**
- **20-30% topsoil**
- **30-40% compost**

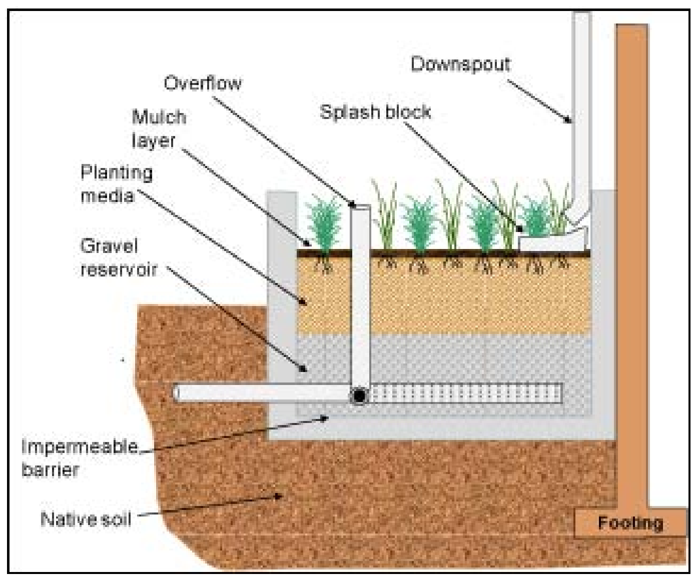


Illustration of a planter box. Adapted from the Bayou Land RC&D BMP Guidance Document.

CONSTRUCTION CONSIDERATIONS

- Provide energy dissipation (e.g., splash block) at each concentrated inlet point
- The use of treated wood or galvanized metal anywhere within the planter box should be avoided
- Material of planter boxes should be selected carefully to blend in and enhance aesthetics of adjacent structures (buildings and sidewalks)
- Plants should be selected carefully to minimize maintenance and function properly. Native plant species and/or hardy cultivars are preferred

MAINTENANCE

- Inspect for erosion and repair areas
- Remove accumulated fine sediments, dead leaves and trash to restore surface permeability
- Eradicate weeds and prune back excess plant growth that interferes with facility operation
- Periodically observe function under wet weather condition

Tree Box Filter

DESCRIPTION

Tree box filters are a proprietary biotreatment device that is designed to mimic natural systems such as bioretention areas by incorporating plants, soil, and microbes. Tree box filters are installed at curb level and consist of an open bottom concrete barrel filled with a porous soil media, an underdrain in crushed gravel, and a tree. Tree box filters are highly adaptable solutions that can be used in all types of development and in all types of soils but are especially applicable to ultra-urban areas.

A tree box filter designed to receive runoff from an adjacent parking lot (Littleton, MA).

Applications

- Commonly used in densely urbanized areas such as along roads, highways, sidewalks and parking lots

Advantages

- Reduces volume and rate of runoff
- Smaller footprint required
- May be used as pretreatment device
- Provides decentralized stormwater treatment
- Ideal for redevelopment or in ultra-urban setting

Limitations

- Vegetative maintenance required
- Treats small volumes
- Treats small tributary areas

UNIT PROCESSES	
L	Volume reduction
L	Peak flow reduction
M	Sedimentation
M	Filtration & Sorption
L	Biological processes

TARGET CONSTITUENTS	
H	Nutrients
M	Metals
H	Bacteria
H	Sediment
H	Oil and grease
H	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
TSS Removal (Presumed to remove 80% TSS)
Can be constructed in:
Higher pollutant land use areas as pretreatment device if lined Redevelopment situations

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Estimated cost range of tree filters are between $10,000 and $18,000.

DESIGN CONSIDERATIONS

Note: for more detailed design guidance refer to the 2008 MA Stormwater Handbook

- Design at a minimum to capture and treat the required water quality volume
- **Tree box filters are typically designed in layers as follows (bottom to top):**
  - **Line bottom of excavation with filter fabric**
  - **Install precast concrete barrel (minimum 6 feet in diameter) , approximately 4 feet deep**
  - **Pack a perforated underdrain pipe in a clean, washed crushed stone layer (minimum 24-inch layer)**
  - **Minimum 1 to 2 feet of soil media (see manufacturers specification)**
  - **Minimum 6 inches of ponding depth**
  - **Design an overflow riser pipe with grate, connected to perforated underdrain**
  - **Design curb cut to act as inlet to tree box filter, with rip rap pad at inlet for energy dissipation**
  - **Use a deciduous tree centered in the concrete barrel**
- Design to drain in less than 72 hours

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail in Removal Efficiencies

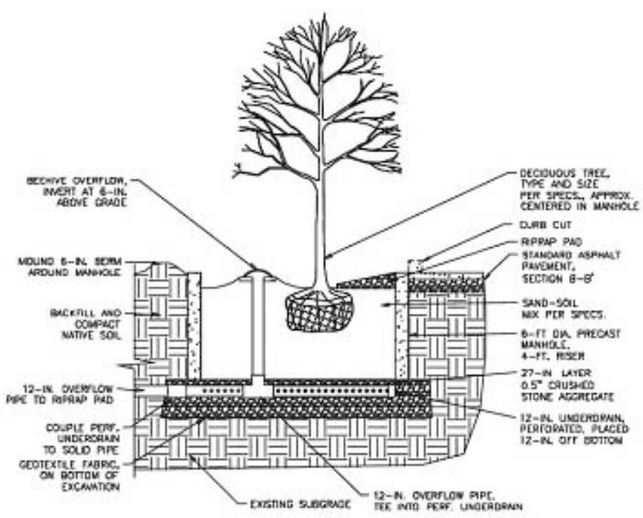
Values based on Filterra® Tree Box Filter, varies by manufacturer

85% Total Suspended Solids reduction

up to 45% Nitrogen reduction

58 to 82% Metals reduction

60 to 70% Phosphorus reduction



Cross-section of a tree box filter adapted from MA DEP Stormwater BMP Handbook

CONSTRUCTION CONSIDERATIONS

- Provide energy dissipation (e.g., rip rap) at each concentrated inlet point.
- Soil mix chosen should support growth of tree.
- Tree shall be selected carefully to blend in and enhance aesthetics of adjacent structures (buildings and sidewalks).

MAINTENANCE

- Annually check tree
- Rake media surface at least twice a year to maintain permeability
- Replace media when tree is replaced (every 5 to 10 years) to restore permeability and pollutant removal efficiency
- Remove accumulated trash and debris to restore permeability

Filterra® Tree Box Filter

DESCRIPTION

Filterra® Treebox Filter is a proprietary treatment system that uses vegetation and a specially designed filter media to remove metals, nutrients, and total suspended solids naturally, similar to bioretention areas. Stormwater runoff from the impervious surface flow into the engineered soil media where pollutants are removed through filtration, plant uptake and biological processes. Stormwater leaves the system through an underdrain to another BMP or the stormwater conveyance system. The Filterra® Tree Box Filter can be installed in highly urbanized environments and can also be a standalone device, or as part of a treatment train. Filterra® is available in various configurations to meet specific site conditions. For additional information, see **http://www.filterra.com/.**

Refer to Tree Box Filter Fact Sheet for Design, Construction and Maintenance information.

Filterra® tree box filter designed to receive runoff from a parking stall (Littleton, MA).

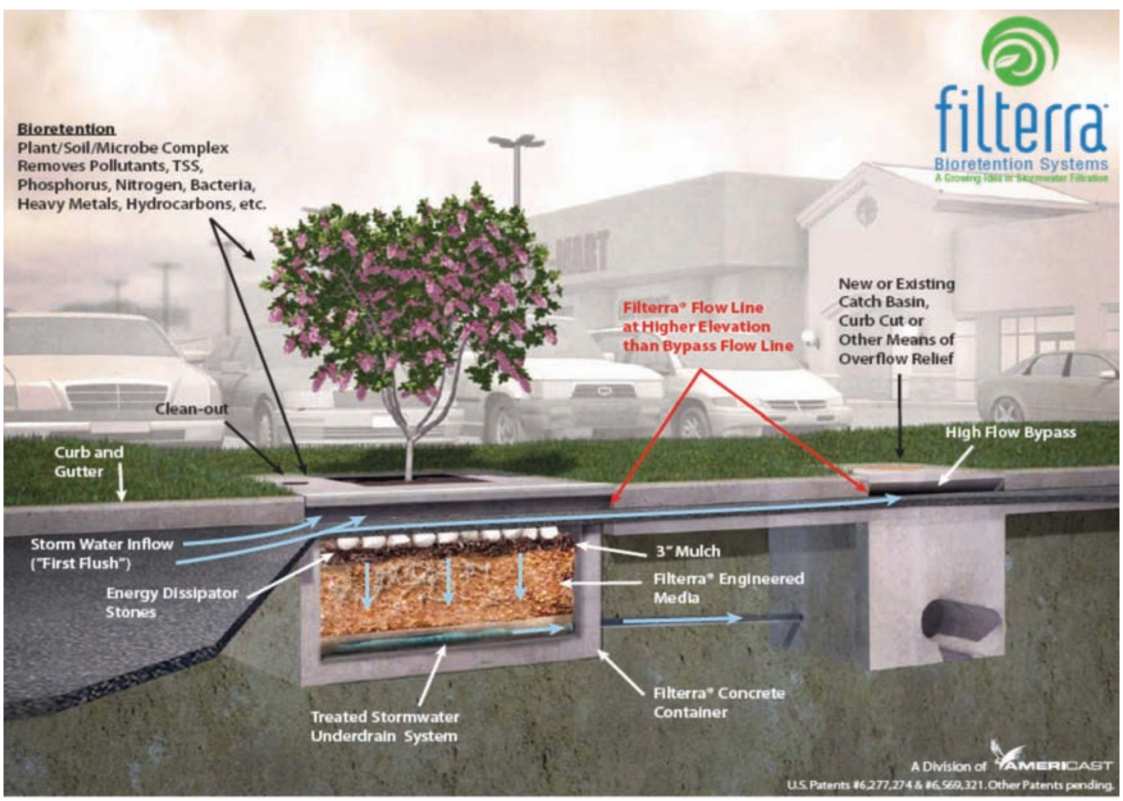


Illustration of a Filterra® Tree Box Filter. (Image source: Filterra).

TREEPOD® Tree Box Filter

DESCRIPTION

The TREEPOD® Biofilter is a precast concrete chamber that uses conventional tree box filter design critera to remove ultra-fine sediment and dissolved pollutants. The pre-filtration chamber separates/ retains trash, debris, and sediment from runoff, which is then removed through a maintenance access cover without the need to replace the soil media. The biofilter system is designed to be used in conjunction with a standard drainage inlet and an internal high flow bypass.

For additional information, see **http://www.kristar.com/.**

Refer to Tree Box Filter Fact Sheet for Design, Construction and Maintenance information.

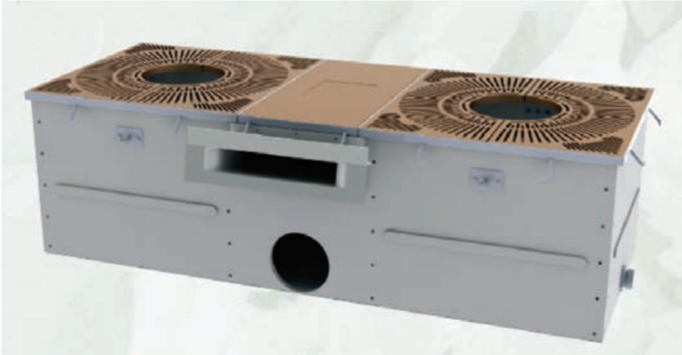


Illustration of a TREEPOD® Biofilter. (Source: Kristar).

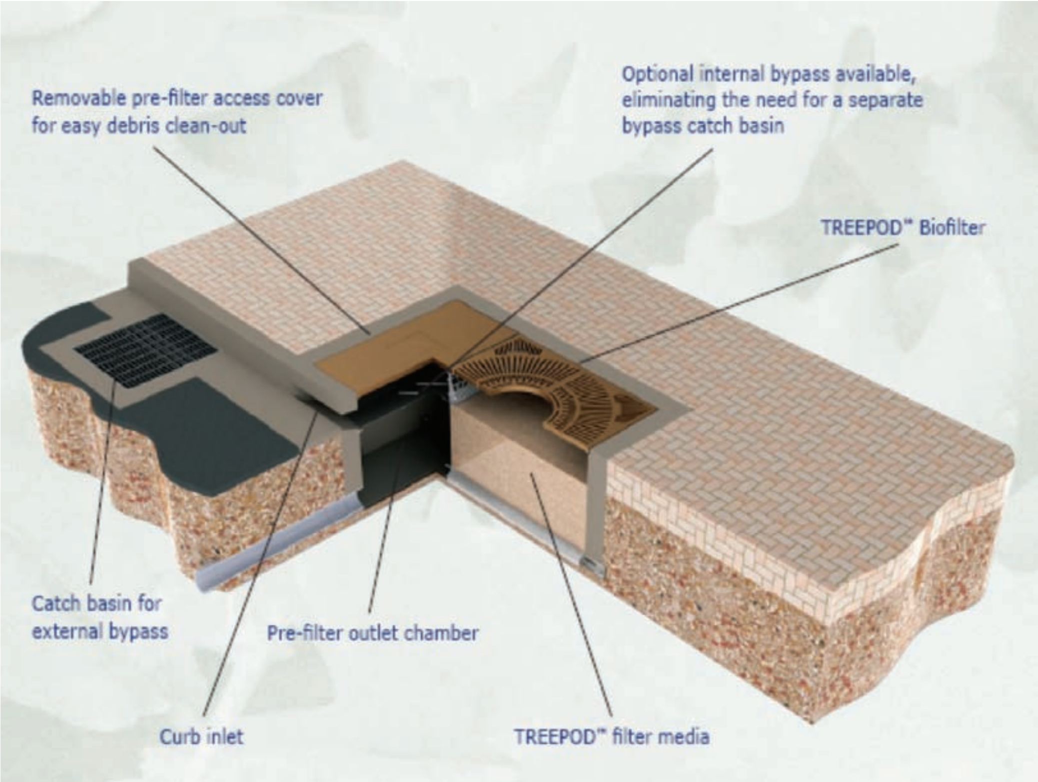


Illustration of a TREEPOD® Biofilter. Adapted from Kristar

Constructed Stormwater Wetland

DESCRIPTION

A constructed stormwater wetland is a system designed to maximize pollutant removal through vegetative uptake, retention, and settling. A typical constructed wetland consists of a sediment forebay to provide pretreatment and dissipate energy, a base with shallow pockets planted with diverse emergent vegetation, deeper areas or micro-pools and a water quality outlet structure. In addition to water quality treatment, constructed wetlands are designed to control peak flow rates from the 2-and 10-year storm through extended detention above the permanent pool elevation. The interactions between the incoming stormwater runoff, aquatic vegetation, wetland soils, and associated physical, chemical, and biological processes are a fundamental part to reducing suspended soils, nutrients, metals, oils and grease, and trash. Site investigations must be conducted prior to design and construction to ensure proper soils, depth to groundwater and suitable land.

There are five types of Constructed Stormwater Wetlands: shallow marsh, basin/wetland, extended detention, pocket, and gravel

Constructed stormwater wetland with stone baffles to create a sinuous flow path (Plymouth, MA)

Applications

- Regional detention and treatment
- Sites without space constraints

Advantages

- Low maintenance cost
- Reduce peak flow rates
- Treatment of large tributary areas
- Removes suspended solids and particulate-bound pollutants
- Provides wildlife habitat
- Aesthetically pleasing

Limitations

- High land requirement
- High capital cost
- Does not provide groundwater recharge
- Potential mosquito habitat if not properly maintained
- Depth to groundwater and bedrock

UNIT PROCESSES	
L	Volume reduction
H	Peak flow reduction
H	Sedimentation
M	Filtration& Sorption
H	Biological processes

TARGET CONSTITUENTS	
M	Nutrients
H	Metals
L	Bacteria
H	Sediment
H	Oil and grease
	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

Peak flow attenuation (if properly designed)

TSS removal with pretreatment

Can be constructed in:

Peak flow attenuation (if properly designed)

TSS removal with pretreatment

LEGEND

H = High

M = Medium

L = Low

NOTES

These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Costs for constructed stormwater can vary widely depending design considerations and volume of treated stormwater. Typical costs range from $50,000 to $250,000+.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Investigate soils, depth to groundwater and bedrock before designing constructed stormwater wetlands
- Develop a water budget to show that the constructed wetland can sustain a continuous water supply, drying time shall not exceed two months
- Design to hold the water quality volume and determine a minimum surface area in relation to the contributing watershed area
- Construction stormwater wetlands shall provide volume for deep water, low marsh, high marsh, and semi-wet areas according to the MA Stormwater Handbook.
    - * Deep water zones (forebay, micro-pool, and deepwater channels) are 1.5 to 6 feet below normal pool elevation and contains submerged floating vegetation
    - * Low marsh zones are 6 to 18 inches below normal pool elevation and contain some emergent wetland plant species
    - * High marsh zones are at normal pool elevation or up to 6 inches below and tend to have a higher surface area to volume ratio than low marsh zones. High marsh zone supports higher diversity and density of wetland plants
    - * Semi-Wet Zone is above normal pool elevation and supports most wetland plants
- Design the sediment forebay to provide at least 10% of total treatment volume at a depth of 4 to 6 feet
- Design a micro-pool prior to the outlet structure to provide at least 10% of total treatment volume, at a depth of 4 to 6 feet deep
- Outlet structure shall be designed to:
    - * Mitigate 2- and 10-year peak flow rates
    - * Include trash racks and anti-seep collars for maintenance and prevent seepage losses
    - * Prevent clogging by installing a bottom drainpipe with inverted elbow
- Design emergency spillway to bypass large storms
- Select native species that are adaptable to a broad range of depth, frequency, and duration of inundation.

Pollutant Removal Efficiencies

Refer to Section 3.4 in the Guidance Document for more detail under Removal Efficiencies

80% Total Suspended Solids reduction with pretreatment

20 to 55% Total Nitrogen reduction

40 to 60% Total Phosphorous reduction

20 to 85% Metals reduction

Up to 75% Pathogens reduction

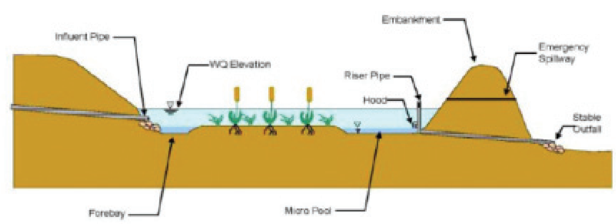


Illustration of Constructed Stormwater Wetland, adapted from the New Orleans Manual

CONSTRUCTION CONSIDERATIONS

- Process to prepare wetland prior to planting (Schueler 1992):
    - * Once volume excavated, grade to create pool, aquatic bench, deep water channels, and other major internal features
    - * Add topsoil and/or wetland mulch to excavated site to support plant growth
    - * Grade to final elevations and stabilize all features above normal pool
    - * Measure wetland depths to nearest inch and modify pond-scape plan
    - * Apply erosion controls and stabilize vegetation
    - * Dewater wetland at least 3 days before planting
- Provide maintenance access to forebay, safety benches, and outlet structure with minimum width of 15 feet and maximum slope of 15%
- Design vegetative buffers around perimeter of wetland to protect from erosion and provide additional removal of sediment and nutrients

MAINTENANCE

- Inspect wetland during both the growing and non-growing season during first 3 years after construction to determine dominant wetland plants, presence of invasive wetland species, accumulation of sediment in forebays and micro-pools, and stability of original depth zones.
- Inspect wetland at least once a year to evaluate health and prevent monocultures of plant species
- Clean out sediment forebay annually to restore storage volume capacity
- Clean out sediment in basin/wetland system at least once every 10 years to restore storage volume

Sand Filter

DESCRIPTION

Sand filters are engineered sand filled depressions that treat stormwater runoff from small tributary areas. Sand filters allow for the percolation of runoff through the void space within the sand before it is eventually released through an underdrain at the bottom of the filter. Stormwater runoff enters the filter from a pretreatment system (sediment forebay or vegetated filter strip) and spreads evenly over the surface. As flows increase, water backs up on the surface of the filter where it is held until it can percolate through the sand. As stormwater passes through the sand, pollutants are trapped in the small pore spaces between sand grains or are adsorbed to the sand surface. The effectiveness and efficiency of a sand filter depends heavily on the pretreatment BMPs performance to settle out sand, clay, and silt particles, which prevent clogging of the sand filter.

Photograph of installed sand filter (Littleton, MA)

Applications

- Can be used in ultra-urban sites with small drainage areas
- Drainage area can be 100% impervious like parking lots
- Redevelopments/Retrofits

Advantages

- Good retrofit capability
- Long design life if properly maintained
- Good for densely populated urban areas or parking lots
- Relatively small footprint area

Limitations

- Pretreatment required to prevent clogging
- Frequent maintenance required
- Costly to build and install
- Limited removal of dissolved constituents
- May not be effective in winter
- Can be unattractive and create odors

UNIT PROCESSES	
L	Volume reduction
L	Peak flow reduction
M	Sedimentation
H	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
M	Nutrients
H	Metals
M	Bacteria
H	Sediment
M	Oil and grease
	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
TSS removal with pretreatment
Can be constructed in:
Higher Pollutant Load Land Use Areas Critical areas Redevelopment and retrofit situations

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Typical costs of sand filters can range from $10,000 to $50,000 per impervious acre depending on design and the use of underground structures and chambers.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Design to handle the required water quality volume
- Design consists of a pretreatment component, a trench containing a gravel bed, a layer of sand, an optional grass/turf layer, and an underdrain surrounded by stone
- Design sand filters as offline systems, away from primary conveyance/detention systems
- Design sediment forebay, at a minimum, to equal filtering capacity
- Design a flow diversion structure to allow design volume into the sand filter and the excess volume to bypass
- **Sand filters are typically designed in layers as follows (from bottom to top):**
  - **Wrap perforated underdrain in a gravel bed layer at a minimum of 6 to 8 inches of 0.5 to 2-inch diameter gravel**
  - **Separate gravel bed and sand layer with filter fabric**
  - **Minimum 18 inches layer of clean, washed "concrete" sand**
  - **Separate sand layer and topsoil layer with filter fabric**
  - **Top layer of leaf compost, peat or topsoil with grass**

Pollutant Removal Efficiencies

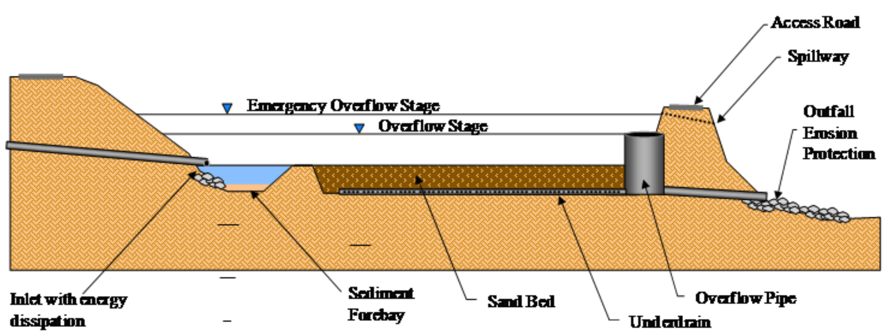
Refer to Section 3.4 in Guidance Document for more detail under Removal Efficiencies

80% Total Suspended Solids reduction with pretreatment

20 to 40% Total Nitrogen reduction

10 to 50%Total Phosphorous reduction

50% to 90% Metals reduction



Cross-section of an above ground sand filter from New Orleans Bayou Land RC&D Stormwater BMP Guidance Tool

CONSTRUCTION CONSIDERATIONS

- Stabilize tributary area during construction to minimize risk of clogging and failure
- Place diversion berms around perimeter during all phases of construction
- Stabilize depth of bed by wetting sand periodically, allowing it to consolidate, and then add extra sand.
- Place all excavated material downstream of sand filter
- Top surface layer of trench should be level to ensure equal distribution of incoming runoff and minimize scouring/erosion
- Place fence around sand filter for safety

MAINTENANCE

- Inspect filter and remove debris after every major storm for first few months to ensure proper function. Inspect every 6 months thereafter to prevent clogging.
- Rake sand to restore infiltration rates
- Remove sediment and trash that have accumulated on top of sand
- Remove top several inches of discolored media (presence of fine sediments) and replace with clean media to restore filtration removal mechanisms

Gravel Trench

DESCRIPTION

Gravel trenches are long, narrow, gravel-filled trenches, which treat stormwater runoff from small drainage areas. Gravel trenches remove stormwater pollutants through infiltration, sedimentation and filtration. Reactive media (e.g., zeolite, activated carbon, oxide-coated sand, etc.) may be incorporated into the design to increase sorption capacity and target specific pollutants. Pretreatment may be provided to prevent clogging of the gravel bed and sub-grade.

A gravel trench designed to infiltrate runoff from an adjacent parking area (Saugus, MA).

Applications

- Parking lot, local roads, highways and small residential developments.
- Road shoulders and medians

Advantages

- Provide groundwater recharge
- Preserves natural water balance
- Suitable for small spaces
- High degree of pollutant runoff control

Limitations

- Requires frequent maintenance to prevent clogging
- Restricted to small drainage areas
- Requires depth to groundwater be greater than 2 feet from bottom of trench
- Requires soils that infiltrate

UNIT PROCESSES	
H	Volume reduction
H	Peak flow reduction
M	Sedimentation
H	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
H	Nutrients
H	Metals
H	Bacteria
H	Sediment
M	Oil and grease
H	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

Peak Flow Attenuation
Groundwater recharge
TSS Removal (with pretreatment)

Can be constructed in:

High Pollutant Load Land Use Areas
Critical Areas
Redevelopment Areas

LEGEND

H = High
M = Medium
L = Low

NOTES

These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Estimated cost range for gravel trenches is $50 to $80 per linear foot.

DESIGN CONSIDERATIONS

Note: for more detailed design guidance refer to the 2008 MA Stormwater Handbook

- Evaluate underlying soil to determine infiltration capacity and depth to groundwater
- Design at a minimum to capture and treat the required water quality volume or groundwater recharge volume (or the larger of the two volumes)
- Contributing drainage area shall be limited to 5 acres or less
- **Gravel trenches are typically designed in layers as follows (bottom to top):**
  - **Line the sides of excavation trench with non-woven filter fabric**
  - **Minimum of 6 inches of clean, washed sand (12 inches preferable)**
  - **Fill trench with 3 to 7 feet of 1.5 to 3 inch diameter washed stone (bank run gravel preferred)**
  - **Install a layer of filter fabric**
  - **Minimum of 2 inches of pea gravel or sand layer**
  - **Minimum of 6 inches of freeboard**
- Install an observation well at the center of the trench for monitoring
- Design to drain within 72 hours

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail in Removal Efficiencies

Total Suspended

Solids (TSS): 80% with pretreatment

Total Nitrogen Reduction: 40 to 70%

Total Phosphorus Reduction: 40 to 70%

Metals Reduction: 85 to 90%

Pathogens: Up to 90%

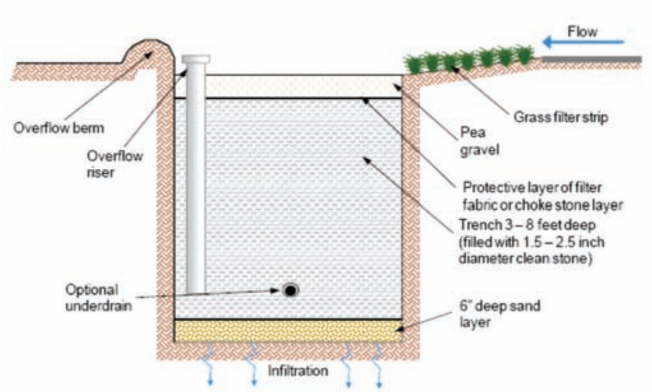


Illustration of gravel trench, adapted from the New Orleans Bayou Land RC&D Stormwater BMP Guidance Tool

CONSTRUCTION CONSIDERATIONS

- Prior to grading of the site, the area of the gravel trench shall be flagged and roped off to prevent compaction of soils by heavy equipment
- Stabilize entire area draining to facility prior to construction
- Excavate and build the trench manually or with light earth-moving equipment
- Place lifts of one to three inches of clean, washed stone in the trench and compact stone with a plate compactor

MAINTENANCE

- Remove trash and debris to prevent clogging and restore permeability
- Remove minor sediment accumulations near inlet structure to prevent clogging
- If clogging is observed, remove top layer of pea gravel and sediment capture layer. If slow conditions persist, entire trench may need to be excavated and replaced
- Periodically observe under wet weather conditions to ensure all components are working properly
- Pollutant Removal Efficiencies

Dry Wells

DESCRIPTION

Dry wells, or seepage pits, are excavated areas filled with gravel and very similar to infiltration trenches. They are designed to receive and treat stormwater runoff from non-metal roofs or metal roofs outside Zone II, Interim Wellhead Protection Area (IWPA) of a public water supply, or an industrial site. Dry wells are constructed to reduce stormwater runoff volumes through increased groundwater recharge and can be used as retrofits of highly urbanized areas. Dry wells are not recommended to treat parking lot runoff or areas with potentially high pollutant loadings.

Typical precast dry well
(Image source: Scioto Valley Precast).

Applications

- Applicable for private and public projects
- Commercial and residential
- Retrofits
- Urban areas adjacent to buildings

Advantages

- Reduce stormwater volume through groundwater discharge
- Efficient removal of trash and sediment
- Simple, low cost

Limitations

- High potential for clogging
- Treats small tributary area
- Can cause structural damage to nearby buildings due to water seepage

UNIT PROCESSES	
H	Volume reduction
M	Peak flow reduction
H	Sedimentation
M	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
L	Nutrients
L	Metals
L	Bacteria
H	Sediment
L	Oil and grease
L	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
Groundwater recharge
TSS removal
Can be constructed in:
Within some critical areas
Redevelopment situations outside industrial sites

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

It is estimated that a typical installation of a dry well will range from $500 to $1,000, depending on size of the well.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Must draw down within 72 hours
- Construct dry well 1 foot below ground surface. Maximum depth should not exceed 10 ft.
- Perforations of inlet pipe into dry well must begin 1 foot from side of well
- Dry well must be placed at least 10 feet away from building foundation
- Line top, bottom, and sides with a geotextile or filter fabric
- Fill with washed 1.5 – 3 inch diameter gravel with a void ratio of 0.40

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail on Removal Efficiencies

Total Suspended Solids (TSS): 80%

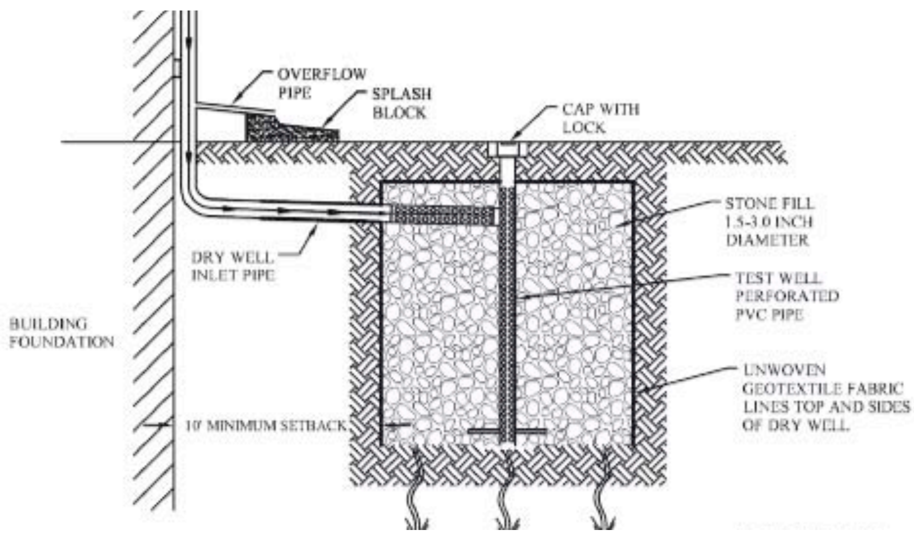


Illustration of a planter box. Adapted from the University of New Hampshire (MADEP handbook)

CONSTRUCTION CONSIDERATIONS

- Stabilize area before construction to prevent clogging
- Do not directly connect to stormwater conveyance system
- Minimize compaction of underlying soils by placing uniformly graded, clean-washed aggregate in 6-inch lifts. This will prevent low infiltration rates and clogging.

MAINTENANCE

- Inspect well at least 4 times a year and after major storm events to ensure that maximum draw down time (72 hours) is not being exceeded
- Clean roof gutters to prevent clogging of dry well
- Replace filter screen as necessary

Proprietary Infiltration Device (CULTECH)

DESCRIPTION

The CULTEC Contactor® and Recharger® chambers replace conventional stormwater retention/detention systems such as ponds, swales, pipe and stone trenches or beds, or concrete structures. The chambers may be used for drywells. Infiltration contact area is maximized by the fully open bottoms and perforated sidewalls. Water is collected in a catch basin or other collective device followed by a CULTEC Stormfilter® to be treated. The water is then directed into the Contactor® or Recharger® chambers and distributed via the side portal internal manifold. For additional information regarding CULTECH Proprietary infiltration devices, see http://www.cultec.com/index.html

Refer to the "subsurface infiltration systems" fact sheet for additional information.

Underground infiltration chamber being installed in the Congamond Lakes watershed (Southwick, MA).

Schematic of the CULTEC Stormwater Chamber (Image source: CULTECH).

Subsurface Infiltration Systems

DESCRIPTION

Subsurface infiltration structures are underground systems that capture and infiltrate runoff into the groundwater through highly permeable rock and gravel. It is usually not practical to infiltrate runoff at the same rate that is generated; therefore, these facilities generally include both a storage component and a drainage component. Typical subsurface infiltration systems that can be installed to enhance groundwater recharge include pre-cast concrete or plastic pits, chambers (manufactured pipes), and perforated pipes.

Image of the ChamberMaxx® subsurface infiltration system (Photo source: Contech)

Applications

- Applicable for private and public projects
- Commercial and residential
- Retrofits
- Urban areas adjacent to buildings

Advantages

- Provides volume reduction and groundwater recharge
- Can reduce downstream flooding
- Efficient removal of trash and sediment
- Can be simple and low cost

Limitations

- High potential for clogging
- Can cause structural damage to nearby buildings due to water seepage
- Standing water creates mosquito breeding potential

UNIT PROCESSES	
H	Volume reduction
M	Peak flow reduction
H	Sedimentation
M	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
L	Nutrients
L	Metals
L	Bacteria
H	Sediment
L	Oil and grease
L	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
Groundwater Recharge
TSS Removal
Can be constructed in:
Within critical areas
Redevelopment situations

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

There are a number of subsurface structures with variable cost depending on the manufacturer. For example, pre-cast concrete dry well type structures typically range in cost from $500 to $1,000 per unit depending on the size.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Widely accepted design standards and procedures for designing subsurface structures are not available. A subsurface structure should be designed to store a specified capture volume for a specified period of time.
- Design each structure to drain within 72 hours after a storm event. The structure should also completely drain between storms.
- Infiltration structures should be designed to infiltrate at least 0.17 inches per hour.
- Take into account structural live and dead loads depending on the location of the structure.

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail on Removal Efficiencies

Total Suspended Solids (TSS): 80%

Nutrients, metals, pathogens: Insufficient data.

CONSTRUCTION CONSIDERATIONS

- Stabilize area before construction to prevent clogging
- Provide an access port or observation well to enable monitoring of the system.
- Do not directly connect to stormwater conveyance system
- Minimize compaction of underlying soils by keeping any heavy construction outside the area of exfiltration.

MAINTENANCE

- Inspect inlets at least twice a year.
- Remove any debris that may be clogging the device

Dry Water Quality Swale

DESCRIPTION

Water quality swales are shallow, open conveyance channels with low-lying vegetation designed to settle out suspended pollutants due to shallow flow depths and slow velocities. Additional pollutant removal mechanisms include volume reduction through infiltration and evapo-transpiration and biochemical processes that provide treatment of dissolved constituents. It is generally accepted that water quality swales have higher pollutant removal efficiencies than grass channels. An effective vegetated swale achieves uniform sheet flow through a vegetated area for at least 10 minutes.

Water quality swale located near Silver Lake in Wilmington, MA

Applications

- Commonly implemented adjacent to highways/roadways
- Applicable for commercial, institutional, and residential purposes
- Retrofit options in urban settings, especially in publicly owned green space

Advantages

- Replace expensive curb and gutter systems
- Can achieve volume and peak flow reduction with proper design
- Reduce driving hazards by keeping stormwater from street surfaces
- Compatible with many LID designs

Limitations

- Can erode during large storms
- Treats small tributary areas
- Not for areas with very flat grades, steep topography, or poorly drained soils
- Higher degree of maintenance than curb and gutter systems

UNIT PROCESSES	
L	Volume reduction
L	Peak flow reduction
H	Sedimentation
L	Filtration& Sorption
M	Biological processes

TARGET CONSTITUENTS	
L	Nutrients
M	Metals
L	Bacteria
H	Sediment
M	Oil and grease
M	Trash and debris

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

STORMWATER STANDARD APPLICABILITY

Provides:

Peak flow reduction at small sites if properly designed

TSS removal with preatreatment

Can be constructed in:

High pollutant load land use areas as pretreatment if lined

Critical Areas (should not be used near shellfish growing areas or bathing beaches)

Redevelopment situations

GENERAL COST CONSIDERATIONS

A typical water quality swale will cost approximately $10 per linear foot but can vary greatly depending on site-specific design considerations.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Dry water quality swale normally consists of: pretreatment (forebay/ vegetated filter strip), ponding area, amended/native permeable soils, grass/vegetation, an underdrain surrounded by 6-inch gravel, and an outlet point.
- Design dry swales to empty between storms or to dewater within at least 72 hours and to convey 10-year storm and prevent erosion during 2-year event.
- The hydraulic residence time (HRT) must be at least 9 minutes for required water quality volume. Use Manning's Equation to calculate the HRT.
- Soil bed should be at least 18 inches deep and contain approximately 50% sand and 50% loam
- Plant with species adapted to varying moisture conditions and can produce dense cover

Pollutant Removal Efficiencies

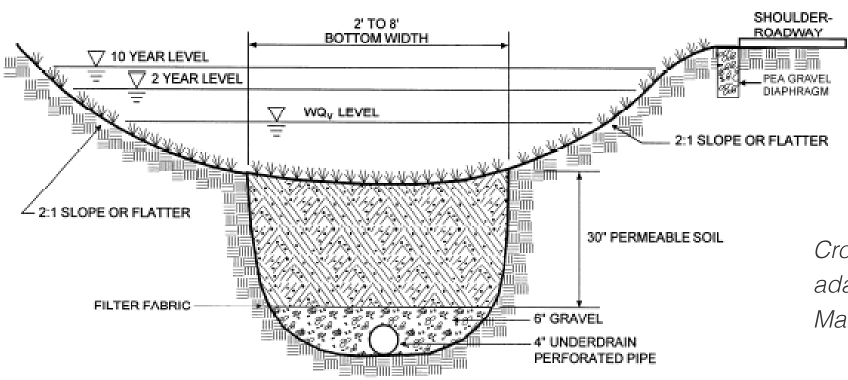
Refer to Section 3.4 of Guidance Document for more detail on removal efficiencies.

Total Suspended Solids

(TSS) Dry and Wet Swale: 70%

Total Nitrogen: 10% to 90%

Total Phosphorous: 20% to 90%



Cross-section of a dry water quality Swale adapted from the Vermont Stormwater Management Manual

CONSTRUCTION CONSIDERATIONS

- Use temporary erosion and sediment controls during construction
- Select vegetation native to area to decrease mortality rate
- Use mulch, matting, straw, and wood chips while seeding and anchor mulch immediately after seeding

MAINTENANCE

- Inspect during first few months to ensure adequate vegetation growth
- Inspect slopes, soil moisture, vegetative health, soil stability, soil compaction, soil erosion, ponding, and sedimentation of swale at least twice a year to maintain overall integrity and efficiency
- Reseed eroded areas to maintain flow reduction and pollutant removal efficiencies

Porous Pavement

DESCRIPTION

Porous pavement is a permeable alternative to conventional asphalt and concrete and constructed in pesdestrian, highly urbanized, or residential settings with low traffic speeds and volumes. A high surface void ratio allows precipitation to pass through the pavement and a stone base, where runoff is retained and sediments and metals are treated to some degree. Porous pavement is designed to achieve peak flow attenuation of small intensity storms and groundwater recharge through infiltration into underlying soils. Porous pavement includes porous asphalt and pervious concrete, which are poured in place, and paving stones and grass pavers, which are typically precast and installed in an interlocking array to create a surface.

Porous pavement parking stalls at Silver Lake in Wilmington, MA.

Applications

- Commercial and industrial parking lots
- Urban and residential settings
- Retrofits
- Low-volume, low-speed areas or pedestrian areas
- Porous pavements are often used in sidewalks

Advantages

- Reduces stormwater volume and peak flow rates
- Used as a retrofit in parking lots
- Reduce sediment and particulate-bound pollutants

Limitations

- Frequent clogging if not maintained
- No sanding in winter
- Compacting of underlying soils is common
- Limited removal of dissolved constituents when underdrains are used

UNIT PROCESSES	
H	Volume reduction
M	Peak Flow Reduction
M	Sedimentation
M	Filtration & Sorption
L	Biological Processes

TARGET CONSTITUENTS	
M	Nutrients
M	Metals
M	Bacteria
H	Sediment
H	Oil and grease
L	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
Groundwater Recharge TSS Removal if storage bed is sized properly

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

It is estimated that a typical installation of porous pavement will cost approximately $8 to $15 per square foot.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Design to retain 0.5 to 1.0 inch of VQv and drain within 72 hours.
- Porous asphalt and pervious concrete must have 10% - 25% void space. Sub-base must have at least 40% void space.
- Storage bed requirements for porous asphalt or pervious concrete developed by the University of New Hampshire are as follows: 1.) 4-in choker course of uniformly graded crushed stone, 2.) filter course at least 12 in thick of poorly graded sand or bank-run gravel, 3.) filter blanket at least 3 inches thick of pea stone gravel, and 4.) reservoir course of uniformly graded crushed stone with high void content.
- Paving stones or grass pavers must have additional 1-inch layer of sand above choker course.
- Include a perforated pipe along bottom of base for even runoff distribution.

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail under Removal Efficiencies

Total Suspended Solids (TSS): 80%

Nutrients, metals, and pathogens: Insufficient data

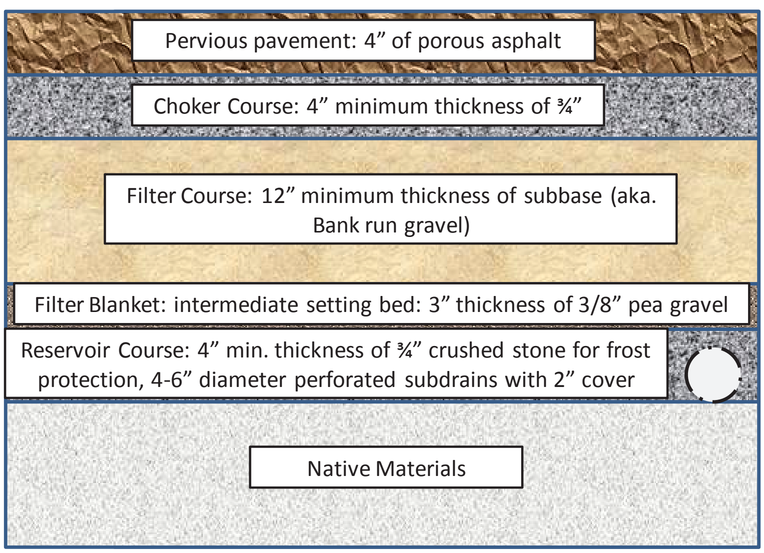


Illustration of a porous pavement cross section. (Cross-Section of porous pavement adapted from University of New Hampshire)

CONSTRUCTION CONSIDERATIONS

- Avoid compacting soils to maintain proper infiltration rate
- Caution must be taken during batching and placing of porous asphalt to prevent an increased percent of sand and/or asphalt than specified
- Do not use in areas of higher pollutant loads without adequate pretreatment
- Construct away from tress to prevent clogging from leaves

MAINTENANCE

- Power wash and vacuum sweep area to prevent clogging
- Do not sand or salt during the winter
- Use snowplows with rollers on bottom to prevent damage to porous pavement
- Periodically observe function under wet weather conditions to determine decrease in performance and clogging

Disconnect Impervious Areas

DESCRIPTION

Disconnecting impervious surfaces from the public stormwater conveyance system and directing runoff to pervious surfaces can reduce stormwater volumes, flow rates, pollutant loadings, and increase groundwater recharge. This practice can be applied in both, residential and commercial, locations. By incorporating small depressions into site grading and routing impervious surface runoff to these locations where permissible, small storm volumes can be retained and the site's rainfall-runoff response time and peak flows can be reduced.

The impervious surface must discharge into a suitable receiving area for the practices to be effective. Typical receiving pervious surfaces include landscaped areas and/or other BMPs (i.e., planter boxes, filter strips, bioretention).

Runoff from roof piped to a pervious area for infiltration (Plymouth, MA)

Applications

- Single- and multi-residential homes
- Commercial
- Densely urbanized areas

Advantages

- Reduce stormwater volume and flow rates
- Simple, low cost, and highly applicable to many situations
- Groundwater recharge

Limitations

- Discharge must be directed to pervious area through sheet flow

UNIT PROCESSES	
L	Volume reduction
M	Peak flow reduction
H	Sedimentation
L	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
H	Nutrients
L	Metals
L	Bacteria
H	Sediment
L	Oil and grease
L	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

Groundwater Recharge (if unlined)

TSS Removal (with pretreatment)

Can be constructed in:

Higher Pollutant Load Land Use Areas

Critical Areas

LEGEND

H = High
M = Medium
L = Low

NOTES

These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Can vary greatly depending on site-specific level-of-effort. For example, an owner of a residential home could simply disconnect their roof leaders to drain into a pervious garden or lawn area.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Runoff must be directed at least 10 ft away from building foundation to prevent basement seepage
- Rooftop area contributing to one downspout must be less than 1,000 ft2
- Rooftop cannot be metal unless outside Zone II or Interim Wellhead Protection Area
- Building cannot be industrial
- Length of qualifying pervious area must be greater than contributing rooftop area divided by 13.3. Width of pervious area must be greater than roof length
- Long-term saturated hydraulic conductivity must be greater than 0.17 in/hr

Pollutant Removal Efficiencies

Largely dependent on quality of roof runoff and receiving BMP that runoff is directed to.

CONSTRUCTION CONSIDERATIONS

- No overlap between qualifying pervious areas to receive credit
- Construction vehicles cannot drive over pervious area to prevent compaction.

MAINTENANCE

- Compacted soil must be amended, tilled, and re-vegetated to restore infiltration capacity
- Clean gutters annually to prevent clogging or downspouts and pervious areas

Rain Barrels/ Cisterns

DESCRIPTION

Cisterns and rain barrels are structural tanks designed to capture stormwater runoff from impermeable surfaces for non-potable use. For uses other than irrigation, a filter system must be implemented. Rain barrels are 50 to 100 gallon covered plastic tanks usually installed above ground to store runoff from residential rooftops. Rain barrels must be disconnected and completely drained before winter to prevent cracking of the barrel. Cisterns are partially or fully burried 100 to 10,000 gallon tanks with a cover and a discharge pump. They may receive runoff from multiple residential roofs, commercial or industrial roofs, and parking decks. Cisterns usually contain a pump to distribute water for intended use.

Rain barrel to receive rooftop runoff installed at the Children's Discovery Museum (Acton, MA).

Applications

- Applicable for private and public projects
- Commercial and residential
- Roof runoff storage
- Dense urban settings
- Retrofits

Advantages

- Use for irrigation and non-potable uses to save money on water utility bill
- Reduce runoff volume entering storm-water conveyance system for small storms
- Simple design and construction
- Small footprint

Limitations

- Provides habitat for mosquitoes if not properly sealed
- Possible cracking of structure during winter months
- Effective implementation requires reliable and constant demand

UNIT PROCESSES	
M	Volume reduction
M	Peak Flow Reduction
L	Sedimentation
L	Filtration & sorption
L	Biological Processes

TARGET CONSTITUENTS

All constituents.

Effectiveness depends on volume and peak flow reductions.

STORMWATER STANDARD APPLICABILITY

Provides:

Peak Flow reduction (small storms)

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Typical costs for a 60 gallon rain barrel range from $60 to $100 while cisterns typically in costs from $1 to $4 gallon. Cistern costs are largely dependent on whether they are constructed above or below grade.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Roof surface can be deducted from impervious area used to determine required water quality volume of other treatment practices when: 1) cistern can store required water quality volume from roof, 2) discharged to infiltration BMP within 72- hours, and 3) operates 365 days a year
- The main design components of a cistern include pipes/downspouts that divert runoff to cistern, an overflow for when cistern is full, and a distribution system to drawdown cistern for intended use.
- Massachusetts State Plumbing Code requires cisterns to be located at least within 10 feet of buildings.
- Treatment of runoff from non-metal roofs is not required for irrigation
- Direct overflow to dry well or infiltration system to further reduce stormwater runoff volumes

Pollutant Removal Efficiencies

Refer to Section 3.4 of Guidance Document for more detail on Removal Efficiencies

Designed for volume reduction and retention of roof tops, not for nutrient, pollutant, or bacteria removal

Rendering of an above- ground cistern designed to collect rooftop runoff.

CONSTRUCTION CONSIDERATIONS

- Covers and screens should be used to prevent mosquitoes from breeding in tanks.
- Foundation for cistern must support weight of cistern and stored water
- Above ground cistern must be secured in place
- Place rain barrels higher than point of use to allow for gravity flow

MAINTENANCE

- Inspect seal of rain barrel to prevent mosquito breeding and leaks
- Clean gutters and roof catchment to prevent clogging of downspouts
- Inspect overflow pipe to provide proper draining of system during large events
- If above ground, drain system before winter to prevent cracking of tank

Green Roofs

DESCRIPTION

Green roofs are vegetated roof covers designed to reduce stormwater volumes through storage of precipitation in a soil media layer and increased evapotranspiration. Green roofs decrease the impervious footprint of buildings and help mimic pre-development hydrology. They are applicable in highly urbanized locations where land is limited and expensive. Due to an observed increase in nitrogen and phosphorous discharged from green roofs, they should not be used in nutrient sensitive waters, or locations where groundwater recharge is a priority due to low baseflows. There are two types of green roofs: intensive green roofs and extensive green roofs. Extensive green roofs are lightweight systems requiring minimal maintenance and a shallow soil media, while intensive green roofs are larger and deeper systems requiring regular maintenance (irrigation, fertilizing, mowing) throughout the year.

A green roof at the WGBH Headquarters, Boston MA
(Image courtesy of Roofmeadow)

Applications

- Applicable for private and public projects
- Commercial, industrial, and residential sites
- New construction or retrofits
- Commonly installed on buildings with flat to low-angle rooftops

Advantages

- Reduce stormwater volume and flow rates
- Reduce heating/cooling cost of building
- Conserve space in highly urbanized areas

Limitations

- If retrofit, requires additional structural analysis of building
- Does not increase groundwater recharge
- May require additional water for irrigation of plants. Irrigation no functional in winter

UNIT PROCESSES	
H	Volume reduction
M	Peak flow reduction
L	Sedimentation
L	Filtration& Sorption
L	Biological processes

TARGET CONSTITUENTS	
L	Nutrients (Potentially increase nitrogen and phosphorous conc.)
L	Metals
L	Bacteria
L	Sediment
L	Oil and grease
L	Trash and debris

STORMWATER STANDARD APPLICABILITY
Provides:
Peak flow attenuation (for small storms)
Can be constructed in:
Redevelopment situations

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Typical installation of modular roof components can range from approximately $20 to $30 per square foot, however costs can range widely depending on the depth of a green roof (i.e., intensive vs. extensive).

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- The green roof should be designed to significantly reduce the peak rate of runoff for small storms. Use a curve number of 86 to calculate peak flow rate attenuation.
- The green roof consists of: a drainage layer, multiple water proof membranes, soil media, vegetation, insulation, and an overflow bypass system
- Membrane/Geotextile: Place an insulation layer, waterproof membrane, and a roofing membrane between the drainage layer and the roof to prevent leaks and damage to roof from stored precipitation and roots of plants. Soil Media (2-6 inches for extensive green roof): Choose a lightweight soil with high retention capacity and less than 5% organic material. Depth must successfully retain water quality volume and should not exceed .4 inches.
- Plants: Choose low-growing, drought-resistant, self-sowing annuals that are tolerant to extreme heat, cold, and high winds
- Overflow by-pass system: Overflow from storms greater than water quality event or during winter months when media is frozen shall be directed to roof leaders.

Pollutant Removal Efficiencies

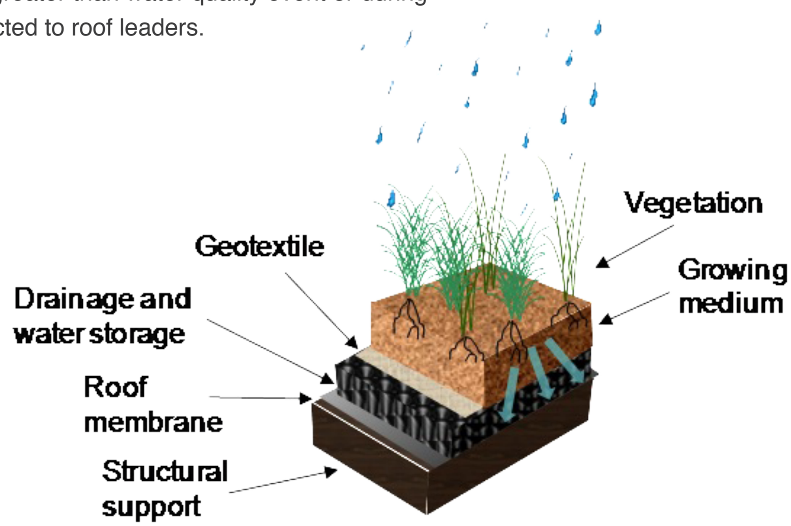
Refer to Section 3.4 of Guidance Document for more detail under Removal Efficiencies

Total Suspended Solids

(TSS): No active removal of suspended solids

Total Phosphorous: Increases TP

Total Nitrogen: No removal to increased TN



Schematic of green roof layering (New Orleans Bayou Land RC&D Stormwater BMP Guidance Tool)

CONSTRUCTION CONSIDERATIONS

- If overflow bypassed to roof leaders, must conform to State Plumbing Code requirements
- Structural support, waterproof membranes, and necessary fire resistant materials (some plants can cause fires) must comply with Massachusetts State Building Codes
- When installing waterproof membranes, pay close attention to seams and application of glues and cement to prevent leaking.

MAINTENANCE

- Add additional mulch, irrigate, weed, and prune plants as necessary to preserve life of roof and established plants
- Remove wooded plants that may become established to preserve roof integrity
- Fertilize intensive green roofs to support growth of plants

Infiltration Basin

DESCRIPTION

Infiltration basins are stormwater impoundments, over permeable soils with vegetated bottoms and side slopes. Infiltration basins are designed to reduce stormwater volumes through exfiltration and groundwater recharge. Pretreatment is vital to ensuring successful performance. There are 2 types of infiltration basins: full exfiltration and partial or off-line exfiltration. Full exfiltration basins are designed to store, treat, and exfiltrate the full required water quality volume and attenuate peak flows. Partial or off-line exfiltration basins are designed to exfiltrate a portion of the runoff (usually the "first flush" or runoff from first 0.5 inches of precipitation), while diverting the remaining runoff to another BMP through flow splitters or weirs. The type of infiltratoin basin is chosen based upon site conditions and limitations.

An infiltration basin installed in a residential neighborhood (Townsend, MA)

Applications

- Contributing drainage area between 2 and 15 acres
- Suitable for sites with gentle slopes, permeable soils, relatively deep groundwater table

Advantages

- Volume reduction
- Groundwater recharge
- Reduces local flooding
- Provides peak flow attenuation
- Can use near cold-water fisheries

Limitations

- Requires pretreatment
- Requires large pervious area
- High maintenance requirement; clogging potential is high
- Not for treating high loads of sediment or other pollutants

UNIT PROCESSES	
H	Volume reduction
M	Peak flow reduction
H	Sedimentation
H	Filtration& Sorption
M	Biological processes

TARGET CONSTITUENTS	
M	Nutrients
H	Metals
H	Bacteria
H	Sediment
M	Oil and grease
H	Trash and debris

STORMWATER STANDARD APPLICABILITY

Provides:

Peak flow attenuation
Groundwater recharge
TSS removal with adequate pretreatment

Can be constructed in:

Higher Pollutant Land Use Areas with pretreatment
Critical Areas

LEGEND
H = High
M = Medium
L = Low

NOTES
These designations are relative to other BMPs selected for these fact sheets. Design variations and enhancements may change the designations.

GENERAL COST CONSIDERATIONS

Infiltration basins are estimated to be $3 to $8 per cubic foot of storage, but can vary significantly based on site-specific design considerations.

DESIGN CONSIDERATIONS

NOTE: for more detailed design guidance refer to 2008 MA Stormwater Handbook

- Evaluate site conditions and determine soils, depth to bedrock and depth to groundwater
- Soils shall have a minimum infiltration rate of 0.50 inches per hour
- To adequately determine soil infiltration rates, take one soil boring for every 5,000 feet of basin area or a minimum of 3 borings for each basin
- Design pretreatment BMP to treat runoff volume prior to discharging into infiltration basin
- Size basin, at a minimum, to capture and retain the required recharge volume
- Include 1 foot of freeboard above the required recharge volume, including the direct precipitation input
- Design basin to drain entire volume in 72 hours

Pollutant Removal Efficiencies

Refer to Section 3.4 in Guidance Document for more details under Removal Efficiencies

With pretreatment:

80% reduction of Total Suspended Solids

50 to 60% reduction of Total Nitrogen

60 to 70% reduction of Total Phosphorous

85 to 90% reduction of Metals

90% reduction of Pathogens

CONSTRUCTION CONSIDERATIONS

- Rope or fence off area selected for infiltration basin
- Prevent construction equipment from working near infiltration basin to prevent soil compaction
- Stabilize inlet channels to prevent erosion
- Till basin floor with rotary tiller to a depth of 12 inches to restore infiltration rates after final grading
- Stabilize infiltration basin bottom and side slopes with dense turf , water-tolerant grass or 6 to 12 inches of coarse sand
- Do not plant trees or shrubs in basin for they increase chance of failure due to root decay or subsurface disturbance
- Do not construct basin in winter or when it is raining to limit compaction and smearing of soil

MAINTENANCE

- Develop and implement an aggressive maintenance and operations plan
- Inspect basin and pretreatment device after major storms to ensure it is functioning properly, for the first few months post construction
- Inspect, at a minimum, twice a year for cracking, erosion, leakage in embankments, tree growth, condition of riprap, sediment accumulation, health of turf and signs of differential settlement
- Mow buffer area, side slopes, and basin bottom at least twice a year
- Remove trash and debris to prevent clogging
- Remove sediment from basin as necessary to prevent clogging

APPENDIX C:

Massachusetts Stormwater Handbook (2008)

Stormwater Management Standards

In 1996, the Massachusetts Department of Environmental Protection (the "Department" or "MassDEP") issued the Stormwater Policy that established Stormwater Management Standards aimed at encouraging recharge and preventing stormwater discharges from causing or contributing to the pollution of the surface waters and groundwaters of the Commonwealth. In 1997, MassDEP published the Massachusetts Stormwater Handbook as guidance on the Stormwater Policy. MassDEP has revised the Stormwater Management Standards and Massachusetts Stormwater Handbook to promote increased stormwater recharge, the treatment of more runoff from polluting land uses, low impact development (LID) techniques, pollution prevention, the removal of illicit discharges to stormwater management systems, and improved operation and maintenance of stormwater best management practices (BMPs). MassDEP applies the Stormwater Management Standards pursuant to its authority under the Wetlands Protection Act, M.G.L. c. 131, § 40, and the Massachusetts Clean Waters Act, M.G.L .c. 21, §§ 26-53. The revised Stormwater Management Standards have been incorporated in the Wetlands Protection Act Regulations, 310 CMR 10.05(6)(k) and the Water Quality Certification Regulations, 314 CMR 9.06(6)(a).

Stormwater runoff results from rainfall and snow melt and represents the single largest source responsible for water quality impairments in the Commonwealth's rivers, lakes, ponds, and marine waters. New and existing development typically adds impervious surfaces and, if not properly managed, may alter natural drainage features, increase peak discharge rates and volumes, reduce recharge to wetlands and streams, and increase the discharge of pollutants to wetlands and water bodies.

The Stormwater Management Standards address water quality (pollutants) and water quantity (flooding, low base flow and recharge) by establishing standards that require the implementation of a wide variety of stormwater management strategies. These strategies include environmentally sensitive site design and LID techniques to minimize impervious surface and land disturbance, source control and pollution prevention, structural BMPs, construction period erosion and sedimentation control, and the long-term operation and maintenance of stormwater management systems.

The Stormwater Management Standards

1. No new stormwater conveyances (e.g. outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

2. Stormwater management systems shall be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates. This Standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

3. Loss of annual recharge to groundwater shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

4. Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). This Standard is met when:

    a. Suitable practices for source control and pollution prevention are identified in a long-term pollution prevention plan, and thereafter are implemented and maintained;
    b. Structural stormwater best management practices are sized to capture the required water quality volume determined in accordance with the Massachusetts Stormwater Handbook; and
    c. Pretreatment is provided in accordance with the Massachusetts Stormwater Handbook.

5. For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable. If through source control and/or pollution prevention all land uses with higher potential pollutant loads cannot be completely protected from exposure to rain, snow, snow melt, and stormwater runoff, the proponent shall use the specific structural stormwater BMPs determined by the Department to be suitable for such uses as provided in the Massachusetts Stormwater Handbook. Stormwater discharges from land uses with higher potential pollutant loads shall also comply with the requirements of the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26-53 and the regulations promulgated thereunder at 314 CMR 3.00, 314 CMR 4.00 and 314 CMR 5.00.

6. Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply, and stormwater discharges near or to any other critical area, require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined by the Department to be suitable for managing discharges to such areas, as provided in the Massachusetts Stormwater Handbook. A discharge is near a critical area if there is a strong likelihood of a significant impact occurring to said area, taking into account site-specific factors. Stormwater discharges to Outstanding Resource Waters and Special Resource Waters shall be removed and set back from the receiving water or wetland and receive the highest and best practical method of treatment. A "storm water discharge" as defined in 314 CMR 3.04(2)(a)1 or (b) to an Outstanding Resource Water or Special Resource Water shall comply with 314 CMR 3.00 and 314 CMR 4.00. Stormwater discharges to a Zone I or Zone A are prohibited unless essential to the operation of a public water supply.

7. A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural best management practice requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

8. A plan to control construction-related impacts including erosion, sedimentation and other pollutant sources during construction and land disturbance activities (construction period erosion, sedimentation, and pollution prevention plan) shall be developed and implemented.

9. A long-term operation and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed.

10. All illicit discharges to the stormwater management system are prohibited.

Applicability

Except as expressly provided herein, stormwater runoff from all industrial, commercial, institutional, office, residential and transportation projects including site preparation, construction and redevelopment, and all point source stormwater discharges from said projects shall be managed according to the Stormwater Management Standards.

The Stormwater Management Standards shall not apply to:

(1) A single-family house;
(2) Housing development and redevelopment projects comprised of detached single-family dwellings on four or fewer lots provided that there are no stormwater discharges that may potentially affect a critical area;

(3) Multi-family housing development and redevelopment projects with four or fewer units, including condominiums, cooperatives, apartment buildings and townhouses, provided that there are no stormwater discharges that may potentially affect a critical area; and
(4) Emergency repairs to roads or their drainage systems.

The Stormwater Management Standards shall apply to the maximum extent practicable to the following:

(1) Housing development and redevelopment projects comprised of detached single-family dwellings on four or fewer lots that have a stormwater discharge that may potentially affect a critical area;
(2) Multi-family housing development and redevelopment projects, with four or fewer units, including condominiums, cooperatives, apartment buildings, and townhouses, that have a stormwater discharge that may potentially affect a critical area;
(3) Housing development and redevelopment projects comprised of detached single-family dwellings on five to nine lots, provided there is no stormwater discharge that may potentially affect a critical area;
(4) Multi-family housing development and redevelopment projects with five to nine units, including condominiums, cooperatives, apartment buildings, and townhouses, provided there is no stormwater discharge that may potentially affect a critical area;
(5) Marinas and boat yards, provided that the hull maintenance, painting and service areas are protected from exposure to rain, snow, snow melt, and stormwater runoff; and
(6) Footpaths, bikepaths and other paths for pedestrian and/or nonmotorized vehicle access.

Critical areas include Outstanding Resource Waters as designated in 314 CMR 4.00, Special Resource Waters as designated in 314 CMR 4.00, recharge areas for public water supplies as defined in 310 CMR 22.02 (Zone Is, Zone IIs and Interim Wellhead Protection Areas for groundwater sources and Zone As for surface water sources), bathing beaches as defined in 105 CMR 445.000, cold-water fisheries as defined in 310 CMR 10.04 and 314 CMR 9.02, and shellfish growing areas as defined in 310 CMR 10.04 and 314 CMR 9.02.

For phased projects, the determination of whether the Stormwater Management Standards apply is made on the entire project as a whole including all phases. When proposing a development or redevelopment project subject to the Stormwater Management Standards, proponents shall consider environmentally sensitive site design that incorporates low impact development techniques in addition to stormwater best management practices.

Project proponents seeking to demonstrate compliance with some or all of the Stormwater Management Standards to the maximum extent practicable shall demonstrate that:

(1) They have made all reasonable efforts to meet each of the Standards;
(2) They have made a complete evaluation of possible stormwater management measures, including environmentally sensitive site design, low impact development techniques that minimize land disturbance and impervious surfaces, structural stormwater best management practices, pollution prevention, erosion and sedimentation control, and proper operation and maintenance of stormwater best management practices; and
(3) If full compliance with the Standards cannot be achieved, they are implementing the highest practicable level of stormwater management.

The Stormwater Management Standards (Standards 4, 5, 6, 8, and 9) require project proponents to develop a construction-period erosion, sedimentation, and pollution prevention plan and long-term pollution prevention and operation and maintenance plans. The level of detail in these plans should reflect the complexity of the project and the nature and extent of the impacts that may arise both during and after construction. For small residential projects that are subject to jurisdiction under the Wetlands Protection Act and that are required to meet the Stormwater Management Standards only to the maximum extent practicable, the issuing authority has broad discretion to tailor this requirement to the specific stormwater impacts of the project and require the construction period erosion and sedimentation control plan and the long-term pollution prevention and operation and maintenance plans only to the extent that they are necessary to address those impacts.

Even if the Stormwater Management Standards do not apply, a proponent still must implement erosion and sedimentation control if the project is located in a wetland resource area or associated Buffer Zone. See CMR 10.05(6). Although the Stormwater Management Standards do not apply, a person constructing a single-family house that extends into the Buffer Zone must control erosion and sedimentation within wetland resource areas and the Buffer Zone.

Environmentally Sensitive Site Design and Low Impact Development Techniques

The Wetlands Regulations, 310 CMR 10.04, and the Water Quality Certification Regulations, 314 CMR 9.02, define environmentally sensitive site design to mean design that incorporates low impact development techniques to prevent the generation of stormwater and non-point source pollution by reducing impervious surfaces, disconnecting flow paths, treating stormwater at its source, maximizing open space, minimizing disturbance, protecting natural features and processes, and/or enhancing wildlife habitat. The Wetlands Regulations, 310 CMR 10.04, and the Water Quality Certification Regulations, 314 CMR 9.02, define low impact development (LID) techniques to mean innovative stormwater management systems that are modeled after natural hydrologic features. Low impact development techniques manage rainfall at the source using uniformly distributed decentralized micro-scale controls. Low impact development techniques use small cost-effective landscape features located at the lot level.

Proponents of projects subject to the Stormwater Management Standards must consider environmentally sensitive site design and low impact development techniques to manage stormwater. Proponents shall consider decentralized systems that involve the placement of a number of small treatment and infiltration devices located close to the various impervious surfaces that generate stormwater runoff in place of a centralized system comprised of closed pipes that direct all the drainage from the entire site into one large dry detention basin.

MassDEP has established an “LID Site Design Credit” to encourage developers to incorporate LID techniques in their projects.[1] In exchange for directing runoff from roads and driveways to vegetated open areas, preserving open space with a conservation restriction, or directing rooftop runoff to landscaped or undisturbed areas, MassDEP allows developers to reduce or eliminate the traditional BMPs used to treat and infiltrate stormwater.

Incorporating environmentally sensitive design that uses the land to filter and recharge the water back into the ground and that reduces the amount of paved areas is a critical first step in creating sustainable development. Inspired by EEA’s Smart Growth Toolkit, MassDEP believes that the LID Site Design Credit protects our natural resources, encourages cluster development, and reduces the environmental impacts of growth.[2] By using this credit, proponents can reduce the volume of stormwater subject to Standard 3 - the Recharge Standard, and Standard 4 - the Water Quality Standard.

Explanation of the Standards

Standard 1: No new stormwater conveyances (e.g. outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

This standard allows the direct discharge of stormwater to waters and wetlands provided the discharge is adequately treated. The term “treated” refers to the implementation of stormwater management systems that are specifically designed to achieve sediment and contaminant removal rates that adequately protect groundwater, surface waters and wetlands in accordance with all applicable statutes,

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[1] Information on the LID Site Design Credit is found in Volume 3 of the Massachusetts Stormwater Handbook.
[2] Smart Growth Toolkit - http://www.mass.gov/envir/sgtk.htm

regulations, permits, and approvals, the other standards, and the technical specifications set forth in Volume 2 of the Massachusetts Stormwater Handbook. The level of treatment required by the other standards is based on whether the discharge impacts a critical area, is from a land use with a higher potential pollutant load, or to soils with a rapid infiltration rate.

The requirement that stormwater discharges must not cause erosion in wetlands or waters of the Commonwealth means that there must be no wearing away of the soil or land surface in excess of natural conditions. To prevent erosion and sedimentation, BMPs and associated pipes and other conveyances must be properly designed and installed in accordance with Volume 2 of the Massachusetts Stormwater Handbook. The use of level spreaders or other techniques at the point of discharge is required to minimize erosion. For projects subject to jurisdiction under the Wetlands Protection Act, the applicant shall demonstrate to the issuing authority that the discharge velocities will not cause erosion or scouring at the point of discharge or downstream. Discharge velocities from BMPs should take into account factors such as soils, slope and the type of receiving resource.

Standard 2: Stormwater management systems shall be designed so that the post-development peak discharge rates do not exceed pre-development peak discharge rates. This Standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

To prevent storm damage and downstream and off-site flooding, Standard 2 requires that the post-development peak discharge rate is equal to or less than the pre-development rate from the 2-year and the 10-year 24-hour storms. BMPs that slow runoff rates through storage and gradual release, such as LID techniques, extended dry detention basins, and wet basins, must be provided to meet Standard 2. Where an area is within the 100-year coastal flood plain or land subject to coastal storm flowage, the control of peak discharge rates is usually unnecessary and may be waived.

For projects subject to jurisdiction under the Wetlands Protection Act, the issuing authority relies on TR 20 and 55[3], which are guides for estimating the effects of land use changes on runoff volume and peak rates of discharge published by Natural Resource Conservation Service (NRCS*)*. Applicants must calculate runoff rates from pre-existing and post-development conditions. Measurement of peak discharge rates is calculated at a design point, typically the lowest point of discharge at the downgradient property boundary. The topography of the site may require evaluation at more than one design point, if flow leaves the property in more than one direction. An applicant may demonstrate that a feature beyond the property boundary (e.g. culvert) is more appropriate as a design point.

Proponents must also evaluate the impact of peak discharges from the 100-year 24-hour storm. If this evaluation shows that increased off-site flooding will result from peak discharges from the 100-year 24-hour storms, BMPs must also be provided to attenuate these discharges. [4]

Standard 3: Loss of annual recharge to groundwater shall be eliminated or minimized through the use of environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

The intent of this standard is to ensure that the infiltration volume of precipitation into the ground under post-development conditions is at least as much as the infiltration volume under pre-development

[3] NRCS TR 20&55 - http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/tool_mod.html. See the Hydrology Handbook for Conservation Commissioners, http://www.mass.gov/dep/water/laws/hydrol.pdf.

[4] The evaluation may show that retaining the 100-year 24-hour storm event is not needed. In some cases, retaining stormwater from the 100-year 24-hour storm event onsite may aggravate downstream impacts, because of the project's location within the watershed and the timing of the release of stormwater.

conditions. Standard 3 requires the restoration of recharge, using infiltration measures and careful site design. Through judicious use of low impact development techniques and other approaches that minimize impervious surfaces and mimic natural conditions, new developments can approximate pre-development recharge for most storms.

The NRCS classifies soils into four hydrologic groups, A thru D, indicative of the minimum infiltration obtained for a soil after prolonged wetting[5]. Group A soils have the lowest runoff potential and the highest infiltration rates, while Group D soils have the highest runoff potential and the lowest infiltration rates. The required recharge volume, the stormwater volume that must be infiltrated, shall be determined using existing site conditions and the infiltration rates set forth below.

Hydrologic Group Volume to Recharge (x Total Impervious Area)	
Hydrologic Group	Volume to Recharge x Total Impervious Area
A	0.60 inches of runoff
B	0.35 inches of runoff
C	0.25 inches of runoff
D	0.10 inches of runoff

For each NRCS Hydrologic Group on the site, the required recharge volume equals the recharge volume set forth above multiplied by the total area within that NRCS Hydrologic Group that is impervious. Infiltration of these volumes must be accomplished using appropriate BMPs. The following BMPs may be used to infiltrate stormwater in compliance with Standard 3: dry wells; infiltration basins; infiltration trenches; subsurface structures; leaching catch basins; exfiltrating bioretention areas[6] and porous pavement. Some proprietary BMPs can also be used to infiltrate stormwater in compliance with Standard 3. Proponents can reduce the volume of stormwater that they are required to recharge by using the LID Site Design Credit.

Infiltration BMPs must be designed, constructed, operated, and maintained in accordance with the specifications and procedures set forth in Volume 2 of the Massachusetts Stormwater Handbook. To size infiltration BMPs so that they infiltrate the required recharge volume, proponents may use the static method or one of the two dynamic methods specified in Volume 3.[7] The static method assumes that no infiltration occurs until the recharge device is filled to the elevation associated with the required recharge volume, is easy to calculate, and generally results in a larger recharge volume than the dynamic methods. The dynamic methods assume that that the recharge BMP is infiltrating as it fills and require certain technical calculations that take this recharge into account when sizing the infiltration BMP.

MassDEP recognizes that it may be difficult to infiltrate the required recharge volume on certain sites because of soil conditions[8]. For sites comprised solely of C and D soils and bedrock at the land

[5] Soil Groups – http://soils.usda.gov/education/

[6] Bioretention areas are an example of a BMP that may be designed to act as a filtering practice or an infiltration device. Bioretention areas that act solely as filters have an underdrain that captures runoff and conveys it to another BMP before it is discharged to a surface water, a wetland, or another BMP. These bioretention areas may be lined. Bioretention areas designed to infiltrate do not have those features. To distinguish the two types of bioretention areas, this Handbook will refer to bioretention areas designed to infiltrate as “exfiltrating bioretention areas” and other bioretention areas as “filtering bioretention areas".

[7] A detailed explanation of procedures that must be followed when applying the static method and the two dynamic methods is set forth in Volume 3.

[8] It may also be difficult for MassHighway to recharge the required recharge volume at every point along an add-a -lane project. For this reason, MassDEP allows MassHighway to use the macro approach, which allows MassHighway to recharge additional runoff at certain locations along a portion of the highway within a subwatershed to compensate for sections of the roadway in the same subwatershed where it may be difficult to recharge the entire required recharge volume. MassDEP and MassHighway intend to

surface, proponents are required to infiltrate the required recharge volume only to the maximum extent practicable. MassDEP also recognizes that on some sites, there is a risk that infiltrating the required recharge volume may cause or contribute to groundwater contamination. Consequently, MassDEP requires infiltration only to the maximum extent practicable on the following sites: sites where recharge is proposed at or adjacent to an area classified as contaminated, sites where contamination has been capped in place; sites that have an Activity and Use Limitation (AUL) that precludes inducing runoff to the groundwater, pursuant to MGL Chapter 21E and the Massachusetts Contingency Plan 310 CMR 40.0000; sites that are the location of a solid waste landfill as defined in 310 CMR 19.000; and sites where groundwater from the recharge location flows directly toward a solid waste landfill or 21E site.[9]

For purposes of Standard 3, "to the maximum extent practicable" means that:

(1) The applicant has made all reasonable efforts to meet the Standard;
(2) The applicant has made a complete evaluation of all possible applicable infiltration measures, including environmentally sensitive site design that minimizes land disturbance and impervious surfaces, low impact development techniques, and structural stormwater best management practices; and
(3) If the post-development recharge does not at least approximate the annual recharge from pre-development conditions, the applicant has demonstrated that s/he is implementing the highest practicable method for infiltrating stormwater.

To ensure the long-term operation of infiltration BMPs, pretreatment is required before discharge to an infiltration BMP. For infiltration of stormwater runoff from land uses with higher potential pollutant loads, discharges to the ground within an area with a rapid infiltration rate (greater than 2.4 inches per hour), a Zone II or Interim Wellhead Protection Area, and discharges to the ground near any of the following critical areas: Special Resource Waters, Outstanding Resource Waters, bathing beaches, shellfish growing areas, or cold-water fisheries, at least 44% of the total suspended solids must be removed prior to discharge to the infiltration structure. A discharge is near a critical area, if there is a strong likelihood of a significant impact occurring to said area, taking into account site-specific factors.

Runoff from non-metal roofs may be discharged to a dry well without any pretreatment. Runoff from metal roofs may be discharged to a dry well without pretreatment, only if the roof is located outside the Zone II or Interim Wellhead Protection Area of a public water supply and outside an industrial site. Infiltration of runoff from a metal roof that is located within the Zone II or Interim Wellhead Protection Area of a public water supply and/or at an industrial site requires pretreatment by means of a BMP capable of removing metals, such as a sand filter, organic filter, filtering bioretention area or equivalent. Metal roofs are galvanized steel or copper.

When designing infiltration BMPs, adequate subsurface information needs to be obtained[10]. Infiltration systems must be installed in soils capable of absorbing the recharge volume (i.e. not D soils). Infiltration structures must be able to drain fully within 72 hours. In addition, there must be at least a two-foot separation between the bottom of the infiltration structure and the seasonal high groundwater table.

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provide additional information on the macro approach in the MassHighway Stormwater Handbook for Highways and Bridges when it is revised to reflect the 2008 changes in the Stormwater Management Standards.

[9] A mounding analysis is needed if a site falls within this category. See Volume 3.

[10] The required minimum infiltration rate is 0.17 inches per hour. D soils have an infiltration rate that is below this minimum. To determine the infiltration rate, proponents must perform a soil evaluation using the methodologies set forth in Volume 3.

Table RR

Rules for Groundwater Recharge
All BMPs must be designed according to the specifications and procedures in Volumes 2 and 3 of the Massachusetts Stormwater Handbook. **Except as expressly provided herein, entire required recharge volume must be infiltrated.** **Required recharge volume must be infiltrated only to the maximum extent practicable, if:** **The site is comprised wholly of C and D soils and bedrock at the land surface; Recharge is proposed at or adjacent to a site that has:** ➢ **been classified as contaminated;** ➢ **contamination that has been capped in place;** ➢ **an Activity and Use Limitation (AUL) that precludes inducing runoff to the groundwater pursuant to MGL Chapter 21E and the Massachusetts Contingency Plan, 310 CMR 40.0000;** ➢ **has a solid waste landfill as defined in 310 CMR 19.000; or** ➢ **groundwater from the recharge area that flows directly toward a solid waste landfill or 21E site.** **Design Requirements:** **At least 44% of the TSS must be removed prior to discharge to the infiltration structure if the discharge is:** ➢ **within a Zone II or Interim Wellhead Protection Area;** ➢ **near an Outstanding Resource Water or Special Resource Water;** ➢ **near a shellfish growing area, cold-water fishery, or bathing beach;** ➢ **from a land use with higher potential pollutant loads; or** ➢ **within an area with a rapid infiltration rate (greater than 2.4 inches per hour).** **Except as set forth below, roof runoff from may be discharged to the ground via a dry well without pretreatment. The discharge of roof runoff to the ground requires pretreatment by means of a BMP capable of removing metals, such as a sand filter, organic filter or filtering biorention area, if the roof is a metal roof that is located in the Zone II or Interim Wellhead Protection Area of a public water supply and/or at an industrial site. Metal roofs are galvanized steel or copper.** **Depth to groundwater: At a minimum there should be a two-foot separation between bottom of structure and seasonal high groundwater.** **Minimum Infiltration Rate. 0.17 inches per hour.** **All infiltration structures must be able to drain fully within 72 hours.** **General Setback Requirements:** **Soil Absorption Systems for Title 5 System: 50 ft.** **Private wells: 100 ft.** **Public wells: Outside Zone I** **Public reservoir, surface water sources for public water systems and their tributaries: Outside Zone A** **Other surface waters: 50 ft.** **Property Line: 10 feet** **Building foundations (including slabs): >10 to 100 ft. depending on type of recharge BMP. See BMP description for exact minimum setback.** **Specific BMPs have additional setback requirements. See Volume 2, Chapter 2.**

Standard 4: Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). This standard is met when:

a) Suitable practices for source control and pollution prevention are identified in a long-term pollution prevention plan, and thereafter are implemented and maintained;
b) Structural stormwater best management practices are sized to capture the required water quality volume as determined in accordance with the Massachusetts Stormwater Handbook; and
c) Pretreatment is provided in accordance with the Massachusetts Stormwater Handbook.

This standard applies after the site is stabilized.[11] Since removal efficiency may vary with each storm, 80% TSS removal is not required for each storm. It is the average removal over the year that is required to meet the standard. The required water quality volume, the runoff volume requiring TSS treatment, is calculated as follows:

The required water quality volume equals 1.0 inch of runoff times the total impervious area of the post-development project site for a discharge

- from a land use with a higher potential pollutant load;
- within an area with a rapid infiltration rate (greater than 2.4 inches per hour);
- within a Zone II or Interim Wellhead Protection Area;
- near or to the following critical areas:
  - Outstanding Resource Waters,
  - Special Resource Waters,
  - bathing beaches,
  - shellfish growing areas,
  - cold-water fisheries.

The required water quality volume equals 0.5 inches of runoff times the total impervious area of the post-development site for all other discharges.

Standard 4 requires the development and implementation of suitable practices for source control and pollution prevention. These measures must be identified in a long-term pollution prevention plan. The long-term pollution prevention plan shall include the proper procedures for the following:

- good housekeeping;
- storing materials and waste products inside or under cover;
- vehicle washing;
- routine inspections and maintenance of stormwater BMPs;
- spill prevention and response;
- maintenance of lawns, gardens, and other landscaped areas;
- storage and use of fertilizers, herbicides, and pesticides;
- pet waste management;
- operation and management of septic systems; and
- proper management of deicing chemicals and snow[12].

The long-term pollution prevention plan shall provide that sand piles be contained and stabilized to prevent the discharge of sand to wetlands or water bodies, and, where feasible, covered. If a Total Maximum Daily Load (TMDL)[13] has been developed that indicates that use of fertilizers containing nutrients must be reduced, the long-term pollution prevention plan shall also include a nutrient management

[11] Construction period requirements are found in Standard 8.
[12] Snow & Deicing Policies - http://www.mass.gov/dep/water/laws/policies.htm#snowsalt
[13] Information on TMDLs is set forth in Volume 1, Chapter 2.

plan. The long-term pollution prevention plan may be prepared as a separate document or combined with the Operation and Maintenance Plan required by Standard 9.[14]

BMPs must be selected so that a total of 80% TSS removal is provided by one or more BMPs.[15] Typically a stormwater management system will have several BMPs that will control flow rates and retain contaminants. In this BMP "process train", more than one BMP will be removing TSS. The goal is to ensure that the cumulative effect of the treatment train is the removal of at least 80% of the annual average TSS load. Where there is more than one outfall or treatment train, each outfall or treatment train shall achieve 80% TSS removal prior to discharge.[16]

BMPs must be designed, constructed, operated and maintained in accordance with the specifications and procedures set forth in Volumes 2 and 3 of the Massachusetts Stormwater Handbook. Standard 4 has been designed in a manner that makes it unnecessary for the permitting authority to verify a TSS load for the site in order to confirm removal rates. Assuming all BMPs are properly designed, the percentage of TSS removed by the entire system shall be calculated by applying the TSS removal rates set forth in Table TSS for each BMP in the order in which it is used in the stormwater management system.[17] Generally, monitoring is not required to confirm removal percentages. Nevertheless, monitoring or sampling may be appropriate to ensure protection of critical areas or to verify the effectiveness of alternative technologies that are not included in Table TSS or do not have a specified TSS removal rate and that have only limited data about their long-term performance.

The BMP design removal rates cannot be added directly to arrive at 80%. For example, if the first BMP in a system has a 60% removal rate, and the second BMP has a 20% removal rate, adding 60% and 20% will not achieve the desired 80% TSS removal rate; only 68 % of the TSS will be removed. The reason is that the second BMP removes only the percentage of TSS that is routed to it after an initial amount of TSS has been removed by the first BMP. In this example, after the stormwater was routed through the first BMP, 60% of the sediment was removed. The remaining 40% was routed to the second BMP that removed 20% of that 40% (not 20% of the entire load). The second BMP therefore removed an additional 8%, leaving 12% still to be removed (60%+8%=68%; 80%-68%=12%).

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[14] Proponents are required to prepare a Stormwater Report that includes both the long- term pollution prevention plan and the operation and maintenance plan Information on the Stormwater Report is set forth in Volume 3.

[15] If there is a Total Maximum Daily Load (TMDL) that indicates that stormwater BMPs are needed to reduce the concentration in stormwater runoff of pollutants other than TSS such as nitrogen and phosphorus, the BMPs selected must be consistent with the TMDL. See Volume 1, Chapter 2.

[16] 80% TSS removal is not required at an outfall with only a *de minimus* stormwater discharge. In that event, a proponent may demonstrate compliance with the 80% TSS removal requirement by using a weighted average. See Volume 3 for a description of the highly limited circumstances in which a discharge from a stormwater outfall will be considered *de minimus* and the procedures for applying a weighted average. Because of right-of-way constraints, MassDEP anticipates that MassHighway redevelopment projects and add-a-lane projects may in some circumstances have to rely on weighted averages to meet the TSS removal requirement. MassDEP and Mass Highway intend to provide additional information on this approach in the MassHighway Stormwater Handbook for Highways and Bridges, when it is revised to reflect 2008 changes to the Stormwater Management Standards.

[17] The following rules apply to Table TSS. If pretreatment is required, the total removal efficiency includes the terminal treatment BMP and the pretreatment BMP. For purposes of assessing compliance with the 44% TSS removal pretreatment requirement, a separate credit is awarded for the required pretreatment BMP. For example, for the leaching catch basin/deep sump catch basin combination, 80% is the total TSS removal credit for both BMPs. No additional TSS removal credit is given for the deep sump catch basin. However, the separate 25% TSS removal credit for the deep sump catch basin counts towards the 44% pretreatment requirement, if it is applicable.

Table TSS

TSS Removal Efficiencies for Best Management Practices	
Best Management Practice (BMP)	**TSS Removal Efficiency**
Non-Structural Pretreatment BMPs	
Street Sweeping	0-10%, See Volume 2, Chapter 1.
Structural Pretreatment BMPs	
Deep Sump Catch Basins	25% only if used for pretreatment and only if off-line
Oil Grit Separator	25% only if used for pretreatment and only if off-line
Proprietary Separators	Varies – see Volume 2, Chapter 4.
Sediment Forebays	25% if used for pretreatment
Vegetated filter strips	10% if at least 25 feet wide, 45% if at least 50 feet wide
Treatment BMPs	
Bioretention Areas including rain gardens	90% provided it is combined with adequate pretreatment
Constructed Stormwater Wetlands	80% provided it is combined with a sediment forebay
Extended Dry Detention Basins	50% provided it is combined with a sediment forebay
Gravel Wetlands	80% provided it is combined with a sediment forebay
Proprietary Media Filters	Varies – see Volume 2, Chapter 4
Sand/Organic Filters	80% provided it is combined with sediment forebay
Treebox filter	80% provided it is combined with adequate pretreatment
Wet Basins	80% provided it is combined with sediment forebay
Conveyance	
Drainage Channels	For conveyance only. No TSS Removal credit.
Grass Channels (formerly biofilter swales)	50% if combined with sediment forebay or equivalent
Water Quality Swale – wet & dry	70% provided it is combined with sediment forebay or equivalent
Infiltration BMPs	
Dry Wells	80% for runoff from non-metal roofs; may also be used for runoff from metal roofs but only if metal roof is not located within a Zone II, or IWPA or at an industrial site
Infiltration Basins & Infiltration Trenches	80% provided it is combined with adequate pretreatment (sediment forebay or vegetated filter strip, grass channel, water quality swale) prior to infiltration
Leaching Catch Basins	80% provided a deep sump catch basin is used for pretreatment
Subsurface Structure	80% provided they are combined with one or more pretreatment BMPs prior to infiltration.
Other BMPs	
Dry Detention Basins	For peak rate attenuation only. No TSS Removal credit.
Green Roofs	See Volume 2. Chapter 2. May reduce required water quality volume. No TSS Removal Credit.
Porous Pavement	80% if designed to prevent runon and with adequate storage capacity. Limited to uses identified in Volume 2, Chapter 2.
Rain Barrels and Cisterns	May reduce required water quality volume. No TSS Removal Credit.

Standard 5: For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable. If, through source control and/or pollution prevention, all land uses with higher potential pollutant loads cannot be completely protected from exposure to rain, snow, snow melt and stormwater runoff, the proponent shall use the specific structural stormwater BMPs determined by the Department to be suitable for such uses as provided in the Massachusetts Stormwater Handbook. Stormwater discharges from land uses with higher potential pollutant loads shall also comply with the requirements of the Massachusetts Clean Waters Act, M.G.L.c. 21, §§ 26-53 and the regulations promulgated thereunder at 314 CMR 3.00, 314 CMR 4.00 and 314 CMR 5.00.

Land uses with higher potential pollutant loads are defined in 310 CMR 10.04 and 314 CMR 9.02 to include the following: Land uses identified in 310 CMR 22.20B(2), 310 CMR 22.20C(2)(a)-(k) and (m), 310 CMR 22.21(2)(a)(1)-(8) and 310 CMR 22.21(2)(b)(1)-(6), areas within a site that are the location of activities that are subject to an individual National Pollutant Discharge Elimination System (NPDES) permit or the NPDES Multi-Sector General Permit[18]; auto fueling facilities (gas stations); exterior fleet storage areas; exterior vehicle service and equipment cleaning areas; marinas and boatyards; parking lots with high-intensity-use; confined disposal facilities and disposal sites.

Land uses with higher potential pollutant loads include the industrial sectors regulated by the NPDES Multi-Sector General Permit Program. These sectors include manufacturing: mineral, metal, oil and gas; hazardous waste treatment or disposal facilities; solid waste facilities; wastewater residual landfills; recycling facilities; steam electric plants; transportation facilities; treatment works; and light industrial activity. Land uses with higher potential pollutant loads also include any land uses that are regulated by an individual NPDES permit or that are subject to individual effluent limits established by EPA. Land uses with higher potential loads include land uses that the Department has determined are not suitable for Zone IIs and Zone As of public water supplies, including, without limitation,[19] the following: automobile junk yards; the removal of sand and gravel within four feet of the historical high water mark; the storage of hazardous materials, liquid petroleum, liquid propane, chemical fertilizers, pesticides, manures, septage, sludge, road-deicing materials or sanding materials; snow or ice that has been removed from roads and is contaminated with de-icing chemicals; cemeteries, mausoleums; bulk oil terminals; commercial washing of vehicles and car washes. In addition, land uses with higher potential pollutant loads include: exterior fleet storage areas; exterior vehicle service maintenance and cleaning areas; marinas and boatyards; and parking lots with high-intensity-uses (1000 vehicle trips per day or more). Shopping centers, malls, and large office parks typically have high-intensity-use parking lots. Finally, land uses with higher potential pollutant load include confined disposal facilities as defined in 314 CMR 9.02 and disposal sites as defined in M.G.L. c. 21E and 310 CMR 40.000.

For the purpose of Standard 5, stormwater discharges from land uses with higher potential pollutant loads require treatment by the specific structural BMPs determined to be suitable for treating runoff from such land uses. These BMPs are listed in Table LUHPPL. This requirement applies only to stormwater discharges that come into contact with the actual area or activity on the site that may generate the higher potential pollutant load. Runoff from other portions of the project site that does not come into contact with these specific areas or activities and does not mix with the runoff from these areas or activities does not require the structural BMPs that are determined to be suitable for treating runoff from land uses with higher potential pollutant loads. For example, on the site of a chemical manufacturing plant, runoff

[18] As of the date of publication of this Handbook, the NPDES Multi-Sector General Permit issued in 2000 has expired and has been administratively continued. To date, EPA has not issued a new permit. For purpose of the Stormwater Standards, the land uses subject to the 2000 NPDES Multi-Sector General Permit are land uses with higher potential pollutant loads. A full list of these land uses is set forth in the 2000 NPDES Multi-Sector General Permit. See http://cfpub1.epa.gov/npdes/stormwater/msgp.cfm#permit_factsheet.

[19] The complete text of the regulations that identify the land uses that are not suitable for Zone As and Zone IIs is set forth in 310 CMR 22.20B(2), 310 CMR 22.20C(2)(a) and 310 CMR 22.21(2)(a) and 310 CMR 22.21(b) i. See http://www.mass.gov/dep/water/laws/regulati.htm#dw.

from any grassed open space or parking area without high-intensity use, which is separate from the chemical distribution, loading and storage areas, does not have to be treated with a BMP listed in Table LUHPPL.

A detailed source control and pollution prevention plan is crucial for sites with land uses that have higher potential pollutant loads. [20] To mitigate the potential impact of stormwater discharges from land uses with higher potential pollutant loads, the long-term pollution prevention plan shall include measures that eliminate or minimize any discharges that come into contact with the particular land uses that have the potential to generate high concentrations of pollutants. A proponent can fulfill this requirement by placing all industrial materials or activities in a storm-resistant shelter to prevent exposure to rain, snow, snow melt and runoff, or by placing all materials and wastes stored outside in sealed containers on impervious surfaces with adequate containment. The long-term pollution prevention plan shall also provide for the use of emergency shut-offs where appropriate to isolate the system in the event of an emergency spill or other unexpected event. Proponents of MassHighway projects can meet this requirement by implementing the containment procedures outlined in the MassHighway Stormwater Handbook [21].

Standard 5 expressly provides that a stormwater discharge from a land use with a higher potential pollutant load must comply with all applicable laws, regulations, permits and approvals, including 314 CMR 3.00, 314 CMR 4.00, and 314 CMR 5.00. Pursuant to 314 CMR 3.00 and 314 CMR 5.00, MassDEP has authority to require a discharge permit or other corrective action if it determines that a stormwater discharge is contaminated by contact with process wastes, raw materials, toxic pollutants or hazardous substances, oil and grease, or is a significant contributor of pollution to waters of the Commonwealth. To avoid additional requirements under 314 CMR 3.00, 314 CMR 5.00, and Standard 5, a project proponent should implement a pollution prevention plan that prevents stormwater runoff from coming into contact with significant pollutant sources.

As stated earlier, a stormwater discharge from a land use with a higher potential pollutant load also requires treatment by the specific structural BMPs determined by MassDEP to be suitable for treating discharges from such use.[22] Like all stormwater discharges, stormwater discharges from land uses with higher potential pollutant loads require the use of a treatment train that provides 80% TSS removal prior to discharge. As can be seen from Table LUHPPL, this treatment train shall provide for at least 44% TSS removal prior to discharge to the infiltration BMP and shall also be designed to treat 1.0 inch of runoff times the total impervious area at the post-development site. If the land use is one that has the potential to generate runoff with high concentrations of oil and grease such as a high-intensity-use parking lot, gas station, fleet storage area, or vehicle service and equipment cleaning area, the treatment train must include an oil grit separator, sand filter, filtering bioretention area or equivalent.[23] See Table LUHPPL.

[20] If the land use is also subject to the NPDES Multi-Sector General Permit, a Stormwater Pollution Prevention Plan (SWPPP) will also be required. To avoid duplication of effort, a project proponent may prepare one document that satisfies the SWPPP requirements of the NPDES Multi-Sector General Permit and the long-term pollution prevention plan requirements of Standards 4 and 5.

[21] Mass Highway Handbook - http://www.mhd.state.ma.us/default.asp?pgid=content/publicationmanuals&sid=about

[22] To make sure that proponents have the most up-to-date list of these BMPs, proponents should consult the MassDEP web site.

[23] Any BMP chosen to remove oil and grease including, without limitation, the oil grit separator, must be designed in accordance with the specifications set forth in Volume 2, Chapter 2.

<table>
<tr><td colspan="2">Best Management Practices for Land Uses with Higher Potential Pollutant Loads (Standard 5)
• Discharges from certain land uses with higher potential pollutant loads may be subject to additional requirements including the need to obtain an individual or general discharge permit pursuant to the MA Clean Waters Act or Federal Clean Water Act.
• All proponents must implement source control and pollution prevention.
• All BMPs shall be designed in accordance with specifications and sizing methodologies in the Massachusetts Stormwater Handbook Volumes 2 and 3.
• The required water quality volume equals 1 inch times the total impervious area of the post-development site.
• Many land uses have the potential to generate higher potential pollutant loads of oil and grease. These land uses include, without limitation, industrial machinery and equipment and railroad equipment maintenance, log storage and sorting yards, aircraft maintenance areas, railroad yards, fueling stations, vehicle maintenance and repair, construction businesses, paving, heavy equipment storage and/or maintenance, the storage of petroleum products, high-intensity-use parking lots, and fleet storage areas. To treat the runoff from such land uses, the following BMPs must be used to pretreat the runoff prior to discharge to an infiltration structure: an oil grit separator, a sand filter, organic filter, filtering bioretention area, or equivalent.
• At least 44% TSS removal is required prior to discharge to an infiltration device.
• Until they complete the STEP or TARP verification process outlined in Volume 2, proprietary BMPs may not be used as a terminal treatment device for runoff from land uses with higher potential pollutant loads. For purposes of this requirement, subsurface structures, even those that have a storage chamber that has been manufactured are not considered propriety BMPs, since the treatment occurs in the soil below the structure, not in the structure.</td></tr>
<tr><td>Pretreatment</td><td></td></tr>
<tr><td rowspan="5"></td><td>Deep Sump Catch Basin</td></tr>
<tr><td>Oil Grit Separator</td></tr>
<tr><td>Proprietary Separators: See Volume 2 Chapter 4</td></tr>
<tr><td>Sediment Forebays</td></tr>
<tr><td>Vegetated Filter Strip (must be lined)</td></tr>
<tr><td colspan="2">Treatment</td></tr>
<tr><td rowspan="8">Sand Filters, Organic Filters, Proprietary Media Filters, Wet Basins, Filtering Bioretention Areas, and Extended Dry Detention Basins must be lined and sealed unless at least 44% of TSS has been removed prior to discharge to the BMP.</td><td>Filtering Bioretention Areas including rain gardens</td></tr>
<tr><td>Constructed Stormwater Wetlands</td></tr>
<tr><td>Dry Water Quality Swales</td></tr>
<tr><td>Extended Dry Detention Basins</td></tr>
<tr><td>Gravel Wetlands</td></tr>
<tr><td>Proprietary Media Filter. (Does not include catch basin inserts) (Proprietary Media Filters may be used for terminal treatment for runoff from land uses with higher potential pollutant loads, only if verified for such use by the TARP or STEP process. See Volume 2.)</td></tr>
<tr><td>Sand /Organic Filters</td></tr>
<tr><td>Wet Basins</td></tr>
<tr><td>Infiltration</td><td></td></tr>
<tr><td rowspan="5"></td><td>Exfiltrating Bioretention Areas including rain garden</td></tr>
<tr><td>Infiltration Basins</td></tr>
<tr><td>Infiltration Trenches</td></tr>
<tr><td>Leaching Catch Basins</td></tr>
<tr><td>Subsurface Structures</td></tr>
</table>

Standard 6: Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply and stormwater discharges near or to any other critical area require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined by the Department to be suitable for managing discharges to such areas, as provided in the Massachusetts Stormwater Handbook. A discharge is near a critical area if there is a strong likelihood of a significant impact occurring to said area, taking into account site-specific factors. Stormwater discharges to Outstanding Resource Waters and Special Resource Waters shall be removed and set back from the receiving water or wetland and receive the highest and best practical method of treatment. A "storm water discharge" as defined in 314 CMR 3.04(2)(a)1. or (b) to an Outstanding Resource Water or Special Resource Water shall comply with 314 CMR 3.00 and 314 CMR 4.00. [24] Stormwater discharges to a Zone I or Zone A are prohibited unless essential to the operation of the public water supply.

Critical areas are Outstanding Resource Waters as designated in 314 CMR 4.00, Special Resource Waters as designated in 314 CMR 4.00, recharge areas for public water supplies as defined in 310 CMR 22.02 (Zone Is, Zone IIs and Interim Wellhead Protection Areas for groundwater sources and Zone As for surface water sources), bathing beaches as defined in 105 CMR 445.000, cold-water fisheries as defined in 314 CMR 9.02 and 310 CMR 10.04, and shellfish growing areas as defined in 314 CMR 9.02 and 310 CMR 10.04.

Cold-water fisheries are waters in which the mean of the maximum daily temperature over a seven-day period generally does not exceed 68°F (20°C) and, when other ecological factors are favorable (such as habitat), are capable of supporting a year-round population of cold-water stenothermal aquatic life. Waters designated as cold-water fisheries by the Department in 314 CMR 4.00, and waters designated as cold-water fishery resources by the Division of Fisheries and Wildlife, are cold-water fisheries. Waters where there is evidence based on a fish survey that a cold-water fish population and habitat exist are also cold-water fisheries.

A shellfish growing area is land under the ocean, tidal flats, rocky intertidal shores and marshes and land under salt ponds when any such land contains shellfish. Shellfish growing areas include land that has been identified and shown on a map published by the Division of Marine Fisheries as a shellfish growing area, including any area identified on such map as an area where shellfishing is prohibited. Shellfish growing areas shall also include land designated by the Department in 314 CMR 4.00 as suitable for shellfish harvesting with or without depuration. In addition, shellfish growing areas shall include shellfish growing areas designated by the local shellfish constable as suitable for shellfishing based on the density of shellfish, the size of the area, and the historical and current importance of the area for recreational and commercial shellfishing.

A list of Outstanding Resource Waters is published in the Surface Water Quality Standards, 314 CMR 4.00[25]. This list includes Class A public water supplies approved by MassDEP and their tributaries, active and inactive reservoirs approved by MassDEP, certain waters within Areas of Critical Environmental Concern, certified vernal pools, and wetlands bordering Class A waters. Wetlands bordering other Class B, SB, or SA ORWs are also Outstanding Resource Waters. Pursuant to the Surface Water Quality Standards, 314 CMR 4.00, MassDEP may designate as Special Resource Waters certain waters of exceptional significance such as waters in national or state parks and wildlife refuges.

Bathing beaches include public and semi-public bathing beaches as defined by the Massachusetts Department of Public Health in 105 CMR 445.000[26]. The Department of Public Health maintains an inventory of public and semi-public bathing beaches.

[24] If an NPDES Construction General Permit or Multi-Sector General Permit is required for a discharge to an ORW, DEP must approve the Stormwater Pollution Prevention Plan (SWPPP).
[25] Surface Water Quality Standards – http://www.mass.gov/dep/service/regulations/314cmr04.pdf
[26] Standards for Bathing Beaches – http://www.mass.gov/Eeohhs2/docs/dph/regs/105cmr445.pdf

Recharge areas for public water supplies are defined in the Drinking Water Regulations, 310 CMR 22.02[27], and include the Zone A for surface water supplies and the Zone II and Interim Wellhead Protection Areas for groundwater supplies. The Zone A means the land area between the surface water source and the upper boundary of the bank, the land area within a 400-foot lateral distance from the upper boundary of the bank of a Class A surface water source as defined in the Surface Water Quality Standards, 314 CMR 4.05(3), and the land area within a 200-foot lateral distance from the upper boundary of the bank of a tributary or associated surface water body. The Zone II means the area of an aquifer that contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated. The Interim Wellhead Protection Area is used for groundwater sources for public water supplies that lack a Zone II that has been approved by MassDEP.

Source control and pollution prevention are particularly important for critical areas. All projects that have the potential to impact critical areas shall implement a source control and pollution prevention program that includes proper management of snow and deicing chemicals. To protect critical areas, road salt must be properly stored within a Zone II or Interim Wellhead Protection Area or near an Outstanding Resource Water, Special Resource Water, shellfish growing area, bathing beach or cold-water fishery. The use of salt for the deicing of impervious surfaces must be minimized within water supply protection areas and any area near an Outstanding Resource Water, Special Resource Water, fresh water beach, or cold-water fishery. The long-term pollution prevention strategies for sites near critical areas must also incorporate designs that allow for shutdown and containment where appropriate to isolate the system in the event of an emergency spill or other unexpected event. Proponents of MassHighway projects may satisfy this requirement by implementing the containment procedures outlined in the Mass Highway Stormwater Handbook[28] .

A stormwater discharge within a Zone II or Interim Wellhead Protection Area or near or to an Outstanding Resource Water, a Special Resource Water, a bathing beach, shellfish growing area, or cold-water fishery requires the use of a treatment train that provides 80% TSS removal prior to discharge. This treatment train must use the structural BMPs determined by MassDEP to be suitable for such areas as set forth in Tables CA 1 through CA 4.[29] With the exception of runoff from a non-metal roof, and runoff from metal roofs located outside the Zone II or Interim Wellhead Protection Area of a public water supply or an industrial site, the treatment train shall provide for at least 44% TSS removal prior to discharge to the infiltration structure. For discharges within a Zone II or Interim Wellhead Protection Area or near or to an Outstanding Resource Water, a Special Resource Water, a shellfish growing area, a bathing beach, or a cold-water fishery, the treatment BMPs must be designed to treat the required water quality volume, a volume equal to one inch times the total impervious surfaces at the post-development site. All BMPs must be designed, constructed, operated and maintained in accordance with the specifications set forth in Volume 2 of the Massachusetts Stormwater Handbook.

[27] Recharge Areas – http://www.mass.gov/dep/water/ccdefreg.pdf
[28] Mass Highway Stormwater Handbook - http://www.mhd.state.ma.us/default.asp?pgid=content/publicationmanuals&sid=about
[29] To make sure that they have the most up-to-date list of these BMPs, proponents should consult the MassDEP web site.

Table CA 1 Standard 6

Stormwater BMPs for Discharges Near or To Shellfish Growing Areas and Bathing Beaches If applicable, proponent must comply with Coastal Wetlands Regulations[30]. All BMPs must be designed in accordance with specifications and sizing methodologies in Volumes 2 and 3 of the Massachusetts Stormwater Handbook. Required Water Quality Volume = 1.0 inch times impervious area. At least 44 % TSS removal must be provided prior to discharge to infiltration BMP. For discharges near or to shellfish growing areas or bathing beaches, proprietary BMPs may be used only for pretreatment, unless verified by TARP or STEP for other uses. For the purpose of this requirement, subsurface structures, even those that have a storage chamber that has been manufactured are not proprietary BMPs, since the pretreatment occurs in the soil below the structure, not in the structure itself.	
Pretreatment:	Deep Sump Catch Basin
	Oil Grit Separators
	Proprietary Separators See Volume 2.
	Sediment Forebays
	Vegetated Filter Strips
Treatment: Sand Filters, Organic Filters, Proprietary Media Filters, Filtering Bioretention Areas, and Wet Basins must be lined and sealed if at least 44% TSS has not been removed prior to discharge to the BMP.	
	Filtering Bioretention Areas including rain gardens
	Constructed Stormwater Wetlands *(highly recommended)*
	Gravel Wetlands
	Proprietary Filter Media (*Proprietary Media Filters may not be used as terminal treatment for discharges near or to critical areas unless they have been verified for such use through the TARP or STEP process. See Volume 2. Proprietary media filters do not include catch basin inserts.)*
	Sand /Organic Filters
	Wet Basins
Infiltration:	
	Exfiltrating Bioretention Areas including rain gardens
	Dry Wells *(runoff from non-metal roofs and runoff from metal roofs located outside of the Zone II or Interim Wellhead Protection Area of a public water supply and outside of an industrial site only.)*
	Infiltration Basins *(highly recommended)*
	Infiltration Trenches *(highly recommended)*
	Subsurface Structures

[30] Coastal Wetlands Regulations – http://www.mass.gov/dep/service/regulations/310cmr10a.pdf#41

Table CA 2: Standard 6

Stormwater Discharges Near or To Outstanding Resource Waters including Vernal Pools and Surface Water Sources for Public Water Systems	
1. Construction Sites of 1 acre or more must file a Notice of Intent (WM 09) with MassDEP requesting approval of the Stormwater Pollution Prevention Plan (SWPPP), if they discharge to an ORW. 2. Stormwater discharges to ORWs must be set back from the receiving water or wetland and receive the highest and best practical method of treatment. 3. Stormwater BMPs must be set back 100' from a certified vernal pool and comply with 310 CMR 10.60[31]. Proponents must perform a habitat evaluation and demonstrate that the stormwater BMPs meet the performance standard of having no adverse impact on the habitat functions of a certified vernal pool. 4. Unless essential to operation of a public water system, stormwater BMPs are prohibited within the Zone A. 5. BMPs must be designed according to the specifications and sizing methodologies in Volumes 2 and 3 of the Massachusetts Stormwater Handbook. 6. Required Water Quality Volume = 1.0 inch times impervious area. 7. At least 44% TSS must be removed prior to discharge to infiltration BMP. 8. For discharges near or to ORWs, proprietary BMPs may be used for pretreatment only unless verified by TARP or STEP for other uses. For the purpose of this requirement, subsurface structures, even those that have a storage chamber that has been manufactured are not proprietary BMPs, since the pretreatment occurs in the soil below the structure, not in the structure itself. See Volume 2.	
Pretreatment BMPS	Deep Sump Catch Basin Oil Grit Separator Proprietary Separators: See Volume 2 Sediment Forebay Vegetated Filter Strip
Treatment BMPs Sand Filters, Organic Filters, Proprietary Media Filters, Filtering Bioretention Areas, and Wet Basins must be lined and sealed unless at least 44% TSS has been removed prior to discharge to the BMP.	Filtering Bioretention areas including rain gardens Constructed Stormwater Wetlands *(do not use near certified vernal pool)* Gravel Wetlands (*do not use near certified vernal pool)* Proprietary Media Filter (*Proprietary Media Filters may not be used for terminal treatment for discharges near or to critical areas, unless the filter has been verified for such use through the TARP or STEP process. See Volume 2. Proprietary Media Filters do not include Catch Basin Inserts.)* Sand /Organic Filters Wet Basins (*do not use near certified vernal pool*)
Infiltration BMPs	Exfiltrating Bioretention areas including rain gardens Dry wells *(runoff from non-metal roofs and runoff from metal roofs located outside the Zone II or Interim Wellhead Protection Area of a public water supply or an industrial site only.)* Infiltration Basins *(highly recommended)* Infiltration Trenches *(highly recommended)* Subsurface Structures

For information on vernal pools, see MassDEP's Wildlife Habitat Guidance: http://www.mass.gov/dep/water/laws/policies.htm#wetlguid

[31] Wildlife Habitat – http://www.mass.gov/dep/service/regulations/310cmr10a.pdf#98

Table CA 3 Standard 6

Stormwater Discharges within Zone Is, Zone IIs and Interim Wellhead Protection Areas	
Unless necessary to manage stormwater from essential drinking water facilities, no stormwater BMPs may be located within the Zone I. Proponents must comply with local source water protection ordinances, bylaws, and regulations. The Drinking Water Regulations, 310 CMR 22.21(2)(b)(7)[32], require the development of land use controls in the Zone II that prohibit land uses that result in rendering 15% or 2500 square feet of a lot impervious, whichever is larger, unless a system of artificial recharge that does not degrade groundwater quality is provided. Developers can comply with these land use controls by designing, constructing, operating and maintaining a stormwater management system in compliance with the Stormwater Management Standards. BMPs must be designed according to the specifications and sizing methodologies in Volumes 2 and 3 of the Massachusetts Stormwater Handbook. Required Water Quality Volume =1.0 inch times impervious area. At least 44% TSS must be removed prior to discharge to the infiltration structure. For discharges within the Zone I, Zone II or IWPA, proprietary BMPs may be used for pretreatment only, unless verified for other uses by TARP or STEP. For the purpose of this requirement, subsurface structures, even those that have a storage chamber that has been manufactured are not proprietary BMPs, since the pretreatment occurs in the soil below the structure, not in the structure itself. See Volume 2.	
Pretreatment BMPS	Deep Sump Catch Basin Oil Grit Separator Proprietary Separators: See Volume 2. Sediment Forebay Vegetated Filter Strip
Treatment BMPs Sand Filters, Organic Filters, Proprietary Media Filters, Filtering Bioretention Areas and Wet Basins must be lined and sealed unless 44% of TSS has been removed prior to discharge to the BMP.	Filtering Bioretention Areas including rain gardens Constructed Stormwater Wetlands Gravel Wetlands Proprietary Filter Media (*Proprietary Media Filter may not be used for terminal treatment for discharges near or to critical areas unless the filter has been verified by the TARP or STEP process. See Volume 2. Proprietary Media Filters do not include Catch Basin Inserts.)* Sand/Organic Filters Wet Basins
Infiltration BMPs	Exfiltrating Bioretention areas Dry wells (*runoff from non-metal roofs and runoff from metal roofs located outside the Interim Wellhead Protection Area or Zone II of a public water supply or an industrial site only)* Infiltration Basins *(highly recommended)* Infiltration Trenches *(highly recommended)* Subsurface Structures

[32] Drinking Water Regulations – http://www.mass.gov/dep/water/ccdefreg.pdf

Best Management Practices for Cold-Water Fisheries.	
All BMPs must be designed in accordance with specifications in Volume 2 of the Massachusetts Stormwater Handbook**.** Required Water Quality Volume = 1.0 times impervious area. At least 44% TSS removal required prior to discharge to infiltration structure. For discharges near or to cold-water fisheries, proprietary BMPs may be used for pretreatment only, unless verified for such other uses by STEP or TARP. For the purpose of this requirement, subsurface structures, even those that have a storage chamber that has been manufactured are not proprietary BMPs, since the pretreatment occurs in the soil below the structure, not in the structure itself. See Volume 2.	
Pretreatment:	Deep Sump Catch Basins
	Oil Grit Separator
	Proprietary Separators: See Volume 2
	Sediment Forebays
	Vegetated Filter Strips
Treatment: Sand Filters, Organic Filters, Proprietary Media Filters. Water Quality Swales, Grass Channels, and Filtering Bioretention Areas must be lined and sealed unless at least 44% TSS has been removed prior to discharge to the BMP.	Filtering Bioretention Areas including rain gardens with linings
	Dry Water Quality Swales
	Grass Channels
	Leaching Catch Basins
	Proprietary Media Filter (*Proprietary Media Filter may not be used for terminal treatment for discharges of stormwater runoff near or to a critical area unless verified through the TARP or STEP process. See Volume 2. Proprietary Media Filters do not include catch basin inserts).*
	Sand/Organic Filters
	Wet Water Quality Swales
Infiltration:	Infiltration Trenches
	Infiltration Basins
	Subsurface Structures
	Exfiltrating Bioretention Area including rain gardens
	Dry Wells *(runoff from non metal roofs and runoff from metal roofs located outside the Zone II or Interim Wellhead Protection Area of a public water supply or an industrial site only)*

Standard 7: A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural stormwater best management practice requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

For purposes of the Stormwater Management Standards, redevelopment projects are defined to include the following:

1. Maintenance and improvement of existing roadways, including widening less than a single lane, adding shoulders, correcting substandard intersections, improving existing drainage systems, and repaving;
2. Development, rehabilitation, expansion and phased projects on previously developed sites, provided the redevelopment results in no net increase in impervious area; and

3. Remedial projects specifically designed to provide improved stormwater management, such as projects to separate storm drains and sanitary sewers and stormwater retrofit projects.

All redevelopment projects must fully comply with the provisions of the Stormwater Management Standards requiring the development and implementation of a construction period erosion and sedimentation control plan, a pollution prevention plan, an operation and maintenance plan, and the prohibition of illicit discharges. All redevelopment projects are also required to meet the following Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural stormwater best management practice requirements of Standards 4, 5, and 6[33] and improve existing conditions. Existing stormwater discharges are also required to comply with Standard 1 only to the maximum extent practicable.

For purpose of Standard 7, "To the maximum extent practicable" means that:

(1) Proponents of redevelopment projects have made all reasonable efforts to meet the applicable Standard;
(2) They have made a complete evaluation of possible stormwater management measures including environmentally sensitive site design that minimizes land disturbance and impervious surfaces, low impact development techniques, and stormwater BMPs; and,
(3) If not in full compliance with the applicable Standard, they are implementing the highest practicable level of stormwater management.

Generally, an alternative is practicable if it can be implemented within the site being redeveloped, taking into consideration cost, land area requirements, soils, and other site constraints. However, offsite alternatives may also be practicable. For example, pursuing an easement for locating stormwater controls on an adjacent lot where adequate capacity exists or can be provided may be a practicable alternative. Economic factors must be weighed as redevelopment projects attempt to meet the standards. The scope and effort to be undertaken to meet the standards should reflect the scale and impacts of the proposed project and the classification and sensitivity of the affected wetlands and water resources.

As stated earlier, all redevelopment projects must improve existing conditions. New stormwater controls (retrofitted or expanded) must be incorporated into the design and result in a reduction in annual stormwater pollutant loads from the site. Proponents of redevelopment projects shall make full use of all opportunities for controlling the sources of pollution and to incorporate environmentally sensitive site design and low impact development techniques. This is particularly important for constrained redevelopment sites where it is not possible to install BMPs that treat the entire water quality volume (i.e. 0.5 inch or 1.0 inch rule). All redevelopment projects shall also incorporate measures that will address water quantity issues by reducing the peak and total runoff from the site and by increasing recharge. Actions to improve existing conditions should be geared to addressing known water quality and water quantity problems such as documented failures to meet the Surface Water Quality Standards, low stream flow, or repeated flood events.

Volume 2 Chapter 3 contains a redevelopment checklist that both the issuing authority and the applicant can use to determinine whether the stormwater management system for a redevelopment project has been designed in accordance with all the requirements of Standard 7. For MassHighway projects involving less than a single lane, the Storm Water Handbook for Highway and Bridges may be used in lieu of the redevelopment checklist.

The portion of a property that is currently undeveloped is not a redevelopment and thus does not fall under Standard 7. To the extent a project includes development of previously undeveloped areas, the

[33] The maximum extent practicable standard applies to the 80% TSS removal requirement of Standards 4 through 6. For redevelopment projects, stormwater management system must be designed to remove 80% of TSS only to the maximum extent practicable. The maximum extent practicable standard also applies to redevelopment projects with existing stormwater discharges to Zone Is, Zone As, Outstanding Resource Waters, and Special Resource Waters subject to Standard 6.

project must comply fully with all the Stormwater Management Standards. The following example demonstrates how the Stormwater Management Standards apply to a site that includes both new development and redevelopment.

Suppose a 5-acre site with 2 acres of impervious surfaces including parking, a warehouse, and manufacturing plant, will be redeveloped into a mixed-use development with 3 acres of impervious surfaces. A pollution prevention plan, an erosion and sedimentation control plan and a long-term operation and maintenance plan must be prepared for the entire site in accordance with the applicable provisions of Standards 4 through 6, 8, and 9. All illicit discharges to the stormwater system must be eliminated in accordance with Standard 10. Because there is an additional acre of impervious surface, stormwater runoff from at least one acre of impervious surface must be directed to stormwater best management practices that are designed and constructed in accordance with all the Stormwater Management Standards. The remaining two acres of impervious surfaces included in the project may be treated as a redevelopment. Runoff from that portion of the project may be directed to structural stormwater best management practices that are designed and constructed to meet Standards 2 through 6 only to the maximum extent practicable. New stormwater outfalls must be designed in compliance with Standard 1. Existing outfalls are required to comply with Standard 1 only to the maximum extent practicable. The stormwater management system must also improve existing conditions. Because the site is located in a watershed where surface waters often experience low flow, the proponent can fulfill the requirement to improve existing conditions by maximizing opportunities for infiltration and by minimizing water use by installing a rain barrel or cistern.

Standard 8: A plan to control construction-related impacts, including erosion, sedimentation, and other pollutant sources during construction and land disturbance activities (construction period erosion, sedimentation, and pollution prevention plan) shall be developed and implemented.

During land disturbance and construction activities, project proponents must implement controls that prevent erosion, control sediment movement, and stabilize exposed soils to prevent pollutants from moving offsite or entering wetlands or waters. Land disturbance activities include demolition, construction, clearing, excavation, grading, filling, and reconstruction.

For all projects subject to Wetlands jurisdiction, a construction period erosion, sedimentation, and pollution prevention plan that identifies the party or parties responsible for implementing the plan or any components thereof must be submitted.[34] The Order of Conditions should require the responsible party or parties to implement the plan as approved by the Conservation Commission, until the site is fully stabilized and the temporary erosion and sedimentation controls are removed.

Projects that disturb one acre of land or more are required to obtain coverage under the NPDES Construction General Permit issued by EPA and prepare a Stormwater Pollution Plan (SWPPP)[35]. To avoid duplication of effort, a project proponent can prepare a single document that satisfies the SWPPP requirements of the Construction General Permit and the construction period erosion, sedimentation and pollution prevention plan requirements of Standard 8. For all projects that are required to obtain coverage under the Construction General Permit, the issuing authority shall require submission of the SWPPP before land disturbance commences. If the proponent is not using the SWPPP as its construction period erosion,

[34] For projects subject to jurisdiction under the Wetlands Protection Act, the construction period pollution prevention and erosion and sedimentation control plan should ordinarily be included in the Stormwater Report submitted with the Notice of Intent. For highly complex projects, where the proponent demonstrates that submission with the Notice of Intent is not possible, the issuing authority has the discretion to issue an Order of Conditions authorizing a project prior to submission of the construction period pollution prevention and erosion and sedimentation control plan. However, any such Order must provide that no work including site preparation and land disturbance may commence unless and until a construction period pollution prevention and erosion and sedimentation control plan that meets the requirements of Standard 8 as further elaborated by the Massachusetts Stormwater Handbook has been approved by the issuing authority.

[35] EPA NPDES – http://cfpub.epa.gov/npdes/stormwater/cgp.cfm

sedimentation and pollution prevention plan, the issuing authority shall require implementation of any measures in the SWPPP that were not included in the plan.

The construction period erosion, sedimentation and pollution prevention plan must identify all stormwater management activities that are needed during land disturbance and construction, including source control and pollution prevention measures, BMPs to address erosion and sedimentation, stabilization measures, and procedures for operating and maintaining the BMPs, especially in response to wet weather events and frost. The plan shall include a schedule for sequencing construction and stormwater management activities that minimizes land disturbance by ensuring that vegetation is preserved to the extent practicable, and disturbed portions of the site are stabilized as quickly as possible.

The BMPs used during construction must be different from the BMPs that will be used to handle stormwater after construction is completed and the site is stabilized. Many stormwater technologies (infiltration technologies) are not designed to handle the high concentrations of sediments typically found in construction runoff, and thus must be protected from construction-related sediment loadings.

All construction period BMPs must be properly designed, and sediment traps must be sized to provide adequate capacity and retention time to allow for proper settling of fine-grained soils. Construction period BMPs must be properly operated and maintained. For more information on erosion and sediment control, see Volume 2 of the Massachusetts Stormwater Handbook and the Nonpoint Source Manual, and the Erosion and Sedimentation Control Guidelines: A Guide for Planners, Designers and Municipal Officials[36,37].

Standard 9: A Long -Term Operation and Maintenance (O&M) Plan shall be developed and implemented to ensure that stormwater management systems function as designed.

The Long-Term Operation and Maintenance Plan shall at a minimum include:

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

The Operation and Maintenance Plan shall identify best management practices for implementing maintenance activities in a manner that minimizes impacts to wetland resource areas.[38]

For projects subject to jurisdiction under the Wetlands Protection Act, the Conservation Commission and MassDEP will take the actions set forth below to ensure compliance with Standard 9. Unless and until another party accepts responsibility, the Conservation Commission and MassDEP shall presume that the

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[36] MA Erosion & Sedimentation Control Guidelines - http://mass.gov/dep/water/esfull.pdf

[37] Nonpoint Source Manual (formally known as the MegaManual): http://projects.geosyntec.com/NPSManual/

[38] Some proponents may have developed an operation and maintenance plan for stormwater BMPs to meet the requirements of the National Pollutant Discharge System Elimination System (NPDES) Multi-Sector General Permit or the NPDES General Permit for Municipal Separate Storm Sewer Systems (MS4 Permit). To avoid duplication of effort, proponents may be able to prepare one plan for the operation and maintenance of stormwater BMPs that fulfills the requirements of Standard 8 and the applicable NPDES general stormwater permit. The Operation and Maintenance Plan must be included in the Stormwater Report. See Volume 3.

owner of the BMP is the landowner of the property on which the BMP is located, unless there is a legally binding agreement with another entity that accepts responsibility for the operation and maintenance. If an applicant envisions that the municipality may accept responsibility for the operation and maintenance of a stormwater BMP, the applicant shall notify the Conservation Commission and make available to the municipal official responsible for stormwater management the design and operation and maintenance plan for the BMP in order that the municipal official may have an opportunity to review and provide comments to the Conservation Commission within a reasonable period of time prior to the issuance of the Final Order of Conditions. It is recommended that the Conservation Commission solicit comments from the responsible municipal official.

To ensure compliance with Standard 9, the Order of Conditions should include the continuing conditions set forth below.

(1) All stormwater BMPs shall be operated and maintained in accordance with the design plans and the Operation and Maintenance Plan approved by the issuing authority.

(2) The responsible party shall:

- (a) maintain an operation and maintenance log[39] for the last three years, including inspections, repairs, replacement and disposal (for disposal, the log shall indicate the type of material and the disposal location);
- (b) make this log available to MassDEP and the Conservation Commission upon request; and
- (c) allow members and agents of the MassDEP and the Conservation Commission to enter and inspect the premises to evaluate and ensure that the responsibility party complies with the Operation and Maintenance Plan requirements for each BMP.

These same continuing conditions should be included in the Certificate of Compliance.

The Order of Conditions should also include a condition requiring the responsible party to submit an O & M Compliance statement when requesting a Certificate of Compliance. The O & M Compliance Statement shall identify the party responsible for implementation of the Operation and Maintenance Plan and state that:

- a. the site has been inspected for erosion and appropriate steps have been taken to permanently stabilize any eroded areas;
- b. all aspects of the stormwater BMPs have been inspected for damage, wear and malfunction, and appropriate steps have been taken to repair or replace the system or portions of the system so that the stormwater at the site may be managed in accordance with the Stormwater Management Standards;
- c. future responsible parties must be notified of their continuing legal responsibility to operate and maintain the structure; and
- d. the Operation and Maintenance Plan for the stormwater BMPs is being implemented.

In the case of stormwater BMPs that are serving more than one lot, the applicant shall include with the Notice of Intent a mechanism for implementing and enforcing the Operation and Maintenance Plan. The applicant shall identify the lots or units that will be serviced by the proposed stormwater BMPs. The applicant shall also provide a copy of the legal instrument (deed, homeowner's association, utility trust or other legal entity) that establishes the terms of and legal responsibility for the operation and maintenance of stormwater BMPs. In the event that the stormwater BMPs will be operated and maintained by an entity, municipality, state agency or person other than the sole owner of the lot upon which the stormwater management facilities are placed, the applicant shall provide a plan and easement deed that provides a right of access for the legal entity to be able to perform said operation and maintenance functions. It is recommended that the Order of Conditions include a condition requiring that the responsible party provide a copy of the Order of Conditions and the legal instrument to each unit or lot owner at or before the

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[39] This is a rolling log in which the responsible party records all operation and maintenance activities for the past three years.

purchase of each unit or lot to be serviced by the stormwater BMPs. When requesting the issuance of a Certificate of Compliance, the applicant shall identify to the Conservation Commission or MassDEP in writing the entity with legal responsibility for the operation and maintenance of the stormwater BMPs and provide a copy of the recorded instrument creating the responsible entity.

Prior to issuing a Certificate of Compliance, the Conservation Commission or MassDEP should inspect the site to determine whether the Stormwater BMPs are operating as designed so that the stormwater at the site may be managed in accordance with the Stormwater Management Standards. In conducting the inspection, the Conservation Commission or MassDEP should look for indicia that the stormwater BMPs are not functioning as designed. Evidence of problems with stormwater BMPs may include without limitation sand plumes at outfalls, excessive sands in catch basins, oil sheens, stressed vegetation, accumulated litter, and/or failure of the BMP to drain after 72 hours. No Certificate of Compliance should be issued unless and until the stormwater BMPs are functioning in accordance with the Final Order of Conditions and the Stormwater Management Standards.

Standard 10: All illicit discharges to the stormwater management system are prohibited.

Standard 10 prohibits illicit discharges to stormwater management systems. The stormwater management system is the system for conveying, treating, and infiltrating stormwater on-site, including stormwater best management practices and any pipes intended to transport stormwater to the groundwater, a surface water, or municipal separate storm sewer system. Illicit discharges to the stormwater management system are discharges that are not entirely comprised of stormwater. Notwithstanding the foregoing, an illicit discharge does not include discharges from the following activities or facilities: firefighting, water line flushing, landscape irrigation, uncontaminated groundwater, potable water sources, foundation drains, air conditioning condensation, footing drains, individual resident car washing, flows from riparian habitats and wetlands, dechlorinated water from swimming pools, water used for street washing and water used to clean residential buildings without detergents.

Proponents of projects within Wetlands jurisdiction must demonstrate compliance with this requirement by submitting to the issuing authority an Illicit Discharge Compliance Statement verifying that no illicit discharges exist on the site and by including in the pollution prevention plan measures to prevent illicit discharges to the stormwater management system, including wastewater discharges and discharges of stormwater contaminated by contact with process wastes, raw materials, toxic pollutants, hazardous substances, oil, or grease. The Illicit Discharge Compliance Statement may be filed with the Notice of Intent. If the Illicit Discharge Compliance Statement has not been filed, the Final Order of Conditions shall require the submission of an Illicit Discharge Compliance Statement prior to the discharge of stormwater runoff to the post-construction stormwater best management practices. The issuing authority should not issue a Certificate of Compliance until it has determined that the Illicit Discharge Compliance Statement has been submitted, has reviewed the Illicit Discharge Compliance Statement, and has verified that there are no illicit discharges at the site.

The Illicit Discharge Compliance Statement must be accompanied by a site map that is drawn to scale and that identifies the location of any systems for conveying stormwater on the site and shows that these systems do not allow the entry of any illicit discharges into the stormwater management system. The site map shall identify the location of any systems for conveying wastewater and/or groundwater on the site and show that there are no connections between the stormwater and wastewater management systems and the location of any measures taken to prevent the entry of illicit discharges into the stormwater management system. For redevelopment projects, the Illicit Discharge Compliance Statement shall also document all actions taken to identify and remove illicit discharges, including, without limitation, visual screening, dye or smoke testing, and the removal of any sources of illicit discharges to the stormwater management system.

Many municipal and state agencies that own and operate roadways are also subject to coverage under the NPDES General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (the MS4 Permit). State agencies and municipalities covered by the MS4 Permit are required to have a stormwater management program that includes illicit discharge detection and elimination. For roadways covered by the MS4 Permit, the proponent may demonstrate compliance with Standard 10 by documenting the actions taken to identify and eliminate illicit discharges under the MS4 Permit. To prevent duplication of effort, the proponent may submit copies of reports prepared to satisfy the illicit discharge detection and elimination program requirements of the MS4 Permits as its Illicit Discharge Compliance Statement.

Legal Framework for Stormwater Management

In 1996, MassDEP issued the Stormwater Policy that established the Stormwater Management Standards. Since that time, MassDEP has applied the Stormwater Management Standards pursuant to its authority under the Massachusetts Clean Waters Act, M.G.L.c. 21, §§ 26-53, and the Wetlands Protection Act, M.G.L .c. 131, § 40. In accordance with the Wetlands Regulations, 310 CMR 10.05(6)(b), Conservation Commissions and MassDEP issue Final Orders of Conditions that require that stormwater be managed in accordance with the Stormwater Management Standards. Pursuant to the Massachusetts Clean Waters Act and 314 CMR 9.06, MassDEP also applies the Stormwater Management Standards when reviewing projects that require a Water Quality Certification. MassDEP has incorporated the Stormwater Management Standards into the Wetlands Protection Act Regulations, 310 CMR 10.05(6)(b)(1)(a), and the Water Quality Certification Regulations, 314 CMR 9.06(1)(a).

MassDEP continues to apply the Stormwater Management Standards pursuant to its authority under the Massachusetts Clean Waters Act. Acting jointly with the EPA, MassDEP issues general permits regulating certain municipal separate storm sewer systems and construction dewatering. Through the State's Water Quality Certification, the general permit for municipal separate storm sewer systems (the MS4 Permit) requires compliance with the Stormwater Management Standards.[1]

Pursuant to the Massachusetts Clean Waters Act and the regulations promulgated thereunder at 314 CMR 3.04 and 314 CMR 5.04, MassDEP has authority to require that certain existing stormwater discharges obtain a permit. More specifically, MassDEP may require an existing stormwater discharge to obtain a permit under the Clean Waters Act if it determines that the discharge is contaminated with process wastes, raw materials, toxic pollutants, hazardous substances, or oil and grease. MassDEP may also determine that a stormwater discharge that does not comply with the Stormwater Management Standards is a significant contributor of pollutants to the waters of the Commonwealth and thus requires a permit.

Stormwater Management and the Wetlands Protection Act Regulations

The Wetlands Protection Act establishes a public review and permitting process to protect wetland resources and further the interests identified in the Act. These interests are as follows:

[1] See 314 CMR 3.00. At the time of the publication of this handbook, the MS4 permit currently in effect is due to expire in 2008. When a new permit is issued, there will be a new water quality certification. EPA has also issued other NPDES general stormwater permits: a general permit for construction sites that disturb one acre or more of land, the Construction General Permit, and a general permit for certain industrial activities, the Multi-Sector General Permit. The Construction General Permit is due to expire in 2008 and the Multi-Sector General Permit has been administratively continued after expiring in 2005. For the latest information on all the NPDES stormwater permits, see http://cfpub1.epa.gov/npdes/home.cfm?program_id=6 and http://www.epa.gov/region1/topics/water/stormwater.html.

- Protection of public and private water supply;
- Protection of groundwater supply;
- Flood control;
- Storm damage prevention;
- Pollution prevention;
- Protection of fisheries;
- Protection of land containing shellfish; and,
- Protection of wildlife habitat.

If not properly managed and treated, stormwater discharges to areas subject to jurisdiction under the Act have the potential to impair some or all of these interests. To address this potential impairment, the Wetlands Regulations, 310 CMR 10.05(6)(k), provide that except as expressly provided therein, all industrial, commercial, institutional, office, residential and transportation projects, including site preparation, construction, and redevelopment in an Area Subject to Protection under the Act or the Buffer Zone, and all point source stormwater discharges from said projects within an Area Subject to Protection Under the Act and the Buffer Zone, shall be managed according to the Stormwater Management Standards. The exceptions are set forth in 310 CMR 10.05(6)(l) and (m). For information on the exceptions, see Chapter 1, pp. 2-3.

Proponents are not allowed to alter wetland resource areas to comply with the Stormwater Management Standards. Thus, the Wetland Regulations, 310 CMR 10.05(6)(k), expressly provide that stormwater best management practices may not be constructed in a wetland resource area other than isolated land subject to flooding, bordering land subject to flooding, riverfront area, or land subject to coastal storm flowage.

Point Source Discharges

A point source discharge is a discernible, confined and discrete conveyance of pollutants as opposed to a diffuse non-point source of pollution, which generally involves overland flow. Because a direct point source discharge may result in wetland alterations by changing drainage characteristics, sedimentation patterns, flood storage areas, and water temperature, thereby affecting the physical, chemical or biological characteristics of the receiving waters, the Wetlands Regulations, 310 CMR 10.05(6)(b)(1), require that all Final Orders of Conditions regulate the quality and quantity of point source stormwater discharges.

The Wetland Regulations, 310 CMR 10.03(4), provide that if the Department has issued a surface water discharge permit in conjunction with a National Pollutant Discharge Elimination System Permit (NPDES) for a point source discharge of pollutants, the effluent limits set forth in that permit shall be presumed to protect the interests identified in the Wetlands Protection Act. The Wetlands Regulations, 310 CMR 10.03(4), further provide that this presumption may be rebutted by creditable evidence. The purpose of the rebuttable presumption is to avoid subjecting a point source discharge to possibly conflicting requirements under the Clean Waters Act, M.G.L. c. 21, §§ 26-53, and the Wetlands Protection Act, M.G.L. c. 131 § 40.

When 310 CMR 10.03(4) took effect, the presumption applied only to NPDES permits that established specific numerical effluent limits for discharges from wastewater treatment facilities. At that time, there were no NPDES permits for stormwater discharges. As more fully detailed below, there are now many NPDES permits for stormwater discharges, including individual permits as well as general permits such as the Construction General Permit, the Multi-Sector General Permit, and the general permit for Municipal Separate Storm Sewer Systems (the MS4 Permit). The vast majority of the NPDES general stormwater permits do not establish specific numerical effluent limits. An NPDES Permit that does not establish such limits should not be presumed to protect the interests of the Wetlands Protection Act in place of the one specific numerical effluent limit established by the Stormwater Management Standards, the 80% TSS removal standard set forth in Standard 4.

Moreover, there is little chance for conflicts between the requirements of the NPDES general stormwater permits and the Stormwater Management Standards. Through the state's water quality certification, the Construction General Permit requires compliance with the Stormwater Management Standards. New development and redevelopment of industrial sites that are required to obtain coverage under the Multi-Sector General Permit are also required to comply with the Stormwater Management Standards through the State's Water Quality Certification. Like other development or redevelopment projects, projects covered by a general NPDES general stormwater permit must comply with the Stormwater Management Standards.

Erosion and Sedimentation Control

The Wetlands Regulations also recognize that stormwater discharges may adversely impact wetland resource areas during construction. To prevent this impact, the Wetlands Regulations, 310 CMR 10.05(6)(b)(1), provide that the Order of Conditions shall impose conditions to control erosion and sedimentation within resource areas and the Buffer Zone. Erosion and sedimentation control is required, even if the project is a single-family house that is exempt from the requirement to comply with the Stormwater Management Standards. For projects subject to the Stormwater Management Standards, Standard 8, set forth in the Wetlands Regulations at 310 CMR 10.06(6)(k)(8), requires the development and implementation of a construction-period erosion, sedimentation and pollution prevention plan.

Wetland Resource Areas and Buffer Zones

The Wetlands Regulations, 310 CMR 10.02, define Areas Subject to Protection under the Act (Wetland Resource Areas) to include the following:

- Coastal wetland areas, i.e. coastal banks, coastal beaches, coastal dunes, land under the ocean, designated port areas, barrier beaches, rocky intertidal shores, land under salt ponds, land containing shellfish, land subject to coastal storm flowage, and salt marsh; and

- Inland wetland resource areas, i.e. bordering vegetated wetlands (wet meadows, marsh, swamp or bog bordering any creek, river, stream, pond or lake), bank, land under water, land subject to flooding, and the riverfront area.

The Wetlands Regulations, 310 CMR 10.02(2), further define the Buffer Zone to mean the area within 100 feet of certain Wetland Resource Areas. The Wetland Resource Areas that have a Buffer Zone are:

Any bank		the ocean
any freshwater wetland		any estuary
any coastal wetland		any creek
any beach		any river
any dune	*BORDERING ON*	any stream
any flat		any pond
any pond		or any lake
any marsh		
or any swamp		

Stormwater Discharges Outside Wetland Resource Areas

In some cases, a stormwater discharge to Wetland Resource Areas may originate outside any Wetland Resource Area and outside the Buffer Zone. Consistent with 310 CMR 10.05(6)(b)(1), local conservation commissions and MassDEP have the authority to impose conditions on the quality and quantity of the discharge even though it comes from a source that is located outside wetlands jurisdiction. In light of this authority, the Final Order of Conditions should require that the stormwater be managed so that when the stormwater is discharged within the Wetland Resource Area or Buffer Zone, it complies with the Stormwater Management Standards. Moreover, the Final Order of Conditions should include this requirement, even if the project proponent has to install additional stormwater BMPs in an area outside Wetlands jurisdiction.

For example, a developer proposes to locate an overflow discharge pipe within the Buffer Zone from an extended dry detention basin that is installed outside the Buffer Zone. Although the issuing authority cannot regulate the extended dry detention basin, the Final Order of Conditions should require that the Stormwater Management Standards be met at the point of discharge, since the overflow pipe is located within jurisdiction. To ensure that the discharge can meet this requirement, the developer should design the extended dry detention basin in accordance with the specifications and procedures set forth in Volumes 2 and 3 of the Stormwater Management Handbook, and the issuing authority should request information about the design of the extended dry detention basin during the permitting process.

Regulatory Requirements After the Fact

As stated earlier, jurisdiction under the Wetlands Protection Act does not extend beyond Wetland Resource Areas and the Buffer Zone. The situation changes if an activity occurring outside jurisdiction results in the alteration of a Wetland Resource Area. In that event, the activity may be regulated after the fact. The Wetlands Regulations, 310 CMR 10.02(2)(d) and 310 CMR 10.05(6)(b)(1), provide that if the issuing authority determines that an activity outside the Areas Subject to Protection Under MGL c. 131, sec. 40 and outside the Buffer Zone, has in fact altered an Area Subject to Protection Under MGL c. 131, sec. 40, it may require the filing of a Notice of Intent, issue an Enforcement Order, or include in an Order of Conditions any conditions that are necessary to protect the interests of the Act. If the issuing authority exercises after-the-fact jurisdiction, it may be extremely costly to a developer, since s/he may have to redesign the project to accommodate stormwater BMPs.

For example, a conservation commission or MassDEP does not have jurisdiction over a stormwater discharge pipe located 105 feet from a bordering vegetated wetland or 205 feet from a perennial stream. Given this location, it is likely that the first heavy rainstorm will erode the channel and alter the wetland resource area. To avoid the additional costs that may arise from being subject to after-the-fact jurisdiction, a prudent developer should be proactive and implement stormwater management practices to prevent any unauthorized wetland alterations.

Issuing authorities also have authority to regulate activities outside Wetlands jurisdiction, when additional stormwater is routed through an existing outfall pipe and results in an alteration of a wetland resource area. Project proponents and municipal officials should work together to ensure adequate pretreatment prior to discharge to the municipal storm drain system. Municipal separate storm drain systems covered by the MS4 permit can ensure such pretreatment by establishing and implementing adequate post construction stormwater controls as required by that permit.

Conversion of Impervious Surfaces to Pervious Surfaces

The Wetlands Regulations, 310 CMR 10.02(1)(f), exempt from regulation under the Act the conversion of impervious to vegetated surfaces in the Buffer Zone and the Riverfront Area, provided erosion and sedimentation controls are implemented during construction and the work does not take place in a wetland resource area other than the Riverfront Area. Through this exemption, the Wetlands Regulations make it easy for property owners to decrease impervious surfaces.

Operation and Maintenance of Stormwater Management Systems

The Wetlands Regulations, 310 CMR 10.02(3), provide that a bordering vegetated wetland, land under water, land subject to flooding, or riverfront area created for stormwater management purposes may be maintained without the filing of a Notice of

Intent, provided the work is limited to the maintenance of the system and conforms to an Order of Conditions issued after 1983. The Wetlands Regulations, 310 CMR 10.02(3), have been revised to provide that all stormwater management systems designed and constructed after November 18, 1996, the effective date of the Stormwater Management Standards, may be maintained without the filing of a Notice of Intent. This exemption from filing a Notice of Intent applies to subsurface structures or leaching catch basins within a Wetland Resource Area or Buffer Zone and water quality swales or bioretention areas constructed in an area outside Wetlands jurisdiction for which no Order of Conditions has been issued, provided the stormwater management system was designed and constructed in accordance with the Stormwater Management Standards. If the system was constructed in a wetland resource area or associated Buffer Zone, this exemption applies only if the system was constructed in accordance with all applicable provisions of the Wetlands Regulations.

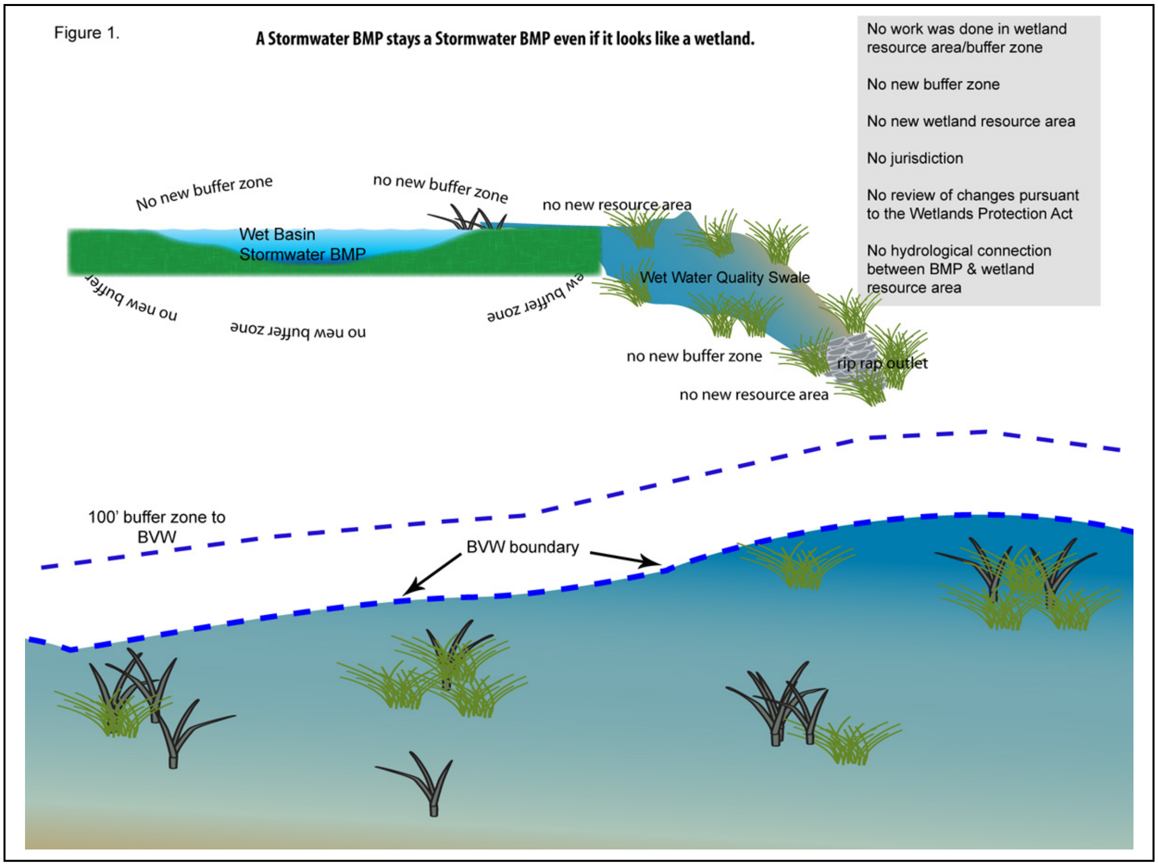
To qualify for this provision, the work must be limited to maintenance and best practical measures must be used to avoid and minimize impacts to wetland resource areas outside the footprint of the stormwater management system. Best practical measures are technologies, designs, measures or engineering practices that are in general use to protect similar interests. Work done in accordance with an Operation and Maintenance Plan qualifies for this exemption, provided the plan requires implementation of best practical measures to minimize wetland impacts during maintenance. In the absence of an Operation and Maintenance Plan, the party responsible for maintenance may file a Request for Determination of Applicability requesting the issuing authority to determine whether the proposed maintenance activities fall within the exemption.

Jurisdiction Over Stormwater Management Systems

To encourage increased use of low impact development techniques that rely on above-ground stormwater BMPs that mimic natural hydrologic conditions, the Wetlands Regulations, 310 CMR 10.02(2)(d), have been modified to provide that the installation of stormwater management systems designed and constructed on or after January 2, 2008 in accordance with the Stormwater Management Standards do not create any additional Wetland Resource Area or Buffer Zone. The Wetland Regulations, 310 CMR 10.02(4), further provide that review of future modifications to any such systems located within a wetland resource area or Buffer Zone shall be limited to the stormwater functions of the system, compliance with the Stormwater Management Standards, and those performance standards that would apply in the absence of the stormwater management system.

For example, a stormwater management system that includes a water quality swale, an infiltration basin, and a riprap outlet is designed and constructed in accordance with the Stormwater Management Standards on or after January 2, 2008 in a portion of the site that is outside any wetland resource area and outside the Buffer Zone. No additional wetland resource area or Buffer Zone is created solely as a result of the installation of the stormwater management system. Ten years later, the project proponent proposes to fill in the infiltration basin and replace it with a subsurface structure also located outside a wetland resource area or Buffer Zone. The project proponent can fill in the infiltration basin and replace it with a subsurface structure without filing a Notice of Intent, Notice or

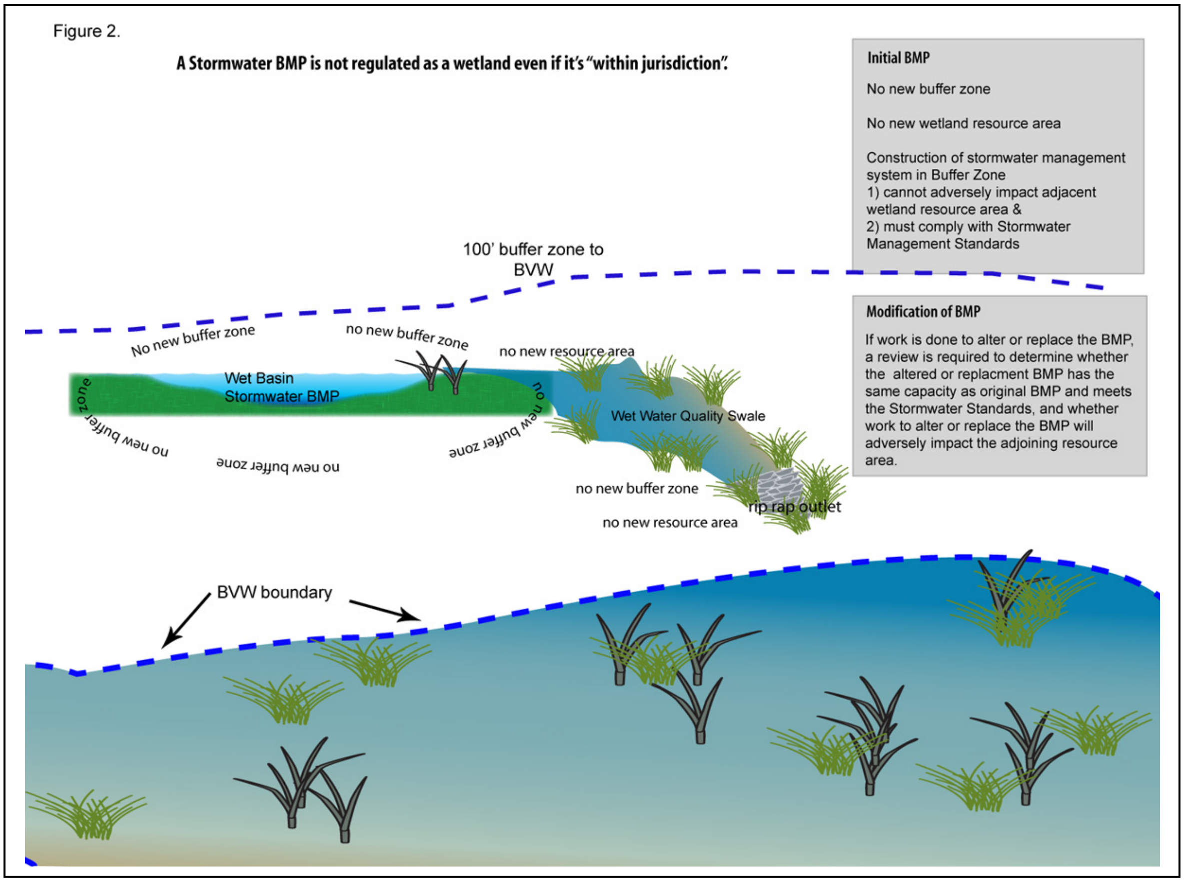
Resource Area Delineation or Request for Determination of Applicability, since both the infiltration basin and the subsurface structure are located in upland. See Figure 1.



Alternatively, suppose the entire stormwater management system, including the water quality swale, infiltration basin, and riprap outlet, is constructed for stormwater management purposes in the Buffer Zone in accordance with the Stormwater Management Standards on or after January 2, 2008. As with the earlier example, no additional wetland resource area or Buffer Zone is created solely as a result of the installation of the stormwater management system. See Figure 2.

Ten years later, the project proponent proposes to fill in the infiltration basin and replace it with a subsurface structure outside a wetland resource area or Buffer Zone. The project proponent is required to file a Notice of Intent, Notice of Order for Resource Area Delineation, or Request for Determination of Applicability, since the original stormwater management system is located in the Buffer Zone. As part of this filing, the project proponent has to show that the water quality swale, infiltration basin and riprap outlet are components of a stormwater management system constructed in the Buffer Zone on or after January 2, 2008, in accordance with the Stormwater Management Standards.

Figure 2.



In this case, it should be easy for the proponent to meet this burden by submitting the Order of Conditions permitting the installation of the original stormwater management system and the plans referenced therein[2]. The Conservation Commission would then review the proposed change to determine whether (a) the replacement system provides the same design capacity as the initial system to attenuate the peak discharge rate, recharge the groundwater and remove total suspended solids; (b) the replacement system complies with the Stormwater Management Standards to the extent they are applicable including, without limitation, Standard 8 - the erosion and sedimentation control standard; and (c) whether the alteration of the system located in the Buffer Zone adversely affects the adjacent wetland resource area.

Additionally, suppose a proponent designs and constructs, in accordance with the Stormwater Management Standards on or after January 2, 2008, a stormwater management system that includes a water quality swale, infiltration basin, and riprap outlet located on a portion of the site that is outside a wetland resource area and outside the Buffer Zone.   The construction of the infiltration basin and water quality swale does

[2] A continuing condition providing that the stormwater management system may not be changed without the approval of the issuing authority must be included in the Order of Conditions and Certificate of Compliance.

not by itself create any additional wetland resource area or Buffer Zone subject to regulation under the Wetlands Protection Act. Over time, however, the wetland resource area expands, moving the wetland boundary and the boundary of the Buffer Zone. The entire wetland resource area, including the expansion, is an Area Subject to Protection Under M.G.L .c. 131, § 40, and any work in that area and associated Buffer Zone requires the Filing of a Notice of Intent, Request for Determination of Applicability, or Notice of Resource Area Delineation. See Figure 3

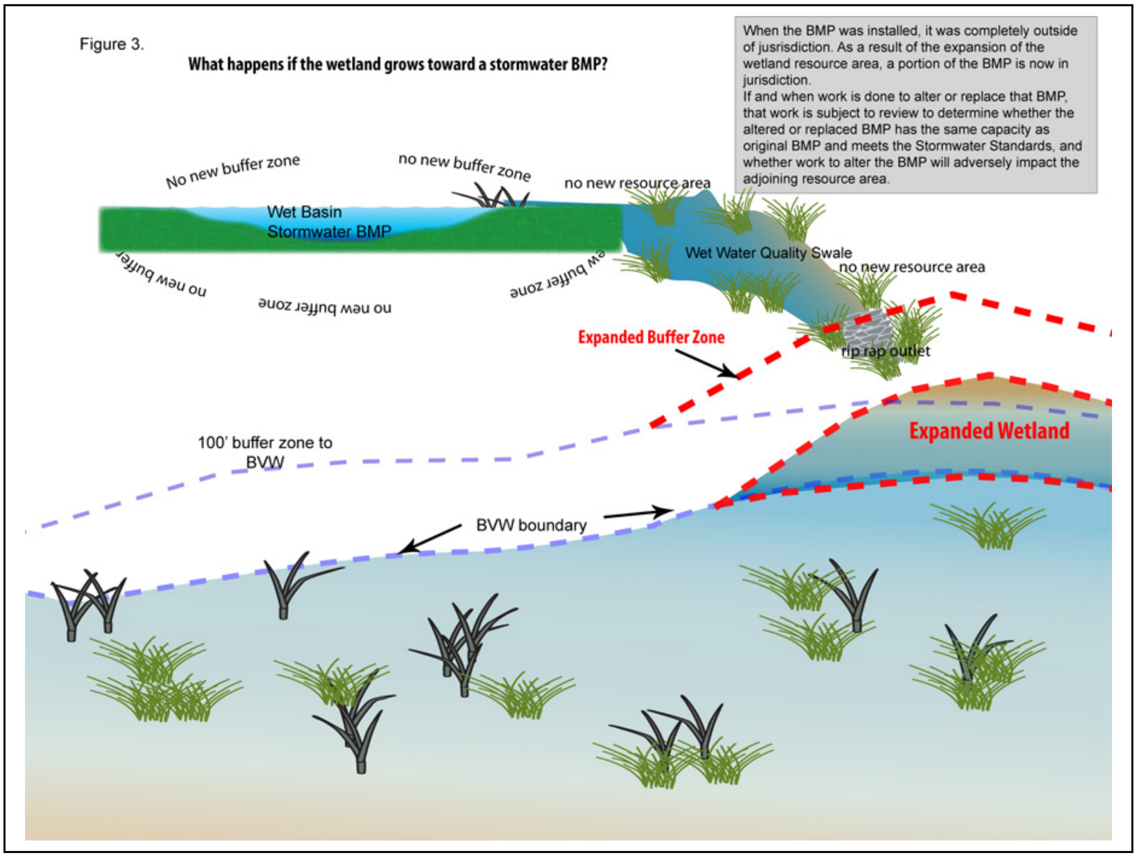


Figure 3.
What happens if the wetland grows toward a stormwater BMP?

Ten years later, the proponent proposes to fill in the water quality swale, infiltration basin, and riprap outlet, and replace it with a vegetated filter strip, subsurface structure, and riprap outlet, all located outside the boundaries of the expanded wetland resource area and associated Buffer Zone. Because the wetland resource area has expanded, the original riprap outlet is within the Buffer Zone at the time of the proposed work. The alteration of the original riprap outlet within the Buffer Zone requires the filing of a Notice of Intent, Request for Determination of Applicability, or Notice of Resource Area Delineation. See Figure 3.

Once again, the project proponent has the burden of proving that the stormwater management system was constructed on or after January 2, 2008 in accordance with the Stormwater Management Standards and that the system was originally constructed outside any wetland resource area or Buffer Zone. It would be easy for the proponent to meet this burden if, prior to constructing the stormwater management system, s/he had obtained a Negative Determination of Applicability, an Order of Resource Area Delineation (ORAD), or an Order of Conditions for any work on the project that occurred within a resource area or Buffer Zone.

In the absence of a Negative Determination, ORAD, or Order of Conditions, the project proponent would have to rely on whatever credible evidence is available to prove that the original water quality swale, infiltration basin and riprap outlet is a stormwater management system that was originally constructed on or after January 2, 2008 in accordance with the Stormwater Management Standards in a portion of the site that was outside a wetland resource area or associated Buffer Zone. Obtaining the necessary credible evidence may not be easy. To establish that the system was designed on or after January 2, 2008, the project proponent may be able to rely on the local approvals, if any, for the stormwater management system. To establish that the basin was constructed outside wetlands jurisdiction, the proponent may be able to rely on other available information, such as wetland maps prepared by MassDEP or other state or local agencies, any Orders or Determinations issued for the site prior to the project or subsequent to the project, any Orders or Determinations for nearby sites, and existing conditions (soils, plants, hydrology) within the portion of the site surrounding the infiltration basin.

Assuming the project proponent meets the required burden of proof, the Conservation Commission would then review the proposed alteration to determine whether the proposed replacement system provides the same capacity as the original design to attenuate peak discharge rates, recharge the groundwater, and remove total suspended solids, and complies with the Stormwater Management Standards including, without limitation, Standard 8 - the erosion and sedimentation control standard. The Conservation Commission would also determine whether the elimination of the original riprap outlet in the Buffer Zone adversely affects the adjoining wetland resource area

The Right to Appeal the Order of Conditions

Conservation Commissions and MassDEP issue Orders of Conditions that require compliance with the Stormwater Management Standards. Applicants and others may appeal these conditions to MassDEP in the same way as they appeal any other requirements of the Order of Conditions. Moreover, if a Commission issues an Order of Conditions that is inconsistent with the Stormwater Management Standards, MassDEP may intervene unilaterally and issue a Superseding Order that requires compliance with the Standards[3].

Underground Injection Control Program

The Underground Injection Control Regulations, 310 CMR 27.00, require the registration of certain infiltration best management practices. As of the date of publication of this

[3] Applicants and others may appeal a Superseding Order issued by MassDEP by requesting an adjudicatory hearing. The rules for requesting an adjudicatory hearing are set forth in 310 CMR 10.05(7)(j).

manual, all dry wells, infiltration trenches, subsurface structures, and leaching catch basins must be registered. Depending on the design, bioretention areas may have to be registered. [4]

Stormwater, the Federal Clean Water Act, and the State Clean Waters Act.

Stormwater and the 401 Water Quality Certification

Under Section 401 of the federal Clean Water Act, an applicant for a federal permit for any activity resulting in a discharge to waters of the United States must obtain certification that the discharge will comply with state water quality standards and other appropriate requirements of state law. Section 404 permits for the discharge of dredged or fill material issued by the U.S. Army Corps of Engineers frequently trigger the state's 401 jurisdiction. Discharges include the filling of wetlands, the redeposit of dredged or excavated material from activities such as mechanized land clearing or ditching, and the placement of piling when it has the effect of fill. Waters of the United States include navigable waters, their tributaries, wetlands adjacent to navigable waters, and other wetlands that possess a significant nexus with navigable waters. States may add conditions to certify that state water quality standards will be met.

The 401 Water Quality Certification Program has been coordinated with the state's Wetlands Protection Act Program. As a result, most projects approved by the Conservation Commission under the Wetland Protection Act do not need further state review under the 401 Program. These projects meet the Stormwater Management Standards through compliance with the Wetlands Protection Act. Some types of projects, including those with potentially large wetland impacts and those that are not subject to the Wetlands Protection Act, require an individual 401 certification. Projects requiring an individual 401 Water Quality Certification include activities that will result in the loss of more than 5,000 square feet of bordering and isolated vegetated wetlands and land under water, the discharge of dredged or fill material to Outstanding Resource Waters, real estate subdivisions unless there is a recorded deed restriction providing notice to subsequent purchasers limiting the amount of fill, and the discharge of dredged or fill material to a salt marsh or to rare and endangered species habitat in an isolated vegetated wetland.

For these projects, the 401 Water Quality Certification regulations include specific provisions for stormwater discharges. The Water Quality Certification Regulations, 314 CMR 9.06(5), provide:

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[4] For information on the UIC program and its application to infiltration BMPs, see http://www.epa.gov/npdes/pubs/sw_class_v_wells_fs.pdf. See also http://www.mass.gov/dep/water/laws/uicqa.htm.

- No discharge of dredged or fill material is permitted for the impoundment or detention of stormwater for purposes of controlling sedimentation or other pollutant attenuation.

- Discharge of dredge or fill material may be permitted to manage stormwater for flood control purposes only where there is no practicable alternative and provided that best management practices are implemented to prevent sedimentation or other pollution. No discharge of dredged or fill material is permitted for the impoundment or detention of stormwater in Outstanding Resource Waters for any purposes

The Water Quality Certification Regulations, 314 CMR 9.06(6), provide that stormwater discharges shall be provided with stormwater best management practices to attenuate pollutants and to provide a setback from the receiving water or wetland in accordance with the Stormwater Management Standards. The Water Quality Certification Regulations, 314 CMR 9.06, incorporate the Stormwater Management Standards.

Designation of Stormwater Discharges

Under the Surface Water Discharge Regulations, 314 CMR 3.00, stormwater discharges other than discharges from municipal separate storm sewer systems that require coverage under the MS4 general permit, are exempt from the requirement to obtain an individual or general surface water discharge permit unless MassDEP has made a designation in accordance with 314 CMR 3.04(2). [5] MassDEP may make a designation if it determines that: (1) the discharge is or may be a significant contributor of pollution to waters of the Commonwealth, (2) the discharge is contaminated by contact with process wastes, raw materials, toxic pollutants, hazardous substances, oil or grease, and does not meet the Stormwater Management Standards, (3) the discharge is subject to effluent limitation guidelines or toxic pollutant effluent standards, or (4) the discharge is located in an industrial plant or plant-associated area and there is a potential for significant discharge of stormwater contaminated by contact with process wastes, raw materials, toxic pollutants or hazardous substances, and the discharge has not obtained coverage under a general permit. Any stormwater discharge designated by MassDEP will be required to obtain a discharge permit or to take other corrective action. Designated stormwater discharges may be permitted by an individual permit, a general permit or an alternative general permit.

Stormwater Discharges and Total Maximum Daily Loads

A total maximum daily load (TMDL) is the greatest amount of a pollutant that a water body can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation, and fishing. A TMDL specifies how much of a specific pollutant can come

[5] MassDEP has similar authority to require certain stormwater discharges to the groundwater to obtain a permit. See 314 CMR 5.04.

from various sources, including stormwater discharges, and identifies strategies for reducing the pollutant discharges from these sources. MassDEP has prepared TMDLs that indicate that in many watersheds action is needed to reduce the concentrations of bacteria, phosphorus, and nitrogen in stormwater discharges, including, without limitation, implementation of specific stormwater BMPs.

Proper selection of non-structural and structural stormwater management practices is an essential component of any plan to reduce these pollutants. These non-structural BMPs begin with environmentally sensitive site design, pollution prevention and source control. By reducing impervious surfaces and allowing stormwater to infiltrate into the ground and by selecting a landscape design that minimizes the need for fertilizers and pesticides, developers can substantially reduce the concentration of pollutants in stormwater runoff from development and redevelopment projects. Once a project is complete, ongoing action is needed to prevent additional pollutants from entering the stormwater management system. Raw materials and wastes should be stored inside or under cover with adequate containment. Snow, sand, deicing chemicals, fertilizers, pesticides, and solid waste should be properly managed. An effective street-sweeping program should be implemented. Structural BMPs that can remove the pollutants of concern must be designed, constructed, operated and maintained. Infiltration BMPs, bioretention areas, constructed stormwater wetlands, and filter systems may be effective tools for reducing the concentration of nutrients and bacteria in stormwater discharges.

If a proponent is proposing a project that is in the watershed of a water body with a TMDL, and if the project is subject to wetlands jurisdiction, the proponent must select structural BMPs that are consistent with the TMDL. Because pollution prevention is an interest identified in the Wetlands Protection Act, conservation commissions and MassDEP may require use of such BMPs when reviewing projects subject to jurisdiction under the Act. The TMDL may contain information on appropriate BMPs. See http://mass.gov/dep/water/resources/tmdls.htm.

Stormwater and the National Pollutant Discharge Elimination System (NPDES) Permitting Program

The federal Clean Water Act authorizes the United States Environmental Protection Agency (the EPA) to regulate point sources that discharge pollutants into waters of the United States, including stormwater runoff from drainage systems. Under the NPDES Phase 1 Stormwater Program, the EPA, since 1990, has issued general permits for municipal separate storm sewer systems in cities and counties with populations of 100,000 or more, stormwater runoff from specific industrial activities, and stormwater runoff from construction sites that disturb 5 acres or more of land. In 2003, the NPDES Phase II Stormwater Program took effect, and EPA began regulating municipal separate storm sewer systems in additional urbanized areas, and stormwater runoff from construction activities that disturb one acre or more of land, through a general permit.

Stormwater and the NPDES General Permit for Municipal Separate Storm Sewer Systems (the MS4 Permit)

MassDEP and EPA jointly issue the permit for municipal separate small sewer systems or MS4 Permit. See 314 CMR 3.06(11)(b). The MS4 general permit requires the development and implementation of a stormwater management plan that includes six specified minimum measures.

These measures are as follows:

- **Public education and outreach.** The public education program must provide information on the impact of stormwater discharges and identify steps the public can take to reduce pollutants in stormwater, such as actions to ensure the proper use and disposal of landscape and garden chemicals including fertilizers and pesticides, protecting and restoring riparian vegetation, and properly disposing of used motor oil or hazardous waste.

- **Public involvement and education.** The public involvement program shall be done in compliance with all applicable state and local public notice requirements, including, without limitation, the Open Meetings Law and the Public Records Act. The public must be involved in developing, implementing and reviewing the stormwater management program.

- **Illicit discharge detection and elimination.** An illicit discharge is any discharge to a municipal separate storm sewer that is not comprised entirely of stormwater, discharges from fire-fighting activities, and certain designated non-stormwater discharges. An illicit discharge detection and elimination program requires a map of the storm sewer system that identifies the location of all outfalls and the names of all surface waters that receive discharges from those outfalls. As part of this program, there must be a regulatory mechanism that prohibits non-stormwater discharges into the municipal separate storm sewer system and provides for appropriate enforcement. The program must include a plan to detect and address non-stormwater discharges, including illegal dumping, and to inform public employees, businesses and the general public of the hazards associated with illicit connections and improper waste disposal.

- **Construction site runoff control program.** The construction site runoff control program must reduce pollutants from construction activities that result in a land disturbance of greater than or equal to one acre. The construction site runoff control program must include a regulatory mechanism that requires proper management of construction sites, with sanctions to ensure compliance. The program shall require (a) sediment and erosion controls including BMPs and LID techniques to minimize land disturbance; (b) proper management of wastes, including construction debris, concrete truck wash-out chemicals, litter and sanitary wastes; (c) procedures for site plan review that examine water quality impacts; (d) procedures for public input; and (e) procedures for inspection and enforcement of control measures. The program may rely on Standard 8 of the Stormwater Management Standards for construction site runoff control. To apply Standard 8 to areas outside the jurisdiction of the Wetlands Protection Act requires a local ordinance, bylaw or regulation.

- **Post-Construction stormwater management.** The post-construction stormwater management program must apply to projects that disturb one acre or more. The program must include a regulatory mechanism with sanctions, requirements for the long-term operation and maintenance of best management practices, and controls to prevent or minimize impacts to water quality. The program may rely on the Stormwater Management Standards for post-construction stormwater management. To apply those standards to areas outside the jurisdiction of the Wetlands Protection Act requires a local ordinance, bylaw, or regulation.

- **Pollution prevention and good housekeeping in municipal operations.** The pollution prevention and good housekeeping program must include the development and implementation of a program for preventing and reducing the concentration of pollutants found in stormwater runoff from municipal operations, including parks and open space, fleet maintenance, building maintenance, new construction and land disturbance, roadway drainage system maintenance, and the stormwater system.

The MS4 permit requires the permittee to develop measurable goals for the implementation of the stormwater management program and to report on its progress on meeting those goals. Based on a Total Maximum Daily Load or equivalent water quality assessment, the MS4 permit may require the implementation of measures in addition to the six minimum controls, if EPA and/or MassDEP determine that such additional measures are necessary to protect water quality.

The first MS4 general permit was issued in 2003 and is due to expire in 2008.[6] In Massachusetts, 237 cities and towns have applied for and obtained coverage under the 2003 MS4 general permit. For a map showing Massachusetts municipalities covered by the MS4 Permit, see EPA's site at
http://www.epa.gov/region1/npdes/stormwater/ma.html.

To comply with the MS4 general permit, many cities and towns have enacted local ordinances, bylaws, and regulations that apply to existing stormwater discharges as well as stormwater discharges from new development and redevelopment, both during and after construction. These local requirements include construction and post-construction controls on development and redevelopment projects that disturb one acre or more of land, including projects outside the jurisdiction of the Wetlands Protection Act, and regulations requiring the removal of illicit connections to the municipal separate storm

[6] Through the State's Water Quality Certification, the 2003 MS 4 Permit requires compliance with the Stormwater Management Standards and the Surface Water Quality Standards. The 2003 permit required permittees in high and medium stressed basins to meet the recharge standard in areas outside of jurisdiction under the Wetlands Protection Act.

sewer system. If a TMDL has been established, these regulations may address pollutants other than TSS. Proponents of projects located in municipalities that are covered by the MS4 permit must comply with these local requirements.

Stormwater Discharges from Construction Activities (Construction General Permit)

Construction sites that disturb one or more acres and that discharge stormwater to a surface water of the United States, or to a municipal separate storm sewer system that discharges to a surface water of the United States, are required to obtain coverage under the NPDES General Permit for Storm Water Discharges from Construction Activities (also known as the "Construction General Permit" or "CGP") issued by the EPA. Although the state has not joined with EPA in issuing the construction general permit, Massachusetts has issued a 401 Water Quality Certification for the permit. The Water Quality Certification requires compliance with certain state regulations and policies, including the Massachusetts Clean Waters Act, the Massachusetts Water Quality Standards, the Surface Water Discharge Permit Program Regulations, the Wetlands Protection Act, the Wetlands Regulations, Final Orders of Conditions issued pursuant to the Wetlands Protection Act, the Massachusetts Stormwater Management Policy, and the Massachusetts Endangered Species Act. If the requirements of the water quality certification are violated, MassDEP has the authority to require that the violations be corrected and to take any action authorized by the General Laws of the Commonwealth, the Massachusetts Clean Waters Act, and the regulations promulgated thereunder.

The CGP requires the preparation of a Stormwater Pollution Prevention Plan (SWPPP). The SWPPP must include a plan to implement both pollution prevention and erosion and sedimentation control during construction. If the permit covers a stormwater discharge to a water body for which a TMDL has been developed, the SWPPP must document compliance with the TMDL. If the permit covers a discharge to an Outstanding Resource Water, the SWPPP must be submitted to MassDEP so that the Department may review it for compliance with the surface water quality standards.[7] The Construction General Permit is scheduled to expire in 2008[8].

Stormwater Discharges from Construction Dewatering

Stormwater and/or groundwater discharges that are pumped and drained from excavations or other points of accumulation are required to obtain an individual or general NPDES permit from EPA and MassDEP. A notice of intent must be submitted to both EPA and MassDEP at least 30 days prior to the discharge. MassDEP reviews and approves all discharges into Class A or Class SA waters. If the discharge is to an impaired water, an individual permit is required. If EPA or MassDEP believes that the

[7] The SWPPP should be submitted along with BRP WM09. See http//www.mass.gov/dep/water/approvals/wm09.pdf.

[8]. For information on the latest Construction General Permit see http://www.epa.gov/region1/topics/water/stormwater.html and http://cfpub2.epa.gov/npdes/stormwater/cgp.cfm.

general permit does not adequately protect actual environmental conditions, including the preservation of endangered species, it may require an individual permit for other discharges. For discharges to the Fort River in Amherst, the Mill River in Easthampton, and the Mill River in Whately, EPA and MassDEP are required to make a case-by-case determination of whether a general permit is sufficient to protect the federally listed endangered dwarf wedge mussel.

The general permit prohibits the discharge of materials or chemicals in amounts that would be toxic and discharge that violates state or federal water quality standards. The general permit requires that all discharges pass through settling basins or other treatment systems to remove total suspended solids. The general permit establishes specific effluent limitations and monitoring requirements for Total Suspended Solids, oil and grease, and pH.

Stormwater Discharges from Industrial Activities

Stormwater discharges associated with certain industrial sectors are required to obtain an individual NPDES permit or coverage under the NPDES Storm Water Multi-Sector General Permit. This permit is issued only by EPA and requires that the discharger comply with the surface water quality standards, 314 CMR 4.00 and prepare a SWPPP. If there are stormwater discharges to an Outstanding Resource Water, the discharger must submit the SWPPP to MassDEP.[9]

The SWPPP must identify potential sources of pollutants that may reasonably be expected to affect the quality of the stormwater discharges, describe and ensure implementation of practices to reduce pollutants in stormwater discharges, and ensure compliance with the permit. The SWPPP must include BMPs to minimize pollutants in the discharge so that the discharge will not cause or contribute to violations of water quality standards. The BMPs should be a suite of stormwater controls that prevent pollution and are economically reasonable and appropriate in light of current industry practice[10].

If a TMDL has been approved for the receiving water, the SWPPP must be consistent with the TMDL. If at any time after authorization under a general permit, EPA determines that the discharge may cause or have the reasonable potential to cause or contribute to a violation of water quality standards, EPA may require the permittee to develop a supplemental action plan to address the water quality concerns or to apply for an individual permit.

The Multi-Sector General Permit provides that the discharges must comply with 314 CMR 3.00, 314 CMR 4.00, 314 CMR 9.00 and 310 CMR 10.00. New development and

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[9] The SWPPP should be submitted along with BRP WM09. See http//www.mass.gov/dep/water/approvals/wm09.pdf.

[10] EPA has developed guidance on preparing a SWPPP for the Multi-Sector General Permit. Proponents preparing long-term pollution prevention plans for sites with land uses with higher potential pollutant loads may find this information helpful. See http://cfpub2.epa.gov/npdes/stormwater/msgp.cfm.

the redevelopment of existing industrial facilities subject to the multi-sector general permit must comply with the state regulations and policy, including the Massachusetts Stormwater Standards. Existing discharges subject to the multi-sector general permit do not need to obtain an individual or general state discharge permit unless the discharge is designated by MassDEP in accordance with 314 CMR 3.04(2).

Chapter 1
The Three Components of Stormwater Management

The most effective stormwater management plans include a comprehensive program of activities and controls, including prudent site design, aggressive pollution prevention, source control measures, and well-designed structural BMPs keyed to meeting a particular stormwater management standard, along with regular operation and maintenance of the BMPs. The best stormwater management plans are those that simulate natural hydrologic conditions, by gradually recharging groundwater and slowing runoff that flows to collection systems and receiving waters. To meet the Stormwater Management Standards, a project proponent needs to consider the following three stormwater management components in this order of priority:

- **Site Planning: Design the development using environmentally sensitive site design and low impact development techniques to preserve natural vegetation, minimize impervious surfaces, slow down times of concentration, and reduce runoff;**
- **Source Controls, Pollution Prevention, and Construction Period Erosion and Sediment Control:** Implement nonstructural measures to prevent pollution or control it at its source; and
- **Structural BMPs: Design, construct and maintain structural BMPs to attenuate peak flows, capture and treat runoff, and provide recharge to groundwater.**

Applicants select the best combination of control measures to meet the Stormwater Management Standards. The most cost-effective approach relies on the site planning and the nonstructural approaches discussed in this chapter. Maintaining pre-development hydrologic conditions through proper site planning and nonstructural approaches that preserve natural vegetation and prevent erosion and sedimentation is a highly effective pollution prevention strategy. By reducing or eliminating the need for structural BMPs, this approach results in a well-designed development with a stormwater management system that suits the land and minimizes costs.

A. Site Planning

Integrating comprehensive stormwater management into the site development process from the outset is the most effective approach for reducing and preventing potential pollution and flooding problems. Early stormwater management planning will generally minimize the size and cost of structural solutions. Stormwater management efforts which incorporate structural BMPs into the site design at the final stages frequently result in the construction of unnecessarily large and costly facilities, which may fail due to improper design, siting, engineering, operation or maintenance.

Who Does Site Planning for Stormwater?
Site planning is the responsibility of the project proponent. Certain components of site planning may require technical expertise (e.g., hydrology, engineering, landscaping), and in such cases, professional consultants and/or design engineers should do comprehensive site planning. Before and during the permit review process, collaborative efforts among various parties, including developers, consultants, technical staff, planning boards, and conservation commissions, frequently lead to final design plans that meet mutual goals.

Who Reviews Site Plans for Stormwater Management?
In most cases, site plan review, including review of the stormwater management system, is conducted at the local level by planning boards under the authority of the Subdivision Control Act or local regulations. Local zoning bylaws, for example, may establish special requirements for additional review through zoning districts or special permits that may require more stringent protection than the Stormwater Management Standards. If the project involves activity within a wetland resource area or associated Buffer Zone, the site design is subject to review by the conservation commission. If the Order of Conditions issued by the conservation commission is appealed, MassDEP reviews the project. The *Massachusetts Nonpoint Pollution Source Management Manual* (http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman) published by MassDEP (2006) provides additional information on site plan review and stormwater planning.

Careful site designs minimize the size and related material, construction, and maintenance costs of structural stormwater controls. Site planning should include the preparation of accurate and complete site plan maps and narratives. Stormwater controls must be developed for both construction activities and post-construction conditions. If the project is subject to review under the Wetlands Protection Act, the construction and post-construction controls should be addressed separately in the plans and narrative descriptions provided with the Notice of Intent under the Wetlands Protection Act.

What is Environmentally Sensitive Site Design?
Conventional development strategies treat stormwater as a secondary component of site design, usually managed with “pipe-and-basin” systems that collect rainwater and discharge it off-site. In contrast, environmentally sensitive site design embraces hydrology as an integrating framework for site design, not a secondary consideration. Existing conditions influence the location of roadways, buildings, and parking areas, as well as the nature of the stormwater management system. Environmentally sensitive site design is a multi-step process that involves identifying important natural features, placing buildings and roadways in areas less sensitive to disturbance, and designing stormwater management systems that create relationships between development and natural hydrology. The attention to natural hydrology, stormwater “micromanagement,” nonstructural approaches, and vegetation results in a more attractive, multifunctional landscape with development and maintenance costs comparable to or less than conventional strategies that rely on pipe-and-basin approaches.

Landscaping is an important component of environmentally sensitive site design. Ecological landscaping strategies seek to minimize the amount of lawn area and enhance the property with native, drought-resistant species; as a result, property owners use less water, pesticides, and fertilizers.[1] The maintenance of vegetated buffers along waterways can also enhance the site and help protect water quality.

What Types of Development Can Accommodate Environmentally Sensitive Site Design?
Environmentally sensitive site design can be applied to both residential and nonresidential developments as well as redevelopment projects. Environmentally sensitive site design begins with assessing the environmental and hydrologic conditions of a site and identifying important natural features such as streams and drainage ways, floodplains, wetlands, water supply protection areas, high-permeability soils, steep slopes, erosion-prone soils, woodland

[1] See More Than Just a Yard Ecological Landscape Tools for Massachusetts Homeowners. See http://www.mass.gov/envir/mwrc/pdf/More_Than_Just_Yard.pdf.

conservation areas, farmland, and meadows. This investigation helps to determine which "conservation areas" should be protected from development and construction impacts, and which site features (such as natural swales) should be incorporated into the stormwater management system.

The site analysis also identifies a "development envelope" where development can occur with minimal impact to hydrology and other ecologic, scenic, or historic features. In general, the development envelope includes upland areas, ridge lines and gently sloping hillsides, and slowly permeable soils outside of wetlands, leaving the remainder of the site in a natural undisturbed condition. It is important to protect mature trees and to limit clearing and grading to the minimum amount needed for buildings, access, and fire protection. Converting wooded areas to lawns increases the volume of runoff that must be managed.[2] The design should confine construction activity, including stockpiles and storage areas, to those areas that will be permanently altered, and clearly delineate the construction fingerprint.

What are the Most Common Environmentally Sensitive Site Design Techniques?
Specific environmentally sensitive site design techniques that minimize the creation of new runoff, enhance groundwater recharge, and remove suspended solids include minimizing impervious surfaces, fitting the development to the terrain, preserving and capitalizing on natural drainage systems, and reproducing pre-development hydrologic conditions. Each technique is discussed in detail below.

<u>Minimize Impervious Surfaces</u>
Replacing natural cover and soils with impervious surfaces leads to increased runoff volume and velocity, larger pollutant loads, and may adversely affect long-term hydrology and natural systems through flooding and channel erosion. Research demonstrates a marked drop in fish, amphibian, and insect species when the percent imperviousness within a watershed exceeds 15%.

Careful site planning can reduce the impervious area created by pavement and roofs and the volume of runoff and pollutant loading requiring control. Moreover, as the impervious surface area of a development increases, the size and expense of the stormwater control facilities also increase. Minimizing impervious surfaces mitigates this problem. Local zoning codes and development standards, such as those addressing road widths or cluster zoning, affect the amount of runoff generated by projects. Development practices that fail to minimize impervious surfaces rely on extensive conveyance networks to discharge stormwater runoff into receiving waters and adversely impact water quality.

[Note: To ensure a reliable source of safe drinking water, it is essential that impervious areas be minimized in certain recharge areas. To further that goal, the Massachusetts Drinking Water Regulations (310 CMR 22.00) require that municipalities proposing new groundwater sources for the public water system enact land use controls that prohibit land uses within the Zone II that render impervious more than 15% square feet of a lot, or 2,500 square feet, whichever is greater, unless a system for artificial recharge of precipitation is provided that will not result in the degradation of groundwater quality. The Drinking Water Regulations impose a similar requirement on municipalities proposing new surface water sources.]

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[2] Converting wooded areas to lawns increases the peak volume of runoff that must be attenuated in accordance with Standard 2. Standard 4 requires proponents that convert wooded areas to lawns to include proper management of fertilizers, herbicides, and pesticides in their pollution prevention plan. The EPA lists urban forestry as a stormwater management BMP. See http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

Common approaches that proponents can take to minimize impervious surfaces include:

- *Maintain as much of the pre-development vegetation as possible,* especially larger trees that may be on site. Vegetation absorbs water and reduces the amount of stormwater runoff. Proponents should locate structures to minimize shading effects on vegetation and roots and protect them from damage during the construction phase.
- *Maintain natural buffers and drainage ways.* Natural buffers located between development sites and wetlands infiltrate runoff, reduce runoff velocity, and remove some suspended solids. Natural depressions and channels act to slow and store water, promote sheet flow and infiltration, and filter pollutants.
- *Minimize the creation of steep slopes.* Steep slopes have significant potential for erosion and increase sediment loading. Avoid using slopes greater than 2:1.
- *Minimize placement of new structures or roads over porous or erodible soils:* Porous soils provide the best and most inexpensive mechanism for infiltrating stormwater, reducing runoff volume and peak discharges, and providing groundwater recharge and treatment by infiltration and adsorption through the soil strata. Proponents should avoid disturbing unstable soils that are likely to erode.
- *Reduce frontage and other setbacks.*
- *Modify Zoning to Allow Planned Unit Developments* that limit the density of development while maximizing the amount of undisturbed open space and *Cluster Developments* that cluster or group buildings closer together to maximize the amount of undisturbed open space.
- *Reduce the horizontal footprint of buildings and parking areas.* Footprint size can be reduced by constructing a taller building, including parking facilities within the building itself, while maintaining the same floor to area (FAR) ratio.
- *Reduce to one lane,* or eliminate if practical, on-street parking lanes on local access roads.
- *Limit sidewalks to one side*, or eliminate if practical, on local low-traffic roads.
- *Use shallow grass channels or water quality swales with check dams to manage runoff and snowmelt from roads and parking lots.* Guidelines for the use of grass channels and water quality swales are found in Chapter 2 of this Volume.
- *Use porous pavement* when possible for sidewalks, driveways, transition areas between pavement edge and swales, or overflow parking areas.

<u>Fit the Development to the Terrain</u>
Match road patterns to land forms. For example, in rolling terrain, local streets should branch from collector streets, ending in short loops or cul-de-sacs along ridgelines. Grids may be more appropriate in areas where the topography is characteristically flat. Preserve natural drainage ways by interrupting and bending the road grid around them. Grass channels or water quality swales can be constructed along street right-of-ways or on the back of lots to convey runoff without abrupt changes in the direction of flow.

<u>Preserve and Use Natural Drainage Systems</u>
The standard approach of using curbing on streets and parking areas impairs natural drainage systems. Curbs are widely held to be the signature of quality development; they provide a neat, “improved” appearance and also help delineate roadway edges. Because curb-and-gutter streets trap runoff in the roadbed, storm inlets and drains are logical solutions to providing good drainage for the roadbed.

Unfortunately, a requirement for curb-and-gutter streets can create significant stormwater management problems. Because storm drains operate on gravity flow, their efficiency is maximized if they are located in the lowest areas of the site. Storm drain pipes are usually located in valleys and low areas, destroying natural drainage ways. Natural filtration and infiltration capacities are lost in the most strategic locations.

Further, in most instances, storm drains are designed for short-duration, high-frequency storms (1-hour duration with 2, 5, or 10-year return periods) and not for flood flows (24-hour duration, 50 and 100-year return period), which are handled by street and gutter flows after the storm drain capacity is exceeded. The result is that the natural drainage ways are converted from slow moving, permeable, absorptive, vegetated waterways to fast moving, impervious, self-cleaning, paved waterways, thereby increasing hydraulic efficiency, peak discharges and flood volumes.

Natural waterways that are paved and specifically designed to be quickly drained by culverted stormwater management systems minimize channel storage times as well as reduce base flows and groundwater recharge. When examined in the context of environmentally sensitive site design, the net effect of the seemingly beneficial decision to use curbs can initiate a snowball effect that amplifies the extremes in the hydrologic cycle, increasing flood flows and reducing base flows.

Curb-and-gutter developments also affect water quality. Trace metals from automobile emissions and hydrocarbons from automobile crankcase oil and fuel spillage are directly deposited on paved surfaces. For the most frequent rainfalls, the first flush of stormwater runoff washes these deposits into the storm drain system, which is designed to keep in suspension the particles to which the pollutants adhere. The particles, together with their attached pollutants, are delivered via the runoff water to receiving waters where reductions in velocity permit them to settle out. Nutrient-rich runoff from surrounding lawns quickly moves through the paved system with no opportunity to come into contact with plant roots and soil surfaces. The result is rapid delivery of contaminants to lakes, streams, estuaries, and wetlands.

If natural vegetated drainage ways are preserved, flood volumes, peak discharges, and base flows can be maintained at pre-development levels. Trace metals, hydrocarbons, and other pollutants will bind to the underlying soils and organic matter. The infiltration process allows separation of the nutrients and other contaminants from the stormwater as it percolates through the subsurface soils.

<u>Reproduce Pre-development Hydrologic Conditions</u>

The goal of matching pre-development hydrologic conditions should be addressed at the site planning level. The full spectrum of hydrologic conditions, including peak discharge, runoff volume, infiltration capacity, base flow levels, groundwater recharge, and maintenance of water quality, can be examined through a comprehensive approach involving the entire site and even offsite areas contributing runoff to the site. Peak discharges, runoff volume, infiltration recharge, and water quality are directly related to the amount and location of impervious area required by development plans.

Past efforts focused on the reduction of the frequency and severity of flooding, primarily by lowering peak discharges to match pre-development levels with adequate storage (e.g., detention systems). Some waterways were deliberately designed to increase runoff removal with higher flow rates and smooth conveyances (e.g., storm drains, paved gutters, and waterways) so as to be self-cleaning, while ignoring infiltration and water quality issues. MassDEP does not recommend implementing these "solutions".

Standard 3 of the Stormwater Management Standards requires that proponents preserve infiltration at predevelopment levels in order to maintain base flow and groundwater recharge. Along with adequate pretreatment, infiltration of stormwater through the soil will generally remove pollutants and sediments and improve water quality.

Are there Limitations to Environmentally Sensitive Site Design?
Some environmentally sensitive site designs that seek to cluster development and reduce lot coverage may conflict with local land use regulations or public perceptions about what type of development is desirable.[3] For example, a compact multi-story building may be more visible than a single-story building with a larger footprint. To address this problem, developers, advocates and regulators who recognize the value of environmentally sensitive site design must educate the public.

Integrating Site Design, Pollution Prevention, and Structural BMPs
The time to integrate source controls and pollution prevention measures into the stormwater management system is during site design. During the planning process, a proponent should consider source control and pollution prevention measures, such as placing a roof over a fueling area or landscaping to minimize the need for fertilizers. These measures can reduce the requirements for stormwater control, prevent the discharge of pollutants to receiving waters, and result in substantial cost-savings.

During the site planning process, proponents should also consider the locations of structural BMPs and the need to provide ongoing access to those BMPs for maintenance. Some BMPs, such as infiltration basins, have specific site and construction requirements. The proponent should identify site constraints, such as depth to groundwater and nearby septic systems or wells, so the BMP will not fail or adversely affect on-site septic systems or wells.

Site planning can help identify the most appropriate points to direct discharges from BMPs. To avoid erosion and prevent system failure, proponents should locate discharge points on low slopes and stable soils away from the edges of wetlands. Where suitable, developers should use infiltration trenches for surface runoff and dry wells for uncontaminated runoff from non-metal roofs. The stormwater management system should be designed to separate the collection and treatment of contaminated and uncontaminated runoff.

The costs of rehabilitating or retrofitting failed stormwater management systems can be significant. These costs can be avoided by addressing stormwater runoff from the start. With careful planning, a proponent can design a stormwater management system that meets the Stormwater Management Standards, reduces the cost of stormwater management, facilitates long-term maintenance, and enhances the marketability and aesthetic qualities of the development.

Additional Resources and Links for Environmentally Sensitive Site Design:
Low Impact Development Design Strategies: An Integrated Design Approach; Prince George's County, Maryland, Department of Environmental Resources; June 1999. (available at http://www.epa.gov/owow/nps/lid/)

[3] The Metropolitan Area Planning Council has developed a checklist that allows local communities to determine whether their local bylaws and ordinances prevent the use of environmentally sensitive design. See http://www.mapc.org/regional_planning/LID/LID_codes.html

Better Site Design: A Handbook for Changing Development Rules in Your Community; Center for Watershed Protection; 1998. Site Planning for Urban Stream Protection; Thomas Schueler; Center for Watershed Protection; 1995.

Conservation Design for Subdivisions: A Practical Guide for Creating Open Space Networks; Randall Arendt; Island Press; 1996.

"Site Analysis." James A. LaGro, Jr.; John Wiley and Sons; 2001 *An Introduction to Better Site Design*; Article 45 from Watershed Protection Techniques; Center for Watershed Protection; 2000.

B. Nonstructural Approaches: Source Control and Pollution Prevention

Source controls can reduce the types and concentrations of contaminants in stormwater runoff and improve water quality. Source controls cover a wide range of practices including local bylaws and regulations, materials management at industrial sites, fertilizer and pest management in residential areas, reduced road salting in winter, erosion and sediment controls at construction sites, and comprehensive snow management.

Effective site planning is essential to source control and pollution prevention. Reducing impervious surfaces and runoff volumes prevents the transport of pollutants. The guiding principle for pollution prevention is to minimize the volume of runoff and the contact of stormwater with potential pollutants. Because nonstructural practices can reduce stormwater pollutant loads and quantities, the size and expense of structural BMPs (or in rare cases, even the need for structural BMPs) can be reduced, thereby affording substantial cost savings.

The *Massachusetts Nonpoint Pollution Source Management Manual* (http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman) published by MassDEP (2006) provides a detailed summary of the pollutants associated with specific land use activities. These summaries can be used to identify the potential pollutants at a site, so that suitable controls can be implemented.

Street and Parking Lot Sweeping

One effective nonstructural source control is street and parking lot sweeping. Many municipalities and some private entities (e.g., commercial shopping areas or office parks) have street sweeping programs. Although intended to provide important nonpoint source pollution control, many street sweeping programs are not effective at capturing the peak sediment loads.

The NURP study (EPA, 1983) indicates that sweeping streets once a year using rotary brush sweepers resulted in no TSS removal. A study conducted by the USGS (Smith, 2002) along the Southeast Expressway in Boston indicates that sweeping yielded a net increase in sediment, because the road shoulder was not stabilized and contributed more sediment to the Southeast Expressway than the sweepers could remove.

There are many reasons that some street sweeping programs are not effective.

- The period immediately following winter snowmelt, when road sand and other accumulated sediment and debris is washed off, is frequently missed by street sweeping programs.
- Larger particles of street dirt may prevent smaller particles from being collected.
- The entire width of roadway may not be swept.
- Sweepers may be driven too quickly to achieve maximum efficiency.
- Land surfaces along the paved surfaces may not be entirely stabilized.

Other studies have shown that if done properly, street sweeping can be highly effective. Breault 2005 indicates that sweepers can achieve high removal efficiencies. That study assessed total solids removal, and included large particles. Zarriello 2002 verified the effectiveness of high efficiency sweepers.

There are three factors in particular that can have a major influence on the effectiveness of a street sweeping program: **access, the type of sweeper, and the frequency of sweeping**.

Effective sweeping requires access to the areas to be swept. Parked cars impede street sweeping. Studies have shown that up to 95% of the solids on a paved surface accumulate within 40 inches of the curb, regardless of land use. It is essential that applicants or those responsible for stormwater maintenance have the ability to impose parking regulations to facilitate proper sweeping, particularly in densely populated or heavily traveled areas, so that sweepers can get as close to curbs as possible.

A good street sweeping program requires an efficient sweeper. There are three types of sweepers: Mechanical, Regenerative Air, and Vacuum Filter. Each has a different ability to remove TSS.

- Mechanical: Mechanical sweepers use brooms or rotary brushes to scour the pavement. Although most of the sweepers currently in use in Massachusetts are mechanical sweepers, they are not effective at removing TSS (from 0% to 20% removal). Mechanical sweepers are especially ineffective at picking up fine particles ("fines") (less than 100 microns).
- Regenerative Air: These sweepers blow air onto the road or parking lot surface, causing fines to rise where they are vacuumed. Regenerative air sweepers may blow fines off the vacuumed portion of the roadway or parking lot, where they contaminate stormwater when it rains.
- Vacuum filter: These sweepers remove fines along roads. Two general types of vacuum filter sweepers are available - wet and dry. The dry type uses a broom in combination with the vacuum. The wet type uses water for dust suppression. Research indicates vacuum sweepers are highly effective in removing TSS. The best ones (in terms of pollutant removal efficiencies) typically cost about $240,000 to $310,000.

Regardless of the type chosen, the efficiency of street sweeping is increased when sweepers are operated in tandem.

The frequency of sweeping is a major factor in determining efficiency. Unlike other stormwater treatment practices that function whenever it rains, street sweeping only picks up street dirt when streets and parking lots are actually swept. TSS removal efficiency is determined based on annual loading rates. If a road were swept only once a year with a sweeper that is 100% efficient, it would remove only a small fraction of the annual TSS load.

Street dirt accumulates on roads and parking lots and runs off in response to precipitation. The average interval between precipitation events in Massachusetts is approximately 3 days. Therefore, the hypothetical maximum effectiveness for street dirt removal requires sweeping at least once every 3 days, with a street sweeper with 100% efficiency at removing solids on paved surfaces before they become suspended. Modeling studies by Claytor (1999) in the Pacific Northwest suggest that optimum pollutant removal occurs when surfaces are swept every two weeks.

Because street sweeping may be an effective source reduction tool, a credit towards the 80% TSS removal standard *may* be available. ***At the discretion of the issuing authority****, a street sweeping program is eligible to receive credit towards the 80% TSS removal standard as set forth in the Table SS 1.*

TSS REMOVAL CREDITS FOR STREET SWEEPING

Table SS 1

TSS Removal Rate	High Efficiency Vacuum Sweeper – Frequency of Sweeping	Regenerative Air Sweeper – Frequency of Sweeping	Mechanical Sweeper (Rotary Broom)
10%	Monthly Average, with sweeping scheduled primarily in spring and fall.	Every 2 Weeks Average, with sweeping scheduled primarily in spring and fall.	Weekly Average, with sweeping scheduled primarily in spring and fall.
5%	Quarterly Average, with sweeping scheduled primarily in spring and fall.	Quarterly Average, with sweeping scheduled primarily in spring and fall.	Monthly Average, with sweeping scheduled primarily in spring and fall.
0%	Less than above	Less than above	Less than above

Street sweeping is not recommended as a practice to receive a TSS removal credit for post-construction period runoff, if the road or parking lot shoulders are not stabilized.

All TSS Removal Credits shown in Table SS 1 assume that the sweeping program gives special attention to sweeping paved surfaces in March/April before spring rains wash residual sand from winter applications into streams. If this assumption is not correct, the issuing authority should reduce the TSS removal credit by 50%.

Planning Considerations

In deciding whether street sweeping is an effective option, consider factors such as whether road and parking lot shoulders are stabilized, the speed at which the sweepers will need to be driven (safety factor such as along a highway), whether access is available to the curb (whether vehicles parked along the curb line will preclude sweeping of the curb line), the type of sweepers, and whether the sweepers will be operated in tandem. Municipalities or private developers that are planning to purchase a new street sweeper should consider vacuum sweepers, because they are most consistently effective.

Maintenance

Reuse and Disposal of Street Sweepings

Once removed from paved surfaces, the sweeping must be handled and disposed of properly. MassDEP's Bureau of Waste Prevention has issued a written policy regarding the reuse and disposal of street sweepings. These sweepings are regulated as a solid waste, and can be used in three ways:

- In one of the ways already approved by MassDEP (e.g., daily cover in a landfill, additive to compost, fill in a public way)
- If approved under a Beneficial Use Determination
- Disposed in a landfill

MassDEP provides guidance and standards for handling, reusing, and disposing of street sweepings. (For more information, go to: www.mass.gov/dep/recycle/laws/stsweep.htm)

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Additional research underway in Wisconsin by the USGS, anticipated to be published in 2008, should provide additional information regarding removal efficiencies.

Pollution Prevention Plans

One of the most important undertakings for identifying potential pollutant sources and associated control requirements at a site is to prepare the source control and pollution prevention plan required by Standard 4. It is important for businesses, industries and municipalities to take a fresh look at their current management practices to reduce pollution at its source and ensure that they are meeting their environmental legal obligations. Businesses and towns can save money by preventing pollution, rather than cleaning up after the fact.

Industrial dischargers that are covered by the NPDES Multi-Sector General Permit are required to prepare a Stormwater Pollution Prevention Plan (SWPPP). A SWPPP prepared in accordance with the requirements of the Multi-Sector General Permit can be used to fulfill the source control and pollution prevention plan requirements of Standards 4, 5, and 6.

Likewise, many state agencies and municipalities are covered by the NPDES General Permit for Municipal Separate Storm Sewer Systems (MS4 Permit) that requires the implementation of good housekeeping and pollution prevention. State and local agencies subject to the MS4 Permit may be able to develop one plan that fulfills the source control and pollution prevention requirements of the Stormwater Management Standards and the MS4 Permit.

The source control and pollution prevention plan required by Standard 4 is intended to:

- **Identify potential sources of pollution that may affect the quality of stormwater discharges, and**
- **Describe and ensure the implementation of practices to reduce the pollutants in stormwater discharges.**

A source control and pollution prevention plan must describe all potential sources of pollutants and identify methods to eliminate and reduce those sources, including minimizing the use of hazardous materials or oil including pesticides, herbicides, fertilizers, and deicing chemicals; diverting stormwater from potential pollutant sources; keeping all hazardous materials or oil inside or under cover; implementing good housekeeping, preventive maintenance, snow and snowmelt management; and spill prevention and response procedures.

Certain land uses with higher potential pollutant loads located within the Zone II of a public water supply area require additional pollution prevention measures. These land uses include:

- landfills and open dumps,
- landfills handling wastewater residuals and/or septage,
- automobile graveyards and junkyards,
- stockpiling and disposal of snow or ice removed from highways,
- petroleum fuel oil and heating oil bulk stations and terminals,
- wastewater treatment plants permitted pursuant to 314 CMR 5.00,
- hazardous waste facilities subject to regulation under 310 CMR 30.00,
- waste oil retention facilities,
- treatment works for the remediation of contaminated ground or surface waters,
- floor drainage systems,
- storage of any of the following materials: sludge, septage, sodium chloride, chemically treated abrasives or other chemicals used for the removal of ice or snow, chemical fertilizers, animal manures, liquid hazardous materials or petroleum products.

For all such land uses that commence or are expanded on or after January 2, 2008, the source control and pollution prevention plan must include measures to prevent the land use from coming into contact with rain, snow, snowmelt and runoff.

Construction Period Erosion and Sedimentation Control

Construction period erosion and sedimentation control is an essential component of pollution prevention and environmentally sensitive site design. Construction period activities increase the potential for erosion and sedimentation at a site. Erosion is the wearing away of the land surface by running water, wind, ice, or other causes. Soil erosion is usually caused by the force of water falling as raindrops and by the force of water flowing in rills and streams. Raindrops falling on bare or sparsely vegetated soil detach soil particles. Water running along the surface of the ground picks up these particles and carries them along as it flows downhill towards a stream system.

Sedimentation is the deposition of soil particles that have been transported by water and wind. The quantity and size of the material transported increases with the velocity. Sedimentation occurs when the medium, air or water, in which the soil particles are carried, is slowed long enough to allow particles to settle out. Heavier particles, such as gravel and sand, settle out sooner than finer particles, such as clay.

There are four principal factors that influence the potential for erosion: soil type, surface cover, topography, and climate. These factors are interrelated in their effect on erosion potential. Variability in terrain, soils, and vegetation makes erosion control unique to each development. Erosion and resulting sedimentation generally occur in Massachusetts only when the soil is disturbed. The seriousness of the problem is a function of the topography and size of the disturbed area, the characteristics of the soils, the climate, and the vegetative cover.

As a rule of thumb:

- The more fine-grained material there is in a soil, the greater the amount of material that will be picked up by water flowing across its surface;
- The steeper the slope, the faster the water will move, thus being able to carry more soil; and,
- The larger the unprotected surface, the larger the potential for problems.

Topographic features distinctly influence erosion potential. Watershed size and shape, for example, affect runoff rates and volumes. Slope length and steepness are key elements in determining the volume and velocity of runoff and erosion risks. As both slope length and gradient increase, the rate of runoff increases and the potential for erosion is magnified. Swales and channels concentrate surface flow, which results in higher velocities. Exposed south-facing soils are hotter and drier, which makes vegetation more difficult to establish.

Where storms are frequent, intense, or of long duration, erosion risks increase. The high erosion risk period of the year results from seasonal changes in temperature, as well as variations in rainfall. When precipitation falls as snow, no erosion will take place immediately. In the spring, however, the hazards will be high. Most plants are still dormant. The existing vegetative cover is less able to buffer the raindrops. The ground is still partially frozen, or else saturated from melting snow, and its absorptive capacity is reduced. That is why it is necessary to stabilize exposed areas in the fall, before the period of high erosion risk in the spring.

Assess the Site

The first step in controlling erosion and sedimentation is to assess the site for possible erosion and sediment problems. Erosion and sedimentation hazards associated with site development include increased water runoff, soil movement, sediment accumulation, and higher peak flows caused by:

- Removal of plant cover and a large increase in soil exposed to erosion by wind and water
- Changes in drainage areas caused by regrading the terrain, diversions or road construction
- A decrease in the area of soil which can absorb water because of construction of streets, building, sidewalks or parking lots
- Changes in volume and duration of water concentrations caused by altering steepness, distance and surface roughness
- Soil compaction by heavy equipment, which can reduce water intake of soils to 1/20 or less of the original rate
- Prolonged exposure of unprotected sites and service areas to poor weather conditions

- Altering the groundwater regime in a way that may adversely affect drainage systems, slope stability, survival of existing vegetation and establishment of new plants
- Exposing subsurface materials that are too rocky, too acidic or otherwise unfavorable for establishing plants
- Obstructing streamflow by new buildings, dikes and landfills
- Inappropriate timing and sequencing of construction and development activities
- Abandonment of sites before construction is completed

Develop an Erosion and Sediment Control Plan

After this assessment is complete, a construction period erosion and sedimentation control plan must be prepared as required by Standard 8. Construction sites that disturb at least one acre of land are required to obtain coverage under the NPDES Construction General Permit and prepare a SWPPP. A SWPPP prepared in accordance with the Construction General Permit satisfies the erosion and sedimentation control plan requirement of Standard 8.[4]

At a minimum, the construction period erosion and sedimentation control plan required by Standard 8 must be prepared in accordance with the *Erosion and Sedimentation Guidelines: A Guide for Planners, Designers, and Municipal Officials* and shall include the following items:

- **Brief narrative**
- **Vicinity map**
- **Site topography map**
- **Site development plan**
- **Erosion and sedimentation control plan drawing**
- **Detail drawings and specifications**
- **Vegetation planning**

The erosion and sedimentation control plan must identify the party(ies) responsible for implementing the erosion and sedimentation control plan or any component(s) thereof. The Conservation Commission's Order of Conditions should require the responsible parties to implement the erosion and sedimentation control plan as approved by the Conservation Commission during land disturbance activities. Land disturbance activities include demolition, construction, clearing, excavation, grading, filling, and reconstruction. The requirement to implement the erosion and sedimentation control plan should end with the final stabilization of the site and the removal of the temporary erosion and sedimentation controls.

[4] For projects subject to jurisdiction under the Wetlands Protection Act, the construction period pollution prevention and erosion and sedimentation control plan should ordinarily be included in the Stormwater Report submitted with the Notice of Intent. For highly complex projects, where the proponent demonstrates that submission with the Notice of Intent is not possible, the issuing authority has the discretion to issue an Order of Conditions authorizing a project prior to submission of the construction period pollution prevention and erosion and sedimentation control plan. In any event, all Orders of Condition shall provide that no work, including site preparation and land disturbance, may commence unless and until a construction period pollution prevention plan that meets the requirements of Standard 8 as further elaborated by the Massachusetts Stormwater Handbook has been approved by the issuing authority.

Site Planning and Construction Sequencing

Because any modification of a site's drainage features or topography requires protection from erosion and sedimentation, the erosion and sedimentation control plan should include site planning and construction sequencing. Typically the staging of construction activities will depend upon these site factors:

- Existing soil limitations
- Existing slope and construction grading limitations
- Drainage problems
- Exposed soils during construction

The staging of construction activities to reduce sedimentation and the designation of areas to leave undisturbed during construction will reduce the size of construction BMPs, which reduces construction costs.

In developing a construction sequencing plan, the following factors should be considered:

- *Review and consider all existing conditions in the initial site selection for the project.* Select portions of the site that are suitable for the project rather than force the terrain to conform to development needs. Ensure that development features follow natural contours. Steep slopes, areas subject to flooding, and highly erodible soils severely limit a site's use, while level, well-drained areas offer few restrictions. Control seepage and high water table conditions. Any modification of a site's drainage features or topography requires protection from erosion and sedimentation.
- *Limit disturbance. Careful site selection will help on this point.* The site, or corridor, should be able to accommodate the development with a minimum of grading. The development plan should fit its topographic, soil, and vegetative characteristics with a minimum of clearing and grading. Natural cover should be retained and protected wherever possible. Critically erodible soil, steep slopes, stream banks, and drainage ways should be identified. The development can then be planned to disturb these vulnerable areas as little as possible.
- *Stabilize and Protect Disturbed Areas as Soon as Possible.* Two methods are available for stabilizing disturbed areas: mechanical (or structural) methods and vegetative methods. In some cases, both are combined in order to retard erosion.
- *Keep Stormwater Runoff Velocities Low*. The removal of existing vegetative cover during development and the resulting increase in impermeable surface area after development will increase both the volume and velocity of runoff. These increases must be taken into account when providing for erosion control.
- *Protect Disturbed Areas from Stormwater Runoff.* Best management practices can be utilized to prevent water from entering and running over the disturbed area. Diversions and other control practices intercept runoff from higher watershed areas, store or divert it away from vulnerable areas, and direct it toward stabilized outlets.
- *Retain Sediment within the Corridor or Site Area.* Sediment can be retained by two methods: filtering runoff as it flows and detaining sediment-laden runoff for a period of time so that the soil particles settle out. The best way to control sediment, however, is to prevent erosion.

Construction period erosion and sedimentation control and pollution prevention measures

In addition to construction sequencing, the erosion and sedimentation control plan must include source control and pollution prevention measures, construction period BMPs to address erosion and sedimentation, procedures for operating and maintaining the BMPs especially in response to wet weather events, actions to control mosquitoes during construction, and stabilization measures. Information on mosquito control is set forth in Chapter 5. Pollution prevention activities include storing construction materials away from wetland resource areas and catch basin inlets and preserving natural vegetation wherever possible.

The erosion and sedimentation control plan should specify the structural BMPs to be used during construction. The Massachusetts Erosion and Sediment Control Guidelines list 45 different kinds of Construction Period BMPs, from Brush Barriers, Check Dams and Dust Control to Inlet Protection, Outlet Protection and Stabilization to Sediment Fences. The BMPs selected for the project should reflect the needs identified in the project's erosion and sediment control plan. The erosion and sedimentation control plan must include design cross-sections and required freeboard for each construction period BMP. See Erosion and Sedimentation Guidelines, a Guide for Planners, Designers and Municipal Officials, http://www.mass.gov/dep/water/essec2.pdf - 62.[5]

When considering which control measures to use, always evaluate the consequences of a measure failing. Failure of a practice may be hazardous or damaging to both people and property. For example, a large sediment basin failure can have disastrous results; low points in dikes can allow them to overflow and cause major gullies. The BMPs used during construction must be distinct from the BMPs that will be used to handle stormwater after construction is completed and the site is stabilized. Many stormwater technologies (infiltration technologies) are not designed to handle the high concentrations of sediments typically found in construction runoff, and thus must be protected from construction-related sediment loadings. All construction period BMPs must be properly designed, and sediment traps or basins must be sized to provide adequate capacity and retention time to allow for proper settling of fine-grained soils.

Operation, Inspection, and Maintenance of Construction Period Best Management Practices.

The erosion and sedimentation control plan shall include a schedule for implementing the stormwater management activities during land disturbance and construction that establishes a sequence in which these activities will be implemented as the project proceeds. The plan should also state when temporary practices will be removed and how disturbed areas and any areas designated for waste disposal will be stabilized.

The erosion and sedimentation control plan should specify who is responsible for maintenance of construction period BMPs, and when maintenance will be provided. The maintenance schedule should be based on site conditions, design safeguards, construction sequence, and anticipated weather conditions. For each construction period BMP, the erosion and sedimentation control plan must specify the amount of allowable sediment accumulation, and detail what will be done with the sediment removed.

Inspections

The erosion and sedimentation control plan must also include a description of how the site will be inspected and maintained during land disturbance. Essential parts of the inspection program must include:

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[5] The EPA has developed fact sheets for the BMPs that may be used to control erosion and sedimentation during construction. See http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=4

- Inspection during or immediately following initial installation of sediment controls.
- Inspection following severe rainstorms to check for damage to controls.
- Inspection prior to seeding deadlines, particularly in the fall.
- Final inspection of projects nearing completion to ensure that temporary controls have been removed, stabilization is complete, drainage ways are in proper condition, and the final contours agree with the proposed contours on the approved plan.

The erosion and sedimentation control plan should call for interim inspections as manpower and workload permit, giving particular attention to the maintenance of installed controls. The erosion and sedimentation control plan should require that all inspections be documented in a written report or log. These reports should contain the date and time of inspections, dates when land-disturbing activities begin, comments concerning compliance or noncompliance, and notes on any verbal communications concerning the project.

Additional information on preparing and implementing pollution prevention plans is contained in *Stormwater Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices* (EPA-832-R-92-006) or *Stormwater Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices* (EPA-832-R-92-005), available through Office of Water Resource Center at 202- 566-1729, NTIS at 800-553-6847, or the Educational Resources Information Center/Clearinghouse at 800-538-3742.

Snow and Snowmelt Management

Snow Disposal

A pollution prevention plan must provide for proper management of snow and deicing materials. The application and storage of deicing materials, most commonly salts such as sodium chloride, can lead to water quality problems for surrounding areas. Salts, gravel, sand, and other materials are applied to highways and roads to reduce the amount of ice or to provide added traction during winter storm events. Salts lower the melting point of ice, allowing roadways to stay free of ice buildup during cold winters. Sand and gravel increase traction on the road, making travel safer.

Finding a place to dispose of snow contaminated with deicing materials poses a challenge to municipalities and businesses as they clear roads, parking lots, bridges, and sidewalks. While we are all aware of the threats to public safety caused by snow, collected snow that is contaminated with road salt, sand, litter, and automotive pollutants such as oil also threatens public health and the environment.

As snow melts, road salt, sand, litter, and other pollutants are transported into surface water or through the soil where they may eventually reach the groundwater. Road salt and other pollutants can contaminate water supplies and may be toxic to aquatic life. Sand washed into waterbodies can create sand bars or fill in wetlands and ponds, impacting aquatic life, causing flooding, and affecting our use of these resources. To avoid these impacts, private and public entities must plan how they will manage snow before winter begins.

Deicing Materials

To prevent increased pollutant concentrations in stormwater discharges, the amount of road salt applied should be reduced. Calibration devices for spreaders in trucks aid maintenance workers in the proper application of road salts. Many drinking water supply watersheds in Massachusetts use lower amounts of road salt to protect the resource. Reduced salt areas should be designated next to roads and wetlands. The amount of salt applied should be varied to reflect site-specific characteristics, such as road width and design, traffic concentration, and proximity to surface waters. Alternative materials, such as sand or gravel, calcium chloride, and calcium magnesium acetate may be used in especially sensitive areas. MassHighway is developing a Generic Environmental Impact Report on Snow and Ice Control that evaluates options for reducing the impact of deicing materials on water resources. Information about road deicing materials can also be found at the American Association of State Highway and Transportation Officials web site at: http://www.transportation.org/

Proper Storage of Deicing Materials

Proper snow management involves the proper storage of deicing materials. Covering stored road salts may be costly; however, the benefits are greater than the perceived costs. Storing road salts correctly prevents the salt from lumping together, which makes it easier to load and apply. In addition, covering salt storage piles reduces salt loss from stormwater runoff and potential contamination to streams, aquifers, and estuarine areas. Salt storage piles should be located outside the 100-year floodplain for further protection against surface water contamination.

The Massachusetts General Laws, Chapter 85, Section 7A, forbid outside storage of salt in areas that would threaten groundwater and surface water sources for public water supplies or within 200 feet of an established river or estuary. Outside Zone IIs, Zone As and 200 feet of established rivers or estuaries, road salt and other deicing compounds must be stored on sheltered (protected from precipitation and wind), impervious pads. Internal flow within the shelter must be directed to a collection system and external flow directed around the shelter.

The Drinking Water Regulations require municipalities proposing new water sources to enact land use controls that prohibit the uncovered, uncontained storage of road deicing materials within:

- Wellhead Protection Areas (Zone I and Zone II) for public water supply wells and
- Zone A for both new public supply reservoirs

Road salt storage and loading areas are classified as Land Uses with Higher Potential Pollutant Loads. The pollution prevention plan for land uses involving the storage of deicing compounds should include plans to bring the storage into compliance with all applicable laws and regulations. Standard 5 of the Stormwater Management Standards provides that stormwater runoff from road salt storage areas requires the use of the specific structural BMPs determined to be suitable for runoff from land uses with higher potential pollutant loads, unless all salt storage areas are protected from exposure to rain, snow, snowmelt and runoff. MassDEP has issued Guidelines on Deicing Chemical (Road Salt) Storage (1997). See
http://www.mass.gov/dep/water/laws/policies.htm#snowsalt

Snow Disposal Sites

In addition to limiting the use of deicing materials, proper management of snow and snowmelt requires selection of proper sites for snow disposal. MassDEP has developed a guidance document for communities regarding snow disposal, available on the web at:
http://www.mass.gov/dep/water/laws/policies.htm#snowsalt. This guidance document recommends the following procedures.

Site Selection

The key to selecting effective snow disposal sites is to locate them adjacent to or on pervious surfaces in upland areas away from water resources and wells. At these locations, the snowmelt water can filter into the soil, leaving behind sand and debris that can be removed in the springtime. As more fully set forth below, the following areas should be avoided:

- Avoid dumping snow into any waterbody, including rivers, the ocean, reservoirs, ponds, or wetlands. In addition to water quality impacts and flooding, snow disposed of in open water can cause navigational hazards when it freezes into ice blocks.
- Do not dump snow within a Zone II or Interim Wellhead Protection Area (IWPA) of a public water supply well or within 75 feet of a private well, where road salt may contaminate water supplies.
- Avoid dumping snow on high and medium yield aquifers where it may contaminate groundwater.
- Avoid dumping snow in sanitary landfills and gravel pits. Snowmelt water will create more contaminated leachate in landfills posing a greater risk to groundwater. In gravel pits, there is little opportunity for pollutants to be filtered out of the melt water, because groundwater is close to the land surface.
- Avoid disposing of snow on top of storm-drain catch-basins or in stormwater drainage channels or ditches. Snow combined with sand and debris may block a storm drainage system, causing localized flooding. A high volume of sand, sediment, and litter released from melting snow may be quickly transported through the system into surface water.

Site Maintenance

In addition to carefully selecting disposal sites before the winter begins, it is important to prepare and maintain these sites to maximize their effectiveness. The following maintenance measures should be undertaken at all snow disposal sites:

- A silt fence or equivalent barrier should be placed securely on the downgradient side of the snow disposal site.
- To filter pollutants out of the melt water, a 50-foot vegetative buffer strip should be maintained during the growth season between the disposal site and adjacent water bodies.
- Debris should be cleared from the site prior to using the site for snow disposal.
- Debris should be cleared from the site and properly disposed at the end of the snow season and no later than May 15.

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Other Important Pollution Prevention and Source Control Measures

There are many other effective pollution control and source control measures that proponents, citizens and municipalities can undertake to reduce pollutant loads in stormwater, including the following[6]:

- ***Lawn and garden activities***, including application and disposal of lawn and garden care products, and proper disposal of leaves and yard trimmings. Effective measures include: applying pesticides and fertilizers properly, including: timing; application reduction; providing buffer areas (preferably natural vegetation) between surface waters and lawn and garden activities; limiting lawn watering and landscaping with climate-suitable vegetation; providing guidelines for what to expect from landscaping and lawn care professionals; and providing composting guidelines, if not covered elsewhere under solid waste efforts. <http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman> See "More than Just a Yard: Ecological Landscaping Tools for Massachusetts Homeowners." http://www.mass.gov/envir/mwrc/pdf/More_Than_Just_Yard.pdf and Guide to Lawn and Landscape Water Conservation, http:www.mass.gov/envir/mwrc/pdf/LawnGuide.pdf**.**
- ***Turf management*** on golf courses, parks, and recreation areas. Many of the measures described above are applicable to turf management and need to be implemented by caretakers responsible for golf courses and parks and recreation areas (including municipal employees, in some cases).
- ***Pet waste management.*** Pooper-scooper laws for pets should be enacted and implemented. Public outreach is essential to the effectiveness of these laws. Priority resource areas, such as bathing beaches and shellfish growing areas, may need to exclude pets at least for the summer months or at other critical use times. Specific controls for horses and the control of manure may be needed. <http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman>
- ***Integrated Pest Management*** **(IPM)** effectively prevents and controls pests (including weeds) in a way that maximizes environmental benefits at a reduced cost to growers. IPM involves applying an array of techniques and control strategies for pest management – with a focus on using them in the proper amounts and determining when they are most needed. By choosing from all possible pest control methods (e.g., biological controls and beneficial organisms) and rotating methods, resistance to repeated chemical controls can be delayed or prevented. <http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman>
- ***Proper storage, use, and disposal of household hazardous chemicals,*** including automobile fluids, pesticides, paints, and solvents. Information should be provided on chemicals of concern, proper use, and disposal options. Household hazardous waste

[6] Appendix A lists source control and pollution prevention measures for certain land uses .

collection days should be sponsored whenever feasible. Recycling programs for used motor oil, antifreeze, and other products should be developed and promoted.

- ***Storm drain stenciling*** involves labeling storm drain inlets with painted messages warning citizens not to dump pollutants into the drains. The stenciled messages are generally a simple phrase to remind passersby that the storm drains connect to local waterbodies and that dumping pollutes those waters. Some storm drain stencils specify which waterbody the inlet drains to or name the particular river, lake, or bay. Commonly stenciled messages include: "No Dumping. Drains to Water Source," "Drains to River," and "You Dump it, You Drink it. No Waste Here." Pictures can also be used to convey the message, including a shrimp, common game fish, or a graphic depiction of the path from drain to waterbody. Communities with a large Spanish-speaking population might wish to develop stencils in both English and Spanish, or use a graphic alone. <http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman>
- ***Proper operation and maintenance of septic systems.*** Knowledge of proper operation and maintenance of septic systems should be promoted to avoid serious failures.
- *Car Washing*. This management measure involves educating the general public, businesses, municipal fleets (public works, school buses, fire, police, and parks) on the water quality impacts of the outdoor washing of automobiles and how to avoid allowing polluted runoff to enter the storm drain system. Outdoor car washing has the potential to result in high loads of nutrients, metals, and hydrocarbons during dry weather conditions in many watersheds, as the detergent-rich water used to wash the grime off our cars flows down streets and into storm drains. Commercial car wash facilities often recycle their water or are required to treat their wash-water discharge prior to release to the sanitary sewer system. As a result, most stormwater impacts from car washing are from residents, businesses, and charity car wash fundraisers that discharge polluted wash water to the storm drain system.
<http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman>
- ***Commercial operations and activities,*** including parking lots, gas stations, and other local businesses. Recycling, spill prevention and response plans, and proper material storage and disposal should be promoted. Using dry floor cleaners and absorbent materials and limiting the use of water to clean driveways and walkways should be encouraged. Care should be taken to avoid accidental disposal of hazardous materials down floor drains. Floor drains should be inventoried.
- ***Department of Public Works Facilities (DPWs).*** Because of the nature of the activities they perform, such as storing and managing sand, salt, and chemicals, and fueling and maintaining trucks and other equipment, DPWs are in a unique position to prevent a wide range of compounds from becoming stormwater pollutants. MassDEP has developed a Fact Sheet specifically for DPWs:
<http://www.mass.gov/dep/water/resources/nonpoint.htm#megaman>
- **Other efforts, including water conservation and litter control, can be tied to nonpoint source pollution control.**

Local Bylaws and Regulations

Local bylaws, ordinances, and regulations are among the best mechanisms to institute many of the nonstructural controls described above, because they can cover a wide range of pollution prevention issues that fall below federal thresholds or for which no threshold exists. These bylaws are generally proposed by planning boards or conservation commissions, in consultation with other local officials. Stormwater bylaws and earth removal or sediment and erosion control bylaws are among the most common types of local initiatives. Stormwater bylaws establish requirements for site planning and pollution prevention plans in conjunction with design and construction activities. Earth removal or erosion and sediment control bylaws focus specifically on construction activities and controlling soil erosion problems. Many local boards of health have adopted pet waste control bylaws.

MassDEP's *Nonpoint Pollution Source Management Manual* (2006) provides several general suggestions for developing various types of bylaws for nonpoint pollution control, including controlling erosion and sediment, limiting impervious surfaces (or lot clearing), specifying nutrient loading standards, and enhancing site plan review, wetlands protection, and road salt management.

EEA's SmartGrowth Tool Kit (http://www.mass.gov/envir/smart_growth_toolkit/), the EPA website (http://www.epa.gov/owow/nps/ordinance/mol6.htm) and the Stormwater Managers Resource Center website (http://www.stormwatercenter.net) include model bylaws for LID development. See also http://www.mapc.org/regional_planning/Developing_Local_Bylaw.pdf. Technical assistance with the development of local bylaws is available from the Massachusetts Coastal Zone Management Office, or the NRCS Community Assistance Program. Other groups such as regional planning agencies or nonprofit groups such as Massachusetts Association of Conservation Commissions or the Massachusetts Audubon Society may be able to provide assistance with bylaw development.

C. Structural Best Management Practices

This section of Chapter 1 presents information about the structural Best Management Practices (BMPs) that may be used to manage stormwater runoff in accordance with the Stormwater Management Standards. Proponents should consult this section when selecting and evaluating BMPs for a given development or redevelopment. Conservation commissions and other issuing authorities should become familiar with the information presented here to learn whether a BMP is appropriate for a project site, if a drainage system meets the Stormwater Management Standards, and what actions are required to operate and maintain the BMP.

This section of Chapter 1 groups individual BMP technologies according to the principal methods of stormwater management: pretreatment, treatment, conveyance, and infiltration. *Some BMPs fall into several categories, because they serve several functions*. For example, some bioretention areas are designed to act as a filter (hereinafter "filtering bioretention areas"), and others are designed to infiltrate (hereinafter "exfiltrating bioretention areas"). The next section describes the basic issues to consider when choosing a BMP to meet a particular Stormwater Management Standard, including site suitability, design specifications, construction methods, and maintenance requirements.

Note that the BMPs described in this chapter address *post-construction* stormwater management. There are many other BMPs focused expressly on mitigating stormwater impacts *during* construction. Detailed descriptions of these construction-specific BMPs can be found in MassDEP's *Massachusetts Nonpoint Pollution Source Management Manual*, Chapter 6: "Erosion and Sediment Control." (2006), MassDEP's *Erosion and Sedimentation Control Guidelines: A Guide for Planners, Designers, and Municipal Officials* (May 2003), and MassHighway's *Stormwater Handbook for Highways and Bridges* (May 2004).

Chapter 2 contains detailed information on specific post-construction structural stormwater best management practices. For each BMP, there is a discussion of its purpose, advantages and disadvantages, applicability, expected range of pollutant removal effectiveness, planning considerations, design and construction issues and operation and maintenance requirements.

Volume 3 provides the basic calculations needed to design a BMP for conformance with each Standard, including how to determine:

- **The required water quality volume;**
- **The required recharge volume based on hydrologic soil classification; and**
- **The size of the BMP.**

Because increased awareness and attention to stormwater management have encouraged the research and development of new technologies for stormwater management, Chapter 4 provides additional information on innovative and emerging BMP technologies. Some of these technologies have been evaluated as part of EPA's Technology Acceptance Reciprocity Partnership (TARP) or Massachusetts' Strategic Envirotechnology Partnership (STEP). Chapter 4 provides information on the TARP and STEP programs.

The Classes of BMPs

MassDEP divides the stormwater BMPs into several basic classes as shown in Table 2-1. The table also lists manufactured BMPs such as proprietary separators. Each BMP varies to the extent that it conveys, treats, infiltrates, retains, attenuates, and stores stormwater runoff. *Note that some BMPs fit into more than one class because they serve more than one function.* The classes include:

Structural Pretreatment BMPs**: The first BMPs in a treatment train, these measures typically remove the coarse sediments that can clog other BMPs. The settling process generates sediment that must be routinely removed. Maintenance is especially critical for pretreatment BMPs, because they receive stormwater containing the greatest concentrations of suspended solids during the first flush. Some pretreatment devices such as the Oil Grit Separator are required to pretreat the runoff from certain land uses with higher potential pollutant loads, such as gas stations and high intensity use parking lots[7]. The most common pretreatment BMPs include:**

- **Deep Sump Catch Basins**
- **Oil Grit Separators**
- **Proprietary Separators**
- **Sediment Forebays**
- **Vegetated Filter Strips**

Pretreatment BMPs can be configured as on-line or off-line devices. On-line systems are designed to treat the entire water quality volume. Off-line practices are typically designed to receive a specified discharge rate or volume. A flow diversion structure or flow splitter is used to divert the design flow to the off-line practice. To receive TSS removal credit, oil grit separators and deep sump catch basins must be configured as off- line devices.

Treatment BMPs

[7] For such land uses, it may be possible to use a filtering bioretention area, or a sand filter in lieu of an oil grit separator.

There are three main types of Treatment BMPs:

- **Stormwater Treatment Basins**
- **Constructed Stormwater Wetlands**
- **Filtration BMPs**

They are more specifically described below**.**

Stormwater Treatment Basins: These BMPs provide peak rate attenuation by detaining stormwater and settling out suspended solids. The basins that are most effective at removing pollutants have either a permanent pool of water or a combination of a permanent pool and extended detention, and some elements of a shallow marsh. Stormwater basins include:

- **Extended Dry Detention Basins**
- **Wet Basins**

Constructed Wetlands: Constructed stormwater wetlands are designed to maximize the removal of pollutants from stormwater runoff through wetland vegetation uptake, retention and settling. Gravel wetlands remove pollutants by filtering stormwater through a gravel substrate.

- **Constructed Stormwater Wetland**
- **Gravel Wetland**

Filtration BMPs: Filtration systems use media to remove particulates from runoff. They are typically used when circumstances limit the use of other types of BMPs, such as where space is limited–particularly in a highly urbanized setting–or when it is necessary to capture particular industrial or commercial pollutants (e.g., hydrocarbons). In these circumstances, other BMPs might be cost-prohibitive or not as effective. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially exfiltrate into the soil. Filtration BMPs include:

- **Filtering Bioretention Areas and Rain Gardens**
- **Proprietary Media Filter**
- **Sand Filters/Organic Filters**
- **Treebox Filter**

Conveyance BMPs: These BMPs collect and transport stormwater to BMPs for treatment and/or infiltration. These practices may also treat runoff through infiltration, filtration, or temporary storage. A water quality swale usually functions as a runoff conveyance channel and a filtration practice. The vegetation or turf also prevents erosion, filters sediment, and provides some nutrient uptake benefits. Conveyance BMPs include:

- **Drainage Channels**
- **Grass Channels**
- **Water Quality Swales**
    - **Dry**
    - **Wet**

Infiltration BMPs: Infiltration systems are designed primarily to reduce the quantity of stormwater runoff from a particular site. Infiltration techniques reduce the amount of surface flow and direct the water back into the ground. Infiltration practices typically cannot provide channel protection and overbank or extreme flood detention storage. Infiltration BMPs include:

- **Exfiltrating Bioretention Areas and Rain Gardens**
- **Dry Wells**
- **Infiltration Basins**
- **Infiltration Trenches**
- **Leaching Catch Basins**
- **Subsurface Structures**

Other BMPs: Some BMPs do not fit into any of the categories set forth above. These BMPs include the following:

- **Dry Detention Basins**
- **Green Roofs**
- **Porous Pavement**
- **Rain Barrels and Cisterns**

Accessories: BMP accessories are devices that enable BMPs to operate as designed. BMP accessories include the following:

- **Check Dams**
- **Level Spreaders**
- **Outlet Structures**
- **Catch Basin Inserts**

Table 2.1		
BMPs for Controlling Stormwater Quantity		
	Pretreatment BMP	**BMP that requires pretreatment**
Pretreatment		
Deep Sump Catch Basin	**Yes**	**No**
Oil Grit Separators	**Yes**	**No**
Proprietary Separators	**Yes**	**No**
Sediment Forebays	**Yes**	**No**
Vegetated Filter Strips	**Yes**	**No**
Treatment		
Bioretention areas/rain gardens	**No**	**Yes**
Constructed stormwater wetlands	**No**	**Yes**
Extended Dry Detention Basins	**No**	**Yes**
Gravel Wetlands	**No**	**Yes**
Proprietary Media Filters	**No**	**Yes**
Sand/Organic Filters	**No**	**Yes**
Tree Box filters	**No**	**Yes**
Wet basins	**No**	**Yes**
Conveyance		
Grass Channels	**No**	**Yes**
Water Quality Swales – Dry	**No**	**Yes**
Water Quality Swales – wet	**No**	**Yes**
Infiltration BMPs		
Dry Wells	**No**	**No pretreatment required for runoff from non-metal roofs and metal roofs outside Zone II, IWPA and industrial site.**
Infiltration Basins	**No**	**Yes**
Infiltration Trenches	**No**	**Yes**
Leaching Catch Basins	**No**	**Yes**
Subsurface Structures	**No**	**Yes**
Other BMPs		
Dry Detention Basins	**No**	**No**
Green Roofs	**No**	**No**
Porous Pavements	**No**	**No**
Rain Barrels & Cisterns	**No**	**No**

The BMP Selection Process

Once site planning, pollution prevention, and source control measures have been implemented, applicants should integrate structural BMPs into the overall stormwater control system. For the most part, structural BMPs are engineered systems that are typically made of natural materials such as grass and plants, or manufactured materials like steel, fiberglass, and concrete. They act as the last line of defense in protecting the Commonwealth's waters from stormwater pollution. As such, these man-made structures can be highly effective in removing pollutants from stormwater if properly designed and maintained.

The following sections provide guidance for choosing the appropriate structural BMPs for a site by explaining the basic considerations for their use. Each BMP has certain limitations. When designing a stormwater management system for any site, the project proponent, working together with planners and design engineers, should ask the following questions:

- **How can the stormwater management system be designed to meet the standards for stormwater quantity and quality most effectively?**
- **What are the opportunities to meet the stormwater quality standards and the stormwater recharge and peak discharge standards simultaneously?**
- **What opportunities exist to use comprehensive site planning to minimize the need for structural controls?**
- **Are there Critical Areas on or adjacent to the project site?**
- **Does the project involve stormwater discharges from land uses with higher potential pollutant loads?**
- **What are the physical site constraints?**
- **Given the site conditions, which BMP types are most suitable?**
- **What type of development is being proposed and what pollutants does this land use typically generate?**
- **Is there an opportunity to receive the LID Site Design credits by incorporating environmentally sensitive design or low impact development techniques?**
- **Is the future maintenance reasonable and acceptable for this type of BMP?**
- **Has adequate access been provided for maintenance?**
- **Is the BMP option cost-effective?**
- **Does the stormwater discharge near or to an impaired surface water?**
- **Has a TMDL been developed?**
- **Are BMPs available to remove the pollutant of concern?**

The project proponent should consider whether a system of several BMPs is more appropriate for a site than a single BMP structure. Too often, stormwater controls are added to a site plan in its final stages. When planning for stormwater management is done as an afterthought, proponents are not likely to select the most environmentally appropriate and cost-effective practices for controlling runoff.

By engaging in early planning, the proponent can focus on the entire site and identify the best available locations for reducing, infiltrating and treating runoff. Early stormwater management planning can also allow the proponent to combine best management practices into treatment trains. With a treatment train, one or more of the measures can fail without undermining the integrity of the overall site control strategy.

Including stormwater management in the early stages of the planning process gives proponents the opportunity to consider whether a decentralized system comprised of BMPs scattered throughout the site may provide greater environmental benefits at less cost than a centralized system that transports all runoff to a single location for treatment and disposal. Through early planning, a proponent may discover that a decentralized system that uses dry wells for roof runoff, relies on water quality swales rather than curbs and gutters to convey street runoff to additional BMPs, and installs infiltration trenches in front of an extended dry detention basin, is the most cost-effective and environmentally protective approach to achieving compliance with the Stormwater Management Standards.

Stormwater Quantity Management

Approximating a site's pre-development hydrology, including the natural cover, is the primary goal of stormwater quantity management. A site's post-development hydrology can be controlled through a combination of stream bank/channel erosion control (2-year 24-hour storm events), flood control (10-year 24-hour and 100-year 24-hour storm events). Table 2-2 indicates the types of quantity controls provided by specific BMPs.

Table 2-2			
BMPs for Controlling Peak Discharge Rates			
	Peak Discharge Rate Control: 2-Yr. Storm	Peak Discharge Rate Control: 10-Yr. Storm	Peak Discharge Rate Control: 100-Yr. Storm
Pretreatment			
Deep sump catch basins	No	No	No
Oil grit separators	No	No	No
Proprietary separators	No	No	No
Sediment forebays	No	No	No
Vegetated filter strips	With careful design	No	No
Treatment			
Bioretention areas/rain gardens	No	No	No
Constructed stormwater wetlands	Yes	Yes	No
Extended dry detention basins	Yes	Yes	With careful design
Gravel wetlands	Yes	Yes	No
Proprietary media filters	No	No	No
Sand/Organic filters	No	No	No
Tree box filters	No	No	No
Wet Basins	Yes	Yes	With careful design
Conveyance			
Drainage channels	No	No	No
Grass Channels	No	No	No
Water Quality Swales	With careful design	With careful design	No
Infiltration BMPs			
Dry wells	No	No	No
Infiltration Basins	With careful design	With careful design for small sites	With careful design
Infiltration Trenches	Full exfiltration trench systems	Full exfiltration trench systems	Full exfiltration trench systems
Leaching catch basins	Only if sufficient leaching catch basins	Only if sufficient leaching catch basins	No
Subsurface structures	No	No	No
Other BMPs			
Dry detention basins	Yes	Yes	With careful design
Green Roofs	Yes with careful design	No	No
Porous Pavement	Yes with careful design	No	No
Rain barrels & Cisterns	Yes for cistern with careful design	No	No

Stormwater Quality Management
When designing stormwater management systems and screening BMP technologies to meet the water quality management standards, ask the following questions:

- **Does the project affect a sensitive resource?**
- **Based on existing and post-development conditions, what is the volume of stormwater to be treated for water quality?**
- **Is the water quality volume based on 0.5 inch or 1.0 inch of runoff times the impervious area?**
- **What is the best combination of BMP technologies and non-structural practices to achieve the 80% reduction of TSS loadings on an average annual basis?**
- **Does the stormwater discharge impact an impaired surface water? If so, what pollutants are the cause of that impairment? Which BMPs can remove that pollutant?**

Although the Stormwater Management Standards only require removal of TSS, a proponent must consider other pollutants, if the development or redevelopment will affect a surface water that is the subject of a Total Maximum Daily Load (TMDL) that indicates the concentrations of certain pollutants in stormwater runoff must be reduced. In that event, the proponents must design, construct, operate and maintain a stormwater management system that is consistent with the TMDL.

Stormwater Recharge

When designing stormwater management systems to meet the recharge standard, ask the following questions:

- **Based on existing and post-development conditions and soil types, what is the volume of stormwater to be recharged to groundwater?**
- **Will the infiltration BMP exfiltrate stormwater to the ground within a Zone II or Interim Wellhead Protection Area or an area with a rapid infiltration rate (greater than 2.4 inches per hour)?**
- **Is the infiltration BMP near a bathing beach, shellfish growing area, Outstanding Resource Area, Special Resource Area, or cold-water fishery?**
- **What pretreatment measures are needed to ensure that the infiltration BMP can continue to operate as designed?**

Site Suitability/BMP Suitability

In choosing an effective BMP system, it is necessary to determine the most suitable combinations of BMPs based on the characteristics of the site. The basic site requirements for each technology are included in Chapter 2. Site suitability is a major factor in choosing BMPs. Physical constraints at a site may include soil conditions, watershed size, depth to water table, depth to bedrock and slope. For redevelopment projects, physical constraints may include compacted soils or the presence of underground utilities. In some cases, a BMP may be eliminated as an option because of site constraints. Often, however, BMPs can be modified or combined with other BMPs and adapted to site conditions to create an efficient system capable of meeting the Stormwater Management Standards.

The following subsections briefly address the physical site conditions that affect BMP selection.

Soil Suitability

Generally, dry detention basins and extended dry detention basins are suitable in a broad range of soil conditions, but wet basins may have difficulty maintaining water levels in very sandy soils. Soil type is of particular importance to infiltration BMPs. Do not locate infiltration BMPs in areas with low permeability soils. (This would exclude "D" soil groups, as defined by the Natural Resources Conservation Service.) Where infiltration technologies are planned, confirm that the soils have adequate permeability.

Drainage Area/Watershed To Be Served

The size of the contributing area may be a limiting factor in selecting the appropriate BMP technology. Recommendations for appropriate contributing watershed areas are included in the discussion for each technology. Proper site planning can often overcome area constraints. Basins typically require large contributing drainage areas in order to function properly, while infiltration BMPs require smaller drainage areas. For technologies that require large contributing watersheds, additional offsite runoff may be routed to the BMP to increase flows. Conversely, portions of the total runoff can be routed to smaller individual BMPs to allow for the use of lower capacity BMPs. Keep in mind that some BMPs may have more rigorous maintenance and inspection requirements.

Depth to Water Table

Depth to the seasonal high groundwater table is an important factor for stormwater technologies, especially infiltration BMPs. If the seasonal high groundwater table extends to within two feet of the bottom of an infiltration BMP, the site is seldom considered suitable. The groundwater table acts as an effective barrier to exfiltration through the BMP media and soils below and can prevent an infiltration BMP from draining properly. Depending on soil conditions, depth to the groundwater table is also an important factor in reducing the risk of microbial contamination. For constructed stormwater wetlands and wet basins, a groundwater table at or near the surface is desirable. Areas with high groundwater tables are generally more conducive to siting these types of BMPs.

Depth to Bedrock

The depth to bedrock (or other impermeable layers) is a consideration for siting facilities that rely upon infiltration. Bedrock impedes the downward exfiltration of stormwater and prevents infiltration BMPs from draining properly. An area is generally not suitable for infiltration BMPs, if bedrock is within two feet of the bottom of the BMP. Similarly, stormwater basin BMPs are not feasible if shallow bedrock lies beneath the area to be excavated.

Slopes

Site slopes restrict the types of BMP that can be used. Water quality swales and infiltration trenches are not practical when slopes exceed 20%. To achieve water quality benefits and credit for TSS removal, proponents may not site water quality swales or grass channels on slopes greater than 5%. Where there are steeper slopes, the stormwater management system must be carefully designed to prevent stormwater runoff from bypassing the treatment BMPs and causing erosion and off-site flooding.

Thermal Enhancement

The water in wet basins and constructed stormwater wetlands warms up rapidly in summer. Warm water released from BMPs can be lethal to cold-water aquatic organisms. Do not use these BMPs in areas adjacent to designated cold-water streams.

Proximity to Critical Animal Habitats or Endangered Species
Some BMPs can be lethal traps for small animals such as frogs, salamanders, and turtles. Sediment forebays and dry detention basins with excessively steep or vertical side slopes (e.g., concrete steps) or improperly located catch basins can prevent a trapped animal from escaping. LID techniques may be more suitable for managing stormwater while at the same time, protecting indigenous animal populations as well as rare and endangered species.

Proximity to Septic Systems and Water Supplies
When evaluating the suitability of infiltration BMPs such as infiltration trenches, infiltration basins and dry wells, it is critical to consider setback requirements mandated under other state programs such as those addressing septic systems and drinking water supplies. Table 2.3 summarizes setback requirements for infiltration BMPs.

Table 2.3: Setbacks for Infiltration Structures
General Setback Requirements:
Soil Absorption Systems for Title 5 Systems: 50ft.
Private wells: 100 ft.
Public wells: Outside Zone I
Public reservoir, surface water sources for public water systems and their tributaries: Outside Zone A
Other surface waters: 50 ft.
Property Line: 10 feet
Building foundations: >10 to 100 ft., depending on the specific type of infiltration BMP. See infiltration BMP for specific setback.
Specific BMPs have additional setback requirements. See Chapter 2.

Proximity to Foundations
Infiltration of stormwater can cause seepage into foundations when BMPs are located too close to buildings; MassDEP requires a 10 to 100 foot setback depending on specific type of infiltration BMP.

Public Acceptance
Aesthetics are important in gaining acceptance of BMPs. BMPs can either enhance or degrade the amenities of the natural environment and the adjacent community. Careful planning, landscaping and maintenance can make a BMP an asset to a site. Frequently, ownership and maintenance responsibilities for BMPs in new developments fall on adjacent property owners. If adjacent residents will be expected to pay for maintenance, education and acceptance of the BMP are necessary.

BMP Treatment Trains
BMPs in series incorporate several stormwater treatment mechanisms in sequence to enhance the treatment of runoff. Known as “stormwater treatment trains,” they consist of a combination of source control measures, natural features, and structural BMPs to maximize pollutant removal and subsurface recharge. Combining nonstructural and structural measures in series rather than using a single method of treatment improves the levels and reliability of pollutant removal. The effective life of a BMP can be extended by combining it with pretreatment BMPs, such as a vegetated filter strip or sediment forebay, to remove sediment prior to treatment in the

downstream "units." Sequencing BMPs can also reduce the potential for re-suspension of settled sediments by reducing flow energy levels or providing longer flow paths for runoff.

The most suitable components for a treatment train depend on the pollutants to be removed. Pollutants in stormwater fall into two groups: suspended solids and dissolved pollutants. Particle sizes greater than 0.45 micron are considered suspended solids. Pretreatment BMPs (e.g. sediment forebay, oil grit separator) are ordinarily designed to remove suspended solids that have larger particle sizes than the dissolved solids removed by treatment practices that rely on settling (e.g. extended dry detention basins and wet basins s) or filtration (e.g. sand filters and filtering bioretention areas).

There are many combinations of BMPs that can be placed in a treatment train to maximize suspended solids removal. According to Minton (2006), some of the more common ones include:

- **A sediment forebay discharging to a wet basin flowing into a constructed stormwater wetland**
- **A water quality swale flowing into a wet basin or a constructed stormwater wetland**
- **An oil grit separator connected to a sand or organic filter**
- **A sediment forebay discharging to an extended dry detention basin connected to a sand filter**
- **A water quality swale discharging to a vegetated filter strip connected to an infiltration trench.**

BMPs by Land Use

Certain BMPs are more suitable for some land uses than others[8]. Some types of urban land uses contribute higher than normal pollutant loadings of solvents, oils, lubricants, fertilizers, grease, and/or bacteria. Table LUHPPL presents the applicability and use of various BMPs for various land uses with higher potential pollutant loads.

[8] The MassHighway Stormwater Handbook provides information on the information to consider when selecting BMPs for highway projects.

<table>
<tr><td colspan="2">Table LUHPPL: Best Management Practices for Land Uses with Higher Potential Pollutant Loads

Discharges from certain land uses with higher potential pollutant loads may be subject to additional requirements, including the need to obtain an individual or general discharge permit pursuant to the MA Clean Waters Act or Federal Clean Water Act.
All proponents must implement source control and pollution prevention.
All BMPs shall be designed in accordance with specifications and procedures in the Massachusetts Stormwater Handbook Volumes 2 and 3.
The required water quality volume equals 1inch times the total impervious area of the post-development site.
Many land uses have the potential to generate higher potential pollutant loads of oil and grease. These land uses include, without limitation, industrial machinery and equipment and railroad equipment maintenance, log storage and sorting yards, aircraft maintenance areas, railroad yards, fueling stations, vehicle maintenance and repair, construction businesses, paving, heavy equipment storage and/or maintenance, the storage of petroleum products, high-intensity-use parking lots, and fleet storage areas. To treat the runoff from such land uses, the following BMPs must be used to pretreat the runoff prior to discharge to an infiltration structure: an oil grit separator, a sand filter, organic filter, filtering bioretention area or equivalent.
44% TSS removal is required prior to discharge to an infiltration device.
Until they complete the STEP or TARP verification process outlined in Volume 2, proprietary BMPs may not be used as a terminal treatment device for runoff from land uses with higher potential pollutant loads. For the purpose of this requirement, subsurface structures, even those that have a storage chamber that has been manufactured are not proprietary BMPs, since the pretreatment occurs in the soil below the structure, not in the structure itself.
</td></tr>
<tr><td>Pretreatment</td><td></td></tr>
<tr><td rowspan="5"></td><td>Deep Sump Catch Basin</td></tr>
<tr><td>Oil Grit Separator</td></tr>
<tr><td>Proprietary Separators - See Volume 2</td></tr>
<tr><td>Sediment Forebays</td></tr>
<tr><td>Vegetated Filter Strip (must be lined)</td></tr>
<tr><td colspan="2">Treatment</td></tr>
<tr><td rowspan="8">Sand Filters, Organic Filters, Proprietary Media Filters, Wet Basins, Filtering Bioretention Areas, and Extended Dry Detention Basins must be lined and sealed unless 44% of the TSS has been removed prior to discharge to the BMP.</td><td>Filtering Bioretention Areas including rain gardens</td></tr>
<tr><td>Constructed Stormwater Wetlands</td></tr>
<tr><td>Dry Water Quality Swales</td></tr>
<tr><td>Extended Dry Detention Basins</td></tr>
<tr><td>Gravel Wetlands</td></tr>
<tr><td>Proprietary Media Filter. (Does not include catch basin inserts) (Proprietary Media Filters may be used for terminal treatment for runoff from land uses with higher potential pollutant loads, only if verified for such use by the TARP or STEP process. See Volume 2.)</td></tr>
<tr><td>Sand /Organic Filters</td></tr>
<tr><td>Wet Basins</td></tr>
<tr><td>Infiltration</td><td></td></tr>
<tr><td rowspan="5"></td><td>Exfiltrating Bioretention Areas including rain gardens</td></tr>
<tr><td>Infiltration Basins</td></tr>
<tr><td>Infiltration Trenches</td></tr>
<tr><td>Leaching Catch Basins</td></tr>
<tr><td>Subsurface Structures.</td></tr>
</table>

Redevelopment Projects

There are fewer stormwater BMP options for heavily urbanized areas (often called *ultra-urban* areas) compared to less congested areas, because of the restrictions inherent in building in urbanized areas. The primary barrier is space, or more precisely, lack of space. This limitation eliminates many space-intensive options (e.g., extended dry detention basins) and makes BMPs that can be used on a micro-scale and that have smaller "footprints" more attractive. Other considerations that can take the shape of barriers include:

Engineering Concerns
If the discharge point of a BMP is to a storm drain or an underdrain connecting to a storm drain, proponents should avoid overloading the existing system. The BMP will not work if the discharge cannot be efficiently moved off-site or out of manufactured systems like proprietary separators or oil grit separators. BMP selection must include engineering considerations such as available head, hydraulic grade lines, and the presence of pipeline bottlenecks that may worsen flooding.

Underground Utilities
The presence of underground utilities, including gas and water mains, sewer pipes and electric cable conduits in urban areas, can greatly reduce the amount of land available for redevelopment BMPs. Utility conduits can limit the ability to excavate, making BMP siting and sizing difficult.

Given these constraints, the most suitable BMPs for redevelopment include:

- Bioretention Areas/Rain Gardens
- Grass Channels
- Green Roofs
- Subsurface Structures
- Leaching Catch Basins
- Porous Pavement
- Sand Filters/Organic Filters
- Water Quality Swales (Dry)
- Deep Sump Catch Basins
- Dry Wells
- Proprietary Separators
- Infiltration Trenches
- Other Proprietary Technologies
- Rain Barrels and Cisterns
- Vegetated Filter Strips

Table SSR summarizes the ability of each of these redevelopment BMPs to provide groundwater recharge, improve water quality, and attenuate peak flows. Redevelopment projects are required to meet Standard 2, Standard 3, and the structural best management practice requirements of Standards 4, 5 and 6 *to the maximum extent practicable*.

Redevelopment projects must meet all other requirements of the Stormwater Management Standards *and* improve existing conditions using one or more of the above techniques. Chapter 3 provides a detailed checklist to help conservation commissions and applicants determine which BMPs are most appropriate in each case and what types of improvements they provide.

Table SSR

Stormwater Standards and Redevelopment				
BMPs	**Standard 7: Is BMP Suitable for Redevelopment?**	**Standard 2: Does BMP Attenuate Peak Flows?**	**Standard 3: Does BMP Provide Recharge?**	**Standard 4: Does BMP Remove TSS?**
Pretreatment				
Deep sump catch basin	Yes	No	No	Yes
Oil grit separator	Yes	No	No	Yes
Proprietary separators	Yes	No	No	Yes
Sediment forebay	Yes	No	No	Yes
Vegetated filter strip	Yes	Some with careful design	No	Yes
Treatment				
Bioretention area/rain gardens	Yes	No	Depends on design	Yes
Constructed stormwater wetlands	As retrofit for dry detention basin	Yes	No	Yes
Extended dry detention basin	As retrofit for dry detention basin	Yes	No	Yes
Gravel wetlands	As retrofit for dry detention basin	Yes	No	Yes
Proprietary media filters	Yes	No	No	Yes
Sand/Organic filters	Yes	No	No	Yes
Tree box filters	Yes	No	No	Yes
Wet basins	As retrofit for dry detention basin	Yes	No	Yes
Conveyance				
Drainage channels	Yes	No	No	No
Grass channels	Yes	No	No	Yes
Water quality swale-dry	Yes	With careful design	No	Yes
Water quality swale-wet	May not be practicable because of site constraints	N/A	N/A	N/A
Infiltration				
Dry wells	Yes, runoff from nonmetal roofs and metal roofs outside Zone II, IWPA, and industrial sites	No	Yes	Yes
Infiltration basins	May not be practicable because of site constraints	N/A	N/A	N/A
Infiltration trenches	Yes, w/pretreatment	Yes Full Exfiltration System Trenches	Yes	Yes
Leaching catch basins	Yes, w/pretreatment	Yes if sufficient catch basins	Yes	Yes
Subsurface structures	Yes w/pretreatment	No	Yes	Yes
Other BMPs				
Dry detention basin	May not be practicable because of site constraints	N/A	N/A	N/A
Green roofs	Yes	Some with careful design	No	No
Porous pavement	Yes	Some with careful design	Yes	Yes
Rain barrels & cisterns	Yes	Some for cisterns with careful design	No	No

Additional references and links for Redevelopment Projects:
U.S. Department of Transportation, Federal Highway Administration
Stormwater BMPs in an Ultra-Urban Setting: Selection and Monitoring:
www.fhwa.dot.gov/environment/ultraurb/uubmp6p2.htm
California Stormwater Quality Association
www.cabmphandbooks.com/Development.asp
Center for Watershed Protection, Urban Stormwater Retrofit Manual
http://www.cwp.org/PublicationStore/USRM.htm#usrm3

Retrofitting Existing Stormwater Management Measures

MassDEP defines retrofitting as expanding, modifying, or otherwise upgrading existing stormwater management measures. As such, retrofitting stormwater management measures can reduce some of the adverse stormwater quantity and quality impacts caused by existing land developments. In many instances, existing stormwater management measures can be dramatically improved, and downstream water bodies protected, through effective retrofitting.

Beginning in the 1970s, many new developments were constructed with dry detention basins. Many of these facilities were built to attenuate the peak flow impacts of the 10-year, 25-year, and/or 100-year 24-hour storms. Because smaller storms are typically responsible for degrading water quality and eroding stream banks, it makes sense to retrofit such facilities to control these smaller storm events.

Another important benefit of retrofitting stormwater management facilities is the opportunity to correct site nuisances, maintenance problems, and aesthetic concerns. Retrofitting also allows a community to keep pace with new stormwater management regulations and objectives. It can help a community address a particular stormwater quantity or quality problem that has developed as a result of deficiencies in existing stormwater management facilities, or a basin-wide problem that has been identified in a TMDL. Constructing new stormwater management systems at future land development sites will not be sufficient to bring all the waters of the Commonwealth into compliance with the state's water quality standards. To assure that all the state's surface waters meet their existing and designated uses, previously constructed stormwater management facilities located at redeveloped sites must be retrofitted and improved.

In addition to such basic considerations as need and cost, two important factors must be considered when evaluating retrofit possibilities:

1. Health and safety; and
2. Effectiveness.

Review these factors thoroughly before undertaking a stormwater management measure retrofit to justify the cost and effort and ensure the retrofit's long-term success.

Health and Safety

A retrofit must not increase health and safety risks in any way. For example, the storage volume in an existing dry detention basin presently used for stormwater quantity control must not be reduced to provide new stormwater quality enhancement without ensuring that the lost quantity storage will not adversely increase peak basin outflows and cause downstream flooding or erosion.

<u>Effectiveness</u>
In many retrofit situations, it may not be possible to upgrade the stormwater management measure to meet all current groundwater recharge and stormwater quality and quantity standards. This means that relative performance improvements for a range of retrofits must be evaluated to determine which one represents the optimum combination of effectiveness, viability, and cost. As a result, the final retrofit selected for an existing stormwater measure will have to be based on its relative rather than absolute effectiveness. In such relative determinations, both the costs and benefits of the evaluated retrofits become more influential factors than when an absolute performance standard is used. Chapter 3 provides guidance on the BMPs most suitable for retrofitting.

Maintenance Requirements

Too often, BMPs are constructed without plans or obligations for long-term maintenance. Chapter 2 includes the basic maintenance requirements for each structural control. The maintenance requirements for BMPs must be considered during the selection process. Because maintenance is mandatory, it is logical that BMP selection should gravitate toward measures that are more easily maintained. In general, BMPs installed *above ground* are easier to maintain than ones placed *underground.* Further, BMPs that incorporate *natural vegetation* as part of the pollutant removal process, such as bioretention areas, require less maintenance than *engineered and pre-fabricated systems*.

For most BMPs, the maintenance requirements include visual inspections (e.g., inspection of sediment forebays) and physical upkeep (e.g., removing and disposing of sediment, and mowing water quality swales). Whatever the maintenance requirements, the Stormwater Management Standards mandate that all stormwater management facilities have an Operation and Maintenance Plan. The Operation and Maintenance Plan must clearly address the following BMP maintenance issues:

- How and when maintenance is to be performed,
- How and when inspections will be performed, and
- How these tasks will be financed.

The Operations and Maintenance Plan must provide that best practical measures be implemented to conduct maintenance activities in a manner that avoids, minimizes and mitigates adverse impacts to wetland resource areas. BMPs should be designed to minimize maintenance needs wherever possible. Proponents should anticipate future maintenance problems and develop plans to alleviate them as much as possible. Preventative design measures, such as using forebays to trap incoming first-flush sediment, can reduce the future maintenance costs and requirements.

At a minimum, the Operation and Maintenance Plan must also identify:

(1) Stormwater management system owners
(2) The party or parties responsible for operation and maintenance
(3) The routine and non-routine maintenance tasks to be undertaken after construction is complete and a schedule for implementing those tasks
(4) Plan showing the location of all stormwater BMPs
(5) Description and delineation of public safety features
(6) Estimated operations and maintenance budget

For the developer, the most difficult part of preparing a maintenance plan may be identifying the party that is responsible for performing and paying for the long-term maintenance of the BMP. The Order of Conditions should require the responsible party to: (1) implement the Operation and Maintenance Plan; (2) maintain a log of all operation and maintenance activities including without limitation inspections, repairs, replacement and disposal (for disposal, the log shall indicate the type of material and the disposal location); (3) make this log available to the MassDEP and the Conservation Commission; (4) allow the MassDEP and the Conservation Commission to inspect each BMP to determine whether the responsible party is implementing the Operation and Maintenance Plan; and (5) submit the O & M Compliance Statement when requesting a Certificate of Compliance.

Volume 2
Chapter 2: Structural BMP Specifications for the Massachusetts Stormwater Handbook

Structural Pretreatment BMPs

Deep Sump Catch Basin

Oil/Grit Separators

Proprietary Separators

Sediment Forebays

Vegetated Filter Strips

Deep Sump Catch Basin

Description: Deep sump catch basins, also known as oil and grease or hooded catch basins, are underground retention systems designed to remove trash, debris, and coarse sediment from stormwater runoff, and serve as temporary spill containment devices for floatables such as oils and greases.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides no peak flow attenuation
3 - Recharge	Provides no groundwater recharge
4 - TSS Removal	25% TSS removal credit when used for pretreatment. Because of their limited effectiveness and storage capacity, deep sump catch basins receive credit for removing TSS only if they are used for pretreatment and designed as off-line systems.
5 - Higher Pollutant Loading	Recommended as pretreatment BMP. Although provides some spill control capability, a deep sump catch basin may not be used in place of an oil grit separator or sand filter for land uses that have the potential to generate runoff with high concentrations of oil and grease such as: high-intensity-use parking lots, gas stations, fleet storage areas, vehicle and/or equipment maintenance and service areas.
6 - Discharges near or to Critical Areas	May be used as pretreatment BMP. not an adequate spill control device for discharges near or to critical areas.
7 - Redevelopment	Highly suitable.

Advantages/Benefits:

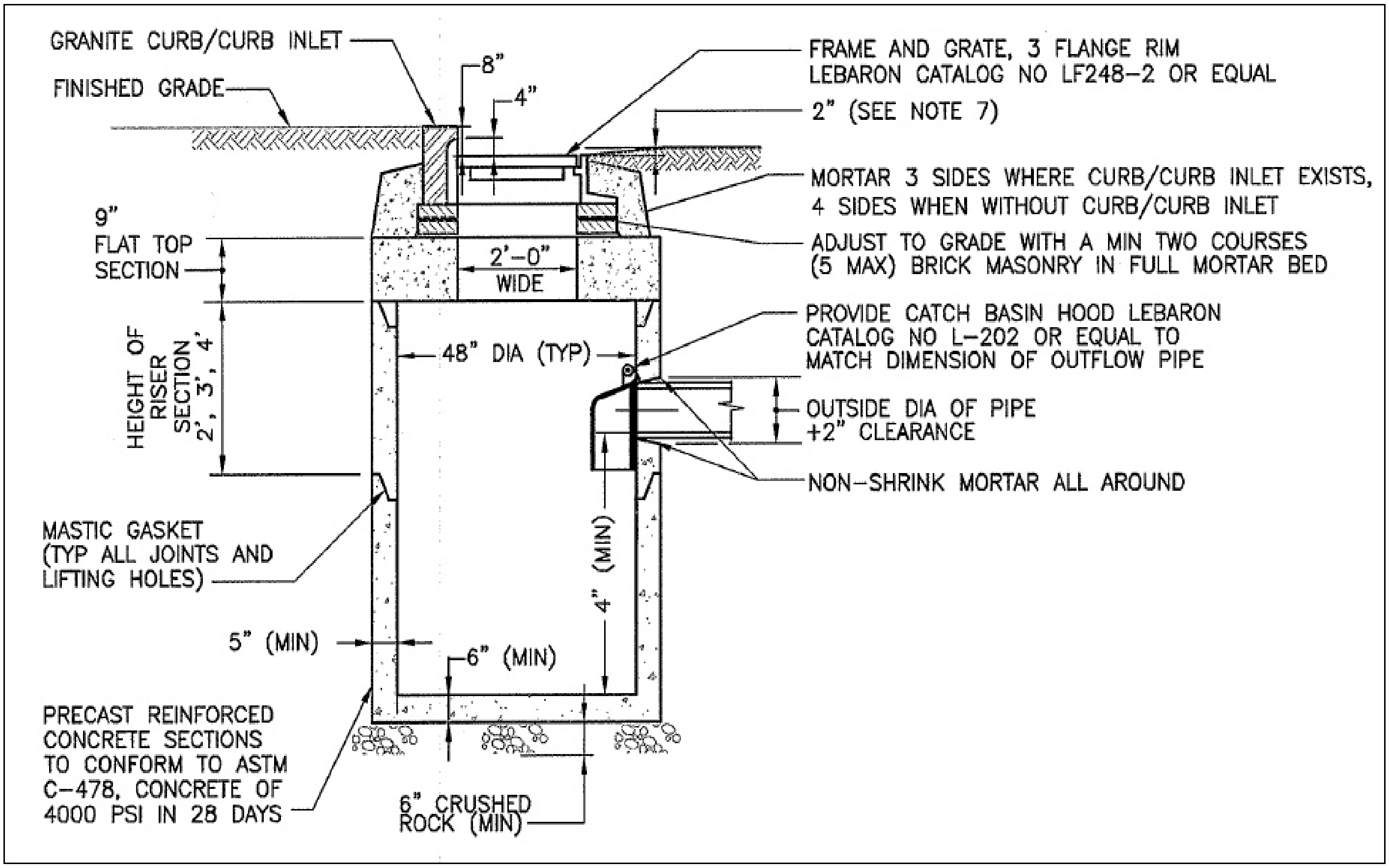
- Located underground, so limited lot size is not a deterrent.
- Compatible with subsurface storm drain systems.
- Can be used for retrofitting small urban lots where larger BMPs are not feasible.
- Provide pretreatment of runoff before it is delivered to other BMPs.
- Easily accessed for maintenance.
- Longevity is high with proper maintenance.

Disadvantages/Limitations:

- Limited pollutant removal.
- Expensive to install and maintain, resulting in high cost per unit area treated.
- No ability to control volume of stormwater
- Frequent maintenance is essential
- Requires proper disposal of trapped sediment and oil and grease
- Entrapment hazard for amphibians and other small animals

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS) - 25% (for regulatory purposes)
- Nutrients (Nitrogen, phosphorus) - Insufficient data
- Metals (copper, lead, zinc, cadmium) - Insufficient data
- Pathogens (coliform, e coli) - Insufficient data



adapted from the University of New Hampshire

Maintenance

Activity	Frequency
Inspect units	Four times per year
Clean units	Four times per year or whenever the depth of deposits is greater than or equal to one half the depth from the bottom of the invert of the lowest pipe in the basin.

Special Features

All deep sump catch basins must include hoods. For MassHighway projects, consult the Stormwater Handbook for Highways and Bridges for hood requirements.

LID Alternative

Reduce Impervious Surface
Disconnect rooftop and non-rooftop runoff
Vegetated Filter Strip

Deep Sump Catch Basin

Suitable Applications

- Pretreatment
- Residential subdivisions
- Office
- Retail

Design Considerations

- The contributing drainage area to any deep sump catch basin should not exceed ¼ acre of impervious cover.
- Design and construct deep sump catch basins as off-line systems.
- Size the drainage area so that the flow rate does not exceed the capacity of the inlet grate.
- Divert excess flows to another BMP intended to meet the water quantity requirements (peak rate attenuation) or to a storm drain system. An off-line design enhances pollutant removal efficiency, because it prevents the resuspension of sediments in large storms.

Make the sump depth (distance from the bottom of the outlet pipe to the bottom of the basin) at least four feet times the diameter of the outlet pipe and more if the contributing drainage area has a high sediment load. The minimum sump depth is 4 feet. Double catch basins, those with 2 inlet grates, may require deeper sumps. Install the invert of the outlet pipe at least 4 feet from the bottom of the catch basin grate.

The inlet grate serves to prevent larger debris from entering the sump. To be effective, the grate must have a separation between the grates of one square inch or less. The inlet openings must not allow flows greater than 3 cfs to enter the deep sump catch basin. If the inlet grate is designed with a curb cut, the grate must reach the back of the curb cut to prevent bypassing. The inlet grate must be constructed of a durable material and fit tightly into the frame so it won't be dislodged by automobile traffic. The inlet grate must not be welded to the frame so that sediments may be easily removed. To facilitate maintenance, the inlet grate must be placed along the road shoulder or curb line rather than a traffic lane.

Note that within parking garages, the State Plumbing Code regulates inlet grates and other stormwater management controls. Inlet grates inside parking garages are currently required to have much smaller openings than those described herein.

To receive the 25% removal credit, hoods must be used in deep sump catch basins. Hoods also help contain oil spills. MassHighway may install catch basins without hoods provided they are designed, constructed, operated, and maintained in accordance with the Mass Highway Stormwater Handbook.

Install the weep hole above the outlet pipe. Never install the weep hole in the bottom of the catch basin barrel.

Site Constraints

A proponent may not be able to install a deep sump catch basin because of:

- Depth to bedrock;
- High groundwater;
- Presence of utilities; or
- Other site conditions that limit depth of excavation because of stability.

Maintenance

Regular maintenance is essential. Deep sump catch basins remain effective at removing pollutants only if they are cleaned out frequently. One study found that once 50% of the sump volume is filled, the catch basin is not able to retain additional sediments.

Inspect or clean deep sump basins at least four times per year and at the end of the foliage and snow-removal seasons. Sediments must also be removed four times per year or whenever the depth of deposits is greater than or equal to one half the depth from the bottom of the invert of the lowest pipe in the basin. If handling runoff from land uses with higher potential pollutant loads or discharging runoff near or to a critical area, more frequent cleaning may be necessary.

Clamshell buckets are typically used to remove sediment in Massachusetts. However, vacuum trucks are preferable, because they remove more trapped sediment and supernatant than clamshells. Vacuuming is also a speedier process and is less likely to snap the cast iron hood within the deep sump catch basin.

Always consider the safety of the staff cleaning deep sump catch basins. Cleaning a deep sump catch basin within a road with active traffic or even within a parking lot is dangerous, and a police detail may be necessary to safeguard workers.

Although catch basin debris often contains concentrations of oil and hazardous materials such as petroleum hydrocarbons and metals, MassDEP classifies them as solid waste. Unless there is evidence that they have been contaminated by a spill or other means, MassDEP does not routinely require catch basin cleanings to be tested before disposal. Contaminated catch basin cleanings must be evaluated in accordance with the Hazardous Waste Regulations, 310 CMR 30.000, and handled as hazardous waste.

In the absence of evidence of contamination, catch basin cleanings may be taken to a landfill or other facility permitted by MassDEP to accept solid waste, without any prior approval by MassDEP. However, some landfills require catch basin cleanings to be tested before they are accepted.

With prior MassDEP approval, catch basin cleanings may be used as grading and shaping materials at landfills undergoing closure (see Revised Guidelines for Determining Closure Activities at Inactive Unlined Landfill Sites) or as daily cover at active landfills. MassDEP also encourages the beneficial reuse of catch basin cleanings whenever possible. A Beneficial Reuse Determination is required for such use.

MassDEP regulations prohibit landfills from accepting materials that contain free-draining liquids. One way to remove liquids is to use a hydraulic lift truck during cleaning operations so that the material can be decanted at the site. After loading material from several catch basins into a truck, elevate the truck so that any free-draining liquid can flow back into the structure. If there is no free water in the truck, the material may be deemed to be sufficiently dry. Otherwise the catch basin cleanings must undergo a Paint Filter Liquids Test. Go to www. Mass.gov/dep/recycle/laws/cafacts.doc for information on all of the MassDEP requirements pertaining to the disposal of catch basin cleanings.

Oil/Grit Separators

Description: Oil/grit separators are underground storage tanks with three chambers designed to remove heavy particulates, floating debris and hydrocarbons from stormwater.

Stormwater enters the first chamber where heavy sediments and solids drop out. The flow moves into the second chamber where oils and greases are removed and further settling of suspended solids takes place. Oil and grease are stored in this second chamber for future removal. After moving into the third outlet chamber, the clarified stormwater runoff is then discharged to a pipe and another BMP. There are other separators that may be used for spill control.

Advantages/Benefits:

- Located underground so limited lot size not a deterrent in urban areas with small lots
- Can be used for retrofits
- Can be installed in any soil or terrain.
- Public safety risks are low.

Disadvantages/Limitations:

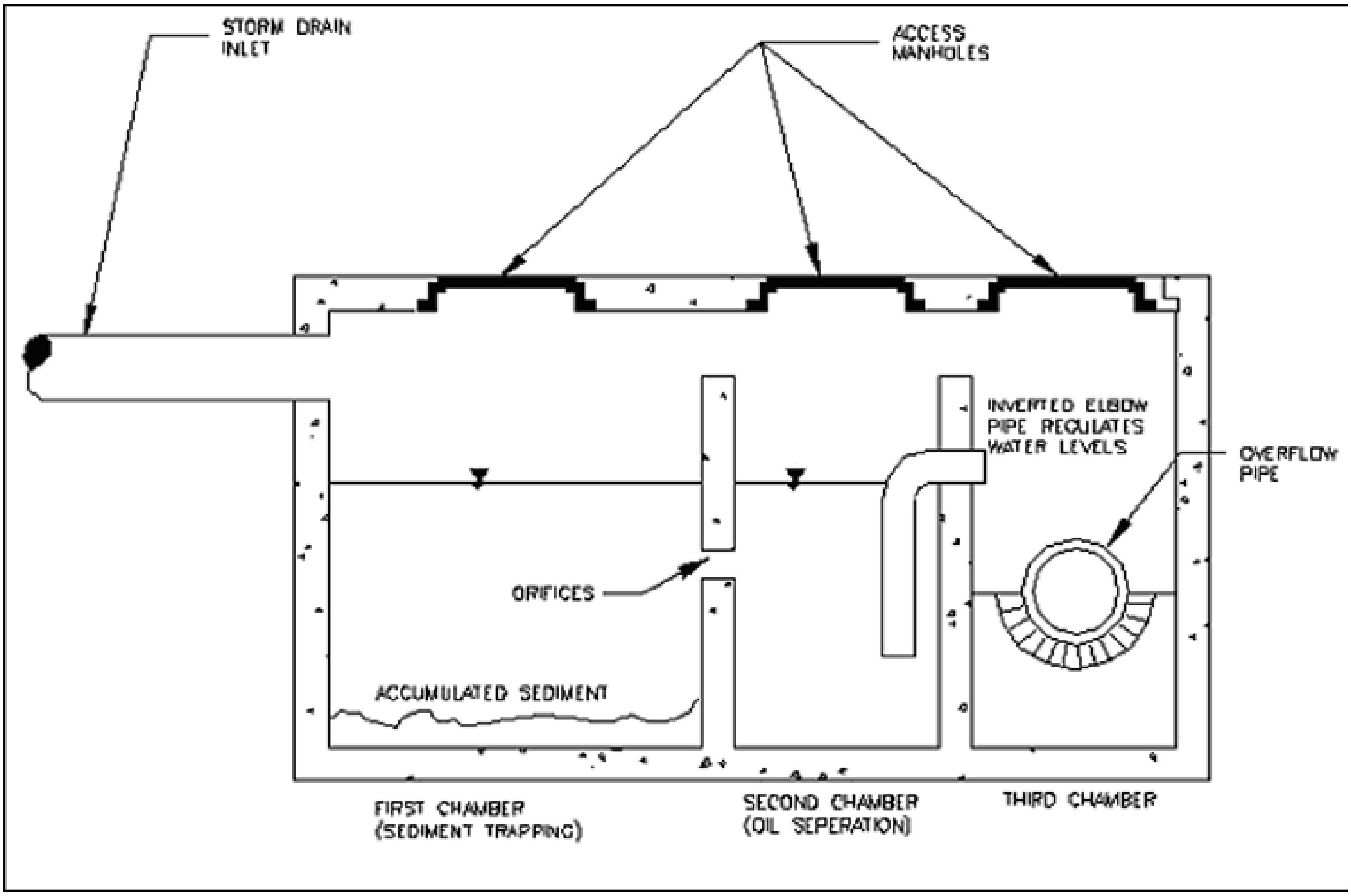
- Limited pollutant removal; cannot effectively remove soluble pollutants, fine particles, or bacteria
- Can become a source of pollutants due to resuspension of sediment unless properly maintained
- Susceptible to flushing during large storms
- Limited to relatively small contributing drainage areas
- Requires proper disposal of trapped sediments and oils
- May be expensive to construct and maintain
- Entrapment hazard for amphibians and other small animals

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS) - 25% for oil grit separator, only when placed off-line and only when used for pretreatment
- Nutrients (Nitrogen, phosphorus) - Insufficient data
- Metals (copper, lead, zinc, cadmium) - Insufficient data
- Pathogens (coliform, e coli) - Insufficient data

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides no peak flow attenuation
3 - Recharge	Provides no groundwater recharge
4 - TSS Removal	25% TSS removal credit when used for pretreatment and placed off-line.
5 - Higher Pollutant Loading	MassDEP requires a pretreatment BMP, such as an oil/grit separator that is capable of removing oil and grease, for land uses with higher potential pollutant loads where there is a risk of petroleum spills such as: high intensity use parking lots, gas stations, fleet storage areas, vehicle and/or equipment maintenance and service areas.
6 - Discharges near or to Critical Areas	May be a pretreatment BMP when combined with other practices. May serve as a spill control device.
7 - Redevelopment	Highly suitable.



MassHighway 2004

Maintenance

Activity	Frequency
Inspect units	After every major storm but at least monthly
Clean units	Twice a year

Oil/Grit Separators

Applicability

Oil grit separators must be used to manage runoff from land uses with higher potential pollutant loads where there is a risk that the stormwater is contaminated with oil or grease. These uses include the following:

- High-Intensity-Use Parking Lots
- Gas Fueling Stations
- Vehicles (including boats, buses, cars, and trucks) and Equipment Service and Maintenance Areas
- Fleet Storage Areas

Design Considerations

- Dovetail design practices, source controls and pollution prevention measures with separator design.
- Place separators before all other structural stormwater treatment practices (except for structures associated with source control/ pollution prevention such as drip pans and structural treatment practices such as deep sump catch basins that double as inlets).
- Limit the contributing drainage area to the oil/grit separator to one acre or less of impervious cover.
- Use oil grit separators only in off-line configurations to treat the required water quality volume.
- Provide pool storage in the first chamber to accommodate the required water quality volume or 400 cubic feet per acre of impervious surface. Confirm that the oil/grit separator is designed to treat the required water quality volume.
- Make the permanent pool at least 4 feet deep.
- Design the device to pass the 2-year 24-hour storm without interference and provide a bypass for larger storms to prevent resuspension of solids.
- Make oil/grit separator units watertight to prevent possible groundwater contamination.
- Use a trash rack or screen to cover the discharge outlet and orifices between chambers.
- Provide each chamber with manholes and access stepladders to facilitate maintenance and allow cleaning without confined space entry.
- Seal potential mosquito entry points.
- Install any pump mechanism downstream of the separator to prevent oil emulsification.
- Locate an inverted elbow pipe between the second and third chambers and with the bottom of the elbow pipe at least 3 feet below the second chamber's permanent pool.
- Provide appropriate removal covers that allow access for observation and maintenance.
- Where the structure is located below the seasonal high groundwater table, design the structure to prevent flotation.
- For gas stations, automobile maintenance and service areas, and other areas where large volumes of petroleum and oil are handled, consider adding coalescing plates to increase the effectiveness of the device and reduce the size of the units. A series of coalescing plates constructed of oil-attracting materials such as polypropylene typically spaced one inch apart attracts small droplets of oil, which begin to concentrate until they are large enough to float to the surface.

Maintenance

Sediments and associated pollutants and trash are removed only when inlets or sumps are cleaned out, so regular maintenance is essential. Most studies have linked the failure of oil grit separators to the lack of regular maintenance. The more frequent the cleaning, the less likely sediments will be resuspended and subsequently discharged. In addition, frequent cleaning also makes more volume available for future storms and enhances overall performance. Cleaning includes removal of accumulated oil and grease and sediment using a vacuum truck or other ordinary catch basin cleaning device. In areas of high sediment loading, inspect and clean inlets after every major storm. At a minimum, inspect oil grit separators monthly, and clean them out at least twice per year. Polluted water or sediments removed from an oil grit separator should be disposed of in accordance with all applicable local, state and federal laws and regulations including M.G.L.c. 21C and 310 CMR 30.00.

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U.S. EPA, 1999, Storm Water Technology Fact Sheet, Water Quality Inlets, EPA 832-F-99-029, http://www.epa.gov/owm/mtb/wtrqlty.pdf

Proprietary Separators

Description: A proprietary separator is a flow-through structure with a settling or separation unit to remove sediments and other pollutants. They typically use the power of swirling or flowing water to separate floatables and coarser sediments, are typically designed and manufactured by private businesses, and come in different sizes to accommodate different design storms and flow conditions. Some rely solely on gravity separation and contain no swirl chamber. Since proprietary separators can be placed in almost any location on a site, they are particularly useful when either site constraints prevent the use of other stormwater techniques or as part of a larger treatment train. The effectiveness of proprietary separators varies greatly by size and design, so make sure that the units are sized correctly for the site's soil conditions and flow profiles, otherwise the unit will not work as designed.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides no peak flow attenuation
3 - Recharge	Provides no groundwater recharge
4 - TSS Removal	Varies by unit. Must be used for pretreatment and be placed first in the treatment train to receive TSS removal credit. Follow procedures described in Chapter 4 to determine TSS credit.
5 - Higher Pollutant Loading	Suitable as pretreatment device.
6 - Discharges near or to Critical Areas	Suitable as pretreatment device or potentially a spill control device
7 - Redevelopment	Suitable as pretreatment device or treatment device if it is not possible to provide other BMPs.

Advantages/Benefits:

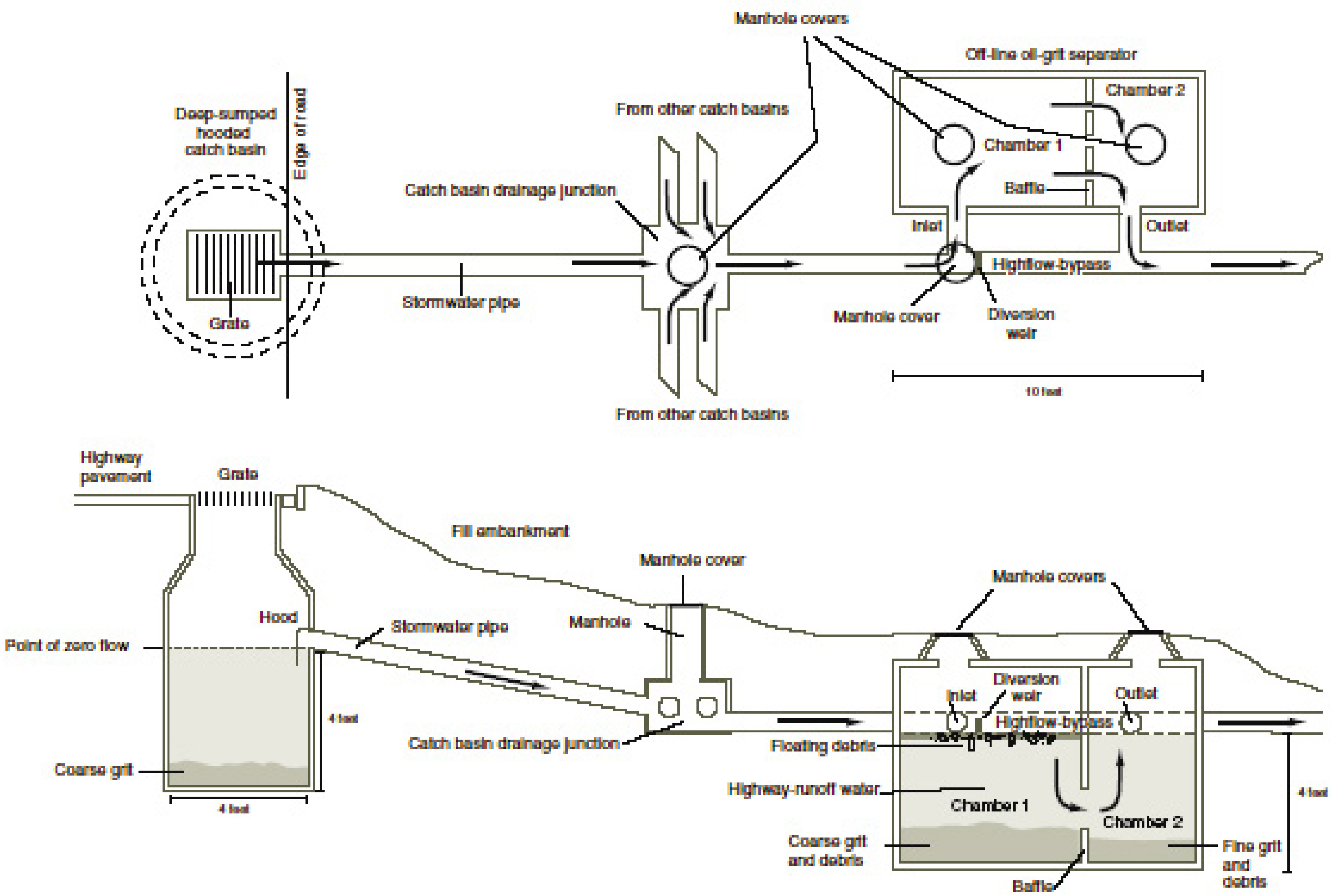
- Removes coarser sediment.
- Useful on constrained sites.
- Can be custom-designed to fit specific needs of a specific site.

Disadvantages/Limitations:

- Removes only coarse sediment fractions
- Provides no recharge to groundwater
- No control of the volume of runoff
- Frequent maintenance is essential

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS) - Varies.
- Nutrients (Nitrogen, phosphorus) - Insufficient data
- Metals (copper, lead, zinc, cadmium) - Insufficient data
- Pathogens (coliform, e coli) - Insufficient data



Schematic section of a deep-sump hooded catch basin and a 1,500-gallon off-line water quality inlet.

adapted from the MassHighway Storm Water Handbook for Highways

Maintenance

Activity	Frequency
Inspect in accordance with manufacturer requirements, but no less than twice a year following installation, and no less than once a year thereafter.	See activity
Remove sediment and other trapped pollutants at frequency or level specified by manufacturer.	See manufacturer information

Special Features

Can be custom-designed to fit specific needs at a specific site.

LID Alternative

Reduce impervious surfaces

Disconnect runoff from non-metal roofs, roadways, and driveways

Proprietary Separators

Applicability
Because they have limited pollutant removal and storage capacity, proprietary separators must be used for pretreatment only. Because they are placed underground, proprietary separators may be the only structural pretreatment BMPs feasible on certain constrained redevelopment sites where space or storage is not available for more effective BMPs. They may be especially useful in ultra-urban settings such as Boston or Worcester. Some proprietary separators may be used for spill control.

Effectiveness
Proprietary separators have a wide range of TSS efficiencies. To assess the ability of proprietary separators to remove TSS and other pollutants, a proponent should follow the procedures set forth in Chapter 4. The specific units proposed for a particular project cannot be effective unless they are sized correctly. Proprietary separators are usually sized based on flow rate. A proprietary separator must be sized to treat the required water quality volume. To be effective at removing TSS and other pollutants the system must be designed, constructed, and maintained in accordance with the manufacturer's specifications and the specifications in this Handbook.

Planning Considerations
To receive TSS removal credit, proprietary separators must be used for pretreatment and placed at the beginning of a stormwater treatment train. They can be configured either in-line or if subject to higher flows, off-line to reduce scouring. They must be sized in accordance with the manufacturer's specifications and the specifications in this Handbook. Proprietary separators used as spill control devices may have to be sized differently than those used for TSS removal.

Design
The design of proprietary separators varies by manufacturer. Units are typically precast concrete, but larger systems may be cast in place. Units may have baffles or other devices to direct incoming water into and through a series of chambers, slowing the water down to allow sediment to drop out into internal storage areas, then directing this pre-treated water to exit to other treatment or infiltration devices. In some cases, flow will be introduced tangentially, to induce swirl or vortex. Units may include skirts or weirs, to keep trapped sediments from becoming re-entrained. Some units combine a catch basin with the treatment function, providing off-line rather than in-line treatment.

Generally they are placed below ground on a gravel or stone base. Make sure all units contain inspection and access ports so that they may be inspected and cleaned. During design, take care to place the inspection and access ports where they will be accessible. Do not place the ports in locations such as travel lanes of roadways/highways and parking stalls.

Construction
Install construction barriers around the excavation area to prevent access by pedestrians. Use diversions and other soil erosion practices up-slope of the proprietary separator to prevent runoff from entering the site before construction of the units is complete. Implement practices to prevent construction period runoff from being discharged to the units until construction is complete and the soil is stabilized. Stabilize all surrounding area and any established outlets. Remove temporary structures after vegetation is established.

Maintenance
Inspect and clean these units in strict accordance with manufacturers' recommendations and requirements. Clean the units using the method specified by the manufacturer. Vactor trucks are typically used to clean these units. Clamshell buckets typically used for cleaning catch basins are almost never allowed by manufacturers. Sometimes it will be necessary to remove sediment manually.

Adapted from:
MassHighway. Storm Water Handbook for Highways and Bridges. May 2004.

Sediment Forebays

Description: A sediment forebay is a post-construction practice consisting of an excavated pit, bermed area, or cast structure combined with a weir, designed to slow incoming stormwater runoff and facilitating the gravity separation of suspended solids. This practice is different from a sediment trap used as a construction period BMP.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides no peak flow attenuation
3 - Recharge	Provides no groundwater recharge
4 - TSS Removal	MassDEP requires a sediment forebay as pretreatment before stormwater is discharged to an extended dry detention basin, wet basin, constructed stormwater wetland or infiltration basin. No separate credit is given for the sediment forebay. For example, extended dry detention basins with sediment forebays receive a credit for 50% TSS removal. Wet basins and constructed stormwater wetlands with sediment forebays receive a credit for 80% TSS removal. When they provide pretreatment for other BMPs, sediment forebays receive a 25% TSS removal credit.
5 - Higher Pollutant Loading	Recommended as a pretreatment BMP
6 - Discharges near or to Critical Areas	Recommended as a pretreatment BMP
7 - Redevelopment	Usually not suitable due to land use constraints

Advantages/Benefits:

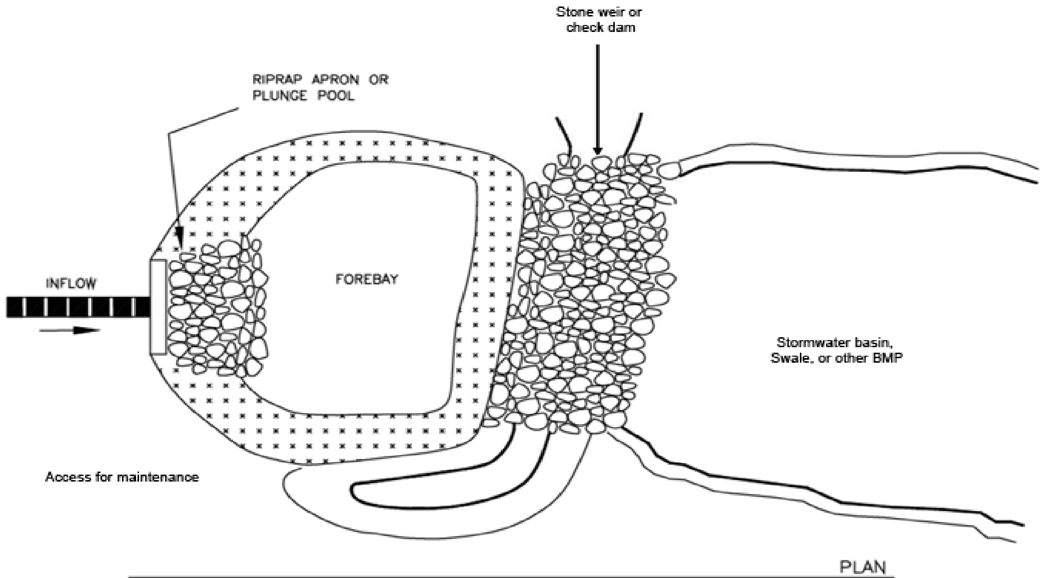
- Provides pretreatment of runoff before delivery to other BMPs.
- Slows velocities of incoming stormwater
- Easily accessed for sediment removal
- Longevity is high with proper maintenance
- Relatively inexpensive compared to other BMPs
- Greater detention time than proprietary separators

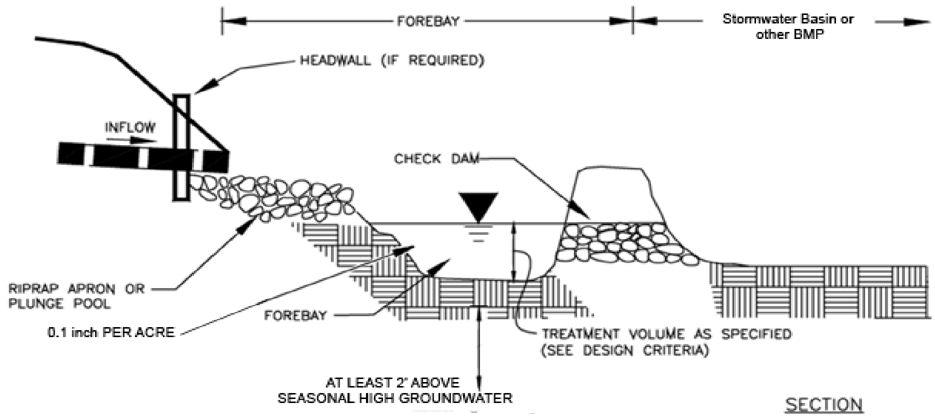
Disadvantages/Limitations:

- Removes only coarse sediment fractions
- No removal of soluble pollutants
- Provides no recharge to groundwater
- No control of the volume of runoff
- Frequent maintenance is essential

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS) - 25%
- Nutrients (Nitrogen, phosphorus) - Insufficient data
- Metals (copper, lead, zinc, cadmium) - Insufficient data
- Pathogens (coliform, e coli) - Insufficient data





adapted from the Vermont Stormwater Handbook

Maintenance

Activity	Frequency
Inspect sediment forebays	Monthly
Clean sediment forebays	Four times per year and when sediment depth is between 3 to 6 feet.

Special Features

MassDEP requires a sediment forebay as pretreatment before discharging to a dry extended detention basin, wet basin, constructed stormwater wetland, or infiltration basin.

MassDEP uses the term sediment forebay for BMPs used to pretreat stormwater after construction is complete and the site is stabilized. MassDEP uses the term sediment trap to refer to BMPs used for erosion and sedimentation control during construction. For information on the design and construction of sediment traps used during construction, consult the Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas: A Guide for Planners, Designers and Municipal Officials.

Sediment Forebays

Design

Sediment forebays are typically on-line units, designed to slow stormwater runoff and settle out sediment.

At a minimum, size the volume of the sediment forebay to hold 0.1-inch/impervious acre to pretreat the water quality volume.

When routing the 2-year and 10-year storms through the sediment forebay, design the forebay to withstand anticipated velocities without scouring.

A typical forebay is excavated below grade with earthen sides and a stone check dam.

Design elevated embankments to meet applicable safety standards.

Stabilize earth slopes and bottoms using grass seed mixes recommended by the NRCS and capable of resisting the anticipated shearing forces associated with velocities to be routed through the forebay. Use only grasses. Using other vegetation will reduce the storage volume in the forebay. Make sure that the selected grasses are able to withstand periodic inundation under water, and drought- tolerant during the summer. MassDEP recommends using a mix of grasses rather than relying upon a single grass species.

Alternatively, the bottom floor may be stabilized with concrete or stone to aid maintenance. Concrete floors or pads, or any hard bottom floor, greatly facilitate the removal of accumulated sediment.

When the bottom floor is vegetated, it may be necessary to remove accumulated sediment by hand, along with re-seeding or re-sodding grasses removed during maintenance.

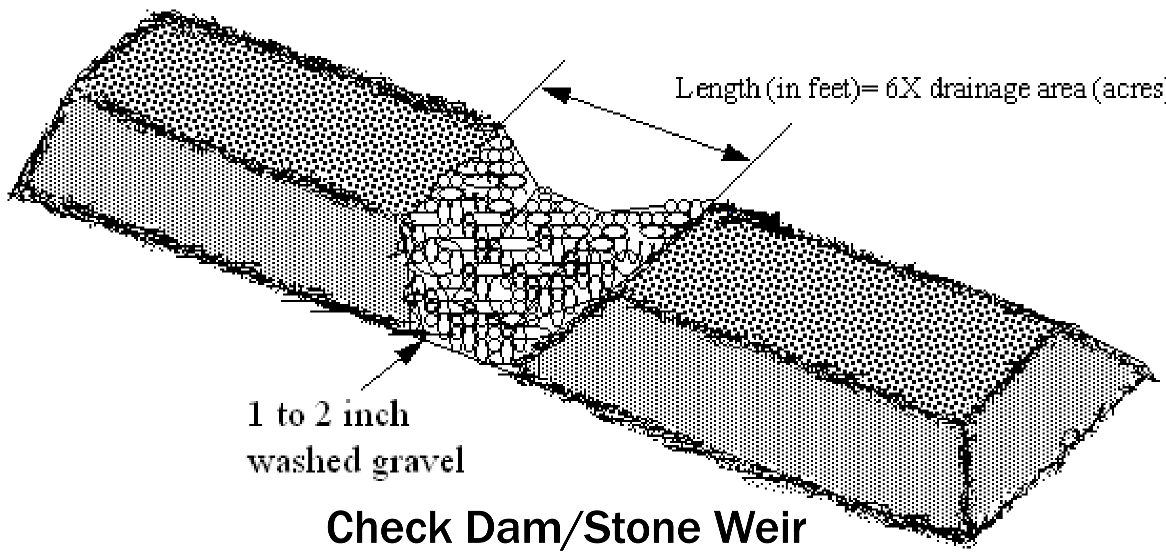
Design sediment forebays to make maintenance accessible and easy. If machinery is required to remove the sediment, carefully incorporate equipment access in the design. Sediment forebays may require excavation so concrete flooring may not always be appropriate.

Include sediment depth markers to simplify inspections. Sediment markers make it easy to determine when the sediment depth is between 3 and 6 feet and needs to be removed. Make the side slopes of sediment forebays no steeper than 3:1. Design the sediment forebay so that the discharge or outflow velocity can control the 2-year peak discharge without scour. Design the channel geometry to prevent erosion from the 2-year peak discharge.

Do not confuse post-construction sediment forebays with the sediment traps used as a construction-period control. Construction-period sediment control traps are sized larger than forebays, because there is a greater amount of suspended solids in construction period runoff. Construction-period sediment traps are sized based on drainage area and not impervious acre. Never use a construction-period sediment trap for post-construction drainage purposes unless it is first brought off-line, thoroughly cleaned (including check dam), and stabilized before being made re-operational.

Refer to the section of this chapter for information on the design of the check dam component of the sediment forebay. Set the minimum elevation of the check dam to hold a volume of 0.1-inch of runoff/ impervious acre. Check dam elevations may be uniform or they may contain a weir (e.g., when the top of the check dam is set to the 2-year or 10-year storm, and the bottom of the weir is set to the top of the 0.1-inch/impervious acre volume). When a weir is included in a stone berm, make sure that the weir is able to hold its shape. Fabric or wire may be required.

Unless part of a wet basin, post construction sediment forebays must be designed to dewater between storms. Set the bottom of the forebay at a minimum of 2 feet above seasonal high groundwater, and place pervious material on the bottom floor to facilitate dewatering between storms. For design purposes, use 72 hours to evaluate dewatering, using the storm that produces either the ½ inch or 1-inch of runoff (water quality volume) in a 24-hour period. A stone check dam can act as a filter berm, allowing water to percolate through the check dam. Depending on the head differential, a stone check dam may allow greater dewatering than an earthen berm.



Check Dam/Stone Weir

MassDEP Stormwater Handbook, 1996

Maintenance

Sediments and associated pollutants are removed only when sediment forebays are actually cleaned out, so regular maintenance is essential. Frequently removing accumulated sediments will make it less likely that sediments will be resuspended. At a minimum, inspect sediment forebays monthly and clean them out at least four times per year. Stabilize the floor and sidewalls of the sediment forebay before making it operational, otherwise the practice will discharge excess amounts of suspended sediments. When mowing grasses, keep the grass height no greater than 6 inches. Set mower blades no lower than 3 to 4 inches. Check for signs of rilling and gullying and repair as needed. After removing the sediment, replace any vegetation damaged during the clean-out by either reseeding or re-sodding. When reseeding, incorporate practices such as hydroseeding with a tackifier, blanket, or similar practice to ensure that no scour occurs in the forebay, while the seeds germinate and develop roots.

Vegetated Filter Strips

Description: Vegetated filter strips, also known as filter strips, grass buffer strips and grass filters, are uniformly graded vegetated surfaces (i.e., grass or close-growing native vegetation) that receive runoff from adjacent impervious areas. Vegetated filter strips typically treat sheet flow or small concentrated flows that can be distributed along the width of the strip using a level spreader. Vegetated filter strips are designed to slow runoff velocities, trap sediment, and promote infiltration, thereby reducing runoff volumes.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides some peak flow attenuation but usually not enough to achieve compliance with Standard 2
3 - Recharge	No recharge credit
4 - TSS Removal	If greater than or equal to 25' and less than 50' wide, 10% TSS removal. If greater than or equal to 50' wide, 45% TSS removal.
5 - Higher Pollutant Loading	May be used as part of a pretreatment train if lined
6 - Discharges near or to Critical Areas	May be used as part of a pretreatment train if lined. May be used near cold-water fisheries.
7 - Redevelopment	Suitable for pretreatment or as a stand-alone practice if sufficient land is available.

Advantages/Benefits:

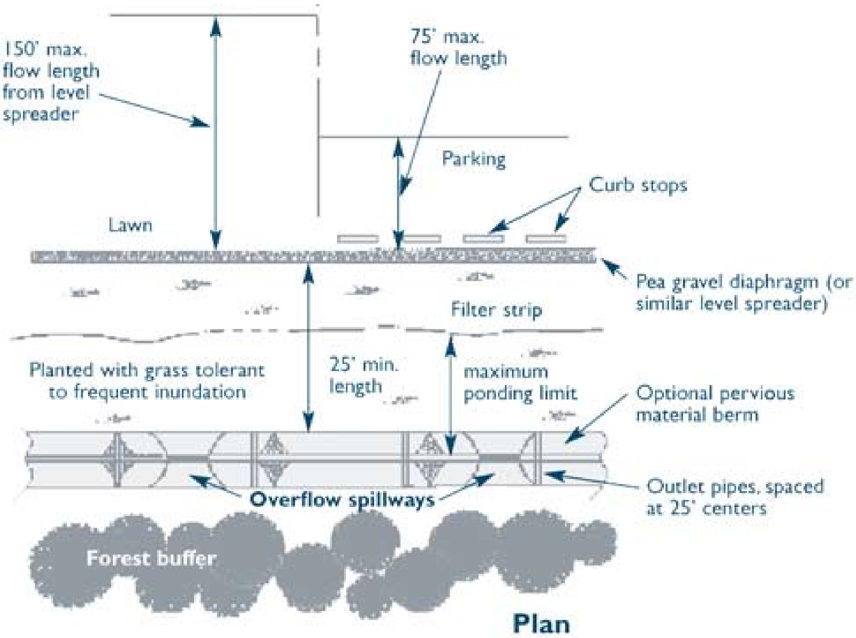
- Reduces runoff volumes and peak flows.
- Slows runoff velocities and removes sediment.
- Low maintenance requirements.
- Serves as an effective pretreatment for bioretention cells
- Can mimic natural hydrology
- Small filter strips may be used in certain urban settings.
- Ideal for residential settings and to treat runoff from small parking lots and roads.
- Can be used as part of runoff conveyance system in combination with other BMPs
- Little or no entrapment hazard for amphibians or other small creatures

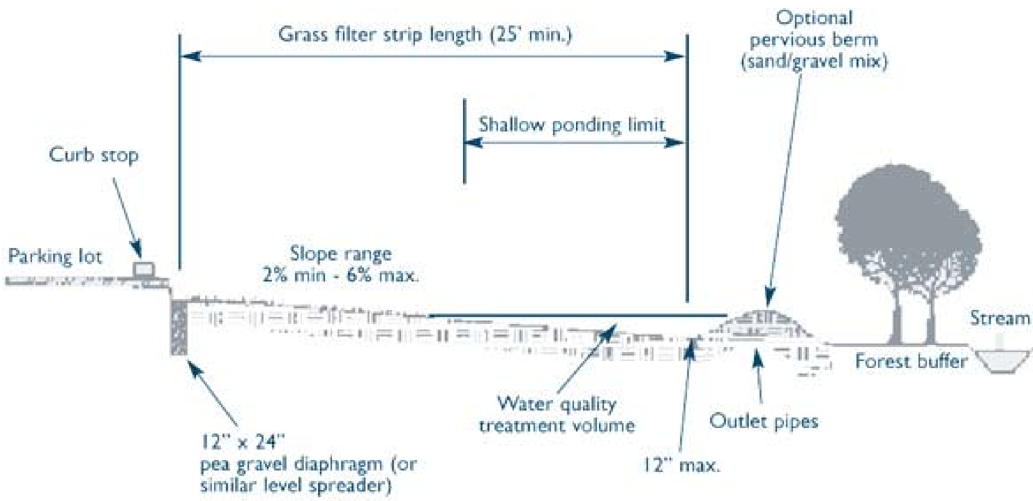
Disadvantages/Limitations:

- Variability in removal efficiencies, depending on design
- Little or no treatment is provided if the filter strip is short-circuited by concentrated flows.
- Often a poor retrofit option due to large land requirements.
- Effective only on drainage areas with gentle slopes (less than 6 percent).
- Improper grading can greatly diminish pollutant removal.

Pollutant Removal Efficiencies

• TSS (if filter strip is 25 feet wide)	10% assumed (Regulatory)
• TSS (if filter strip is 50 feet wide)	45% assumed (Regulatory)
• Nutrients (Nitrogen, phosphorus)	Insufficient data
• Metals (copper, lead, zinc, cadmium)	Insufficient data
• Pathogens (coliform, e coli)	Insufficient data





adapted from the "Design of Stormwater Systems" 1996

Maintenance

Activity	Frequency
Inspect the level spreader for sediment buildup and the vegetation for signs of erosion, bare spots, and overall health.	Every six months during the first year. Annually thereafter.
Regularly mow the grass.	As needed
Remove sediment from the toe of slope or level spreader and reseed bare spots.	As needed

Special Features

Include an impermeable liner and underdrain for discharges from Land Use with Higher Potential Pollutant Loads and for discharges within Zone IIs and Interim Wellhead Protection Areas; for discharges near or to other critical areas or in soils with rapid infiltration rates greater than 2.4 inches per hour.

Vegetated Filter Strips

Applicability

Vegetated filter strips are used to pretreat sheet flow from roads, highways, and small parking lots. In residential settings, they are useful in pretreating sheet flow from driveways. They provide effective pretreatment, especially when combined with bioretention areas and stream buffers. Urban areas can sometimes accommodate small filter strips depending on available land area, making them potential retrofit options in certain urban settings. Vegetated filter strips can also be used as side slopes of grass channels or water quality swales to enhance infiltration and remove sediment.

Effectiveness

Variable TSS removal efficiencies have been reported for filter strips, depending on the size of the contributing drainage area, the width of the filter strip, the underlying parent soil, the land slope, the type of vegetation, how well the vegetation is established, and maintenance practices. Vegetated filter strips may remove nutrients and metals depending on the length and slope of the filter, soil permeability, size and characteristics of the drainage area, type of vegetative cover, and runoff velocity.

Planning Considerations

Vegetated filter strips may be used as a stand-alone practice for redevelopments, only where other practices are not feasible. Vegetated filter strips can be designed to fit within the open space and rights of way that are available along roads and highways. Do not design vegetated filter strips to accept runoff from land uses with higher potential pollutant loads (LUHHPL) without a liner. Vegetated filter strips function best for drainage areas of one acre or less with gentle slopes.

Design

Do not locate vegetated filter strips in soils with high clay content that have limited infiltration or in soils that cannot sustain grass cover.

The filter strip cannot extend more than 50 feet into a Buffer Zone to a wetland resource area.

The contributing drainage area to a vegetated filter strip is limited to one acre of less.

Design vegetated filter strips with slopes between 2 and 6 percent. Steeper slopes tend to create concentrated flows. Flatter slopes can cause ponding and create mosquito-breeding habitat.

Design the top and toe of the slope to be as flat as possible. Use a level spreader at the top of the slope to evenly distribute overland flows or concentrated runoff across the entire length of the filter strip. Many variations of level spreader designs may be used including level trenches, curbing and concrete weirs. The key to any level spreader design is creating a continuous overflow elevation along the entire width of the filter strip.

Velocity dissipation (e.g. by using riprap) may be required for concentrated flows.

Design the filter strip to drain within 24 hours after a storm. The design flow depth must not exceed 0.5 inches.

To recieve TSS removal credit, make the filter strip at least 25 feet long and generally as wide as the area draining to the strip. To prevent high-velocity concentrated flows, the length of the flow path must be limited to 75 feet if the filter strip handles runoff from impervious surfaces, and 150 feet if the filter strip handles runoff from pervious surfaces. The minimum width of the filter strip must be 20% of the length of the flow path or 8 feet, whichever is greater.

To prevent groundwater contamination, the filter strip must be constructed at least 2 feet above seasonal high groundwater and 2 to 4 feet above bedrock.

The filter strip must be planted with grasses that are relatively salt-tolerant. Select grasses to withstand high flow velocities under wet weather conditions.

A vegetated filter strip may be used as a qualifying pervious area for purposes of the LID Site Design Credits for disconnecting rooftop and nonroof top runoff.

Construction

Proper grading is essential to establish sheet flow from the level spreader and throughout the filter strip.

Implement soil stabilization measures until permanent vegetation is established.

Protect the area to be used for the filter strip by using upstream sediment traps.

Use as much of the existing topsoil on the site as possible to enhance plant growth.

Maintenance

Regular maintenance is critical for filter strips to be effective and to ensure that flow does not short-circuit the system. Conduct semi-annual inspections during the first year (and annually thereafter). Inspect the level spreader for sediment buildup and the vegetation for signs of erosion, bare spots, and overall health. Regular, frequent mowing of the grass is required. Remove sediment from the toe of slope or level spreader, and reseed bare spots as necessary. Periodically, remove sediment that accumulates near the top of the strip to maintain the appropriate slope and prevent formation of a "berm" that could impede the distribution of runoff as sheet flow.

When the filter strip is located in the buffer zone to a wetland resource area, the operation and maintenance plan must include strict measures to ensure that maintenance operations do not alter the wetland resource areas. Please note, filter strips are restricted to the outer 50 feet of the buffer zone.

Cold Climate Considerations

In cold climates such as Massachusetts, the depth of soil media that serves as the planting bed must extend below the frost line to minimize the effects of freezing. Avoid using peat and compost media, which retain water and freeze during the winter, and become impermeable and ineffective.

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Treatment BMPs

Bioretention Areas & Rain Gardens

Constructed Stormwater Wetlands

Extended Dry Detention Basins

Proprietary Media Filters

Sand & Organic Filters

Wet Basins

Bioretention Areas & Rain Gardens

Description: Bioretention is a technique that uses soils, plants, and microbes to treat stormwater before it is infiltrated and/or discharged. Bioretention cells (also called rain gardens in residential applications) are shallow depressions filled with sandy soil topped with a thick layer of mulch and planted with dense native vegetation. Stormwater runoff is directed into the cell via piped or sheet flow. The runoff percolates through the soil media that acts as a filter.

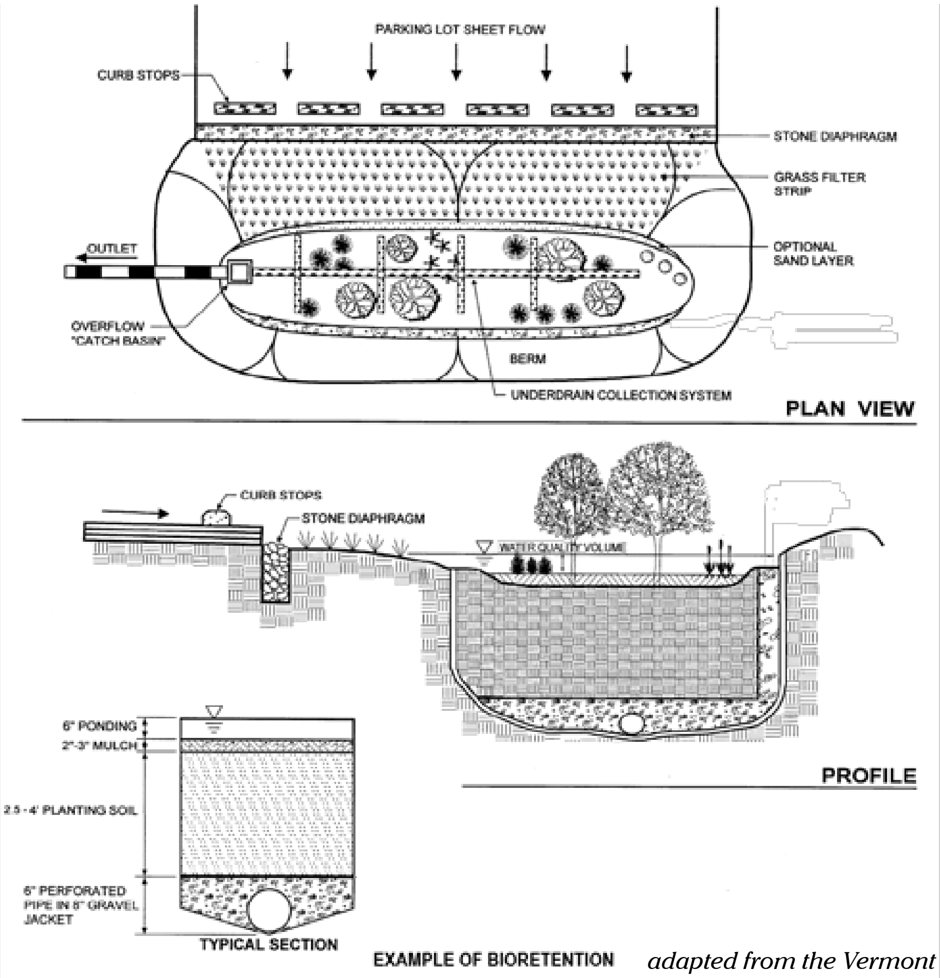
There are two types of bioretention cells: those that are designed solely as an organic filter filtering bioretention areas and those configured to recharge groundwater in addition to acting as a filter exfiltrating bioretention areas. A filtering bioretention area includes an impermeable liner and underdrain that intercepts the runoff before it reaches the water table so that it may be conveyed to a discharge outlet, other best management practices, or the municipal storm drain system. An exfiltrating bioretention area has an underdrain that is designed to enhance exfiltration of runoff into the groundwater.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	N/A
3 - Recharge	An exfiltrating bioretention area provides groundwater recharge.
4 - TSS Removal	90% TSS removal credit with adequate pretreatment
5 - Higher Pollutant Loading	Can be used for certain land uses with higher potential pollutant loads if lined and sealed until adequate pretreatment is provided. Adequate pretreatment must include 44% TSS removal prior to infiltration. For land uses that have the potential to generate runoff with high concentrations of oil and grease such as high intensity use parking lots and gas stations, adequate pretreatment may also include an oil grit separator, sand filter or equivalent. In lieu of an oil grit separator or sand filter, a filtering bioretention area also may be used as a pretreatment device for infiltration practices exfiltrating runoff from land uses with a potential to generate runoff with high concentrations of oil and grease.
6 - Discharges near or to Critical Areas	Good option for discharges near cold-water fisheries. Should not be used near bathing beaches and shellfish growing areas.
7 - Redevelopment	Suitable with appropriate pretreatment

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	90% with vegetated filter strip or equivalent
• Total Nitrogen	30% to 50% if soil media at least 30 inches
• Total Phosphorus	30% to 90%
• Metals (copper, lead, zinc, cadmium)	40% to 90%
• Pathogens (coliform, e coli)	Insufficient data



adapted from the Vermont Stormwater Manual

Special Features:

- Can be lined and sealed to prevent recharge where appropriate
- Adequate pretreatment is essential
- Not recommended in areas with steep slope
- Depth of soil media depends on type of vegetation that is proposed
- Soil media must be 30 inches deep to achieve removal of nitrogen

Advantages/Benefits:

- Can be designed to provide groundwater recharge and preserves the natural water balance of the site
- Can be designed to prevent recharge where appropriate
- Supplies shade, absorbs noise, and provides windbreaks
- Can remove other pollutants besides TSS including phosphorus, nitrogen and metals
- Can be used as a stormwater retrofit by modifying existing landscape or if a parking lot is being resurfaced
- Can be used on small lots with space constraints
- Small rain gardens are mosquito death traps
- Little or no hazard for amphibians or other small animals

Disadvantages/Limitations:

- Requires careful landscaping and maintenance
- Not suitable for large drainage areas

Maintenance

Activity	Frequency
Inspect and remove trash	Monthly
Mow	2 to 12 times per year
Mulch	Annually
Fertilize	Annually
Remove dead vegetation	Annually
Prune	Annually

Bioretention Areas & Rain Gardens

Not all bioretention cells are designed to exfiltrate. Only the infiltration requirements are applicable to bioretention cells intended to exfiltrate.

Applicability

Bioretention areas can provide excellent pollutant removal for the "first flush" of stormwater runoff. Properly designed and maintained cells remove suspended solids, metals, and nutrients, and can infiltrate an inch or more of rainfall. Distributed around a property, vegetated bioretention areas can enhance site aesthetics. In residential developments they are often described as "rain gardens" and marketed as property amenities. Routine maintenance is simple and can be handled by homeowners or conventional landscaping companies, with proper direction.

Bioretention systems can be applied to a wide range of commercial, residential, and industrial developments in many geologic conditions; they work well on small sites and on large sites divided into multiple small drainage areas. Bioretention systems are often well suited for ultra-urban settings where little pervious area exists. Although they require significant space (approximately 5% to 7% of the area that drains to them), they can be integrated into parking lots, parking lot islands, median strips, and traffic islands. Sites can be retrofitted with bioretention areas by replacing existing parking lot islands or by re-configuring a parking lot during resurfacing. On residential sites, they are commonly used for rooftop and driveway runoff.

Effectiveness

Bioretention areas remove pollutants through filtration, microbe activity, and uptake by plants; contact with soil and roots provides water quality treatment better than conventional infiltration structures. Studies indicate that bioretention areas can remove from 80% to 90% of TSS. If properly designed and installed, bioretention areas remove phosphorus, nitrogen, metals, organics, and bacteria to varying degrees.

Bioretention areas help reduce stress in watersheds that experience severe low flows due to excessive impervious cover. Low-tech, decentralized bioretention areas are also less costly to design, install, and maintain than conventional stormwater technologies that treat runoff at the end of the pipe. Decentralized bioretention cells can also reduce the size of storm drain pipes, a major component of stormwater treatment costs. Bioretention areas enhance the landscape in a variety of ways: they improve the appearance of developed sites, provide windbreaks, absorb noise, provide wildlife habitat, and reduce the urban heat island effect.

Planning Considerations

Filtering bioretention areas are designed with an impermeable liner and underdrain so that the stormwater may be transported to additional BMPs for treatment and/or discharge. Exfiltrating bioretention areas are designed so that following treatment by the bioretention area the stormwater may recharge the groundwater.

Both types of bioretention areas may be used to treat runoff from land uses with higher potential pollutant loads. However, exfiltrating bioretention areas may be used to treat runoff from land uses with higher potential pollutant loads, only if pretreatment has been provided to achieve TSS removal of at least 44%. If the land use has the potential to generate runoff with high concentrations of oil and grease, other types of pretreatment, i.e., a deep sump catch basin and oil grit separator or a sand filter, is required prior to discharge of runoff to an exfiltrating bioretention area. A filtering bioretention area may also be used as a pretreatment device for an exfiltrating bioretention area or other infiltration practice that exfiltrates runoff from land uses with a potential to generate runoff with high concentrations of oil and grease.

To receive 90% TSS removal credit, adequate pretreatment must be provided. If the flow is piped to the bioretention area a deep sump catch catch basin and sediment forebay should be used to provide pretreatment. For sheet flow, there are a number or pretreatment options. These options include:

- A vegetated filter strip, grass channel or water quality swale designed in accordance with the specifications set forth in Chapter 2.
- A grass and gravel combination. This should consist of at least 8 inches of gravel followed by 3 to 5 feet of sod. (source: North Carolina Stormwater Manual, 2007, http://h2o.enr.state.nc.us/su/documents/Ch12-Bioretention_001.pdf)
- Pea diaphragm combined with a vegetated filter strip specially designed to provide pretreatment for a bioretention area as set forth in the following table. (source: Georgia Stormwater Manual and Claytor and Schuler 1996)

Dimensions for Filter Strip Designed Specially to Provide Pretreatment for Bioretention Area

Parameter	Impervious Area				Pervious Areas (lawns, etc.)			
Maximum inflow approach length (feet)	35		75		75		100	
Filter strip slope (max=6%)	<2%	>2%	<2%	>2%	<2%	>2%	<2%	>2%
Filter strip minimum length (feet)	10	15	20	25	10	12	15	18

Bioretention areas must not be located on slopes greater than 20%. When the bioretention area is designed to exfiltrate, the design must ensure vertical separation of at least 2 feet from the seasonal high groundwater table to the bottom of the bioretention cell.

For residential rain gardens, pick a low spot on the property, and route water from a downspout or sump pump into it. It is best to choose a location with full sun, but if that is not possible, make sure it gets at least a half-day of sunlight.

Do not excavate an extensive rain garden under large trees. Digging up shallow feeder roots can weaken or kill a tree. If the tree is not a species that prefers moisture, the additional groundwater could damage it. Size the bioretention area using the methodology set forth in Volume 3.

Design

Size the bioretention area to be 5% to 7% of the area draining to it. Determine the infiltrative capacity of the underlying native soil by performing a soil evaluation in accordance with Volume 3. Do not use a standard septic system (i.e., Title 5) percolation test to determine soil permeability.

The depth of the soil media must be between 2 and 4 feet. This range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil and that excavations deeper than 4 feet become expensive. The depth selected should accommodate the vegetation. If the minimum depth is used, only shallow rooted plants and grasses my be used. If there is a Total Maximum Daily Load that requires nitrogen to be removed from the stormwater dischrges, the bioretention area should have a soil media with a depth of at least 30 inches, because nitrogen removal takes place 30 inches below the ground surface. If trees and shrubs are to be planted, the soil media should be at least 3 feet.

Size the cells (based on void space and ponding area) at a minimum to capture and treat the required water quality volume (the first 0.5 inch or 1 inch of runoff) if intended to be used for water quality treatment (Stormwater Standard No. 4), the required recharge volume if used for recharge (Stormwater Standard No. 3), or the larger of the two volumes if used to achieve compliance with both Stormwater Standards 3 and 4.

Cover the bottom of the excavation with coarse gravel, over pea gravel, over sand. Earlier designs used filter fabric as a bottom blanket, but more recent experiences show that filter fabric is prone to clogging. Consequently, do not use fabric filters or sand curtains. Use the Engineered Soil Mix below.

Engineered Soil Mix for Bioretention Systems Designed to Exfiltrate

- The soil mix for bioretention areas should be a mixture of sand compost and soil.
  - o 40 % sand,
  - o 20-30% topsoil, and
  - o 30-40% compost.

- The soil mix must be uniform, free of stones, stumps, roots or similar objects larger than 2 inches. Clay content should not exceed 5%.
- Soil pH should generally be between 5.5-6.5, a range that is optimal for microbial activity and adsorption of nitrogen, phosphorus, and other pollutants.
- Use soils with 1.5% to 3% organic content and maximum 500-ppm soluble salts.
- The sand component should be gravelly sand that meets ASTM D 422.

Sieve Size	Percent Passing
2-inch	100
¾-inch	70-100
¼-inch	50-80
U.S. No. 40	15-40
U.S. No. 200	0-3

- The topsoil component shall be a sandy loam, loamy sand or loam texture.
- The compost component must be processed from yard waste in accordance with MassDEP Guidelines (see http://www.mass.gov/dep/recycle/reduce/leafguid.doc). The compost shall not contain biosolids.

On-site soil mixing or placement is not allowed if soil is saturated or subject to water within 48 hours. Cover and store soil to prevent wetting or saturation.

Test soil for fertility and micro-nutrients and, only if necessary, amend mixture to create optimum conditions for plant establishment and early growth.

Grade the area to allow a ponding depth of 6 to 8 inches; depending on site conditions, more or less ponding may be appropriate.

Cover the soil with 2 to 3 inches of fine-shredded hardwood mulch.

The planting plan shall include a mix of herbaceous perennials, shrubs, and (if conditions permit) understory trees that can tolerate intermittent ponding, occasional saline conditions due to road salt, and extended dry periods. A list of plants that are suitable for bioretention areas can be found at the end of this section. To avoid a monoculture, it is a good practice to include one tree or shrub per 50 square feet of bioretention area, and at least 3 species each of herbaceous perennials and shrubs. Invasive and exotic species are prohibited. The planting plan should also meet any applicable local landscaping requirements.

All exfiltrating bioretention areas must be designed to drain within 72 hours. However, rain gardens are typically designed to drain water within a day and are thus unlikely to breed mosquitoes.

Bioretention cells, including rain gardens, require pretreatment, such as a vegetated filter strip. A stone or pea gravel diaphragm or, even better, a concrete level spreader upstream of a filter strip will enhance sheet flow and sediment removal.
Bioretention cells can be dosed with sheet flow, a surface inlet, or pipe flow. When using a surface inlet, first direct the flow to a sediment forebay. Alternatively, piped flow may be introduced to the bioretention system via an underdrain.

For bioretention cells dosed via sheet flow or surface inlets, include a ponding area to allow water to pond and be stored temporarily while stormwater is exfiltrating through the cell. Where bioretention areas are adjacent to parking areas, allow three inches of freeboard above the ponding depth to prevent flooding.

Most bioretention cells have an overflow drain that allows ponded water above the selected ponding depth to be dosed to an underdrain. If the bioretention system is designed to exfiltrate, the underdrain is not connected to an outlet, but instead terminates in the bioretention cell. If the bioretention area is not designed to exfiltrate, the underdrain is connected to an outlet for discharge or conveyance to additional best management practices.

Construction

During construction, avoid excessively compacting soils around the bioretention areas and accumulating silt around the drain field. To minimize sediment loading in the treatment area, direct runoff to the bioretention area only from areas that are stabilized; always divert construction runoff elsewhere.

To avoid compaction of the parent material, work from the edge of the area proposed as the location of an exfiltrationg bioretention cell. Never direct runoff to the cell until the cell and the contributing drainage areas are fully stabilized.

Place planting soils in 1-foot to 2-foot lifts and compact them with minimal pressure until the desired elevation is reached. Some engineers suggest flooding the cell between each lift placement in lieu of compaction.

Maintenance

Premature failure of bioretention areas is a significant issue caused by lack of regular maintenance. Ensuring long-term maintenance involves sustained public education and deed restrictions or covenants for privately owned cells. Bioretention areas require careful attention while plants are being established

Bioretention Maintenance Schedule

Activity	*Time of Year*	*Frequency*
Inspect & remove trash	Year round	Monthly
Mulch	Spring	Annually
Remove dead vegetation	Fall or Spring	Annually
Replace dead vegetation	Spring	Annually
Prune	Spring or Fall	Annually
Replace entire media & all vegetation	Late Spring/early Summer	As needed*

** Paying careful attention to pretreatment and operation & maintenance can extend the life of the soil media* and seasonal landscaping maintenance thereafter.

In many cases, a landscaping contractor working elsewhere on the site can complete maintenance tasks. Inspect pretreatment devices and bioretention cells regularly for sediment build-up, structural damage, and standing water.

Inspect soil and repair eroded areas monthly. Re-mulch void areas as needed. Remove litter and debris monthly. Treat diseased vegetation as needed. Remove and replace dead vegetation twice per year (spring and fall).

Proper selection of plant species and support during establishment of vegetation should minimize—if not eliminate—the need for fertilizers and pesticides. Remove invasive species as needed to prevent these species from spreading into the bioretention area. Replace mulch every two years, in the early spring. Upon failure, excavate bioretention area, scarify bottom and sides, replace filter fabric and soil, replant, and mulch. A summary of maintenance activities can be found on the previous page.

Because the soil medium filters contaminants from runoff, the cation exchange capacity of the soil media will eventually be exhausted. When the cation exchange capacity of the soil media decreases, change the soil media to prevent contaminants from migrating to the groundwater, or from being discharged via an underdrain outlet. Using small shrubs and plants instead of larger trees will make it easier to replace the media with clean material when needed.

Plant maintenance is critical. Concentrated salts in roadway runoff may kill plants, necessitating removal of dead vegetation each spring and replanting. The operation and maintenance plan must include measures to make sure the plants are maintained. This is particularly true in residential subdivisions, where the operation and maintenance plan may assign each homeowner the legal responsibility to maintain a bioretention cell or rain garden on his or her property. Including the requirement in the property deed for new subdivisions may alert residential property owners to their legal responsibilities regarding the bioretention cells constructed on their lot.

Cold Climate Considerations

Never store snow in bioretention areas. The Operation and Maintenance plan must specify where on-site snow will be stored. All snow dumps must comply with MassDEP's guidance. When bioretention areas are located along roads, care must be taken during plowing operations to prevent snow from being plowed into the bioretention areas. If snow is plowed into the cells, runoff may bypass the cell and drain into downgradient wetlands without first receiving the required water quality treatment, and without recharging the groundwater.

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Plant Species Suitable for Use in Bioretention - Herbaceous Species

Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects/ Disease	Exposure	Form	Height	Root System	Native	Wildlife	
Agrostis alba redtop	FAC	Mesic-Xeric	1-2	H	–	H	H	Shade	Grass	2-3'	Fiberous Shallow	Yes	High	–
Andropogon gerardi bluejoint	FAC	Dry Mesic-Mesic	1-2	–	–	–	–	Sun	Grass	2-3'	Fiberous Shallow	Yes	High	–
Andropogon virginicus broomsedge	–	Wet meadow	1-2	L	–			Full sun	Grass	1-3'		Yes	High	Tolerant of fluctuating water levels and drought.
Carex vulpinoidea fox sedge	OBL	Freshwater marsh	2-4	L	–			Sun to partial sun	Grass	2-3.5'	Rhizome	Yes	High	–
Chelone glabra														
Deschampsia caespitosa tufted hairgrass	FACW	Mesic to wet Mesic	2-4	H	–	H	H	Sun	Grass	2-3'	Fiberous Shallow	Yes	High	May become invasive.
Glyceria striata fowl mannagrass, nerved mannagrass	OBL	Freshwater marsh, seeps	1-2	L	–			Partial shade to full shade	Grass	2-4'	Rhizome	Yes	High	–
Hedera helix English Ivy	FACU	Mesic	1-2	–	–	–	H	Sun	Evergreen ground cover	–	Fiberous Shallow	No	Low	–
Hibiscus palustris														
Iris kaempferi														

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Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects/ Disease	Exposure	Form	Height	Root System	Native	Wildlife	
Lobelia siphilitica														
Lotus Corniculatus birdsfoot-trefoil	FAC	Mesic-Xeric	1-2	H	L	H	H	Sun	Grass	2-3'	Fiberous Shallow	Yes	High	Member of the legume family.
Onoclea sensibilis sensitive fern, beadfern	FACW							Shade		1-3.5'			H	
Pachysandra terminalis Japanese pachysandra	FACU	Mesic	1-2	–	–	–	M	Shade	Evergreen ground cover	–	Fiberous Shallow	No	Low	–
Panicum virgatum switch grass	FAC to FACU	Mesic	2-4	H	–	–	H	Sun or Shade	Grass	4-5'	Fiberous Shallow	Yes	High	Can spread fast and reach height of 6'.
Vinca major large periwinkle	FACU	Mesic	1-2	–	–	–	H	Shade	Evergreen ground cover	–	Fiberous Shallow	No	Low	Sensitive to soil compaction and pH changes.
Vinca minor common periwinkle	FACU	Mesic	1-2	–	–	–	H	Shade	Evergreen ground cover	–	Fiberous Shallow	No	Low	–
Indian grass														
Little bluestem														
Deer tongue														
Green coneflower														

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Scientific Name Common Name	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Aronia arbutifolia (Pyrus arbutifolia) red chokeberry	FACW	Mesic	1-2	H	–	H	M	Sun to partial sun	Deciduous shrub	6-12'	–	Yes	High	Good bank stabilizer. Tolerates drought.
Clethra alnifolia sweet pepperbush	FAC	Mesic to wet Mesic	2-4	H	–	–	H	Sun to partial sun	Ovoid shrub	6-12'	Shallow	Yes	Med	Coastal plain species.
Cornus Stolonifera (Cornus sericea) red osier dogwood	FACW	Mesic-Hydric	2-4	H	H	H	M	Sun or shade	Arching, spreading shrub	8-10'	Shallow	Yes	High	Needs more consistent moisture levels.
Cornus amomum silky dogwood	FAC	Mesic	1-2	L	–	–	M	Sun to partial sun	Broad-leaved	6-12'	–	Yes	High	Good bank stabilizer
Euonymous europaeus spindle-tree	FAC	Mesic	1-2	M	M	M	M	Sun to partial sun	Upright dense oval shrub	10-12'	Shallow	No	No	–
Hamamelis virginiana witch hazel	FAC	Mesic	2-4	M	M	M	M	Sun or shade	Vase-like compact shrub	4-6'	Shallow	Yes	Low	–
Hypericum densiflorum common St. John's wort	FAC	Mesic	2-4	H	M	M	H	Sun	Ovoid shrub	3-6'	Shallow	Yes	Med	–
Ilex glabra inkberry	FACW	Mesic to wet Mesic	2-4	H	H	–	H	Sun to partial sun	Upright dense shrub	6-12'	Shallow	Yes	High	Coastal plain species.
Ilex verticillata winterberry	FACW	Mesic to wet Mesic	2-4	L	M	–	H	Sun to partial sun	Spreading shrub	6-12'	Shallow	Yes	High	–

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Species	Moisture Regime		Tolerance						Morphology			General Characteristics		Comments
Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Itea virginica tassel-white, Virginia sweetspire	OBL	Mesic	1-2	M	–	–	M	Sun or shade	Broad-leaved, deciduous shrub	6-12'	–	Yes	Low	–
Juniperus communis "compressa" common juniper	FAC	Dry Mesic-Mesic	1-2	M	H	H	M-H	Sun	Mounded shrub	3-6'	Deep taproot	No	High	Evergreen
Juniperus horizontalis "Bar Harbor" creeping juniper	FAC	Dry Mesic-Mesic	1-2	M	H	H	M-H	Sun	Matted shrub	0-3'	Deep taproot	No	High	Evergreen
Lindera benzoin spicebush	FACW	Mesic to wet Mesic	2-4	H	–	–	H	Sun	Upright shrub	6-12'	Deep	Yes	High	–
Myrica pennsylvanica bayberry	FAC	Mesic	2-4	H	M	M	H	Sun to partial sun	Rounded, compact shrub	6-8'	Shallow	Yes	High	Coastal plain species.
Physocarpus opulifolius ninebark	FAC	Dry Mesic to wet Mesic	2-4	M	–	–	H	Sun	Upright shrub	6-12'	Shallow	Yes	Med	May be difficult to locate.
Viburnum cassinoides northern wild raisin	FACW	Mesic	2-4	H	H	H	H	Sun to partial sun	Rounded, compacted shrub	6-8'	Shallow	Yes	High	–
Viburnum dentatum arrow-wood	FAC	Mesic to wet	2-4	H	H	H	H	Sun to partial sun	Upright, multi-stemmed shrub	8-10'	Shallow	Yes	High	–
Viburnum lentago nannyberry	FAC	Mesic	2-4	H	H	H	H	Sun to partial sun	Upright, mlti-stemmed shrub	8-10'	Shallow	Yes	High	–

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Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Acer rubrum red maple	FAC	Mesic-Hydric	4-6	H	H	H	H	Partial sun	Single to multi-stem tree	50-70'	Shallow	Yes	High	–
Amelanchier canadensis shadbush	FAC	Mesic	2-4	H	M	–	H	Partial sun	Single to multi-stem tree	35-50'	Shallow	Yes	High	Not recommended for full sun.
Betula nigra river birch	FACW	Mesic-Hydric	4-6	–	M	M	H	Partial sun	Single to multi-stem tree	50-75'	Shallow	Yes	High	Not susceptible to bronze birch borer.
Betula populifolia gray birch	FAC	Xeric-Hydric	4-6	H	H	M	H	Partial sun	Single to multi-stem tree	35-50'	Shallow to deep	No	High	Native to New England area.
Fraxinus americana white ash	FAC	Mesic	2-4	M	H	H	H	Sun	Large tree	50-80'	Deep	Yes	Low	–
Fraxinus Pennsylvanica green ash	FACW	Mesic	4-6	M	H	H	H	Partial sun	Large tree	40-65'	Shallow to deep	Yes	Low	–
Ginko biloba Maidenhair tree	FAC	Mesic	2-4	H	H	H	H	Sun	Large tree	50-80'	Shallow to deep	No	Low	Avoid female species-offensive odor from fruit.
Gleditsia triacanthos honeylocust	FAC	Mesic	2-4	H	M	–	M	Sun	Small caopled large tree	50-75'	Shallow to deep variable taproot	Yes	Low	Select thornless variety.
Juniperus virginiana eastern red cedar	FACU	Mesic-Xeric	2-4	H	H	–	H	Sun	Dense single stem tree	50-75'	Taproot	Yes	Very high	Evergreen
Liquidambar styraciflua sweet gum	FAC	Mesic	4-6	H	H	H	M	Sun	Large tree	50-70'	Deep taproot	Yes	High	Edge and perimeter; fruit is a maintenance problem.
Nyssa sylvatica black gum	FACW	Mesic-Hydric	4-6	H	H	H	H	Sun	Large tree	40-70'	Shallow to deep taproot	Yes	High	–

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Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Platanus acerifolia London plane-tree	FACW	Mesic	2-4	H	–	–	M	Sun	Large tree	70-80'	Shallow	No	Low	Tree roots can heave sidewalks.
Platanus occidentalis sycamore	FACW	Mesic-Hydric	4-6	M	M	M	M	Sun	Large tree	70-80'	Shallow	Yes	Med	Edge and perimeter; fruit is a maintenance problem; tree is also prone to windthrow.
Populus deltoides eastern cottonnwood	FAC	Xeric-Mesic	4-6	H	H	H	L	Sun	Large tree with spreading branches	75-100'	Shallow	Yes	High	Short lived.
Quercus bicolor Swamp white oak	FACW	Mesic to wet Mesic	4-6	H	–	H	H	Sun to partial sun	Large tree	75-100'	Shallow	Yes	High	One of the faster growing oaks.
Quercus coccinea scarlet oak	FAC	Mesic	1-2	H	M	M	M	Sun	Large tree	50-75'	Shallow to deep	Yes	High	–
Quercus macrocarpa bur oak	FAC	Mesic to wet Mesic	2-4	H	H	H	M	Sun	Large spreading tree	75-100"	Taproot	No	High	Native to Midwest.
Quercus palustris pin oak	FACW	Mesic-Hydric	4-6	H	H	H	M	Sun	Large tree	60-80'	Shallow to deep taproot	Yes	High	–
Quercus phellos willow oak	FACW	Mesic to wet Mesic	4-6	H	–	–	H	Sun	Large tree	55-75'	Shallow	Yes	High	Fast growing oak.
Quercus rubra red oak	FAC	Mesic	2-4	M	H	M	M	Sun to partial sun	Large spreading tree	60-80'	Deep taproot	Yes	High	–
Quercus shumardii Shumard's red oak	FAC	Mesic	2-4	H	H	H	M	Sun to partial sun	Large spreading tree	60-80'	Deep taproot	No	High	Native to Southeast.

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Scientific Name **Common Name**	**Indicator Status**	**Habitat**	**Ponding (days)**	**Salt**	**Oil/ Grease**	**Metals**	**Insects/ Disease**	**Exposure**	**Form**	**Height**	**Root System**	**Native**	**Wildlife**	
Sophora japonica Japanese pagoda tree	FAC	Mesic	1-2	M	M	_	M	Sun	Shade tree	40-70'	Shallow	No	Low	Fruit stains sidewalk.
Taxodium distichum bald cypress	FACW	Mesic-Hydric	4-6	_	_	M	H	Sun to partial sun	Typically single stem tree	75-100'	Shallow	Yes	Low	Not well documented for planting in urban areas.
Thuja occidentalis arborvitae	FACW	Mesic to wet Mesic	2-4	M	M	M	H	Sun to partial sun	Dense single stem tree	50-75'	Shallow	No	Low	Evergreen
Zelkova serrata Japanese zelkova	FACU	Mesic	1-2	M	M	_	H	Sun	Dense shade tree	60-70'	Shallow	No	Low	Branches can split easily in storms.

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Constructed Stormwater Wetlands

Description: Constructed stormwater wetlands are stormwater wetland systems that maximize the removal of pollutants from stormwater runoff through wetland vegetation uptake, retention and settling. Constructed stormwater wetlands temporarily store runoff in shallow pools that support conditions suitable for the growth of wetland plants. Like extended dry detention basins and wet basins, constructed stormwater wetlands must be used with other BMPs, such as sediment forebays. There is also an innovative constructed wetland—the gravel wetland—that acts as a filter. Information on the gravel wetland is presented at the end of this section.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	If properly designed, can provide peak flow attenuation.
3 - Recharge	Provides no groundwater recharge.
4 - TSS Removal	Provides 80% TSS removal when combined with sediment forebay for pretreatment
5 - Higher Pollutant Loading	May be used as treatment BMP provided basin bottom is lined and sealed
6 - Discharges near or to Critical Areas	Do not use near cold-water fisheries. Highly recommended for use near other critical areas.
7 - Redevelopment	Suitable if sufficient space is available.

Pollutant Removal Efficiencies

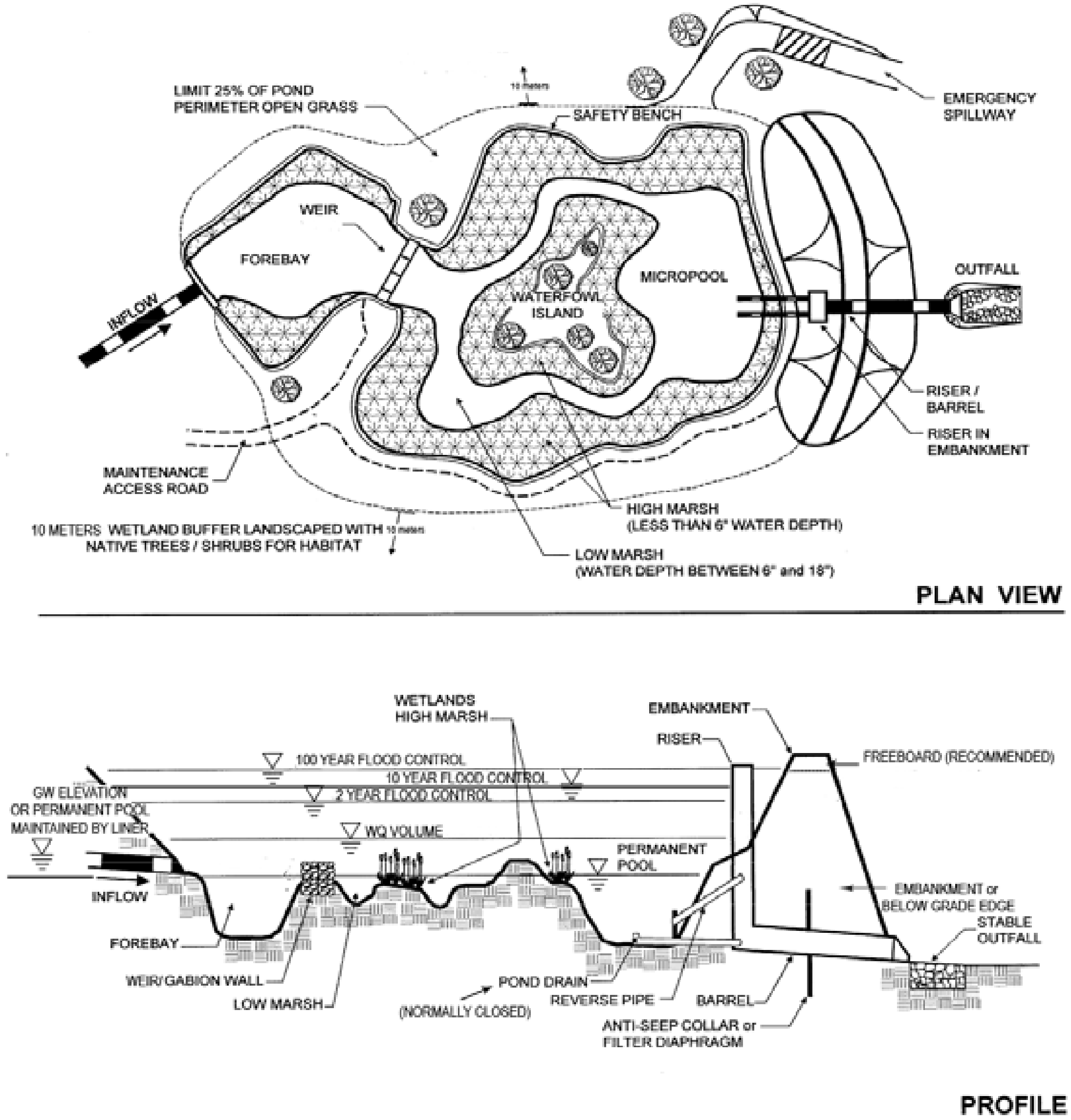
- Total Suspended Solids (TSS) - 80% with pretreatment
- Total Nitrogen - 20% to 55%
- Total Phosphorus - 40% to 60%
- Metals (copper, lead, zinc, cadmium) - 20% to 85%
- Pathogens (coliform, e coli) - Up to 75%

Advantages/Benefits:

- Relatively low maintenance costs.
- High pollutant removal efficiencies for soluble pollutants and particulates.
- Removes nitrogen, phosphorus, oil and grease
- Enhances the aesthetics of a site and provides recreational benefits.
- Provides wildlife habitat.

Disadvantages/Limitations:

- Depending upon design, more land requirements than other BMPs.
- Until vegetation is well established, pollutant removal efficiencies may be lower than anticipated.
- Relatively high construction costs compared to other BMPs.
- May be difficult to maintain during extended dry periods
- Does not provide recharge
- Creates potential breeding habitat for mosquitoes
- May present a safety issue for nearby pedestrians
- Can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools.



Example of Constructed Wetland: Shallow Marsh Type

adapted from Schueler 1992

Maintenance

Activity	Frequency
Inspect wetland during both the growing and non-growing seasons	Twice a year for the first three years of construction,
Clean out forebays	Once a year
Clean out sediment in basin/wetland systems	Once every 10 years

Special Features

There are five basic types of constructed stormwater wetlands: shallow marsh systems, basin/wetland systems, extended detention wetlands, pocket wetlands, and gravel wetlands.

Like other stormwater BMPs, constructed stormwater wetlands may not be located within natural wetland areas other than riverfront area, land subject to coastal storm flowage, isolated land subject to flooding or bordering land subject to flooding.

The Operation and Maintenance Plan for constructed stormwater wetlands must include measures for monitoring and preventing the spread of invasive species.

Constructed Stormwater Wetlands

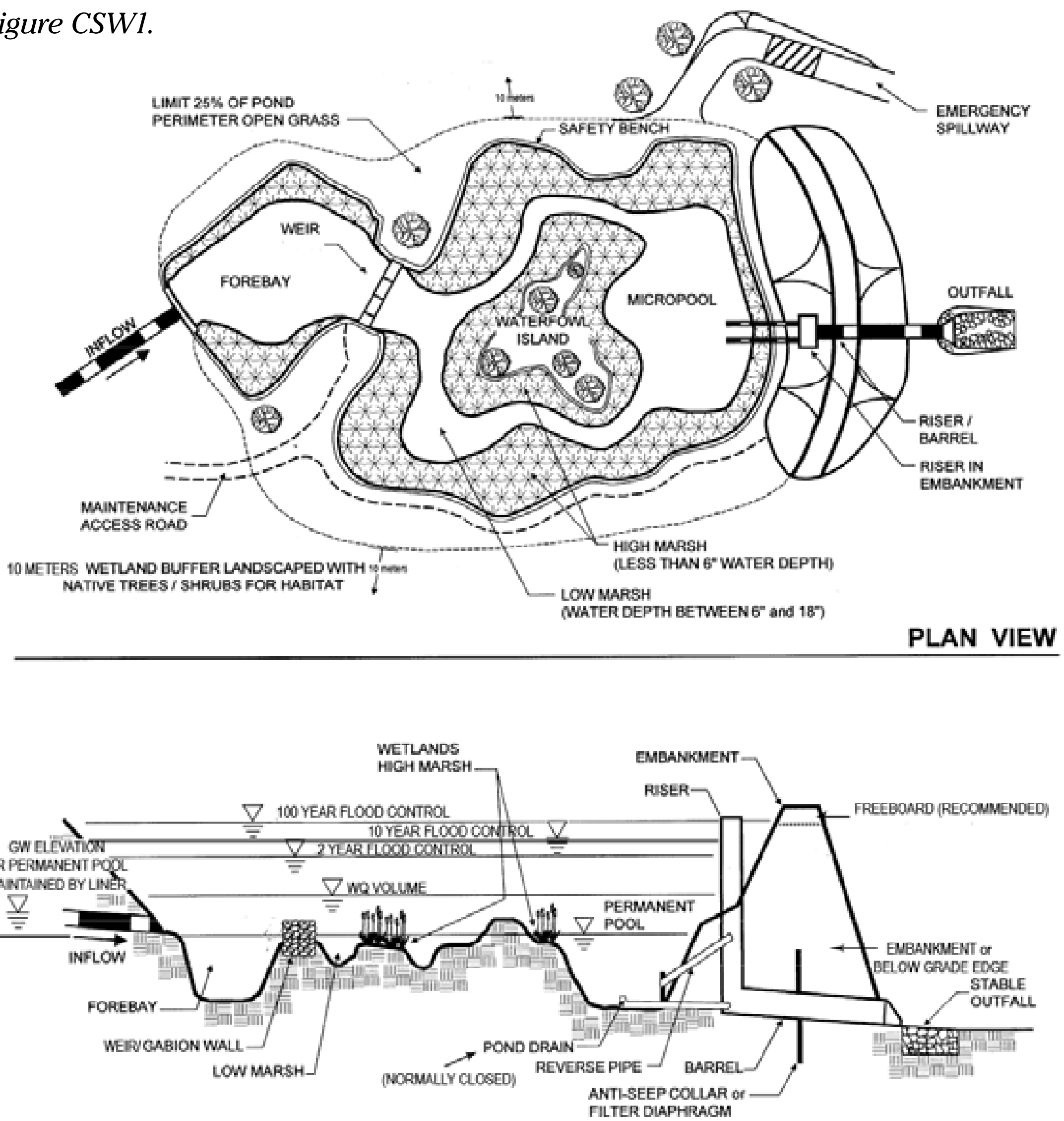
The Five Basic Types of Constructed Stormwater Wetlands

Like wet basins, most constructed stormwater wetlands require relatively large contributing drainage areas and dry weather base flows. Ten acres is the minimum contributing drainage area, although pocket type wetlands may be appropriate for smaller sites, if sufficient groundwater flow is available. There are five basic constructed wetland designs: 1) Shallow Marsh, 2) Basin/Wetland (formerly Pond/Wetland) 3)Extended Detention (ED) Wetland, 4) Pocket Wetland, and 5) Gravel Wetlands. In addition to these designs, there is a sixth type known as a subsurface gravel wetland. However, due to the lack of performance data, MA currently does not recognize subsurface gravel wetlands as having a presumed TSS removal credit.

Shallow marsh systems

Most shallow marsh systems consist of pools ranging from 6 to 18 inches deep during normal conditions. Shallow marshes may be configured with different low marsh and high marsh areas, which are referred to as cells. Shallow marshes are designed with sinuous pathways to increase retention time and contact area. Shallow marshes may require larger contributing drainage areas than other systems, as runoff volumes are stored primarily within the marshes, not in deeper pools where flow may be regulated and controlled over longer periods of time.

Figure CSW1.

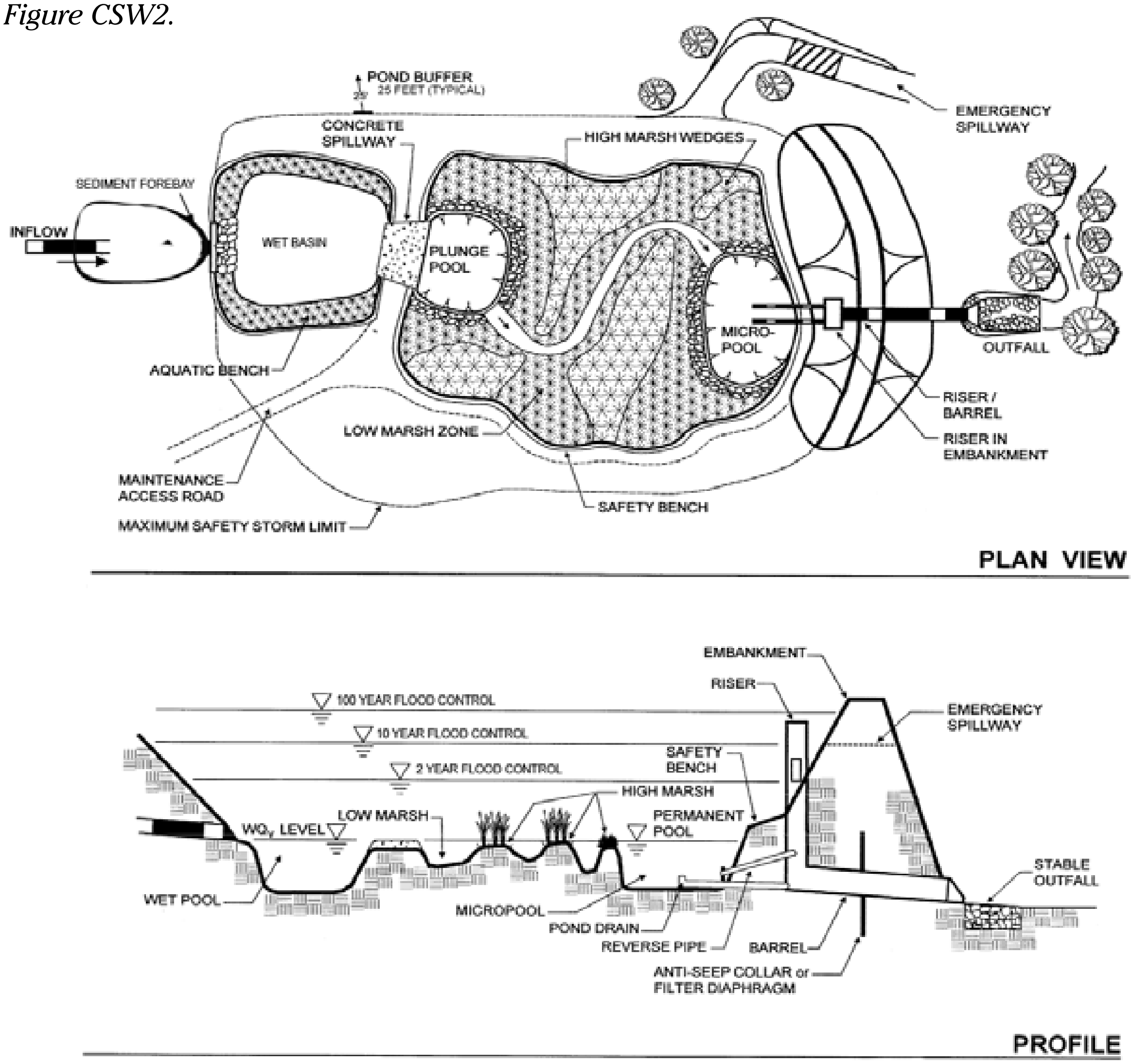


Shallow Marsh Constructed Stormwater Wetland adapted from Schueler 1992

Basin/wetland systems (formerly pond/wetland system)

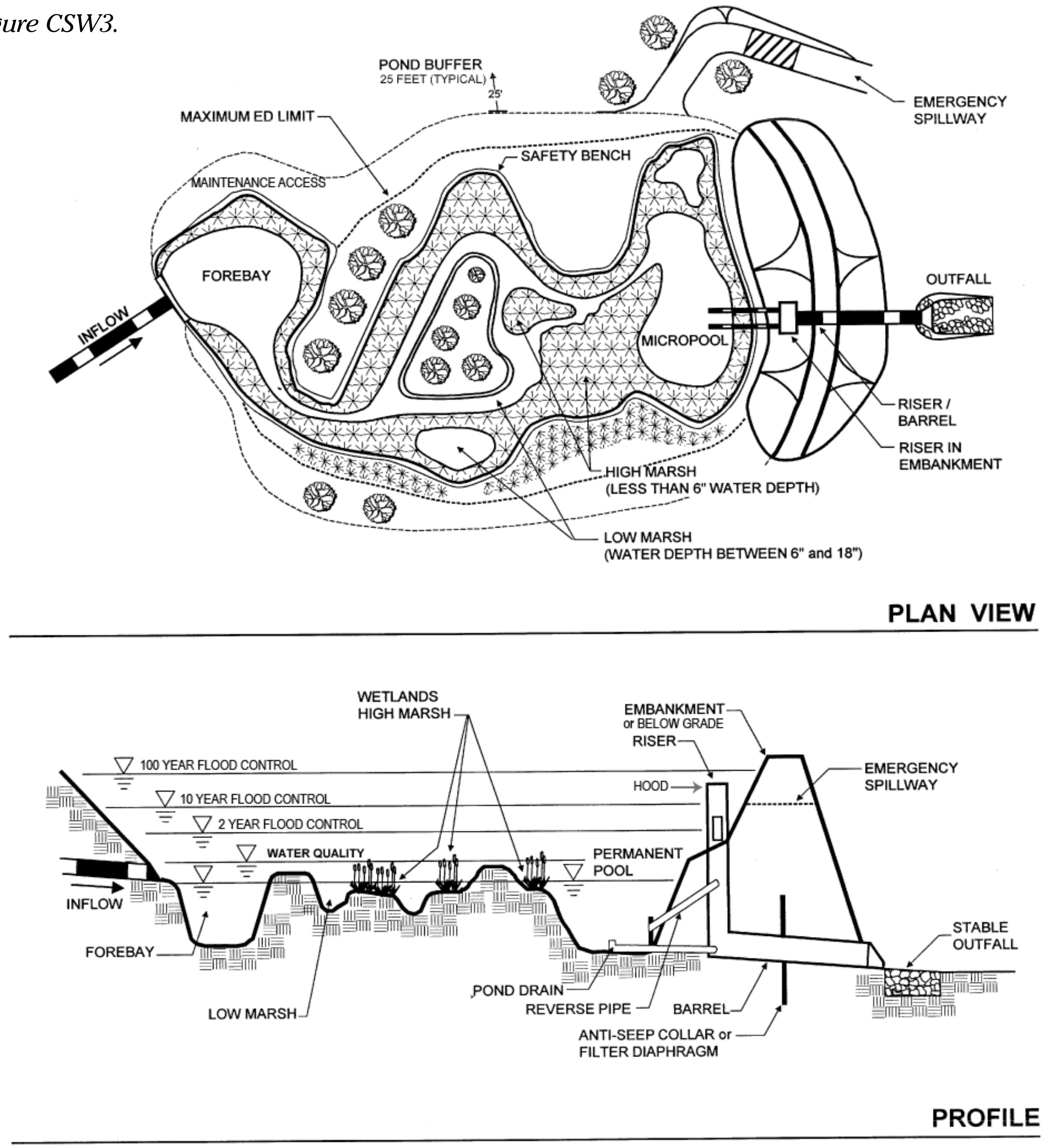
Multiple cell systems, such as basin/wetland systems, use at least one wet basin along with a shallow marsh component. The first cell is a sediment forebay that outlets to a wet basin, which removes particulate pollutants. The wet basin also reduces the velocity of the runoff entering the system. Stormwater then travels to the next cell, which contains a plunge pool. The plunge pool acts as an energy dissipator. Shallow marshes provide additional treatment of runoff, particularly for dissolved pollutants. These systems require less space than the shallow marsh systems and generally achieve a higher pollutant removal rate than other stormwater wetland systems.

Figure CSW2.



Basin/Wetland Constructed Stormwater Wetland adapted from Schueler 1992

Figure CSW3.

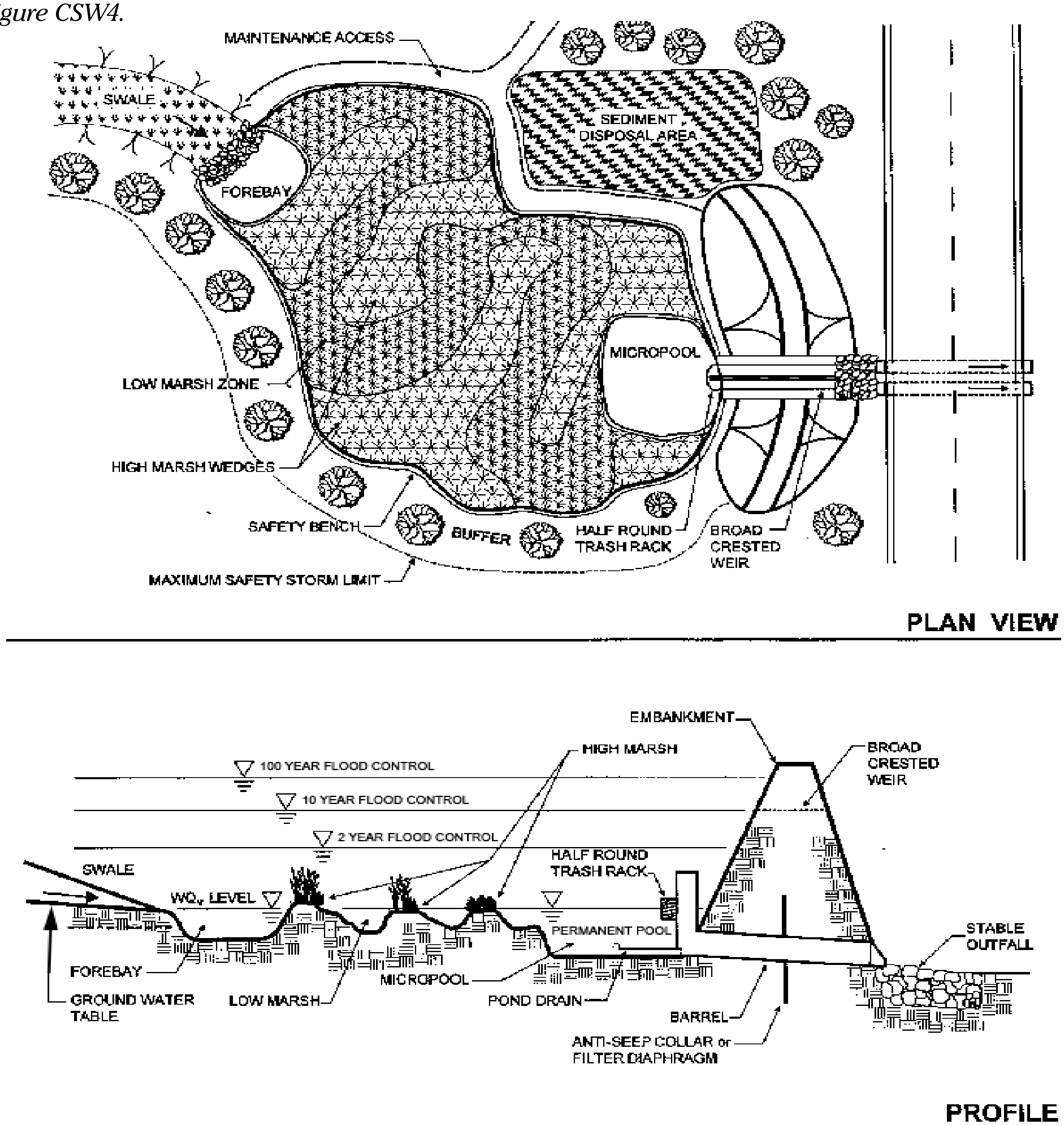


Extended Wetland Constructed Stormwater Wetland adapted from Schueler 1992

Extended detention wetlands

Extended detention wetlands provide a greater degree of downstream channel protection. These systems require less space than shallow marsh systems, because temporary vertical storage substitutes for shallow marsh storage. The additional vertical storage area also provides extra runoff detention above normal elevations. Water levels in the extended detention wetlands may increase by as much as three feet after a storm, and return gradually to normal within 24 hours of the rain event. The growing area in extended detention wetlands expands from the normal pool elevation to the maximum surface water elevation. Wetlands plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above the shallow marsh elevations.

Figure CSW4.



Pocket Wetland Constructed Stormwater Wetland adapted from Schueler 1992

Pocket wetlands

Use these systems for smaller drainage areas from one to ten acres. To maintain adequate water levels, excavate pocket wetlands to the groundwater table. Pocket wetlands that are supported exclusively by stormwater runoff generally will have difficulty maintaining marsh vegetation during normal dry periods each summer.

Applicability

Never use constructed stormwater wetlands to manage runoff during site grading and construction. Site constraints that can limit the suitability of constructed stormwater wetlands include inappropriate soil types, depth to groundwater, contributing drainage area, and available land area. Soils consisting entirely of sands are inappropriate unless the groundwater table intersects the bottom of the constructed wetland or the constructed stormwater wetland is installed over the sand to hold water. Where land area is not a limiting factor, several wetland design types may be possible. Consider pocket wetlands where land area is limited.

Do not locate constructed stormwater wetlands within natural wetland areas. These engineered stormwater wetlands differ from wetlands constructed for compensatory storage purposes and wetlands created for restoration or replication. Typically, constructed stormwater wetlands will not have the full range of ecological functions of natural wetlands. Constructed stormwater wetlands are designed specifically to improve water quality. Note that constructed stormwater wetlands do not create any additional wetland resource area or buffer zones as discussed in Volume 1, Chapter 2.

Before designing and siting constructed stormwater wetlands, investigate soil types, depth to bedrock, and depth to water table. Medium-fine texture soils (such as loams and silt loams) are best at establishing vegetation, retaining surface water, facilitating groundwater discharge, and capturing pollutants. At sites where infiltration is too rapid to sustain permanent soil saturation (such as sandy soils), consider using an impermeable liner. Liners are also required where the potential for groundwater contamination from runoff is high, such as from sites with high potential pollutant loads.

At sites where bedrock is close to the surface, high excavation costs may make constructed stormwater wetlands infeasible. Table CSW.1 lists the recommended minimum design criteria for constructed stormwater wetlands.

Effectiveness

A review of the existing performance data indicates that the removal efficiencies of constructed stormwater wetlands are significantly higher than the removal efficiencies of dry extended detention basins. Indeed constructed stormwater wetlands are among the most effective treatment practices.

To preserve their effectiveness, MassDEP requires placing a sediment forebay as pretreatment for all constructed stormwater wetlands.

Studies indicate that removal efficiencies of constructed stormwater wetlands decline when they are covered by ice or receive runoff derived from snow melt. Performance also declines during the non-growing season and the fall when vegetation dies off. Expect lower pollutant removal efficiencies until vegetation is re-established.

One preferred wetland installation is to combine an off-line stormwater wetland design, for runoff quality treatment, with an on-line runoff quantity control, because large surges of water can damage wetlands. Further, the shallow depths required to maintain the wetlands conflict with the need to store large volumes to control runoff quantity.

Planning Considerations

Carefully evaluate sites when planning constructed stormwater wetlands. Investigate soils, depth to bedrock, and depth to water table before designing, permitting, and siting constructed wetlands. Proponents must consider a “pond-scaping plan” for each constructed stormwater wetland. The plan must contain the location, quantity and propagation methods for the wetland plants as well as site preparation and maintenance. The plan should also include a wetland design and configuration, elevations and grades, a site/soil analysis, estimated depth zones, and hydrological calculations or water budgets. The water budget must demonstrate that a continuous supply of water is available to sustain the constructed stormwater wetland. Develop the water budget during site selection and then check it after the preliminary site design. The water budget analysis must be based on the Thornwaite method, arranging data in a “bookkeeping” or “spreadsheet” format. The water budget must take into account prcipitation, runoff, evaporatranspiration, soil moisture, and groundwater inputs. Drying periods of longer than two months adversely affect the richness of the plant community, so make sure that the water budget confirms that the drying time will not exceed two months.

Table CSW.1
Recommended Design Criteria for Stormwater Wetlands Designs

Design Criteria	Shallow Marsh	Basin/Wetland	ED Wetland	Pocket Wetland	Gravel Wetland (Surface)
Minimum Drainage Area (acres)	≥ 25	≥ 25	≥ 10	≥ 1 to 10	SEE SPECIFICATIONS
Constructed Wetland Surface Area/Watershed Area Ratio[1]	≥ 0.02	≥ 0.01	≥ 0.01	≥ 0.01	
Length to Width Ratio (minimum)	≥ 2:1	≥ 2:1	≥ 2:1	≥ 2:1	
Extended Detention (ED)[2]	NOT ALLOWED	OPTIONAL	YES	OPTIONAL	
Allocation of WQv Volume (wet pools[3]/low and high marsh/ED) in %	30/70/0	70/30/02	20/30/50	20/80/02	
Allocation of Surface Area (wet pools[3]/low marsh/ high marsh/semi-wet) in %	15/40/40/5	45/25/25/5	10/40/40/10	10/45/40/5	
Sediment Forebay[4]	REQUIRED	REQUIRED	REQUIRED	REQUIRED	
Micropool	REQUIRED	REQUIRED	REQUIRED	REQUIRED	
Outlet Configuration	Reverse slope pipe or hooded broad crested weir	Reverse slope pipe or hooded broad crested weir	Reverse slope pipe or hooded broad crested weir	Hooded broad-creasted weir	
Target Allocations	Shallow Marsh	Basin/Wetland	ED Wetland	Pocket Wetland	
	% Surface Area				
Sediment Forebay[4]	5%	0%5	5%	5%	
Micropool	5%	5%	5%	5%	
Deep Water Channel	5%	40%	0%	0%	
Lo Marsh	40%	25%	40%	45%	
High Marsh	40%	25%	40%	40%	
Semi-Wet	5%	5%	10%	5%	
	% WQv Volume				
Sediment Forebay[4]	10%	0%5	10%	10%	
Micropool	10%	10%	10%	10%	
Deep Water Channel6	10%	60%	0%	0%	
Lo Marsh	45%	20%	20%	55%	
High Marsh	25%	10%	10%	25%	
Semi-Wet	0%	0%	50% (ED)	0%	

[1]Constructed Wetland Surface Area includes wet pool, deep water channel, marshes, and semi-wet zone.
[2]ED volume shall be an additional volume above the WQv (except for the ED Wetland)
[3]Wet Pool = Forebay+Micropool+Deep Water
[4]Sediment Forebay for 1/2-inch WQv is 20% of WQv. Only 10% of that Volume may be included in the Constructed Wetland.
[5]Basin Wetland Forebay: Forebay sizing must not be counted as part of WQv. Sediment Forebay Volume = 0.1-inch x Impervious area
[6]Includes "basin" volume in Basin/Wetland Design

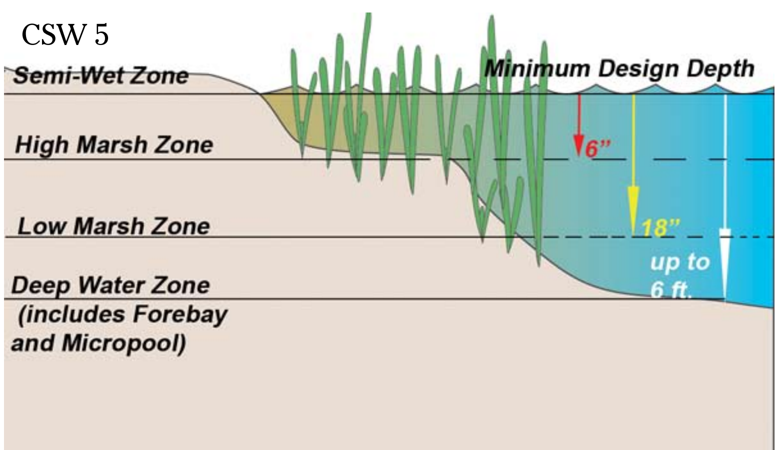
Design

Constructed stormwater wetlands may be designed as on-line systems with permanent pools for both treatment and storage of peak flows. Constructed stormwater wetlands can also be designed as off-line systems with high flows routed around the wetland. The basic constructed stormwater wetland design sizing criteria is set forth in Table CSW.1. Whether designed as an on-line or off-line system, a constructed stormwater wetland must be sized for the required water quality volume.

The ratio of the surface area of the constructed stormwater wetland to longer flow paths through the constructed stormwater wetlands to the contributing watershed area must meet the criteria specified in Table CSW.1. The reliability of pollutant removal tends to increase as the ratio of constructed stormwater wetlands area to watershed area increases.

Design the constructed stormwater wetlands with the required proportion of "depth zones." Each of the constructed wetland designs other than the gravel wetland, has depth zone allocations, which are given as a percentage of the stormwater wetland surface area. Target allocations for these constructed wetland designs are listed in Table CSW.1. The four basic depth zones are (see figure CSW 5):

CSW 5



Deepwater zone

From 1.5 feet to six feet below normal pool elevation. This zone supports little emergent vegetation, but may support submerged or floating vegetation. This zone can be further broken down into forebay, micropool and deepwater channels.

Low marsh zone

Ranges from 6 inches to s18 inches below the normal pool elevation. This area is suitable for growing several emergent wetland plant species.

High marsh zone

Ranges from the normal pool elevation to 6 inches below normal pool elevation. This zone will support a greater density and diversity of emergent wetland species than the low marsh zone. The high marsh zone must have a higher surface area to volume ratio than the low marsh zone (see table CSW.1).

Semi-wet zone

This zone includes those areas above the normal pool elevation that are intermittently inundated and that can be expected to support wetland plants.

Design each constructed stormwater wetland with the required proportion of treatment volumes, which have been represented as a percentage of the three basic depth zones (pool, marsh, extended detention). Table CSW.1 specifies the allocations of treatment volume per zone.

Increase the contact time over the surface area of the marsh, thereby improving treatment efficiency. The constructed stormwater wetland must be designed to achieve a dry weather flow path of 2:1 (length: width) or greater.

Prepare a water budget to demonstrate that the water supply to the constructed stormwater wetland is greater than the expected loss rate. The water budget must be based on the Thornwaite method.

Provide extended detention (ED) for smaller storms. Schueler 1992 lists the following design standards for ED wetlands:

•The volume of the extended detention must be no more than 50% of the total treatment volume.

•The target ED detention time for this volume must be 12 to 24 hours.

- Use V-shaped or proportional weirs to ensure constant detention time for all storm events.
- Extended detention is defined here as the retention and gradual release of a fixed volume of stormwater runoff. For ED wetlands less than 100 acres, the extended detention volume can be assumed to fill instantaneously for design purposes.

- Use a reverse slope pipe and increase the actual diameter of the orifice to the next greatest diameter on the standard pipe schedule. The pipe must be equipped with a gate valve.
- Protect the ED orifice from clogging.
- Make the maximum ED water surface elevation no greater than three feet above the normal pool elevation.

Design each constructed stormwater wetland with a separate cell near the inlet to act as a sediment forebay. Design the forebay with a capacity of at least 10% of the total treatment volume, normally 4 to 6 feet deep. Provide a direct and convenient access for cleanout.

Surround all deep-water cells with a safety bench that is at least ten feet wide, and zero to 18 inches below the normal water depth of the pool.

Place above-ground berms or high marsh wedges at approximately 50-foot intervals, and at right angles to the direction of the flow to increase the dry-weather flow path within the wetland.

Include a four- to six-foot deep micropool before the outlet to prevent the outlet from clogging. Provide a micropool capacity of at least ten percent of the total treatment volume. Use a reverse slope pipe or a hooded, broad-crested weir for outlet control. Locate the outlet from the micropool at least one foot below the normal pool surface.

To prevent clogging, install trash racks or hoods on the riser. To facilitate access for maintenance, install the riser within the embankment. Install anti-seep collars on the outlet barrel to prevent seepage losses and pipe failures. Install a bottom drainpipe with an inverted elbow to prevent clogging and to facilitate complete draining of the wetland for emergency purposes or routine maintenance. Fit both the outlet pipe and the bottom drainpipe with adjustable valves at the outlet ends to regulate flows. Design embankments and spillways in accordance with the state regulations and criteria for dam safety.

All constructed stormwater wetlands must have an emergency spillway capable of bypassing runoff from large storms without damage to the impounding structure.

Provide an access for maintenance, with a minimum width of 15 feet and a maximum slope of 15%, through public or private rights-of-way. Make sure this access extends to the forebay, safety bench and outflow structure and never crosses the emergency spillway, unless the spillway has been designed and constructed for this purpose.

Locate vegetative buffers around the perimeter of the constructed stormwater wetland to control erosion and provide additional sediment and nutrient removal for sheet flow discharging to the constructed stormwater wetland.

Construction

A seven-step process to prepare a wetland bed prior to planting (Shueler 1992):

1. Prepare final pond-scaping and grading plans for the constructed stormwater wetland. At the same time, order wetland plant stocks from aquatic nurseries.
2. Once the constructed stormwater wetland volume has been excavated, grade the wetland to create the major internal features (pool, aquatic bench, deep water channels, etc.).
3. Because deep subsoils often lack the nutrients and organic matter needed to support vigorous plant growth, add topsoil and/or wetland mulch to the wetland excavation. If available, wetland mulch is preferable to topsoil.
4. After the mulch or topsoil has been added, grade the constructed stormwater wetland to its final elevations. Temporarily stabilize all wetland features above the normal pool. After final grading, close the pool drain to allow the pool to fill. MassDEP recommends evaluating the wetland elevations during a standing period of approximately six months to assess how the constructed stormwater wetland responds to storm flows and inundation, where the pond-scaping zones are located, and whether the final grade and micro-topography will persist over time.
5. Before planting, measure the constructed stormwater wetland depths to the nearest inch to confirm planting depth. If necessary, modify the pond-scape plan at this time to reflect altered depths or availability of plant stock.
6. Aggressively apply erosion controls during the standing and planting periods. Stabilize the vegetation in all areas above the normal pool elevation during the standing period (typically by hydroseeding).
7. Dewater the constructed stormwater wetland at least three days before planting, because a dry wetland is easier to plant than a wet one.

Wetland Vegetation

Establishing and maintaining wetland vegetation is important when creating a constructed stormwater wetland. Horner et al. (1994) recommend the following actions when constructing stormwater wetlands:

- In selecting plants, consider the prospects for success over the specific pollutant removal capabilities and plant species growing in nearby natural wetlands. Plant uptake is an important removal mechanism for nutrients, but not for other pollutants. The most versatile genera for pollutant removal are *Carex, Scirpus, Juncus, and Lemna.* Consult the NRCS plant database to determine if the plant is appropriate. The NRCS database lists the plants prohibited for sale in Massachusetts.
- Select native species, avoiding those that are invasive. Because diversification will occur naturally, use a minimum of species adaptable to the various elevation zones within the stormwater wetland.
- Give priority to perennial species that establish themselves rapidly.
- Select species adaptable to the broadest ranges of depth, frequency and duration of inundation (hydroperiod).
- Match site conditions to the environmental requirements of plant selections.
- Take into account hydroperiod and light conditions.
- Give priority to species that have already been used successfully in constructed stormwater wetlands and that are commercially available.
- Avoid using only species that are foraged by the wildlife expected on site.
- Establish woody species after herbaceous species.
- Where applicable, add vegetation that will achieve other objectives, in addition to pollution control.

Plants will develop best when soils are enriched with plant roots, rhizomes, and seed banks. Use "wetlands mulch" to enhance the diversity of the plant community and speed its establishment. Wetlands mulch is hydric soil. This mulch is available where wetland soils are removed during cleaning and dredging of drainage channels, swales, sedimentation basins, dry detention basins, and infiltration basins. Wetland soils are also available commercially. The upper 5.9 inches of donor soil should be obtained at the end of the growing season, and kept moist until installation. Drawbacks to using wetlands mulch are the unpredictable content, limited donor sites, and the potential for the introduction of exotic, opportunistic species. Wetland plants are commercially available through wetland plant nurseries.

Maintenance

Unlike conventional wet basin systems that require large-scale sediment removal at infrequent intervals, constructed stormwater wetlands require small-scale maintenance at regular intervals to evaluate the health and composition of the plant species.

Proponents must carefully observe the constructed stormwater wetland system over time. In the first three years after construction, inspect the constructed stormwater wetlands twice a year during both the growing and non-growing seasons. This requirement must be included in the Operation & Maintenance plan. During these inspections, record and map the following information:

- The types and distribution of the dominant wetland plants in the marsh;
- The presence and distribution of planted wetland species;
- The presence and distribution of invasive wetland species (invasives must be removed);
- Indications that other species are replacing the planted wetland species;
- Percentage of standing water that is unvegetated (excluding the deep water cells which are not suitable for emergent plant growth);
- The maximum elevation and the vegetative condition in this zone, if the design elevation of the normal pool is being maintained for wetlands with extended zones;
- Stability of the original depth zones and the micro-topographic features; and
- Accumulation of sediment in the forebay and micropool; and survival rate of plants (cells with dead plants must be replanted).

Maintenance of Sediment Forebay

Another important maintenance activity is regulating the sediment loading into the constructed stromwater wetland. All constructed stormwater wetlands are required to have a sediment forebay. Sediment accumulating in wetlands reduces water depths, changes the growing conditions for emergent plants, and alters the wetland plant community. Most sediment should be trapped and removed by the forebay or other type of basin before it reaches the wetland. The sediment forebay should be cleaned once a year.

Gravel Wetland

The gravel wetland consists of a series of horizontal flow through treatment cells preceded by a sediment forebay. The University of New Hampshire (UNH) has developed specifications that allow the gravel wetland to treat the required water quality volume; 10% in the forebay and 45 % in each treatment cell. The UNH design calls for excess runoff to overflow into an adjacent swale with side slopes graded at 3:1 or flatter.

Treatment occurs in each cell as stormwater passes horizontally through the microbe rich gravel substrate. The wetland is designed to continuously saturate at a depth that begins four inches below the treatment's surface. This design permits treatment and vegetation growth. To generate this condition, UNH designs the device with an outlet pipe that has an invert 4 inches below the surface.

For information on gravel wetland design, see http://www.unh.edu/erg/cstev/fact_sheets/TUG.pdf.

References

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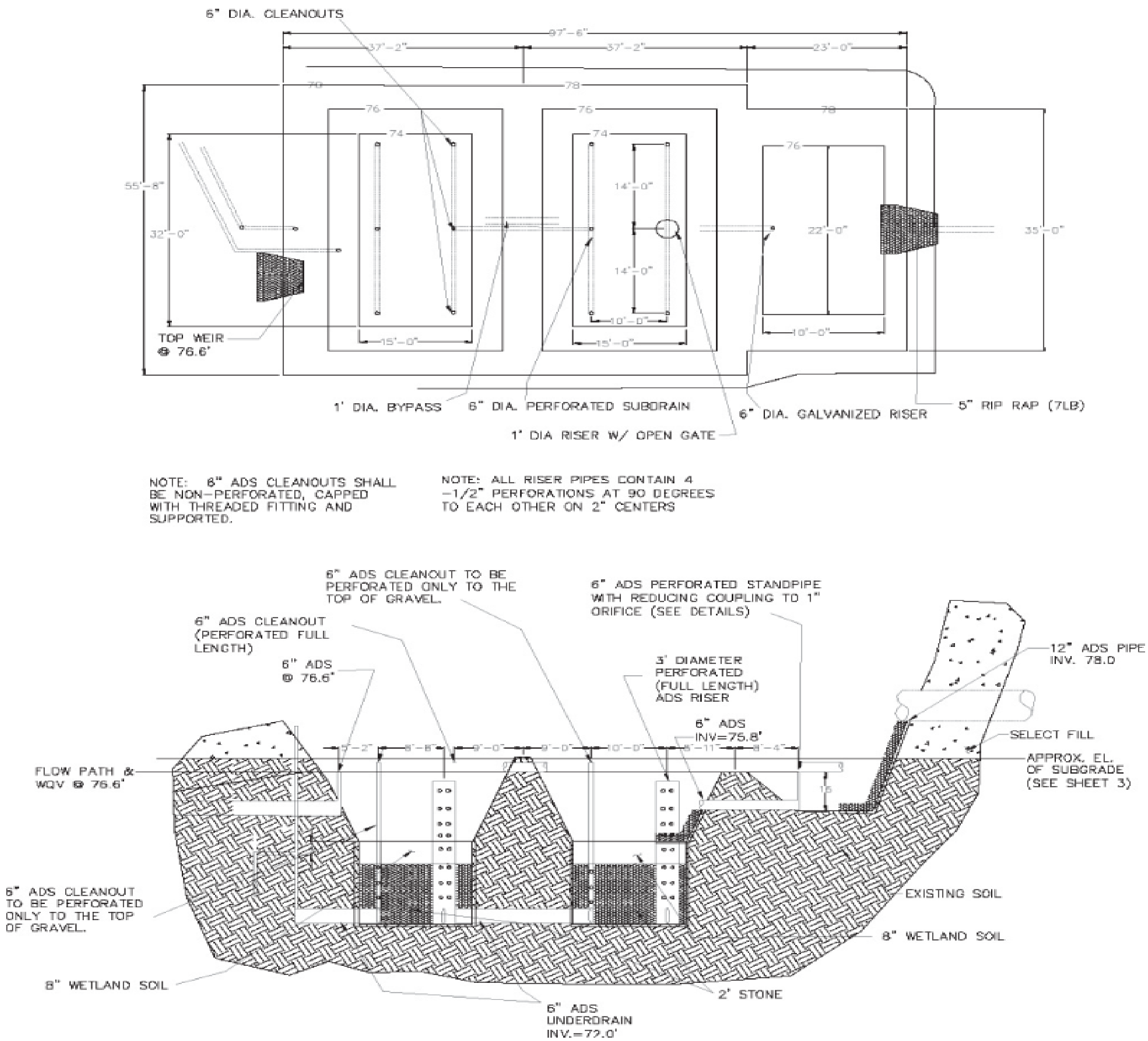
Gravel Wetland



adapted from UNH, 2005

Extended Dry Detention Basin

Description: Extended dry detention basins are modified conventional dry detention basins, designed to hold stormwater for at least 24 hours to allow solids to settle and to reduce local and downstream flooding. Extended dry detention basins may be designed with either a fixed or adjustable outflow device. Pretreatment is a fundamental design component of an extended dry detention basin to reduce the potential for clogging. Other components such as a micropool or shallow marsh may be added to enhance pollutant removal.

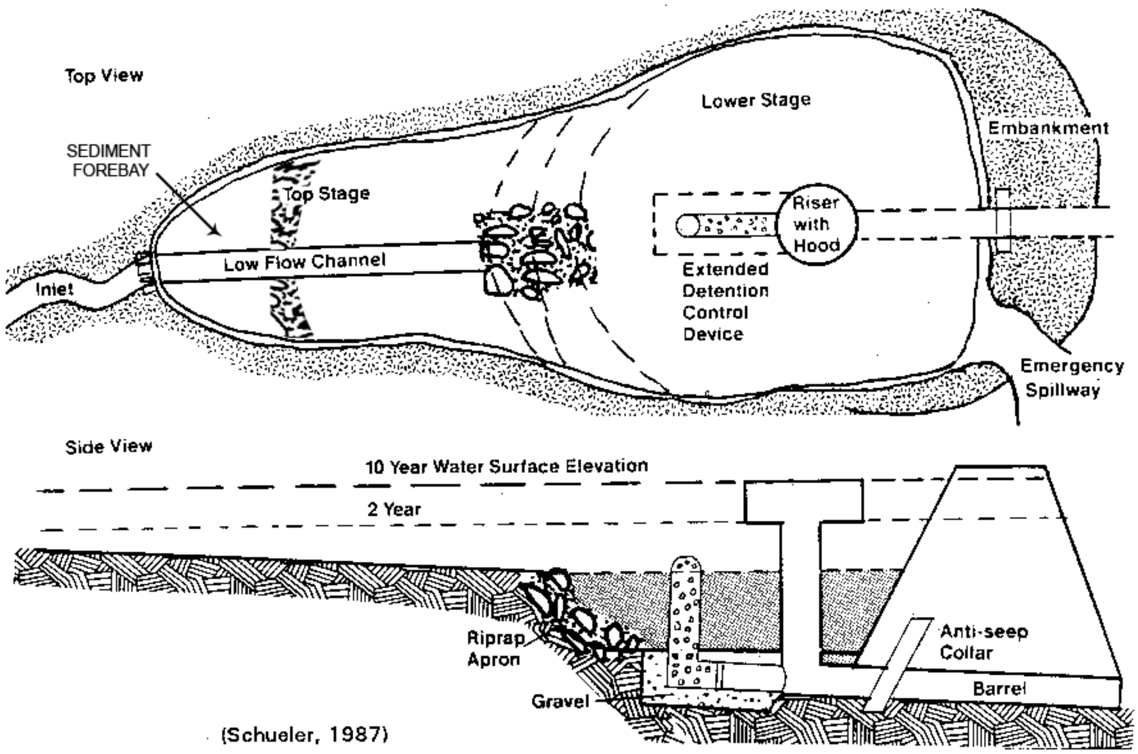
Ability to meet specific standards

Standard	Description
2 - Peak Flow	With proper design can provide peak flow attenuation.
3 - Recharge	Provides no groundwater recharge.
4 - TSS Removal	When combined with sediment forebay provides 50% TSS removal.
5 - Higher Pollutant Loading	May be used as treatment BMP provided basin bottom is lined and sealed. For some land uses with higher potential pollutant loads, may also need oil grit separator, sand filter, lined bioretention area, or equivalent prior to discharge to extended dry detention basin.
6 - Discharges near or to Critical Areas	Shall not be used for discharges near or to critical areas
7 - Redevelopment	Existing dry detention basins may be retrofitted to become extended dry detention basins

Advantages/Benefits:
- Least costly BMP that controls both stormwater quantity and quality.
- Good retrofitting option for existing basins.
- Can remove significant levels of sediment and absorbed pollutants.
- Potential for beneficial terrestrial and aquatic habitat.
- Less potential for hazards than deeper permanent pools.

Disadvantages/Limitations:
- Infiltration and groundwater recharge is negligible, resulting in minimal runoff volume reduction.
- Removal of soluble pollutants is minimal.
- Requires relatively large land area.
- Moderate to high maintenance requirements.
- Potential contributor to downstream warming.
- Sediment can be resuspended after large storms if not removed.

Pollutant Removal Efficiencies
- Total Suspended Solids (TSS) 50% provided it is combined with sediment forebay or equivalent
- Total Nitrogen 15% to 50%
- Total Phosphorus 10% to 30%
- Metals (copper, lead, zinc, cadmium) 30% to 50%
- Pathogens (coliform, e coli) Less than 10%



Maintenance

adapted from Controlling Urban Runoff, Schueler 1987

Activity	Frequency
Inspect extended dry detention basins	At least twice a year and during and after major storms.
Examine the outlet structure for evidence of clogging or outflow release velocities that are greater than design flow.	At least twice a year.
Mow the upper-stage, side slopes, embankment, and emergency spillway.	At least twice a year.
Remove trash and debris.	At least twice a year.
Remove sediment from the basin.	At least once every 5 years.

Special Features

Design extended dry detention basins with two distinct stages; stage one should have the capacity to regulate peak flow rates of large, infrequent storms (10, 25, or 100-year recurrence intervals). Design the lower stages of the basin to detain the 2-year storm for at least 24 hours to remove pollutants from the runoff

LID Alternatives

Bioretention Areas
Decentralized stormwater management system that directs stormwater runoff from different sections of the site to small bioretention areas distributed throughout the site.

Extended Dry Detention Basin

Applicability

Generally, extended dry detention basins are not practical if the contributing watershed area is less than ten acres. MassDEP recommends four acres of drainage area for each acre-foot of storage in the basin. Extended dry detention basins can be used at residential, commercial and industrial sites.

Because they have a limited capability for removing soluble pollutants, extended dry detention basins are more suitable for commercial applications where there are high loadings of sediment, metals and hydrocarbons. Do not use extended dry detention basins by themselves in low-density residential areas, where soluble nutrients from pesticides and fertilizers may be a concern. Combine extended dry detention basins with a shallow marsh system or other BMPs for more efficient pollutant removal.

Existing dry detention basins can be retrofitted as extended dry detention basins at a relatively low cost by simply modifying the outlet structure. Because of the land requirements, extended dry detention basins are not feasible at sites where land costs or space is at a premium. Investigate soils, depth to bedrock, and depth to water table before designing an extended dry detention basin for a site.

Sites where bedrock is close to the surface can significantly increase excavation costs and make extended dry detention basins infeasible. If on-site soils are relatively impermeable, such as soil group D (as defined by the NRCS), problems with standing water may arise. In this case, using a wet basin may be more appropriate. A water table within two feet of the bottom of the extended dry detention basin can also create problems with standing water. On the other hand, if soils are highly permeable, such as well-drained sandy and gravelly soils (NRCS Soil Group A), it will be difficult to establish the shallow marsh component in the basin.

Effectiveness

The primary pollutant removal mechanism in extended dry detention basins is settling; therefore, the degree of pollutant removal depends on whether the pollutant is in the particulate or dissolved form. Expect limited removal for soluble pollutants, but high removal rates for particulate pollutants. Enhanced removal of soluble pollutants in the lower stage of the basin can occur by natural biological removal processes if it is maintained as a shallow wetland. The degree of removal by such wetlands depends on the wetland's size in relation to its loading. When designed properly, extended dry detention basins are effective in reducing pollutant loads and controlling post-development peak discharge rates. Extended dry detention basins may be used to meet Stormwater Management Standards 2 and 4. However extended dry detention basins do little to reduce post-development increases in runoff volume or maintain recharge.

Planning Considerations

Check the soils, depth to bedrock and depth to water table before designing an extended dry detention basin. Where bedrock is close to the surface, high excavation costs may make extended dry detention basins infeasible. If soils on-site are relatively impermeable, or the water table is within two feet of the bottom of the basin, the basin may experience problems with standing water. If soils are highly permeable, it will be difficult to establish a shallow marsh component in the basin, unless a liner is used. Maximum depth of the extended dry detention basin may range from 3 to 12 feet. The depth of the basin may be limited by groundwater conditions or by soils.

Construct extended dry detention basins above the normal groundwater elevation (i.e. the bottom of the basin should not intercept groundwater). If runoff is from a land use with a higher potential pollutant load, provide adequate pretreatment and a greater separation between the bottom of the basin and the seasonal high groundwater table.

To be effective in reducing peak runoff rates, the extended dry detention basin is ordinarily located where it can intercept most of the runoff from the site, usually at the lowest elevation of the site where freshwater wetlands are frequently found. Like all other best management practices, extended dry detention basins may not be constructed in wetland resource areas other than isolated land subject to flooding, bordering land subject to flooding, land subject to coastal storm flowage and riverfront areas. Select a location that will not adversely affect wetland resource areas but will still provide the peak rate attenuation required by Standard 2. Embankments, or dams, created to store more than 15 acre-feet, or that are more than 6 feet high, are under the jurisdiction of the state Office of Dam Safety and are subject to regulation.

Design

[See the following document for complete design references: Design of Stormwater Pond Systems. 1996. Schueler. Center for Watershed Protection.]

Extended dry detention basin design must accommodate large, infrequent storm events for runoff quantity control, as well as small, frequent storm events for runoff quality control. Typically, the first flush of runoff contains the highest concentrations of pollutants. Consequently, design the extended dry detention basin to maximize the detention time for the most frequent storms. Routing calculations for a range of storms should provide the designer with the optimal basin size.

Generally, most particulates settle within the first 12 hours of detention; however, finer particulates may require additional time to settle. The minimum detention time for the Water Quality Volume is 24-hours. The most traditional and easiest method for extended detention routing is the 24 hour brimfull draw down (Required Water Quality Volume/24 hours = Qavg). This sets the average discharge rate. An orifice is then sized based on a max Q = 2*Qavg, using the brimfull head (Qmax = (CA(2gh)1/2) where h is the head when the basin is full to the Required Water Quality Volume (WQv) elevation, g is acceleration due to gravity, A is the net opening area, and C is the orifice coefficient. The orifice coefficient is determined by consulting tables in standard references such as the Civil Engineering Reference Manual for the PE Exam, 10th Edition, by Michael R. Lindeburg, P.E., 2006.

The critical parameters in sizing an extended dry detention basin are storage capacity and the maximum rate of runoff released from the basin. To meet the requirements of Standard 2, design the storage volume to hold the pre-development peak flow.

To maximize sedimentation, design the extended dry detention basin to lengthen the flow path, thereby increasing detention time. To maximize the detention time, locate the inflow points as far from the outlet structure as possible. Long, narrow configurations with length to width ratios of 2:1 provide better removal efficiencies than small deep basins. Consider using internal berms and other baffles to minimize short-circuiting of flows and increase detention times.

Reducing inflow velocities lengthens detention times, enhances sedimentation of solids in incoming runoff, and minimizes the potential for resuspension of settled pollutants. Design all inflow points with riprap or other energy dissipators, such as a baffle below the inflow structure. MassDEP requires a sediment forebay to enhance the removal rates of particulates, decrease the velocity of incoming runoff, and reduce the potential for failure due to clogging.

Design sediment forebays for ease of maintenance. Hard bottom forebays make sediment removal easier. All forebays must be accessible for maintenance by heavy machinery, if necessary.

A low flow channel routes the last remaining runoff, dry weather flow and groundwater to the outlet, which should be installed in the upper stage of the basin to ensure that the extended dry detention basin dries out completely. The maximum flow velocity (which should be set at the 2-year peak discharge rate) depends on the nature of the material used to line the channel. Consider whether a pervious or impervious channel lining is most appropriate.

Pervious linings allow runoff to interact with soil and grass, thereby increasing the sorption of pollutants. Make design velocities in pervious low flow channels high enough to prevent sedimentation but low enough to prevent scouring and erosion.

Impervious channels are simple to construct, easy to maintain, and empty completely after a storm event. Runoff flows and differential settling can undermine impervious channels unless constructed and maintained properly. Locate the top of the impervious channel lining at or below the level of the adjacent grassed areas to ensure thorough drainage of these areas. When designing impervious channels, take into account settlement of the lining and the adjacent areas as well as the potential for frost impacts on the lining. Provide impervious lining with broken stone foundations and weep holes. Consider the potential for erosion or scour along the edges of the lining caused by bank-full velocities. Maintain a low outflow discharge rate at the downstream end of the impervious channel to ensure sufficient treatment of runoff, which backs up and overflows onto the grassed basin bottom.

Use low flow underdrains connected to the principal outlet structure or other downstream discharge point to promote thorough drying of the channel and the basin bottom. Take into account the depth of the low flow channel when preparing the final bottom grading plan. Establish wetland vegetation in a shallow marsh component or on an aquatic bench in the lower stage of the extended dry detention basin to enhance removal of soluble nutrients, increase sediment trapping, prevent sediment resuspension, and provide wildlife and waterfowl habitat. Proper soils and surface depth or groundwater depth are needed to maintain wetland vegetation.

Make the side slopes of the extended dry detention basin no steeper than 3:1, and use intermittent benches to foster vegetative growth and provide for safety. Flatter slopes help to prevent bank erosion during larger storms, make routine bank maintenance tasks (such as mowing) easier, prevent animals from getting trapped, and allow easier access to the basin. Include a multi-stage outlet structure to provide an adequate level of water quality and flood control. To meet the water quantity control standards, use the required design storm runoff rates as the outlet release rates. For water quality control, the release rate will vary with the design storm selected. For extended dry detention basins with shallow marshes or permanent pools, place the lowest stage outlet at an elevation that will create a permanent pool of water.

The type of outlet structure needed will depend on factors such as the type of spillway, basin configuration and extended detention outflow rate. Design the outlet to control the outflow rate without clogging. Locate the outlet structure in the embankment for maintenance, access, safety and aesthetics. Design the outlet to facilitate maintenance; the vital parts of the structure must be accessible during normal maintenance and emergency situations. It also must contain a draw-down valve for complete detention basin draining within 24 hours.

To prevent scour at the outlet, use a flow transition structure, such as a lined apron or plunge pad, to absorb the initial impact of the flow and reduce the velocity to a level that will not erode the receiving channel or area. Design embankments and spillways in accordance with the state regulations for Dam Safety (302 CMR 10.00). All extended dry detention basins must have an emergency spillway capable of bypassing runoff from large storms without damaging the impounding structure.

Provide a public or private right-of-way access for maintenance that is at least 15 feet wide with a maximum slope of 5:1. Make sure this access extends to the forebay, safety bench, and outflow structure, and never crosses the emergency spillway, unless the spillway has been designed for that purpose. Use vegetative buffers around the perimeter of the basin for erosion control and additional sediment and nutrient removal.

Maintenance

Inspect extended dry detention basins at least once per year to ensure that the basins are operating as intended. Inspect extended dry detention basins during and after major storms to determine if the basin is meeting the expected detention times. Examine the outlet structure for evidence of clogging or outflow release velocities that are greater than design flow. Potential problems that should be checked include: subsidence, erosion, cracking or tree growth on the embankment; damage to the emergency spillway; sediment accumulation around the outlet; inadequacy of the inlet/outlet channel erosion control measures; changes in the condition of the pilot channel; and erosion within the basin and banks. Make any necessary repairs immediately. During inspections, note any changes to the extended dry detention basin or the contributing watershed, because these could affect basin performance.

Mow the upper-stage, side slopes, embankment, and emergency spillway at least twice per year. Also remove trash and debris at this time. Remove sediment from the extended dry detention basin as necessary, but at least once every 5 years. Providing an on-site sediment disposal area will reduce the overall sediment removal costs.

Proprietary Media Filters

Description: Media Filters are typically proprietary two-chambered underground concrete vaults that reduce both TSS and other pollutants (e.g., organics, heavy metals, soluble nutrients). After larger particles settle out in the first chamber, stormwater flows through the specific filter media in the second chamber. Selection of the specific media largely depends on the pollutant targeted.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	N/A
3 - Recharge	N/A
4 - TSS Removal	See Vol. 2, Chapter 4
5 - Higher Pollutant Loading	Suitable as pretreatment device
6 - Discharges near or to Critical Areas	Suitable as pretreatment device
7 - Redevelopment	Suitable; if site is severely constrained may be preferred

Advantages/Benefits:

- Suitable for specialized applications, such as industrial sites, for specific target pollutants
- Preferred for redevelopments or in the ultra-urban setting when LID or larger conventional practices are not practical

Disadvantages/Limitations:

- May require more maintenance
- Performance varies depending upon media
- TSS removal variable, depending on media
- “Wet” systems that are designed to retain water can cause mosquito and vector problems unless access points are sealed

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	Variable, depending upon media
• Total phosphorus (TP)	Variable, depending upon media
• Dissolved Inorganic Nitrogen	Variable, depending upon media
• Zinc	Variable, depending upon media
• Pathogens (coliform, e. coli)	Variable, depending upon media

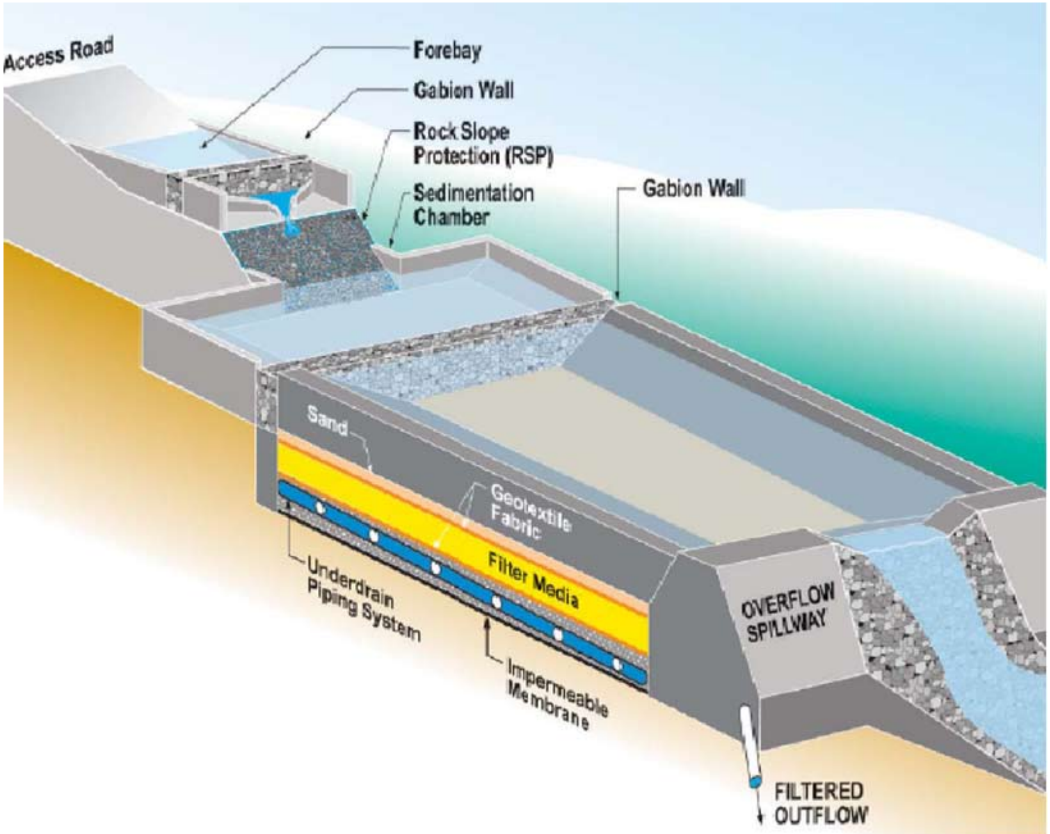


image provided from CALTRANS - California Department of Transportation.

Maintenance

Activity	Frequency
Inspect for standing water, sediment, trash and debris and clogging	2 times per year minimum; follow manufacturer's schedule
Remove accumulated trash and debris	During every inspection
Inspect to determine if system drains in 72 hours	Once a year during wet season after large storm
Inspect filtering media for clogging; replace if clogged	Per manufacturer's specifications

Special Features

Redevelopment, pretreatment for LUHPPL and Critical Areas, and removal of pollutants in addition to TSS

LID Alternatives

Reduce impervious surfaces which reduces volume and rate of runoff
Disconnect runoff by directing runoff to qualifying pervious area

Media Filters

Media Filters are typically two-chambered underground concrete vaults designed to reduce both TSS and other pollutants. The first chamber is usually a pretreatment settling basin. The second chamber is a filter bed containing either sand or other filtering media or an array of media-containing cartridge filters. After larger particles (e.g., TSS) settle out in the first chamber, stormwater flows through the specific filter media in the second chamber, and a portion of the target pollutants are sorbed to the filter media.

Various media are used, including leaf compost, pleated fabric, activated charcoal, perlite, amended sand and perlite, and zeolite, and tend to vary by manufacturer. Selection of the specific media largely depends on the pollutant targeted. Media filters must have the filter medium in the filter beds or the cartridges replaced periodically; following the manufacturer's schedule for operation and maintenance is critical to successful continued effectiveness.

Since Media Filters are Proprietary BMPs, MassDEP has not assigned this group of BMPs a TSS removal rate. Their performance varies depending upon the specific unit selected, the targeted pollutants, and successful design of the system. The procedure described in Volume 2, Chapter 4, must be used by the issuing authority to establish the TSS removal rate that will be used for permitting purposes.

Design

Media Filters are most efficient when designed to operate off-line. Media Filters should contain a by-pass device to allow large stormwater flows from intense precipitation to by-pass the media filters, so as to not cause resuspension of material trapped by the filters. Media Filters must be sized to treat the water quality volume (either ½-inch or 1-inch), depending on whether there is a discharge to a critical area, if the drainage is from a land use with higher potential pollutant load (LUHPPL), or is being directed to a soil with a rapid infiltration rate (hydraulic permeability >2.4 inches/hour). Since most Media Filter designs are based on flow rate, the flow rate must be converted to a Volume using the procedure described in Volume 3.

Media Filters can be either "dry" or "wet" design. "Dry" Media Filters are designed to dewater completely between storms. For design purposes, use 72 hours to evaluate dewatering, using the storm that produces either the ½ inch or 1-inch of runoff (water quality volume) in a 24-hour period. "Wet" Media Filters maintain a permanent pool of water as part of the treatment system.

For media filters constructed or placed below grade, inspection ports and cleanout ports must be included in the design to allow access to the system for maintenance.

Maintenance

For proprietary systems, maintenance must be conducted in strict accordance with the manufacturer's requirements. Clean-out of trapped sediment in the concrete vaults housing the media filters may require the party conducting the maintenance to be trained for confined space entry under OSHA requirements.

"Dry" Media Filters are designed to dewater completely in 72 hours. Prevention of mosquito and vector breeding in dry designs depends on maintenance that ensures that dewatering occurs in 72 hours, that filters are not clogged and trapping water, and that associated BMP accessories (such as level spreaders) dewater as designed. "Wet" Media Filters are more conducive to mosquito and vector problems. Tight-fitting seals can be used to keep mosquitoes and vectors from entering and breeding in the permanent pools, and maintenance may include routine inspection and treatment.

REFERENCES:

California Stormwater Quality Association, 2003, California Stormwater BMP Handbook, Media Filter, Practice No. TC-40, http://www.cabmphandbooks.com/Documents/Development/TC-40.pdf

Connecticut Department of Environmental Protection, 2004, Connecticut Stormwater quality Manual, Media Filters, pp. II-S11-1 to II-S11-3, http://www.ct.gov/dep/lib/dep/water_regulating_and_discharges/stormwater/manual/CH11_MF_S-11.pdf

Idaho Department of Environmental Quality, 2005, Storm Water Best Management Practices Catalog, Media Filter, BMP 7, pp. 43-44, http://www.deq.idaho.gov/water/data_reports/storm_water/catalog/sec_4/bmps/7.pdf

Sand & Organic Filters

Description: Also known as filtration basins, sand and organic filters consist of self-contained beds of sand or peat (or combinations of these and other materials) either underlaid with perforated underdrains or designed with cells and baffles with inlets/outlets. Stormwater runoff is filtered through the sand, and in some designs may be subject to biological uptake. Runoff is discharged or conveyed to another BMP for further treatment. Another type of filter is the tree box filter. Information on this practice appears at the end of this section.

Advantages/Benefits:

- Applicable to small drainage areas of 1 to 10 acres, although some designs may accept runoff of up to 50 acres.
- Good retrofit capability.
- Long design life if properly maintained
- Good for densely populated urban areas and parking lots with high intensity use

Disadvantages/Limitations:

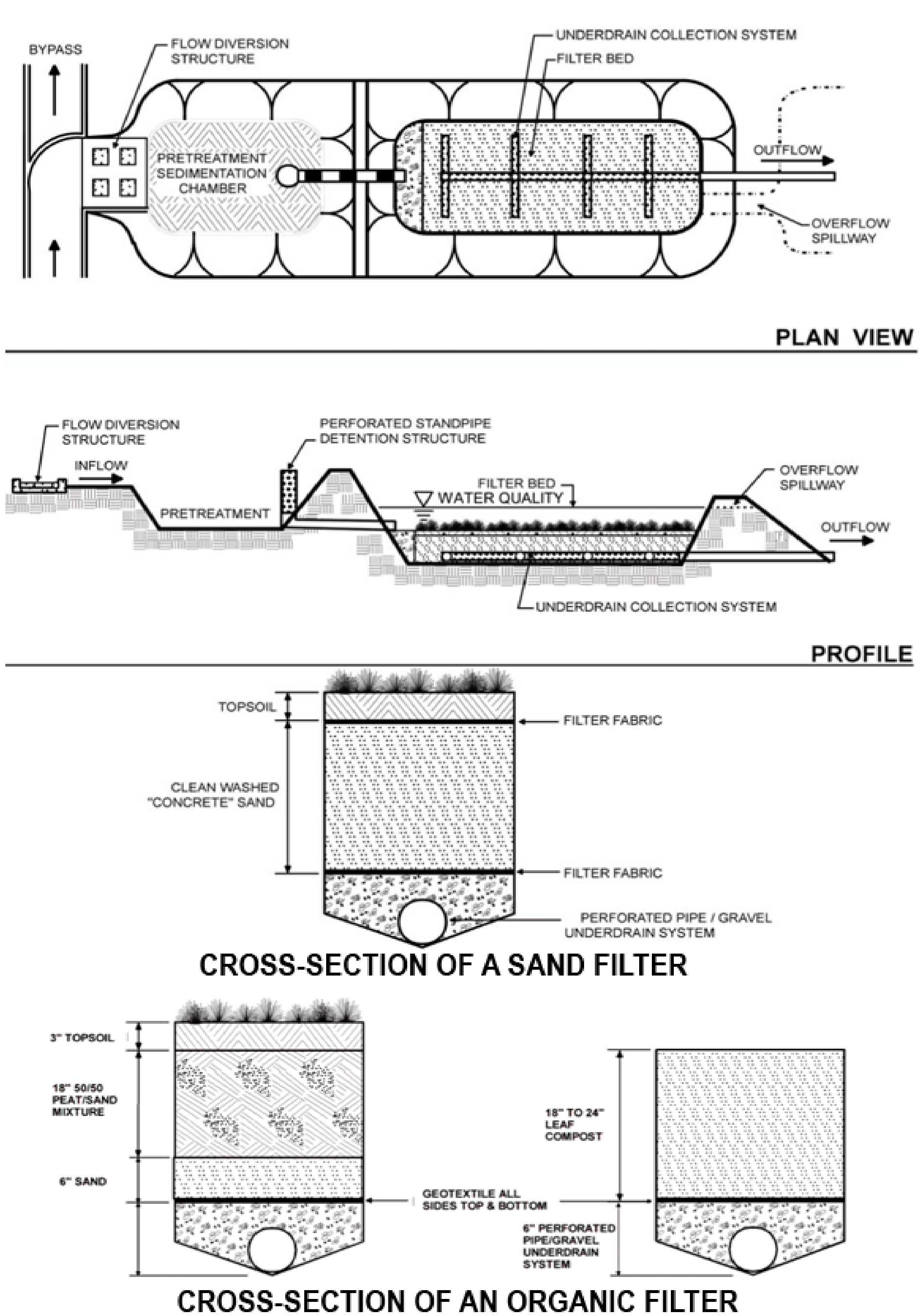
- Pretreatment required to prevent the filter media from clogging.
- Frequent maintenance required.
- Relatively costly to build and install.
- Without grass cover, the surface of sand filters can be extremely unattractive.
- May have odor problems, which can be overcome with design and maintenance.
- May not be able to be used on certain sites because of inadequate depth to bedrock or high groundwater
- May not be effective in winter

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Not applicable
3 - Recharge	Not applicable
4 - TSS Removal	80% TSS removal credit provided it's combined with one or more pretreatment BMPs prior to infiltration.
5 - Higher Pollutant Loading	Can be used in lieu of an oil grit separator for certain land uses with higher potential pollutant loads of oil and grease such as high intensity parking lots and gas stations
6 - Discharges near or to Critical Areas	Recommended treatment BMP.
7 - Redevelopment	Suitable when combined with pretreatment BMP. Good option for ultra urban areas, since they consume no surface space.

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	80% with pretreatment
• Total Nitrogen	20% to 40%
• Total Phosphorus	10% to 50%
• Metals (copper, lead, zinc, cadmium)	50% to 90%
• Pathogens (coliform, e coli)	Insufficient data



adapted from the Vermont Stormwater Manual

Special Features:

Design as off-line device.
Include a Sediment Forebay or equivalent pretreatment device.

LID Alternative:

Bioretention areas

Maintenance

Activity	Frequency
Inspect filters and remove debris	After every major storm for the first few months after construction is complete to ensure proper function and every 6 months thereafter.

Sand Filters

Applicability

Sand filters are adaptable to most developments. They can be installed in areas with thin soils, high evaporation rates, low soil infiltration rates and limited space. Sand filters can be used in ultra-urban sites with small drainage areas that are completely impervious, such as small parking lots and fast food restaurants. They are suitable for many areas that are difficult to retrofit due to space limitations.

Sand filters can be used in areas with poor soil infiltration rates, where groundwater concerns restrict the use of infiltration, or for high pollutant loading areas. Design sand filters as off-line BMPs; they are intended primarily for quality control, not quantity control. A diversion structure, such as a flow splitter or weir, typically routes a portion of the runoff into the sand filter, while the remainder continues on to a stormwater quantity control BMP. Large sand filters can be designed to play a role in the control of peak discharge rates.

Because of the potential for clogging, install sand filters only at sites that have been stabilized. Never use sand filters as sedimentation traps during construction.

Effectiveness

Sand filters improve water quality by straining pollutants through a filtering media and by settling pollutants on top of the sand bed and/or in a pretreatment basin.

Planning Considerations

The surface of sand filters can be unattractive and create odors, and may not be appropriate for residential areas without a grass cover.

Sand filters require a sediment forebay or equivalent pretreatment device. Locate sand filters off-line from the primary conveyance/ detention systems. Design sand filters large enough to handle runoff from the storm associated with the required water quality volume, i.e., one inch or one half inch rain event. Fit stormwater conveyances with flow splitters or weirs to route the required volume of runoff to the sand filter. Allow excess runoff to bypass the sand filter and continue on to another BMP designed to accommodate the necessary stormwater quantity.

Design

See the following for complete design references:

- *Developments in Sand Filter Technology to Treat Stormwater Runoff, Article 105, and Further Developments in Sand Filter Technology, Article 106, in the Practice of Stormwater Protection*
- *Georgia Stormwater Manual 2004*
- *Connecticut Stormwater Manual*
- *North Carolina Department of Environment and Natural Resources Stormwater BMP Manual 2007*

Two key design principles for sand filters are visibility and simplicity. A visible sand filter is more apt to be adequately operated and maintained. Complex designs are more expensive and difficult to operate and maintain. Typically, sand filter systems are designed with two components, a pretreatment component and a filtering component. The pretreatment component is a sediment forebay or vegetated filter strip designed to reduce the sediment load to the filtering component. Pre-settling also slows the runoff velocity and spreads it evenly across the top of the filter component.

Generally, the volume of the sediment forebay should be equal to or greater than the filtering capacity. Design the filter to capture finer silt and clay particles and other pollutants in the runoff. Sand filters are designed to function as a stormwater quality control practice, and not to provide detention for downstream areas. Therefore, locate them as off-line systems, away from the primary conveyance/ detention system.Design the pretreatment component to settle out coarse sediments that may clog the sand filter and reduce its effectiveness.

Use a design filtration rate of 2 inches/hour. Although this rate is low compared to published values for sand, it reflects actual rates achieved by sand filters in urban areas. Using Darcy's Law, design the sand filter to completely drain within 24 hours or less, because there is little storm storage available in the sand filter if a second storm occurs.

Use eighteen inches of 0.02-inch to 0.04-inch diameter sand (smaller sand is acceptable) for the sand bed. Consider that sand may consolidate during construction. Stabilize the depth of the bed by wetting the sand periodically, allowing it to consolidate, and then adding extra sand. There are several possible sand bed configurations; most use a gravel bed at the bottom overlaid with a layer of sand and/or peat, leaf compost, or topsoil/grass. In all configurations, make sure the top surface layer of the bed is level to provide equal distribution of the runoff in the bed. The gravel bed layer is generally composed of 4 to 6 inches of 0.5-inch to 2-inch diameter gravel. Separate the gravel and top media layers with a layer of geotextile fabric to prevent sand from infiltrating into the gravel layer and the underdrain piping.

Recent research (Erickson, et al., 2007) shows that enhancing sand filters with steel wool can reduce phosphorus concentrations by as much as 80%.

Organic Media Filters

Organic media filters are essentially the same as sand filters with the sand media replaced or supplemented with another medium. Two examples are the peat sand filter and the compost sand filter. According to the Center for Watershed Protection, many practioners believe that organic sand filter systems have enhanced pollutant removal for many compounds due to the increased cation exhange capacity achieved by increasing the organic matter. See Performance of Delaware Sand Filter Assessed, Article 107 of the Practice of Watershed Protection.

Maintenance Features Incorporated in Filter Design

Ease of access is essential for sand filter maintenance. Some designs use a geotextile layer, surface screen, or grating at the top to filter out coarse sediment and debris and for ease of maintenance. Typical maintenance for sand filters includes removing the top several inches of discolored sand and replacing it with clean media. Designs should include ramps, manhole steps, or ringbolts that allow a maintenance worker to manually remove this material. In addition, avoid heavy grates or manhole covers that cannot be lifted manually.

Trench Design

Trench designs have lateral underdrain pipes that are covered with 0.5-inch to 2-inch diameter gravel and geotextile fabric. The underdrains are underlaid with drainage matting, which is necessary to provide adequate hydraulic conductivity to the lateral pipes. Reinforce the underdrain piping so it withstands the weight of the overburden. The minimum grade of the piping should be 1/8 inch per foot (at 1% slope). An impermeable liner (clay, geomembrane, concrete) may be required under the filter to protect groundwater. If the impermeable liner is not required, install a geotextile liner, unless the bed has been excavated to bedrock. Make sure that the side slopes of the earthen embankments do not exceed 3:1 (horizontal: vertical). Fencing around sand filters may be needed to reduce safety hazards. Carefully selecting topsoil and sod for natural cover will help reduce the potential for failure. Sod with fine silts and clays will clog the top of the sand filter. Maximize the life of the sand filter by limiting its use to treating runoff from impervious areas only.

Construction

- Take care during construction to minimize the risk of premature failure of the sand filter.
- Diversion berms should be placed around the perimeter of the sand filters during all phases of construction.
- Sand filters should not be used as temporary sediment traps for construction activities.
- Consolidation of material in the sand filters during construction must be taken into consideration. The depth of the bed can be stabilized by wetting the sand periodically, allowing it to consolidate, and then adding extra sand.
- During and after excavation, all excavated materials should be placed downstream, away from the sand filters, to prevent redeposition during runoff events. All excavated materials should be handled properly and disposed of properly during and after construction.

Cold Weather Modifications

Surface sand filters will not provide treatment during the winter. Underground filers are not effective in winter unless the filter bed is placed below the frost line. Peat and compost media are ineffective during the winter in cold climates. These filters retain water and can freeze solid, and thus become impervious.

To prevent freezing, the diameter of the underdrain pipe should be at least 8 inches, and the slope of the underdrain pipe should be at least 1%. Place eighteen inches of gravel at the base of the filter. Make the slope of the inflow pipes at least 2%. In addition, place the filter below the frost line. If freezing cannot be prevented, remove snow from the contributing area and place it elsewhere.

Maintenance

Inspect sand filters after every major storm in the first few months after construction to ensure proper function. Thereafter, inspect the sand filter at least once every 6 months. Sand filters require frequent manual maintenance. Important maintenance tasks include raking the sand and removing surface sediment, trash and debris. Eventually a layer of sediment will accumulate on the top of the sand, which can be easily scraped off using rakes or other devices. Finer sediments will penetrate deeper into the sand over time, necessitating replacement of some (several inches) or all of the sand. Discolored sand indicates the presence of fine sediments. De-water and properly dispose of sand removed from the filter.

References

Erickson, Andrew J., et al., Enhanced Sand Filtration for Storm Water Phosphorus Removal, Journal of Environmental Engineering. Volume 133, Issue 5, pp. 485-497, May 2007.

Tree Box Filter

Description: The Tree Box Filter consists of an open bottom concrete barrel filled with a porous soil media, an underdrain in crushed gravel, and a tree. Stormwater is directed from surrounding impervious surfaces through the top of the soil media. Stormwater percolates through the media to the underlying ground. Treated stormwater beyond the design capacity is directed to the underdrain where it may be directed to a storm drain, other device, or surface water discharge.

Advantages/Benefits:
- May be used as a pretreatment device
- Provides decentralized stormwater treatment
- Ideal for redevelopment or in the ultra-urban setting

Disadvantages/Limitations:
- Treats small volumes

Special Features

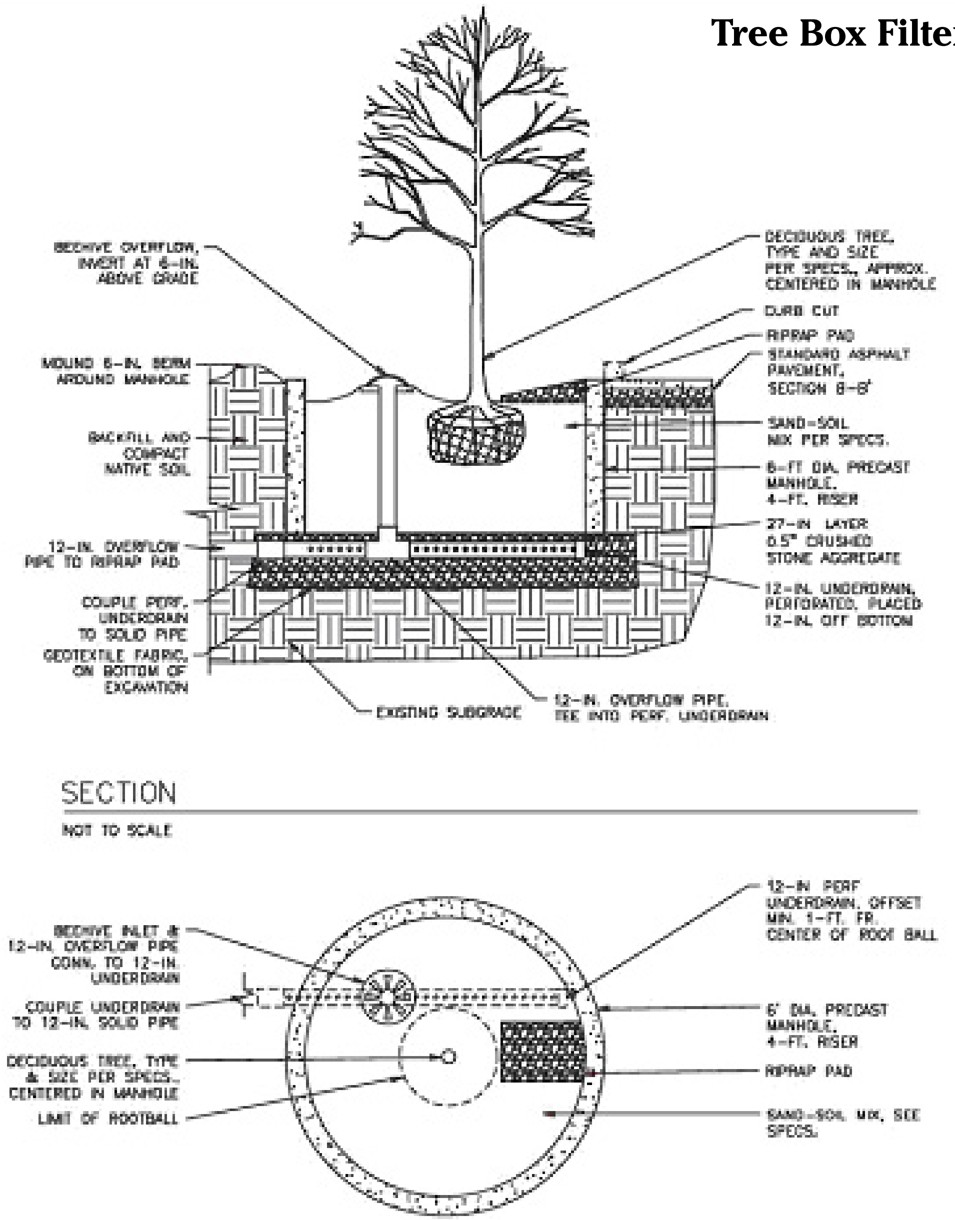
Reduces volume and rate of runoff.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	N/A
3 - Recharge	No infiltration credit
4 - TSS Removal	Presumed to remove 80% TSS
5 - Higher Pollutant Loading	May be used as pretreatment device if lined
6 - Discharges to near or to Critical Areas	Not suitable for vernal pools or swimming areas. At other critical areas, may be used as a pretreatment device.
7 - Redevelopment	May be used for retrofit.

Pollutant Removal Efficiencies
- Total Suspended Solids (TSS)- 80% presumed for regulatory purposes
- Total phosphorus (TP)- Not Reported
- Dissolved Inorganic Nitrogen- Not Reported
- Zinc- Not Reported
- Pathogens (coliform, e. coli)- Not Reported

Tree Box Filter



adapted from the Vermont Stormwater Manual

Maintenance

Activity	Frequency
Check tree	Annually. Expected tree life is 5-10 years.
Rake media surface to maintain permeability	Twice a year
Replace media	When tree is replaced

Wet Basins (formerly wet retention ponds)

Description: Wet basins use a permanent pool of water as the primary mechanism to treat stormwater. The pool allows sediments to settle (including fine sediments) and removes soluble pollutants. Wet basins must have additional dry storage capacity to control peak discharge rates. Wet basins have a moderate to high capacity to remove most urban pollutants, depending on how large the volume of the permanent pool is in relation to the runoff from the surrounding watershed.

Ability to meet specific standards

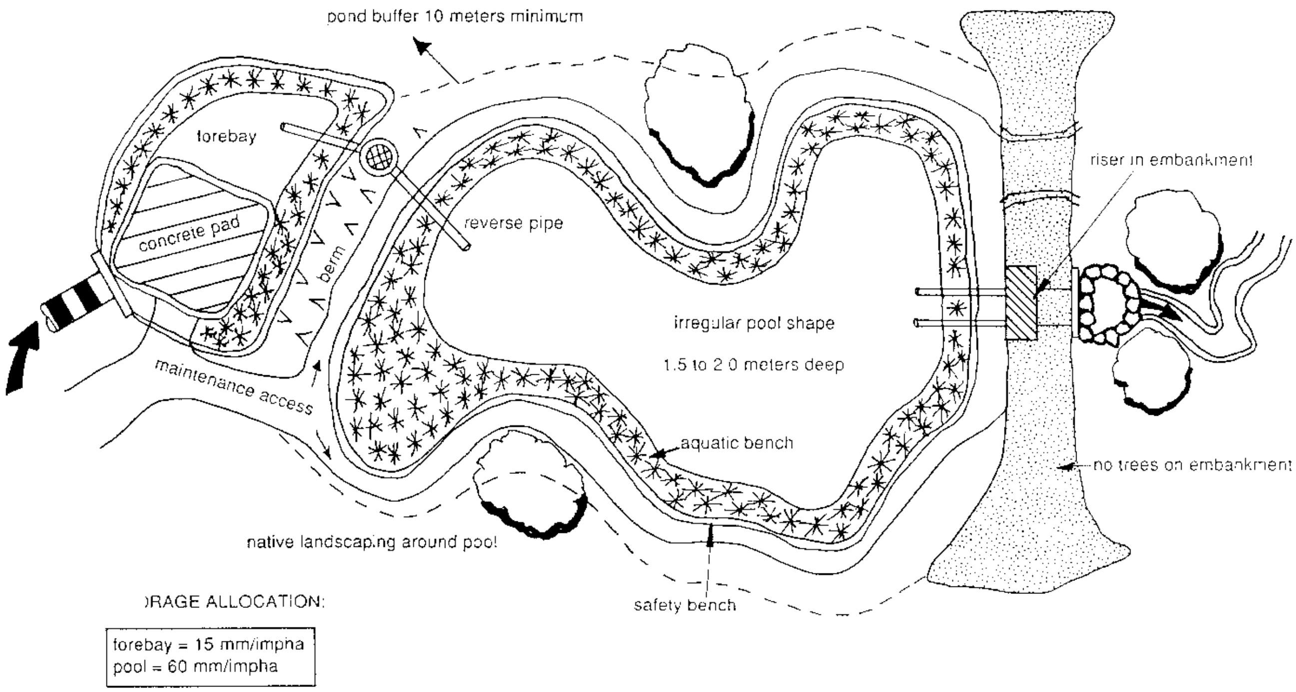
Standard	Description
2 - Peak Flow	Can be designed to provide peak flow attenuation.
3 - Recharge	Provides no groundwater recharge.
4 - TSS Removal	80% TSS removal credit when combined with sediment forebay as pretreatment.
5 - Higher Pollutant Loading	May be used as treatment BMP provided basin bottom is lined and sealed. For some land uses with higher potential pollutant load, may require pretreatment by oil grit separator, sand filter or equivalent prior to discharge to wet basin
6 - Discharges near or to Critical Areas	Do not use for discharges to cold-water fisheries
7 - Redevelopment	Not usually suitable.

Advantages/Benefits:
- Capable of removing both solid and soluble pollutants
- Capable of removing nutrients and metals
- Aesthetically pleasing BMP.
- Can increase adjacent property values when properly planned and sited.
- Sediment generally needs to be removed less frequently than for other BMPs.
- Can be used in retrofits

Disadvantages/Limitations:
- More costly than extended dry detention basins.
- Larger storage volumes for the permanent pool and flood control require more land area.
- Infiltration and groundwater recharge is minimal, so runoff volume control is negligible.
- Moderate to high maintenance requirements.
- Can be used to treat runoff from land uses with higher potential pollutant loads if bottom is lined and sealed.
- Invasive species control required

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	80% with sediment forebay
• Total Nitrogen	10% to 50%
• Total Phosphorus	30% to 70%
• Metals (copper, lead, zinc, cadmium)	30% to 75%
• Pathogens (coliform, e coli)	40% to 90%



adapted from Schueler, 1992

Maintenance

Activity	Frequency
Inspect wet basins to ensure they are operating as designed	At least once a year.
Mow the upper-stage, side slopes, embankment and emergency spillway.	At least twice a year.
Check the sediment forebay for accumulated sediment, trash, and debris and remove it.	At least twice a year.
Remove sediment from the basin.	As necessary, and at least once every 10 years

Special Features

MassDEP requires a sediment forebay as pretreatment to a wet basin.

LID Alternative

1. Design measures to reduce impervious areas, shrinking the size of the wet basin
2. Use if LID site design credits for the water quality volume requirement (Stormwater Standard 4)
3. Decentralized Stormwater Management System that uses vegetative filter strips to direct stormwater runoff to BMPs located throughout the site

Wet Basins

A wet basin may be created by constructing an embankment or excavating a pit. The primary component of a wet basin is the deep, permanent pool, but other components, such as a shallow marsh, may be added to the design *(see basin/wetland design in constructed wetlands section).* MassDEP requires a sediment forebay as pretreatment to a wet basin. The sediment forebay plus the wet basin collectively are credited with an 80% TSS removal rate.

The basic operation of a wet basin allows incoming stormwater to displace the water present in the pool. This stormwater remains until displaced by runoff from another storm event. Increased retention time allows particulates, including fine sediments, to settle out of the water column. The permanent pool also serves to protect deposited sediments from resuspending during large storm events. Another advantage of wet basins is the biological activity of algae and fringe wetland vegetation, which reduces the concentration of soluble pollutants. Wet basins may be designed with a multi-stage outlet structure to control peak rate discharges from different design storms. When properly designed and maintained, wet basins can add recreation, open space, fire protection, wildlife habitat, and aesthetic values to a property.

Applicability

Generally, dry weather base flow and/or large contributing drainage areas are required to maintain pool elevations. The minimum contributing drainage area must be at least 20 acres, but not more than one square mile. Sites with less than 20 acres of contributing drainage area may be suitable only if sufficient groundwater flow is available. Use wet basins at residential, commercial and industrial sites. Because wet basins remove soluble pollutants, they are ideal for sites where nutrient loadings are expected to be high. In such instances, source controls must also be implemented to further reduce nutrient loadings.

Investigate soils, depth to bedrock, and depth to water table before designing a wet basin. At sites where bedrock is close to the surface, high excavation costs may make wet ponds infeasible. If the soils on site are relatively permeable or well drained, such as a soil type in Hydrologic Group A (as defined by the Natural Resource Conservation Service), it will be difficult to maintain a permanent pool. In this situation, it may be necessary to line the bottom of the wet pond to reduce infiltration. Designing wet basins for multiple storms will provide peak rate control. In such instances, design the upper stages of wet basins to provide temporary storage of larger storms (i.e., 10, 25, and 100-year 24-hr. storms). Wet basins are generally ineffective in controlling the post-development increase in runoff volume, although some infiltration does occur, as well as evaporation in summer months.

Planning Considerations

Evaluate soils and depth to bedrock before designing a wet basin. At sites where bedrock is close to the surface, high excavation costs may make wet basins infeasible. If the soils are permeable (A and B soils), heavy drawdown of the basin may occur during dry periods. In these situations, compact the basin soils or install a liner at the bottom of the basin to minimize the potential for drawdown. Specifications for basin materials include (in order of decreasing costs):

- 6-inch clay
- Polyvinyl liner
- Bentonite
- 6 inches of silt loam or finer material

To be effective in reducing peak runoff rates, locate the basin where it can intercept most of the runoff from the site, typically a low elevation that is near freshwater wetlands. Like all stormwater best management practices, wet basins must not be constructed in wetland resource areas other than isolated land subject to flooding, bordering land subject to flooding, land subject to coastal storm flowage, and riverfront area. Select a location that can accommodate the need to attenuate peak discharge rates without adversely impacting nearby wetland resources.

It is preferable to create the wet basin by excavating a pit below the grade of land. When this is not feasible, an earthern embankment can be created. Embankments or dams created to store more than 15 acre-feet, or that are more than 6 feet high, are under the jurisdiction of the Massachusetts Department of Conservation and Recreation (DCR) Office of Dam Safety and must be constructed, inspected, and maintained according to DCR guidelines.

Design

See the following for complete design references:
Wet Extended Detention Pond Design: Step by Step Design. 1995. Claytor.

Volume and geometry are the critical parameters in a wet basin design; the relationship of the volume in the permanent pool to the contributing runoff volume directly affects pollutant removal rates. Generally, bigger is better; however, after a certain threshold level, increasing the pool size results in only marginal increases in pollutant removal. The permanent pool must be sized at a minimum to hold twice the water quality volume (this is equivalent to a VB/VR of 2) when a wet basin is designed to provide peak rate attenuation in addition to water quality treatment. The peak rate volume is an additional volume above the permanent pool. The permanent pool volume must not be counted as part of the volume devoted to storage associated with peak rate attenuation. When designing a wet basin to also accommodate peak rate attenuation, a multiple stage outlet must be included as part of the design.

Make the minimum contributing drainage area at least 20 acres, but no more than one square mile. Sites with less than ten acres of contributing drainage area may be suitable if sufficient groundwater flow is available to maintain the permanent wet pool.

Pool depth is an important design factor, especially for sediment deposition. Use an average pool depth of 3 to 6 feet. Settling column studies and modeling analyses show that shallow basins remove more solids than deeper ones. However, resuspension of settled materials by wind action might be a problem in shallow basins that are less than two feet deep. Depths greater than eight feet may cause thermal stratification. Stratified pools tend to become anoxic (low or no oxygen) more often than shallower ponds. If possible, vary depths throughout the basin.

Providing deeper pools can provide fish habitat. It may be advantageous to introduce fish to the wet basins to reduce mosquito breeding. When designing wet basins to support fish, a fisheries biologist should be consulted. Fish habitat features may include trees to provide shading over the deeper depths. Selection of trees should be done carefully to avoid embankment or sidewall failure.

Use intermittent benches around the perimeter of the basin for safety and to promote vegetation. Design the safety bench to be at least ten feet wide and above normal pool elevations. Make the aquatic bench at least ten feet wide and maintain depths of 12 to 18 inches at normal elevations to support aquatic vegetation. Shallow depths near the inlet will concentrate sediment deposition in a smaller, more accessible area. Deeper depths near the outlet will yield cooler bottom water discharges that may mitigate downstream thermal effects.

Use a minimum pool surface area of 0.25 acres. Enhance the performance of the wet basin by enlarging the surface area to increase volume, instead of deepening the pool, although this increases water temperatures and evaporation rates. The original design of wet basin depths and volumes should take into account the gradual accumulation of sediment. Accumulating sediment in the pool will decrease storage volume and reduce pollutant removal efficiency.

Wet Basin Design Criteria	
Factor	Criteria
Maximum Drainage area	≥20 acres unless sufficient groundwater flow
Permanent Pool Volume	≥2 x WQv (equivalent to Vb/Vr ratio of 2)
Minimum Pool Surface Area	≥0.25 acres
Minimum Length to Width Ratio	≥3:1
Mean Permanent Pool Depth	3 to 6 feet
Maximum Permanent Pool Depth	8 feet
Maximum Pool Slopes	≤3H:1V
Maximum Safety & Aquatic Bench Slopes	≤2H:1V
Perimeter Accessway Width	≥15 feet
Perimeter Vegetative Buffer	≥25 feet
Sediment Forebay	Required (not included in wet basin sizing)
Pool Drain (for maintenance purposes)	Required maximum pool drain time: 40 hours

MassDEP requires a sediment forebay to pretreat stormwater before it enters the wet basin. Forebays trap sediment before the runoff enters the primary pool, effectively enhancing removal rates and minimizing long-term operation and maintenance problems. Removing sediment from the forebay is easier and less costly than from the wet basin pool, so design sediment forebays for ease of maintenance. Hard bottom forebays make sediment removal easier. Make forebays accessible by heavy machinery to faciltate maintenance.

To avoid reducing the pollutant removal capability and to maximize travel distance, locate the inflow points as far from the outlet structure as possible. To maximize stormwater contact and retention time in the pool, use a length to width ratio of at least 3:1.

Set the invert elevation of the inlet pipe at or below the surface of the permanent pool, preferably within one foot of the pool. Pipes discharging above the pool can erode the banks and side slopes. Design all inflow points with riprap or other energy dissipators to reduce inflow velocities.

Establish wetland vegetation on the aquatic bench to enhance the removal of soluble nutrients, facilitate sediment trapping, prevent sediment resuspension, provide wildlife and waterfowl habitat, and conceal trash and debris that may accumulate near the outlet. Six to eighteen inches of water depth are needed for wetland vegetation growth.

Make the slopes of the pools no steeper than 3:1. Flatter slopes help to prevent bank erosion during larger storms and facilitate routine bank maintenance tasks, such as mowing. Flat slopes also provide for public safety, and allow easier access. In addition, design the sides of the pool that extend below the safety and aquatic benches to the bottom of the pool at a slope that will remain stable, usually no steeper than 2:1 (horizontal to vertical).

Design the invert of the wet basin outlet pipe to convey stormwater from approximately one foot below the pool surface and to discharge into the riser in the pond embankment. To prevent clogging, install trash racks or hoods on the riser.

To facilitate access for maintenance, install the riser within the embankment. Place anti-seep collars or filter and drainage diaphragms on the outlet barrel to prevent seepage and pipe failure. Make the vital parts of the structure accessible to maintenance personnel during normal and emergency conditions. Install a bottom drainpipe to allow complete draining of the wet basin in case of emergencies or for routine maintenance.

Fit both the outlet pipe and the bottom drain pipe with adjustable valves at the outer end of the outlet to permit adjustment of the detention time, if necessary.

To prevent scour at the outlet, install a flow transition structure, such as a lined apron or plunge pad, to absorb the initial impact of the flow and reduce the velocity to a level that will not erode the receiving channel or area.

Design embankments and spillways to conform with DCR Dam Safety regulations, if applicable. All wet basins must have an emergency spillway capable of bypassing runoff from large storms without damaging the impounding structure.

Provide an access way for maintenance, with a minimum width of 15 feet and a maximum slope of 15%, by public or private right-of-way. Equipment that will be used for maintenance must be capable of using this access-way. This access should extend to the forebay, safety bench, and outflow structure and should never cross the emergency spillway, unless the spillway has been designed for that purpose. Place vegetative buffers around the perimeter of the wet basin to control erosion and remove additional sediment and nutrients. The vegetative buffer must be at least 33 feet (10 meters). Vegetation must be designed to prevent the introduction of invasive species.

Maintenance

Inspect wet basins at least once per year to ensure they are operating as designed. Inspect the outlet structure for evidence of clogging or excessive outflow releases. Potential problems to check include: subsidence, erosion, cracking or tree growth on the embankment, damage to the emergency spillway, sediment accumulation around the outlet, inadequacy of the inlet/outlet channel erosion control measures, changes in the condition of the pilot channel, erosion within the basin and banks, and the emergence of invasive species. Make any necessary repairs immediately. During inspections, note any changes to the wet basin or the contributing watershed area because these may affect basin performance. At least twice a year, mow the upper-stage, side slopes, embankment and emergency spillway. At this time, also check the sediment forebay for accumulated material, sediment, trash, and debris and remove it. Remove sediment from the basin as necessary, and at least once every 10 years. Providing an on on-site sediment disposal area will reduce the overall sediment removal costs.

References

Galli, J. 1990, Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices. Prepared for the Maryland Department of Environment, Baltimore, MD, by the Metropolitan Council of Governments, Washington, D.C.

Conveyance BMPs

Drainage Channels

Grassed Channel

Water Quality Swale

Drainage Channels

Description: Drainage channels are traditional vegetated open channels that are designed to provide for non-erosive conveyance. They receive no infiltration or TSS removal credit (Standards 3 and 4).

Ability to meet specific standards

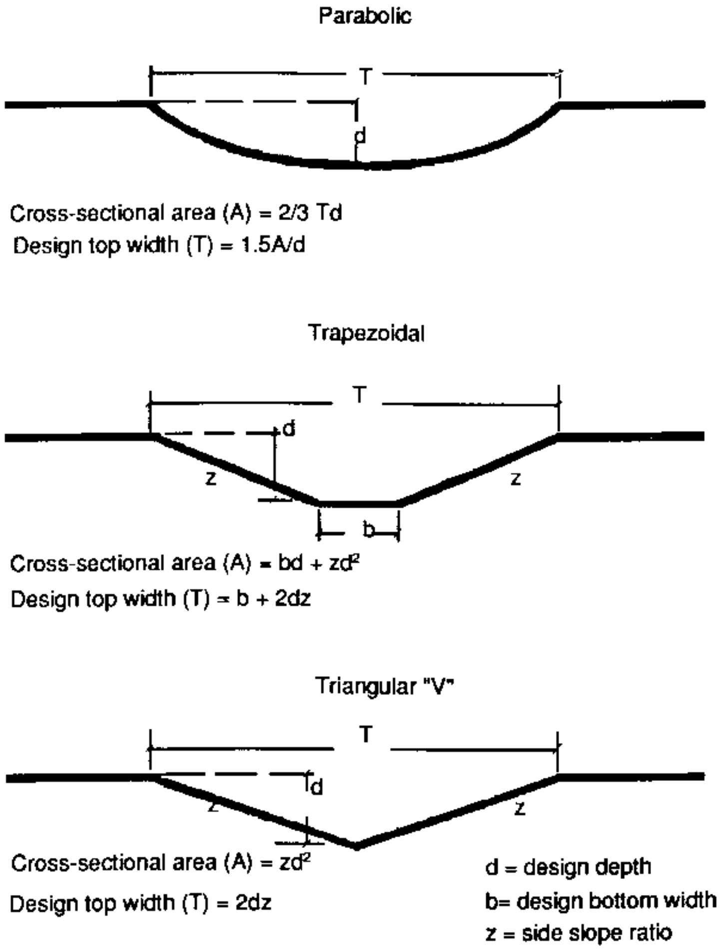
Standard	Description
2 - Peak Flow	Provides no peak flow attenuation
3 - Recharge	Provides negligible groundwater recharge.
4 - TSS Removal	0% TSS removal credit.
5 - Higher Pollutant Loading	Use as conveyance.
6 - Discharges near or to Critical Areas	May be used to achieve temperature reduction for runoff discharging to cold-water fisheries.
7 - Redevelopment	Limited applicability

Pollutant Removal Efficiencies
- Total Suspended Solids (TSS) - 0%
- Nutrients (Nitrogen, phosphorus) - Insufficient data
- Metals (copper, lead, zinc, cadmium) - Insufficient data
- Pathogens (coliform, e coli) - Insufficient data

Advantages/Benefits:
- Conveys stormwater
- Generally less expensive than curb and gutter systems.
- Accents natural landscape.
- Compatible with LID design practices
- Roadside channels reduce driving hazards by keeping stormwater flows away from street surfaces during storms

Disadvantages/Limitations:
- Higher degree of maintenance required than for curb and gutter systems.
- Roadside channels are subject to damage from off-street parking and snow removal.
- Provides limited pollutant removal compared to water quality swales
- May be impractical in areas with flat grades, steep topography or poorly drained soils
- Large area requirements for highly impervious sites.

Figure DC 1



adapted from the University of New Hampshire

Maintenance

Activity	Frequency
Inspect channels to make sure vegetation is adequate and for signs of rilling and gullying. Repair any rills or gullies. Replace dead vegetation.	The first few months after construction and twice a year thereafter.
Mow	As necessary. Grass height shall not exceed 6 inches.
Remove sediment and debris manually	At least once a year
Reseed	As necessary. Use of road salt or other deicers during the winter will necessitate yearly reseeding in the spring.

Special Features

Drainage channels cannot be used to meet the Stormwater Management Standards. They are a component of a larger stormwater management system and serve to convey runoff from impervious surfaces to or from stormwater treatment BMPs.

Drainage Channels

Drainage Channels versus Water Quality Swales

The distinction between drainage channels and water quality swales lies in the design and planned use of the open channel conveyance. Drainage channels are designed to have sufficient capacity to convey runoff safely during large storm events without causing erosion. Drainage channels typically have a cross-section with sufficient hydraulic capacity to handle the peak discharge for the 10-year storm. The dimensions (slope and bottom width) of a drainage channel must not exceed a critical erosive velocity during the peak discharge. They must be vegetated with grasses to maintain bank and slope integrity. Other than basic channel size and geometry, there are no other design modifications to enhance pollutant removal capabilities. Therefore, pollutant removal efficiency is typically low for drainage channels.

Water quality swales and grass channels, on the other hand, are designed for the required water quality volume and incorporate specific features to enhance their stormwater pollutant removal effectiveness. Pollutant removal rates are significantly higher for water quality swales and grass channels. A water quality swale or grass channel must be used in place of the drainage channel when a water quality treatment credit is sought.

Applicability

Drainage channels are suitable for residential and institutional areas of low to moderate density. The percentage of impervious cover in the contributing areas must be relatively small. Drainage channels can also be used in parking lots to break up areas of impervious cover.

Along the edge of roadways, drainage channels can be used in place of curb and gutter systems. However, the effectiveness of drainage channels may decrease as the number of driveway culverts increases. They are also generally not compatible with extensive sidewalk systems. When using drainage channels in combination with roadways and sidewalks, it is most appropriate to place the channel between the two impervious covers (e.g., between the sidewalk and roadway).

The topography of the site should allow for the design of a drainage channel with sufficient slope and cross-sectional area to maintain non-erosive flow velocities. The longitudinal slope of the swale should be as close to zero as possible and not greater than 5%.

Planning Considerations

The two primary considerations when designing a drainage channel are maximizing channel capacity and minimizing erosion. Use the maximum expected retardance when checking drainage channel capacity. Usually the greatest flow retardance occurs when vegetation is at its maximum growth for the year. This usually occurs during the early growing season and dormant periods.

Other factors to be considered when planning for the drainage channel are land availability, maintenance requirements and soil characteristics. The topography of the site should allow for the design of a drainage channel with sufficient slope and cross-sectional area to maintain a non-erosive flow velocity, generally less than five feet per second.

The shape of the cross-sectional channel is also an important planning consideration. Figure DC 1 shows three different design shapes. The V-shaped or triangular cross-section can result in higher velocities than other shapes, especially when combined with steeper side slopes, so use this design only if the quantity of flow is relatively small. The parabolic cross-section results in a wide shallow channel that is suited to handling larger flows and blends in well with natural settings. Use trapezoidal channels when deeper channels are needed to carry larger flows and conditions require relatively high velocities. Select a grass type for the channel lining that is appropriate for site conditions, including one that is able to resist shear from the design flow, is shade tolerant, is drainage tolerant, and has low maintenance requirements. Use vegetation that is water tolerant and has a dense root system. Alternatively, the drainage channel may be lined with stone.

Design

See the following for complete design references:
Site Planning for Urban Stream Protection. 1995. Schueler. Center for Watershed Protection.

The length of the drainage channel depends on the slope, contributing impervious surface area, and runoff volume. Because drainage channels with low velocities can act as sediment traps, add extra capacity to address sediment accumulation without reducing design capacity. Add an extra 0.3 to 0.5

feet of freeboard depth, if sediment accumulation is expected. Use side slopes of 3:1 or flatter to prevent side slope erosion. Make the longitudinal slope of the channel as flat as possible and not greater than 5%.

Install check dams in drainage channels when necessary to achieve velocities of 5 feet per second or less. Do not use earthen check dams because they tend to erode on the downstream side, and it is difficult to establish and maintain grass on the dams. The maximum ponding time behind the check dam should not exceed 24 hours. Use outlet protection at discharge points from a drainage channel to prevent scour at the outlet.

The design for the drainage channel must include access for maintenance. When located along a highway, provide a breakdown lane with a width of 15 feet. When located along a street, off-street parking can be doubled up as the access, provided signs are posted indicating no parking is allowed during maintenance periods. When locating drainage channels adjacent to pervious surfaces, include a 15-foot wide grass strip to provide access for maintenance trucks.

Construction

Use temporary erosion and sediment controls during construction. Soil amendments, such as aged compost that contains no biosolids, may be needed to encourage vegetation growth. Select a vegetation mix that suits the characteristics of the site. Seeding will require mulching with appropriate materials, such as mulch matting, straw, wood chips, other natural blankets, or synthetic blankets. Anchor blanket immediately after seeding. Provide new seedlings with adequate water until they are well established. Refer to the "Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas: A Guide for Planners, Designers, and Municipal Officials" for information regarding seeding, mulching, and use of blankets.

Maintenance

The maintenance and inspection schedule should take into consideration the effectiveness of the drainage channel. Inspect drainage channels the first few months after construction to make sure that there is no rilling or gullying, and that vegetation in the channels is adequate. Thereafter, inspect the channel twice a year for slope integrity, soil moisture, vegetative health, soil stability, soil compaction, soil erosion, ponding, and sediment accumulation.

Regular maintenance tasks include mowing, fertilizing, liming, watering, pruning, weeding, and pest control. Mow channels at least once per year. Do not cut the grass shorter than three to four inches. Keep grass height under 6 inches to maintain the design depth necessary to serve as a conveyance. Do not mow excessively, because it may increase the design flow velocity.

Remove sediment and debris manually at least once per year. Re-seed periodically to maintain the dense growth of grass vegetation. Take care to protect drainage channels from snow removal procedures and off-street parking. When drainage channels are located on private residential property, the operation and maintenance plan must clearly specify the private property owner who is responsible for carrying out the required maintenance. If the operation and maintenance plan calls for maintenance of drainage channels on private properties to be performed by a public entity or an association (e.g. homeowners association), maintenance easements must be obtained.

Grassed Channel (Biofilter Swale)

Description: Grassed Channels (formerly known as Biofilter swales) are treatment systems with a longer hydraulic residence time than drainage channels. The removal mechanisms are sedimentation and gravity separation, rather than filtration. To receive TSS credit, a sediment forebay or equivalent must be provided for pretreatment. Note that the sediment forebay does not receive a separate TSS removal credit.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	N/A
3 - Recharge	No infiltration credit
4 - TSS Removal	50% TSS with adequate pretreatment
5 - Higher Pollutant Loading	N/A
6 - Discharges near or to Critical Areas	Not suitable for vernal pools or bathing beaches. At other critical areas, may be used as a pretreatment device.
7 - Redevelopment	Typically not suited for retrofits.

Advantages/Benefits:

- Provides pretreatment if used as the first part of a treatment train.
- Open drainage system aids maintenance
- Accepts sheet or pipe flow
- Compatible with LID design measures.
- Little or no entrapment hazard for amphibians or other small animals

Disadvantages/Limitations:

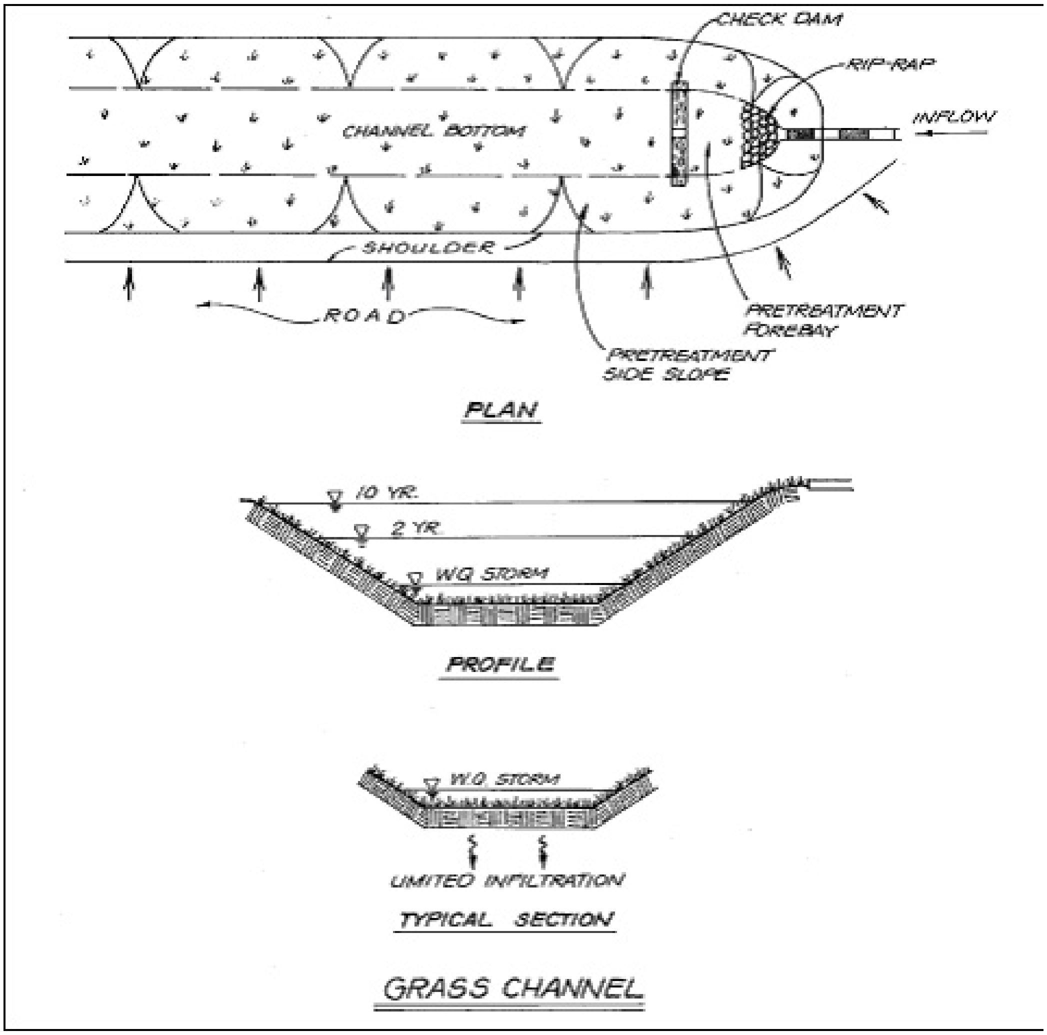
- Short retention time does not allow for full gravity separation·
- Limited biofiltration provided by grass lining.· Cannot alone achieve 80% TSS removal
- Must be designed carefully to achieve low flow rates for Water Quality Volume purposes (<1.0 fps)
- Mosquito control considerations

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	50%[1] for Regulatory Purposes (47%)[2]
• Total phosphorus (TP)	-121%[2]
• Total Nitrogen	Insufficient Data
• Metals (copper, lead, zinc, cadmium)	Insufficient Data
• Pathogens (coliform, e. coli)	Insufficient Data

[1] Atlanta Regional Commission et al, 2001, Georgia Stormwater Manual, Volume 2, Section 3-3-2, http://georgiastormwater.com/vol2/3-3-2.pdf

[2] International Stormwater Database, based on MassDEP analysis of raw influent & effluent values reported in 2005.



adapted from the Vermont Stormwater Manual

Maintenance

Activity	Frequency
Remove sediment from forebay	Annually
Remove sediment from grass channel	Annually
Mow	Once a month during growing season
Repair areas of erosion and revegetate	As needed, but no less than once a year

Special Features

Reduces volume and rate of runoff.

Grass Channels

Grass channels convey and treat stormwater. Grass channels were referred to as biofilter swales in the 1996 MassDEP/CZM Stormwater Handbook, based on the nomenclature coined by the Center for Watershed Protection (CWP). The CWP is now referring to biofilter swales as grass channels – so MassDEP is adopting the same name as the CWP to minimize confusion.

Properly designed grass channels are ideal when used adjacent to roadways or parking lots, where runoff from the impervious surfaces can be directed to the channel via sheet flow. Runoff can also be piped to the channel. If piped, locate the sediment forebay at the pipe outlet and include a check dam separating the forebay from the channel. For sheet flow, use a vegetated filter strip on a gentle slope or a pea gravel diaphragm. Make the longitudinal slope as flat as possible. This increases the Hydraulic Residence Time (HRT) and allows gravity separation of solids and maximizes sediment removal. Install check dams to further increase the HRT.

Review of the International Stormwater Database, updated in 2005, indicates lower TSS removal when compared to similar treatment practices (dry water quality swales, wet water quality swales, and bioretention areas). The information in the International Stormwater Database indicates grass channels are likely to export phosphorus (hence the negative removal efficiency cited above). Grass channels are not a practice suitable for treating stormwater that discharges to waters impaired by phosphorus or for waters where phosphorus TMDLs have been established.

Differences from dry water quality swales, wet water quality swales, bioretention cells, and drainage channels: Dry water quality swales contain a specific soil media mix and underdrain, providing greater treatment than grass channels. Wet water quality swales are designed with a permanent wet channel, whereas grass channels must be designed to completely drain between storms. Bioretention areas, including rain gardens, are designed solely as a treatment practice, and not for conveyance. Lastly, drainage channels act solely as a conveyance, in contrast to properly designed grass channels where runoff flow is deliberately lagged to provide treatment.

Design Considerations

Sizing:

Water Quality Volume: Design grass channels to maximize contact with vegetation and soil surface to promote greater gravity separation of solids during the storm associated with the water quality event (either ½ inch or 1-inch runoff). Design the channel such that the velocity does not exceed 1 foot per second during the 24-hour storm associated with the water quality event. Do not allow the water depth during the storm associated with the water quality event to exceed 4 inches (for design purposes). Make sure the selected design storm provides at least 9 minutes of HRT within the channel. Increasing the HRT beyond 9 minutes increases the likelihood of achieving the 50% TSS removal efficiency. Adding meanders to the swale increases its length and may increase the HRT.

2-year and 10-year conveyance capacity: Design grass channels to convey both the 2-year and 10-year 24-hour storms. Provide a minimum of 1-foot freeboard above the 10-year storm. Make sure that the runoff velocities during the 2-year 24-hour storm do not cause erosion problems.

Channel Length: Length depends on design factors to achieve the minimum 9-minute residence time for the storm associated with the water quality event.

Channel Crossings: In residential settings, driveways will cross over the channel, typically via culverts (pre-cast concrete, PVC, or corrugated metal pipe).

Soils: Grass channels may be constructed from most parent soils, unless the soils are highly impermeable. Soils must be able to support a dense grass growth. MassDEP recommends sandy loams, with an organic content of 10 to 20%, and no more than 20% clay. Highly impermeable soils, such as clays, are not suitable for grass channels, because they do not support dense grass stands. Similarly, gravelly and coarse soils may not be suitable due to their lower moisture retention capability, leading to potential die-back of the grass lining during the summer when the inter-event period between storms is longer than during other times of the year.

Grasses: The grasses serve to stabilize the channel, and promote conditions suitable for sedimentation, such as offering resistance to flow, which reduces water velocities and turbulence. Select a grass height of 6 inches or less. Grasses over that height tend to flatten when water flows

over them, inhibiting sedimentation. Select grasses that produce a fine, uniform and dense cover that can withstand varying moisture conditions. Regularly mow the channel to ensure that the grass height does not exceed 6 inches. Select grasses that are salt tolerant to withstand winter deicing of roadways. In the spring, replant any areas where grasses died off due to deicing. (Franklin 2002 and Knoxville 2003 provide recommendations for the best grass species.)
Pea Gravel Diaphragm: Use clean bank-run gravel, conforming to ASTM D 448, varying in size from 1/8 inch to 3/8 inch (No. 6 stone).
Outlet Protection: Must be used at discharge points to prevent scour downstream of the outlet.
Construction Considerations: Stabilize the channel after it is shaped before permanent turf is established, using natural or synthetic blankets. Never allow grass channels to receive construction period runoff.

Site Constraints

A proponent may not be able to install a grass channel swale because of:

- High groundwater;
- Presence of utilities; or
- Other site conditions that limit depth of excavation because of stability.

Maintenance

Access: Maintenance access must be designed as part of the grass channel. If located adjacent to a roadway, make the maintenance access at least 15 feet wide, which can also be combined with a breakdown lane along a highway or on-street parking along a residential street. When combined with on-street parking, post signs prohibiting parking when the swale is to be inspected and cleaned. Do not use travel lanes along highways and streets as the required maintenance access.
Mowing: Set the mower blades no lower than 3 to 4 inches above the ground. Do not mow beneath the depth of the design flow during the storm associated with the water quality event (e.g., if the design flow is no more than 4 inches, do not cut the grass shorter than 4 inches). Mow on an as-needed basis during the growing season so that the grass height does not exceed 6 inches.
Inspection: Inspect semi-annually the first year, and at least once a year thereafter. Inspect the grass for growth and the side slopes for signs of erosion and formation of rills and gullies. Plant an alternative grass species if the original grass cover is not successfully established. If grass growth is impaired by winter road salt or other deicer use, re-establish the grass in the spring.
Trash/Debris Removal: Remove accumulated trash and debris prior to mowing.
Sediment Removal: Check on a yearly basis and clean as needed. Use hand methods (i.e., a person with a shovel) when cleaning to minimize disturbance to vegetation and underlying soils. Sediment build-up in the grass channel reduces its capacity to treat and convey the water quality event, 2-year and 10-year 24-hour storm.

References:

Atlanta Regional Commission et al, 2001, Georgia Stormwater Management Manual, Volume 2, Section 3-3-2, Grass Channel, http://georgiastormwater.com/vol2/3-3-2.pdf

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International Stormwater BMP Data Base, 2005

Knoxville, City of, 2003, ST-05, Filter Strips and Swales, http://www.ci.knoxville.tn.us/engineering/bmp_manual/ST-05.pdf

Minton, G., 2002, Stormwater Treatment, Resource Planning Associates, Seattle, WA, p. 174

Water Quality Swale

Description: Water quality swales are vegetated open channels designed to treat the required water quality volume and to convey runoff from the 10-year storm without causing erosion.

There are two different types of water quality swales that may be used to satisfy the Stormwater Management Standards:

- Dry Swales
- Wet Swales

Unlike drainage channels which are intended to be used only for conveyance, water quality swales and grass channels are designed to treat the required water quality volume and incorporate specific features to enhance their stormwater pollutant removal effectiveness. Water quality swales have higher pollutant removal efficiencies than grass channels.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	With careful design may be able to reduce peak flow at small sites
3 - Recharge	May not be used to satisfy Standard 3
4 - TSS Removal	Wet swales and dry swales achieve 70% TSS removal when provided with a pretreatment device such as a sediment forebay with a check dam.
5 - Higher Pollutant Loading	Dry swale recommended as pretreatment BMP. Must be lined. For some land uses with higher potential pollutant load, an oil grit separator or equivalent may be required before discharge to the swale.
6 - Discharges near or to Critical Areas	Dry and Wet Swales recommended as treatment BMPs for cold-water fisheries. Must be lined unless 44% TSS has been removed before discharge to swale. Should not be used near shellfish growing areas and bathing beaches.
7 - Redevelopment	Recommended for redevelopments and urban applications if sufficient land is available.

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS)
  1. Dry Swale 70%
  2. Wet Swale 70%
- Total Nitrogen - 10% to 90%
- Total Phosphorus 20% to 90%
- Metals (copper, lead, zinc, cadmium) Insufficient data
- Pathogens (coliform, e coli) Insufficient data

Advantages/Benefits:

- May be used to replace more expensive curb and gutter systems.
- Roadside swales provide water quality and quantity control benefits, while reducing driving hazards by keeping stormwater flows away from street surfaces.
- Accents natural landscape.
- Compatible with LID designs
- Can be used to retrofit drainage channels and grass channels
- Little or no entrapment hazard for amphibians or other small animals

Disadvantages/Limitations:

- Higher degree of maintenance required than for curb and gutter systems.
- Roadside swales are subject to damage from off-street parking, snow removal, and winter deicing.
- Subject to erosion during large storms
- Individual dry swales treat a relatively small area
- Impractical in areas with very flat grades, steep topography or poorly drained soils
- Wet swales can produce mosquito breeding habitat
- Should be set back from shellfish growing areas and bathing beaches

Maintenance

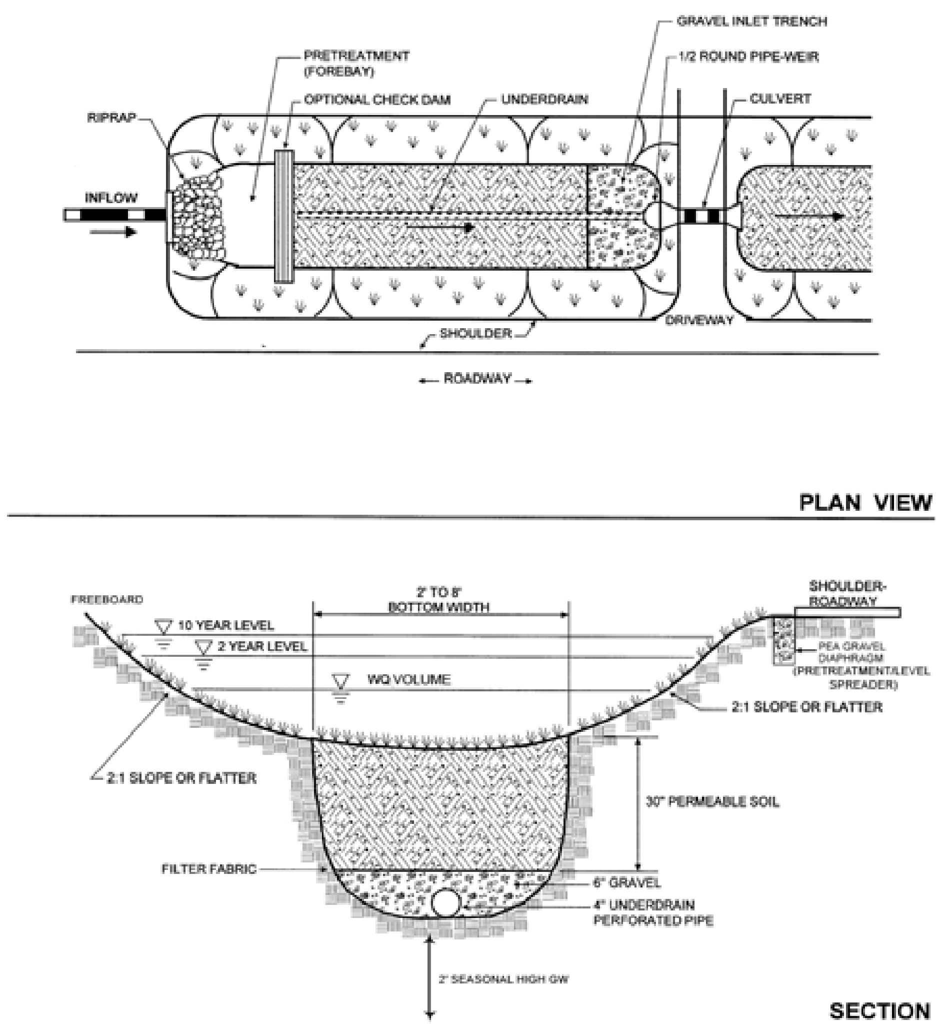
Activity	Frequency
Inspect swales to make sure vegetation is adequate and slopes are not eroding. Check for rilling and gullying. Repair eroded areas and revegetate.	The first few months after construction and twice a year thereafter.
Mow dry swales. Wet swales may not need to be mowed depending on vegetation.	As needed.
Remove sediment and debris manually	At least once a year
Re-seed	As necessary

Special Features

There are two types of swales that may be used to satisfy the Stormwater Management Standards - dry swales and wet swales.

Dry Swale

Dry swales are designed to temporarily hold the water quality volume of a storm in a pool or series of pools created by permanent check dams at culverts or driveway crossings. The soil bed consists of native soils or highly permeable fill material, underlaid by an underdrain system.

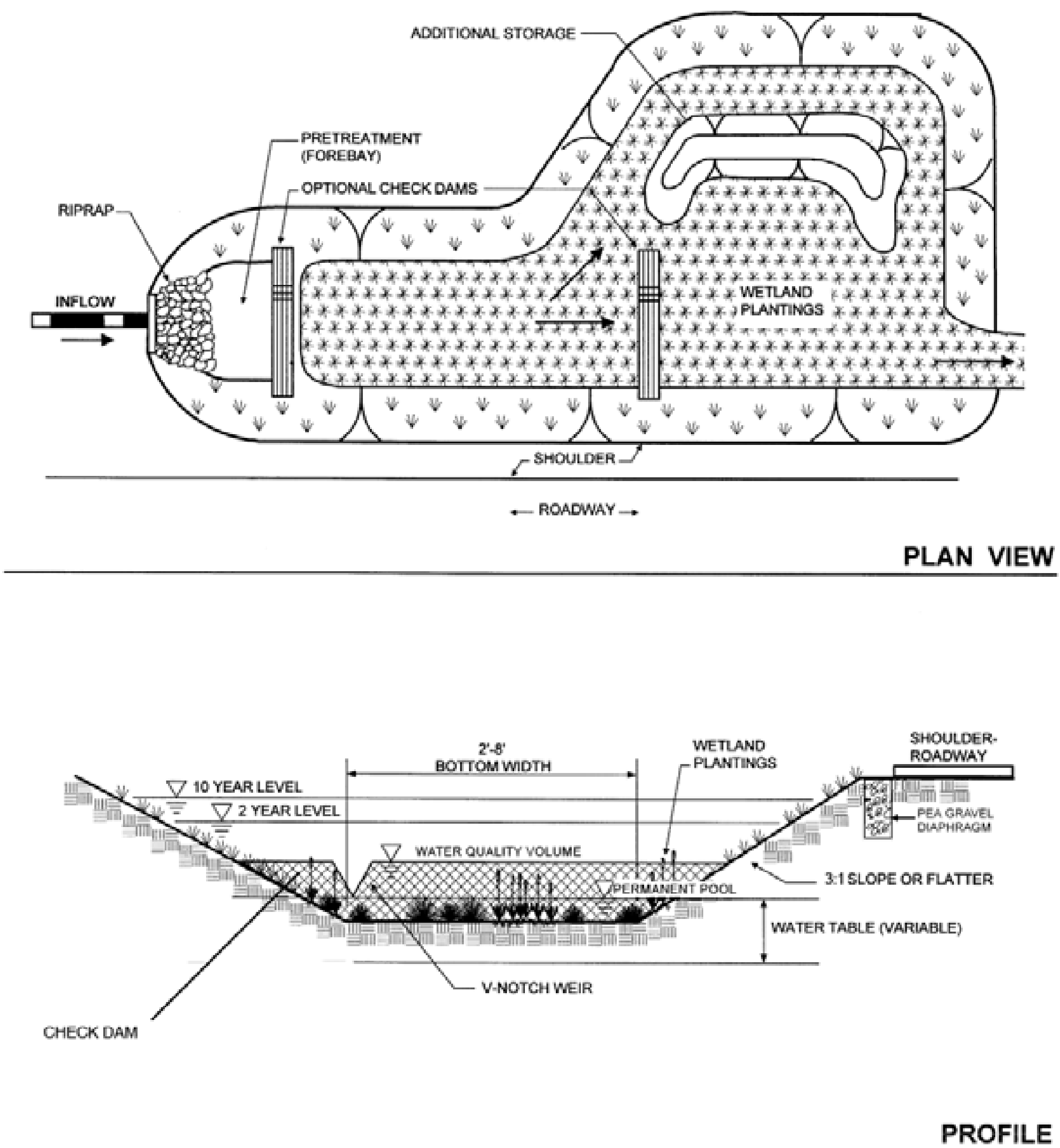


adapted from the Vermont Stormwater Manual

Example of Dry Swale

Wet Swale

Wet swales also temporarily store and treat the required water quality volume. However, unlike dry swales, wet swales are constructed directly within existing soils and are not underlaid by a soil filter bed or underdrain system. Wet swales store the water quality volume within a series of cells within the channel, which may be formed by berms or check dams and may contain wetland vegetation (Metropolitan Council, 2001). The pollutant removal mechanisms in wet swales are similar to those of stormwater wetlands, which rely on sedimentation, adsorption, and microbial breakdown.



Example of Wet Swale

adapted from the Vermont Stormwater Manual

Water Quality Swales

Applicability

Use water quality swales:

- As part of a treatment train
- As one of the best BMPs for areas discharging to cold-water fisheries if they are lined.
- As one of the best BMPs for redevelopments and urban applications.
- For residential and institutional settings (especially dry swales)

Water quality swales have many uses. Dry swales are most applicable to residential and institutional land uses of low to moderate density where the percentage of impervious cover in the contributing areas is relatively low. Wet swales may not be appropriate for some residential applications, such as frontage lots, because they contain standing water that may attract mosquitoes.

Water quality swales may also be used in parking lots to break up areas of impervious cover. Along the edge of small roadways, use water quality swales in place of curb and gutter systems. Water quality swales may not be suitable for sites with many driveway culverts or extensive sidewalk systems. When combining water quality swales with roadways and sidewalks, place the swale between the two impervious areas (e.g. between road and sidewalk or in-between north and south bound lanes of a roadway/highway).

The topography and soils on the site will determine what is appropriate. The topography should provide sufficient slope and cross-sectional area to maintain non-erosive flow velocities. Porous soils are best suited to dry swales, while soils with poor drainage or high groundwater conditions are more suited to wet swales. Design water quality swales to retain and treat the required water quality volume. Because they must also be designed to convey the 2-year and 10-year 24-hour storms, they may have to convey additional runoff volume to other downgradient BMPs.

Planning Considerations

The primary factors to consider when designing a water quality swale are soil characteristics, flow capacity, erosion resistance, and vegetation. Site conditions and design specifications limit the use of water quality swales.

Swale storage capacity should be based on the maximum expected reduction in velocity that occurs during the annual peak growth period. Usually the maximum expected drop in velocity occurs when vegetation is at its maximum growth for the year. Use the minimum level when checking velocity through the swale or the ability of the swale to convey the 2-year 24-hour storm without erosion. This usually occurs during the early growing season and dormant periods.

Other important factors to consider are land availability, maintenance requirements and soil characteristics. The topography of the site should allow for the design of a swale with sufficient slope and cross-sectional area to maintain a non-erosive flow rate, and to retain or detain the required water quality volume. The longitudinal slope of the swale should be as close to zero as possible and not greater than 5%. The grass or vegetation types used in swales should be suited to the soil and water conditions. Wetland hydrophytes (plants adapted to grow in water) or obligate species (i.e., species that occur 99% of the time under natural conditions in wetlands) are generally more water-tolerant than facultative species (i.e., species that occur 67% to 99% of the time under natural conditions in wetlands) and are good selections for wet swales, while dry swales should be planted with species that produce fine and dense cover and are adapted to varying moisture conditions.

Design

See the following for complete design references:
Site Planning for Urban Stream Protection. 1995. Schueler. Center for Watershed Protection.
Watershed Protection Techniques, Volume 2, Number 2, 1996. Center for Watershed Protection.
Biofiltration swale performance, recommendations, and design considerations.
1992. Metro Seattle: Water Pollution Control Department, Seattle,WA.

Access for maintenance must be incorporated into both designs. The maintenance access way must be a minimum of 15 feet wide on at least one longitudinal side of the swale to enable a maintenance truck to drive along the swale and gain access to any one point. When constructed along a highway, the breakdown lane can be used as the access. When constructed in a residential subdivision, an on-street parking lane may double as the maintenance access, provided signs are posted indicating no parking is allowed during periods when the swales are being maintained.

Dry Swales

- Size dry swales to provide adequate residence time for the required water quality volume. Hydraulic Residence Time (HRT) must be a minimum of 9 minutes. Use Manning's Equation to determine the HRT.
- Dry swales should have a soil bed that is a minimum of 18 inches deep and composed of approximately 50% sand and 50% loam.
- Pretreatment is required to protect the filtering and infiltration capacity of the swale bed. Pretreatment of piped flows is generally a sediment forebay behind a check dam with a pipe inlet. For lateral inflows (sheet flow), use a vegetated filter strip on a gentle slope or a "pea gravel diaphragm."
- Design dry swales to completely empty between storms. Where soils do not permit full dewatering between storms, place a longitudinal perforated underpipe on the bottom of the swale bed. The inter-event period used in design to dewater the swale must be no more than 72 hours.
- Dry swales must have parabolic or trapezoidal cross-sections, with side slopes no greater than 3:1 (horizontal: vertical) and bottom widths ranging from 2 to 8 feet.
- Size dry swales to convey the 10-year storm and design swale slopes and backs to prevent erosion during the 2-year event. At least one foot of freeboard must be provided above the volume expected for the 10-year storm.
- Make sure that the seasonal high water table is not within 2 to 4 feet of the dry swale bottom.
- Use outlet protection at any discharge point from a dry swale to prevent scour at the outlet.

Wet Swales

- Size wet swales to retain the required water quality volume.
- Use wet swales only where the water table is at or near the soil surface or where soil types are poorly drained. When the swale is excavated, keep the swale bed soils.
- Pretreatment is required to protect the filtering and infiltration capacity of the wet swale bed. Pretreatment is generally a sediment forebay behind a check dam with a pipe inlet. For lateral inflows, use gentle slopes or a pea gravel diaphragm.
- Use check dams in wet swales to achieve multiple cells. Use V-notched weirs in the check dams to direct low flow volumes.
- Plant emergent vegetation or place wetland soils on the wet swale bottom for seed stock.
- Wet swales are parabolic or trapezoidal in cross-section, with side slopes no greater than 3:1 (horizontal: vertical) and bottom widths ranging from 2 to 8 feet.
- Size wet swales to convey the 10-year 24-hour storm and design wet swale slopes to prevent erosion during the 2-year 24-hour event.
- Use outlet protection at any discharge point from wet swales to prevent scour at the outlet.

Construction

Use temporary erosion and sediment controls during construction. Select the vegetation mix to suit the characteristics of the site. Seeding will require mulching with appropriate materials, such as mulch matting, straw, and wood chips. Anchor the mulch immediately after seeding. Water new seedlings well until they are established. Refer to "Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas: A Guide for Planners, Designers, and Municipal Officials" for information on seeding and mulching.

Maintenance

Incorporate a maintenance and inspection schedule into the design to ensure the effectiveness of water quality swales. Inspect swales during the first few months after installation to make sure that the vegetation in the swales becomes adequately established. Thereafter, inspect swales twice a year. During the inspections, check the swales for slope integrity, soil moisture, vegetative health, soil stability, soil compaction, soil erosion, ponding and sedimentation.

Regular maintenance includes mowing, fertilizing, liming, watering, pruning, and weed and pest control. Mow swales at least once per year. Do not cut the grass shorter than three to four inches, otherwise the effectiveness of the vegetation in reducing flow velocity and removing pollutants may be reduced. Do not let grass height exceed 6 inches.

Manually remove sediment and debris at least once per year, and periodically re-seed, if necessary, to maintain a dense growth of vegetation. Take care to protect water quality swales from snow removal and disposal practices and off-street parking. When grass water quality swales are located on private residential property, the operation and maintenance plan must clearly identify the property owner who is responsible for carrying out the required maintenance. If the operation and maintenance plan calls for maintenance of water quality swales on private properties to be accomplished by a public entity or an association (e.g. homeowners association), maintenance easements must be secured.

Infiltration BMPs


Dry Wells

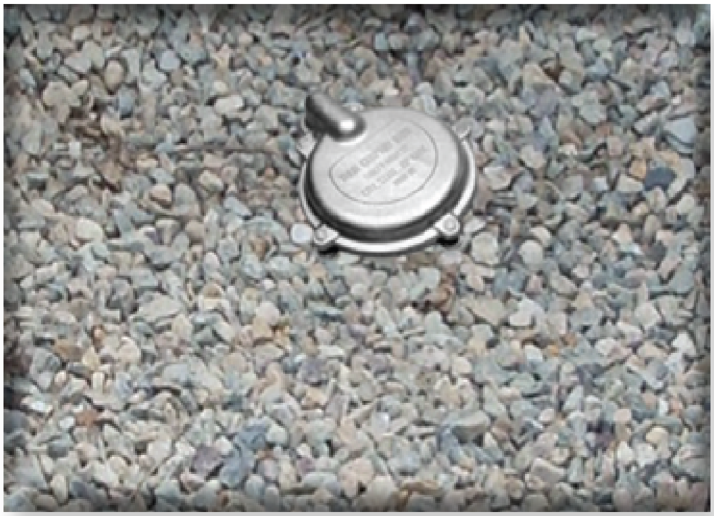

Infiltration Basins


Infiltration Trenches


Leaching Catch Basins


Subsurface Structures

Dry Wells



Description: Dry wells are small excavated pits, backfilled with aggregate, and used to infiltrate uncontaminated runoff from non-metal roofs or metal roofs located outside the Zone II or Interim Wellhead Protection Area of a public water supply and outside an industrial site. Do not use dry wells to infiltrate any runoff that could be significantly contaminated with sediment and other pollutants. Never use dry wells to infiltrate runoff from land uses with higher potential pollutant loads, including parking lot runoff.

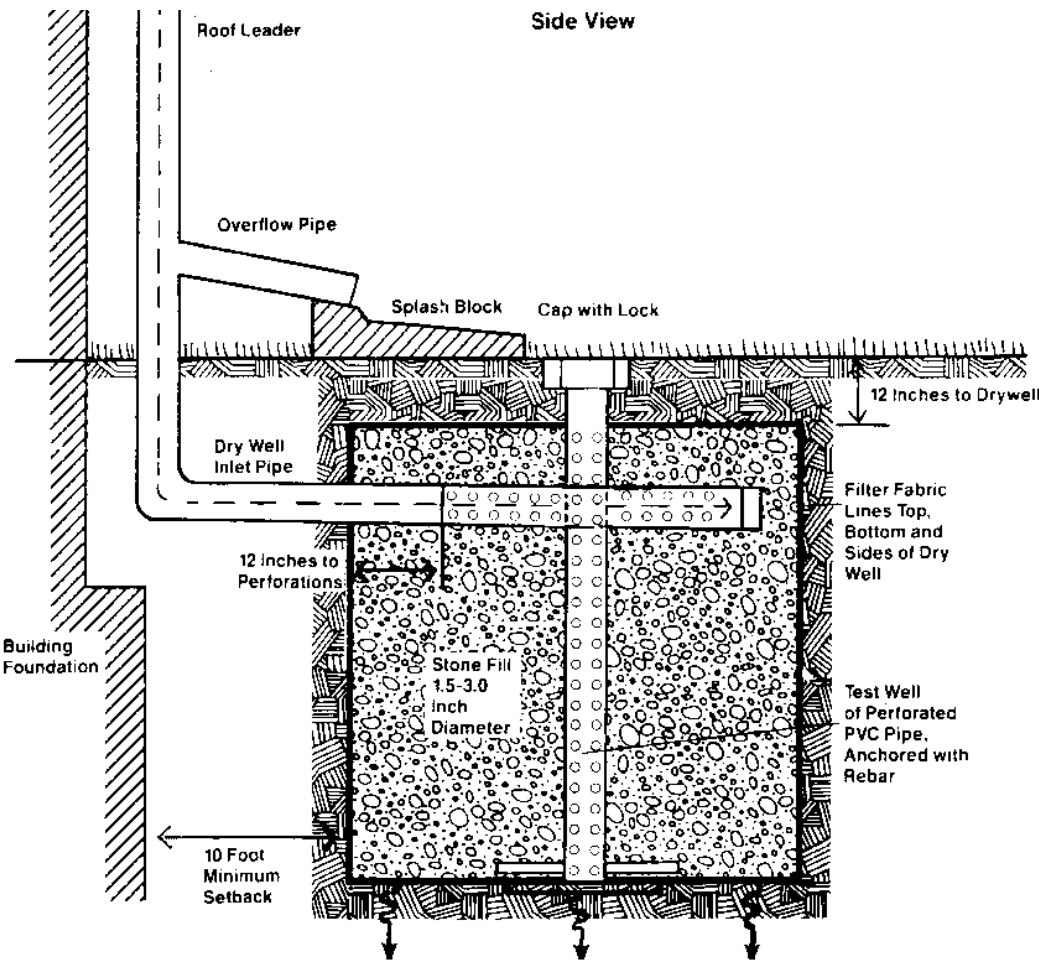
Ability to meet specific standards

Standard	Description
2 - Peak Flow	N/A
3 - Recharge	Provides groundwater recharge.
4 - TSS Removal	80% TSS removal for runoff from non-metal roofs and runoff from metal roofs that are located outside the Zone II or Interim Wellhead Protection Area of a public water supply and outside an industrial site.
5 - Higher Pollutant Loading	May not be used for runoff from land uses with higher potential pollutant loads, May not be used for runoff from metal roofs located at industrial sites.
6 - Discharges near or to Critical Areas	Within a Zone II or IWPAmay be used only for runoff from nonmetal roofs. Outside a Zone II or Interim Wellhead Protection Area, may be used for both metal and nonmetal roofs provided the roof is not located on an industrial site.
7 - Redevelopment	For rooftop runoff from non-metal roofs and from metal roofs located outside a Zone II or IWPA and outside industrial sites.

Advantages/Benefits:
- Applicable for runoff from non-metal roofs and metal roofs located outside of the Zone IIs or IWPA of a public water supply, and outside industrial sites
- Can reduce the size and cost of downstream BMPs and/or storm drains.
- Feasible for new development and retrofit areas
- Provides groundwater recharge

Disadvantages/Limitations:
- Clogging likely when used for runoff other than that from residential rooftops.
- May experience high failure rate due to clogging.
- Only applicable in small drainage areas of one acre or less.
- When located near buildings, potential issues with water seeping into cellars or inducing cracking or heaving in slabs
- Overflow from roof leader must be directed away from sidewalks or driveways

Pollutant Removal Efficiencies
- Total Suspended Solids (TSS) 80%
- Nutrients (Nitrogen, phosphorus) Insufficient data
- Metals (copper, lead, zinc, cadmium) Insufficient data
- Pathogens (coliform, e coli) Insufficient data



adapted from the University of New Hampshire

Maintenance

Activity	Frequency
Inspect dry wells.	After every major storm in the first few months after construction to ensure proper stabilization and function. Thereafter, inspect annually.
Measure the water depth in the observation well at 24- and 48-hour intervals after a storm. Calculate clearance rates by dividing the drop in water level (inches) by the time elapsed (hr).	See activity

Special Features

For uncontaminated runoff from non-metal roofs. May be used for runoff from metal roofs located outside the Zone II or Interim Wellhead Protection Area of a public water supply and outside an industrial site. A metal roof is a roof made of galvanized steel or copper.

LID Alternative

Take advantage of LID site design credit and direct runoff from non-metal roofs to a qualifying pervious area. See Volume 3 for information on disconnecting roof runoff.
Consider green roof.

Infiltration Basins

Description: Infiltration basins are stormwater runoff impoundments that are constructed over permeable soils. Pretreatment is critical for effective performance of infiltration basins. Runoff from the design storm is stored until it exfiltrates through the soil of the basin floor.

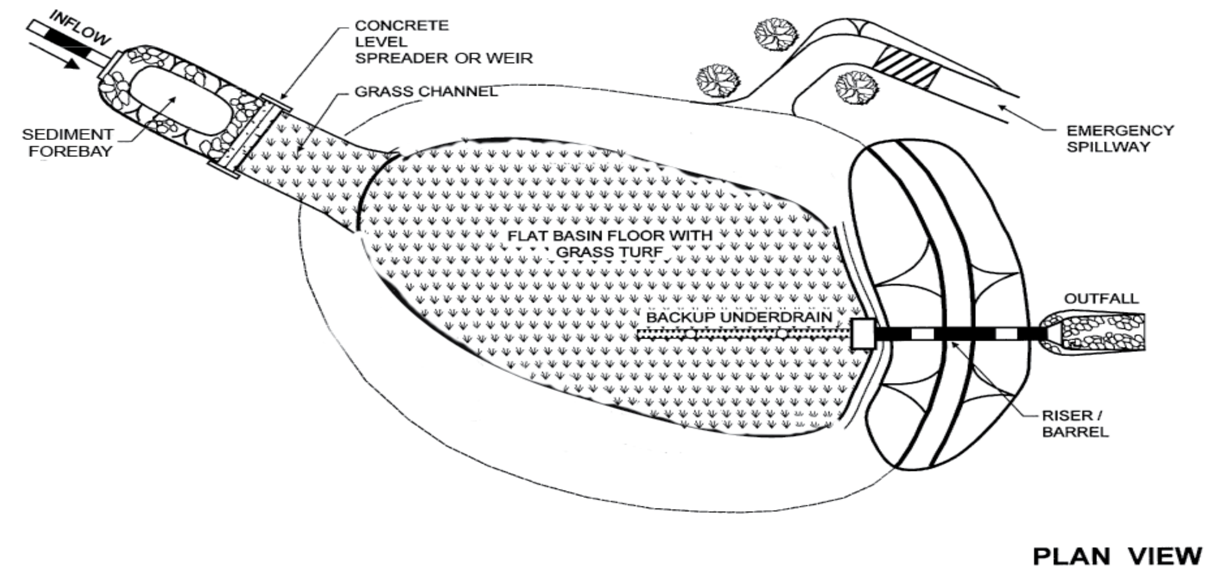
Ability to meet specific standards

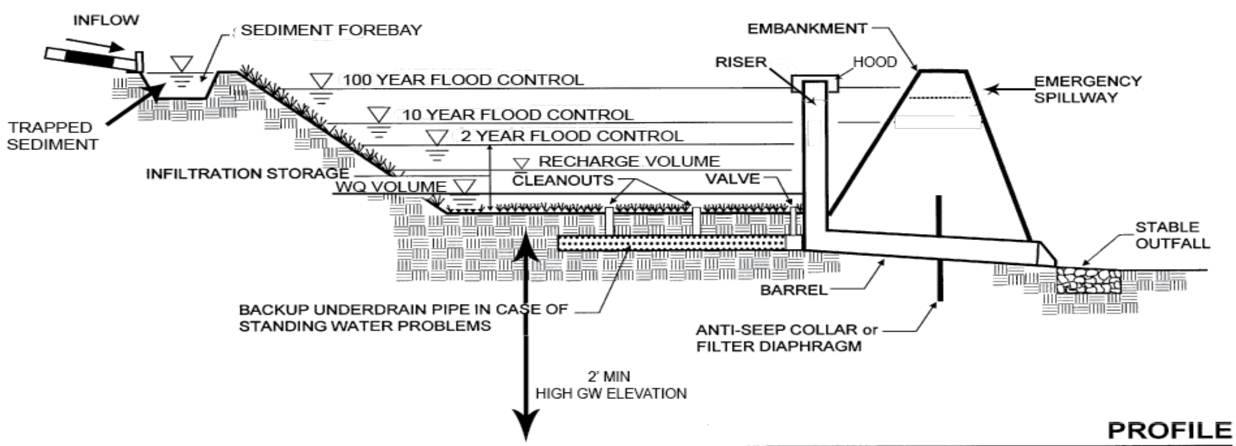
Standard	Description
2 - Peak Flow	Can be designed to provide peak flow attenuation.
3 - Recharge	Provides groundwater recharge.
4 - TSS Removal	80% TSS removal, with adequate pretreatment
5 - Higher Pollutant Loading	May be used if 44% of TSS is removed with a pretreatment BMP prior to infiltration. For some land uses with higher potential pollutant loads, use an oil grit separator, sand filter or equivalent for pretreatment prior to discharge to the infiltration basin. Infiltration must be done in compliance with 314 CMR 5.00
6 - Discharges near or to Critical Areas	Highly recommended, especially for discharges near cold-water fisheries. Requires 44% removal of TSS prior to discharge to infiltration basin
7 - Redevelopment	Typically not an option due to land area constraints

Advantages/Benefits:
- Provides groundwater recharge.
- Reduces local flooding.
- Preserves the natural water balance of the site.
- Can be used for larger sites than infiltration trenches or structures.

Disadvantages/Limitations:
- High failure rates due to improper siting, inadequate pretreatment, poor design and lack of maintenance.
- Restricted to fairly small drainage areas.
- Not appropriate for treating significant loads of sediment and other pollutants.
- Requires frequent maintenance.
- Can serve as a “regional” stormwater treatment facility

Pollutant Removal Efficiencies
- Total Suspended Solids (TSS) 80% with pretreatment
- Total Nitrogen 50% to 60%
- Total Phosphorus 60% to 70%
- Metals (copper, lead, zinc, cadmium) 85% to 90%
- Pathogens (coliform, e coli) 90%





adapted from the Vermont Stormwater Manual

Maintenance

Activity	Frequency
Preventative maintenance	Twice a year
Inspect to ensure proper functioning	After every major storm during first 3 months of operation and twice a year thereafter and when there are discharges through the high outlet orifice.
Mow the buffer area, side slopes, and basin bottom if grassed floor; rake if stone bottom; remove trash and debris; remove grass clippings and accumulated organic matter	Twice a year
Inspect and clean pretreatment devices	Every other month recommended and at least twice a year and after every major storm event.

Special Features: High failure rate without adequate pretreatment and regular maintenance.

LID Alternative: Reduce impervious surfaces. Bioretention areas

Infiltration Basins

The following are variations of the infiltration basin design.

Full Exfiltration Basin Systems

These basin systems are sized to provide storage and exfiltration of the required recharge volume and treatment of the required water quality volume. They also attenuate peak discharges. Designs typically include an emergency overflow channel to discharge runoff volumes in excess of the design storm.

Partial or Off-line Exfiltration Basin Systems

Partial basin systems exfiltrate a portion of the runoff (usually the first flush or the first half inch), with the remaining runoff being directed to other BMPs. Flow splitters or weirs divert flows containing the first flush into the infiltration basin. This design is useful at sites where exfiltration cannot be achieved by downstream detention BMPs because of site condition limitations.

Applicability

The suitability of infiltration basins at a given site is restricted by several factors, including soils, slope, depth to water table, depth to bedrock, the presence of an impermeable layer, contributing watershed area, proximity to wells, surface waters, and foundations. Generally, infiltration basins are suitable at sites with gentle slopes, permeable soils, relatively deep bedrock and groundwater levels, and a contributing watershed area of approximately 2 to 15 acres. Table IB.1 presents the recommended site criteria for infiltration basins.

Pollution prevention and pretreatment are particularly important at sites where infiltration basins are located. A pollution prevention program that separates contaminated and uncontaminated runoff is essential. Uncontaminated runoff can be infiltrated directly, while contaminated runoff must be collected and pretreated using an appropriate combination of BMPs and then rerouted to the infiltration basin. This approach allows uncontaminated stormwater to be infiltrated during and immediately after the storm and permits the infiltration of contaminated stormwater after an appropriate detention time. The Pollution Prevention and Source Control Plan required by Stormwater Standard 4 must take these factors into account. For land uses with higher potential pollutant loads, provide a bypass to divert contaminated stormwater from the infiltration basin in storms larger than the design storm.

Table IB.1 - Site Criteria for Infiltration Basins
1. The contributing drainage area to any individual infiltration basin should be restricted to 15 acres or less.
2. The minimum depth to the seasonal high water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the basin.
3. The minimum infiltration rate is 0.17 inches per hour. Infiltration basins must be sized in accordance with the procedures set forth in Volume 3.
4. One soil sample for every 5000 ft. of basin area is recommended, with a minimum of three samples for each infiltration basin. Samples should be taken at the actual location of the proposed infiltration basin so that any localized soil conditions are detected.
5. Infiltration basins should not be used at sites where soil have 30% or greater clay content, or 40% or greater silt clay content.
6. Infiltration basins should not be placed over fill materials.
7. The following setback requirements should apply to infiltration basin installations: • Distance from any slope greater than 15% - Minimum of 50 ft. • Distance from any soil absorption system- Minimum of 50 ft. • Distance from any private well - Minimum of 100 ft., additional setback distance may be required depending on hydrogeological conditions. • Distance from any public groundwater drinking supply wells - Zone I radius, additional setback distance may be required depending on hydrogeological conditions. • Distance from any surface drinking water supply - Zone A • Distance from any surface water of the commonwealth (other than surface water supplies and their tributaries) - Minimum of 50 ft. • Distance from any building foundations including slab foundations without basements - Minimum of 10 ft. downslope and 100 ft. upslope.

Prior to pretreatment, implement the pollution prevention and source control program specified in the Pollution Prevention and Source Control Plan to reduce the concentration of pollutants in the discharge. Program components include careful management of snow and deicing chemicals, fertilizers, herbicides, and pest control. The Plan must prohibit snow disposal in the basin and include measures to prevent runoff of stockpiled snow from entering the basin. Stockpiled snow contains concentrations of sand and deicing chemicals. At industrial sites, keep raw materials and wastes from being exposed to precipitation. Select pretreatment BMPs that remove coarse sediments, oil and grease, and floatable organic and inorganic materials, and soluble pollutants.

Effectiveness

Infiltration basins are highly effective treatment systems that remove many contaminants, including TSS. However, infiltration basins are not intended to remove coarse particulate pollutants. Use a pretreatment device to remove them before they enter the basin. The pollutant removal efficiency of the basin depends on how much runoff is exfiltrated by the basin.

Infiltration basins can be made to control peak discharges by incorporating additional stages in the design. To do this, design the riser outlet structure or weir with multiple orifices, with the lowest orifice set to achieve storage of the full recharge volume required by Standard 3. Design the upper orifices using the same procedures as extended detention basins. The basins can also be designed to achieve exfiltration of storms greater than the required recharge volume. However, in such cases, make sure the soils are permeable enough to allow the basin to exfiltrate the entire volume in a 72-hour period. This may necessitate increasing the size of the floor area of the basin. Generally, it is not economically feasible to provide storage for large infrequent storms, such as the 100-year 24-hour storm.

Planning Considerations

Carefully evaluate sites before planning infiltration basins, including investigating soils, depth to bedrock, and depth to water table. Suitable parent soils should have a minimum infiltration rate of 0.17 inches per hour. Infiltration basis must be sized in accordance with the procedures set forth in Volume 3. The slopes of the contributing drainage area for the infiltration basin must be less than 5%.

Design

Infiltration basins are highly effective treatment and disposal systems when designed properly. The first step before design is providing source control and implementing pollution prevention measures to minimize sediment and other contaminants in runoff discharged to the infiltration basin. Next, consider the appropriate pretreatment BMPs.

Design pretreatment BMPs to pretreat runoff before stormwater reaches the infiltration basin. For Critical Areas, land uses with potentially higher pollutant loads, and soils with rapid infiltration rates (greater than 2.4 inches/hour), pretreatment must remove at least 44% of the TSS. Proponents may comply with this requirement by proposing two pretreatment BMPs capable of removing 25% TSS. However, the issuing authorities (i.e., Conservation Commissions or MassDEP) may require additional pretreatment for other constituents beyond TSS for land uses with higher potential pollutant loads. If the land use has the potential to generate stormwater runoff with high concentrations of oil and grease, treatment by an oil grit separator or equivalent is required before discharge to the infiltration basin.

For discharges from areas other than Critical Areas, land uses with potentially higher pollutant loads, and soils with rapid infiltration rates, MassDEP also requires some TSS pretreatment. Common pretreatment for infiltration basins includes aggressive street sweeping, deep sump catch basins, oil/grit separators, vegetated filter strips, water quality swales, or sediment forebays. Fully stabilize all land surfaces contributing drainage to the infiltration practice after construction is complete to reduce the amount of sediment in runoff that flows to the pretreatment devices.

Always investigate site conditions. Infiltration basins must have a minimum separation from seasonal high groundwater of at least 2 feet. Greater separation is necessary for bedrock. If there is bedrock on the site, conduct an analysis to determine the appropriate vertical separation. The greater the distance from the bottom of the basin media to the seasonal high groundwater elevation, the less likely the basin will fail to drain in the 72-hour period following precipitation.

Determine soil infiltration rates using samples collected at the proposed location of the basin. Take one soil boring or dig one test pit for every 5,000 feet of basin area, with a minimum of three borings for each infiltration basin. Conduct the borings or test pits in the layer where infiltration is proposed. For example, if the A and B horizons are to be removed and the infiltration will be through the C horizon, conduct the borings or test pits through the C horizon. MassDEP requires that borings be at least 20 feet deep or extend to the depth of the limiting layer.

For each bore hole or test pit, evaluate the saturated hydraulic conductivity of the soil, depth to seasonal high groundwater, NRCS soil textural class, NRCS Hydrologic Soil Group, and the presence of fill materials in accordance with Volume 3. Never locate infiltration basins above fill. Never locate infiltration basins in Hydrologic Soil Group "D" soils. The minimum acceptable final soil infiltration rate is 0.17 inches per hour. Design the infiltration basin based on the soil evaluation set forth in Volume 3.

If the proposed basin is determined to be in Hydrologic Soil Group "C" soils, incorporate measures in the design to reduce the potential for clogging, such as providing more pretreatment or greater media depth to provide additional storage. Never use the results of a Title 5 percolation test to estimate a saturated hydraulic conductivity rate, because it tends to greatly overestimate the rate that water will infiltrate into the subsurface.

Estimate seasonal high groundwater based on soil mottles or through direct observation when borings are conducted in April or May, when groundwater levels are likely to be highest. If it is difficult to determine the seasonal high groundwater elevation from the borings or test pits, then use the Frimpter method developed by the USGS (Massachusetts/ Rhode Island District Office) to estimate seasonal high groundwater. After estimating the seasonal high groundwater using the Frimpter method, re-examine the bore holes or test pits to determine if there are any field indicators that corroborate the Frimpter method estimate.

Stabilize inlet channels to prevent incoming flow velocities from reaching erosive levels, which can scour the basin floor. Riprap is an excellent inlet stabilizer. Design the riprap so it terminates in a broad apron, thereby distributing runoff more evenly over the basin surface to promote better infiltration.

At a minimum, size the basin to hold the required recharge volume. Determine the required recharge volume using either the static or dynamic methods set forth in Volume 3. Remember that the required storage volume of an infiltration basin is the sum of the quantity of runoff entering the basin from the contributing area and the precipitation directly entering the basin. Include one foot of freeboard above the total of the required recharge volume and the direct precipitation volume to account for design uncertainty. When applying the dynamic method to size the basin, use only the bottom of the basin (i.e., do not include side wall exfiltration) for the effective infiltration area.

Design the infiltration basin to exfiltrate in no less than 72 hours. Consider only the basin floor as the effective infiltration area when determining whether the basin meets this requirement.

Design the basin floor to be as flat as possible to provide uniform ponding and exfiltration of the runoff. Design the basin floor to have as close to a 0% slope as possible. In no case shall the longitudinal slope exceed 1%. Enhanced deposition of sediment in low areas may clog the surface soils, resulting in reduced infiltration and wet areas. Design the side slopes of the basin to be no steeper than 3:1 (horizontal: vertical) to allow for proper vegetative stabilization, easier mowing, easier access, and better public safety.

For basins with a 1% longitudinal slope, it will be necessary to incorporate cells into the design, making sure that the depth of ponded water does not exceed 2 feet, because sloped basin floors cause water to move downhill, thereby decreasing the likelihood of infiltration. Make lateral slopes flat (i.e., 0% slope).

After the basin floor is shaped, place soil additives on the basin floor to amend the soil. The soil additives shall include compost, properly aged to kill any seed stock contained within the compost. Do not put biosolids in the compost. Mix native soils that were excavated from the A or B horizons to create the basin with the compost, and then scarify the native materials and compost into the parent material using a chisel plow or rotary device to a depth of 12 inches. Immediately after constructing the basin, stabilize its bottom and side slopes with a dense turf of water-tolerant grass. Use low-maintenance, rapidly germinating grasses, such as fescues. The selected grasses must be capable of surviving in both wet and dry conditions. Do not use sod, which can prevent roots from directly contacting the underlying soil. During the first two months, inspect the newly established vegetation several times to determine if any remedial actions (e.g., reseeding, irrigating) are necessary.

Never plant trees or shrubs within the basin or on the impounding embankments as they increase the chance of basin failure due to root decay or subsurface disturbance. The root penetration and thatch formation of the turf helps to maintain and may even enhance the original infiltration capacity. Soluble nutrients are taken up by the turf for growth, improving the pollutant removal capacity. Dense turf will impede soil erosion and scouring of the basin floor.

In place of turf, use a basin liner of 6 to 12 inches of fill material, such as coarse sand. Clean and replace this material as needed. Do not use loose stone, riprap, and other irregular materials requiring hand removal of debris and weeds.

Design embankments and spillways to conform to the regulatory guidelines of the state's Office of Dam Safety (302 CMR 10.00). Design infiltration basins to be below surrounding grade to avoid issues related to potential embankment failure. All infiltration basins must have an emergency spillway capable of bypassing runoff from large storms without damage to the impounding structure. Design the emergency spillway to divert the storm associated with brimful conditions without impinging upon the structural integrity of the basin. The brimful condition could be the required recharge volume or a design storm (such as the 2-year, 10-year, or 100-year storm if the basin is designed to provide peak rate attenuation in addition to exfiltration). The storm associated with the brimful conditions should not include the one foot of freeboard required to account for design uncertainty. Design the emergency spillway to shunt water toward a location where the water will not damage wetlands or buildings. A common error is to direct the spillway runoff toward an adjoining property not owned by an applicant. If the emergency spillway is designed to drain the emergency overflow toward an adjoining property, obtain a drainage easement and submit it to the Conservation Commission as part of the Wetlands NOI submission. Place vegetative buffers around the perimeter of the basin for erosion control and additional sediment and nutrient removal.

Monitoring wells: Install one monitoring well in the basin floor per every 5,000 square feet of basin floor. Make sure the monitoring well(s) extend 20 feet beneath the basin floor or to the limiting layer, whichever is higher.

Access: Include access in the basin design. The area at the top of the basin must provide unimpeded vehicular access around the entire basin perimeter. The access area shall be no less than 15 feet.

Inlet Structures: Place inlet structures at one longitudinal end of the basin, to maximize the flow path from the inlet to the overflow outlet. A common error is to design multiple inlet points around the entire basin perimeter.

Outlet structures: Infiltration basins must include an overflow outlet in addition to an emergency spillway. Whether using a single orifice or multiple orifices in the design, at a minimum, set the lowest orifice at or above the required recharge volume.

Drawdown device: Include a device to draw the basin down for maintenance purposes. If the basin includes multiple cells, include a drawdown device for each cell.

Fences: Do not place fences around basins located in Riverfront Areas, as required by 310 CMR 10.58(4)(d)1.d. to avoid impeding wildlife movement. In such cases, consider including a safety bench as part of the design.

Construction

Prior to construction, rope or fence off the area selected for the infiltration basin. Never allow construction equipment to drive across the area intended to serve as the infiltration basin.

Never use infiltration basins as temporary sediment traps for construction activities.

To limit smearing or compacting soils, never construct the basin in winter or when it is raining. Use light earth-moving equipment to excavate the infiltration basin because heavy equipment compacts the soils beneath the basin floor and side slopes and reduces infiltration capacity. Because some compaction of soils is inevitable during construction, add the required soil amendments and deeply till the basin floor with a rotary tiller or a disc harrow to a depth of 12 inches to restore infiltration rates after final grading.

Use proper erosion/sediment control during construction. Immediately following basin construction, stabilize the floor and side slopes of the basin with a dense turf of water-tolerant grass. Use low maintenance, rapidly germinating grasses, such as fescues. Do not sod the basin floor or side slopes. After the basin is completed, keep the basin roped or fenced off while construction proceeds on other parts of the site. Never direct construction period drainage to the infiltration basin. After construction is completed, do not direct runoff into the basin until the bottom and side slopes are fully stabilized.

Maintenance

Infiltration basins are prone to clogging and failure, so it is imperative to develop and implement aggressive maintenance plans and schedules. Installing the required pretreatment BMPs will significantly reduce maintenance requirements for the basin.

The Operation and Maintenance Plan required by Standard 9 must include inspections and preventive maintenance at least twice a year, and after every time drainage discharges through the high outlet orifice. The Plan must require inspecting the pretreatment BMPs in accordance with the minimal requirements specified for those practices and after every major storm event. A major storm event is defined as a storm that is equal to or greater than the 2-year, 24-hour storm (generally 2.9 to 3.6 inches in a 24-hour period, depending in geographic location in Massachusetts).

Once the basin is in use, inspect it after every major storm for the first few months to ensure it is stabilized and functioning properly and if necessary take corrective action. Note how long water remains standing in the basin after a storm; standing water within the basin 48 to 72 hours after a storm indicates that the infiltration capacity may have been overestimated. If the ponding is due to clogging, immediately address the reasons for the clogging (such as upland sediment erosion, excessive compaction of soils, or low spots).
Thereafter, inspect the infiltration basin at least twice per year. Important items to check during the inspection include:

- Signs of differential settlement,
- Cracking,
- Erosion,
- Leakage in the embankments
- Tree growth on the embankments
- Condition of riprap,
- Sediment accumulation and
- The health of the turf.

At least twice a year, mow the buffer area, side slopes, and basin bottom. Remove grass clippings and accumulated organic matter to prevent an impervious organic mat from forming. Remove trash and debris at the same time. Use deep tilling to break up clogged surfaces, and revegetate immediately.

Remove sediment from the basin as necessary, but wait until the floor of the basin is thoroughly dry. Use light equipment to remove the top layer so as to not compact the underlying soil. Deeply till the remaining soil, and revegetate as soon as possible. Inspect and clean pretreatment devices associated with basins at least twice a year, and ideally every other month.

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Infiltration Trenches

Description: Infiltration trenches are shallow excavations filled with stone. They can be designed to capture sheet flow or piped inflow. The stone provides underground storage for stormwater runoff. The stored runoff gradually exfiltrates through the bottom and/or sides of the trench into the subsoil and eventually into the water table.

Advantages/Benefits:
- Provides groundwater recharge.
- Reduces downstream flooding and protects stream bank integrity for small storms.
- Preserves the natural water balance of the site.
- Provides a high degree of runoff pollution control when properly designed and maintained.
- Reduces the size and cost of downstream stormwater control facilities and/or storm drain systems by infiltrating stormwater in upland areas.
- Suitable where space is limited.

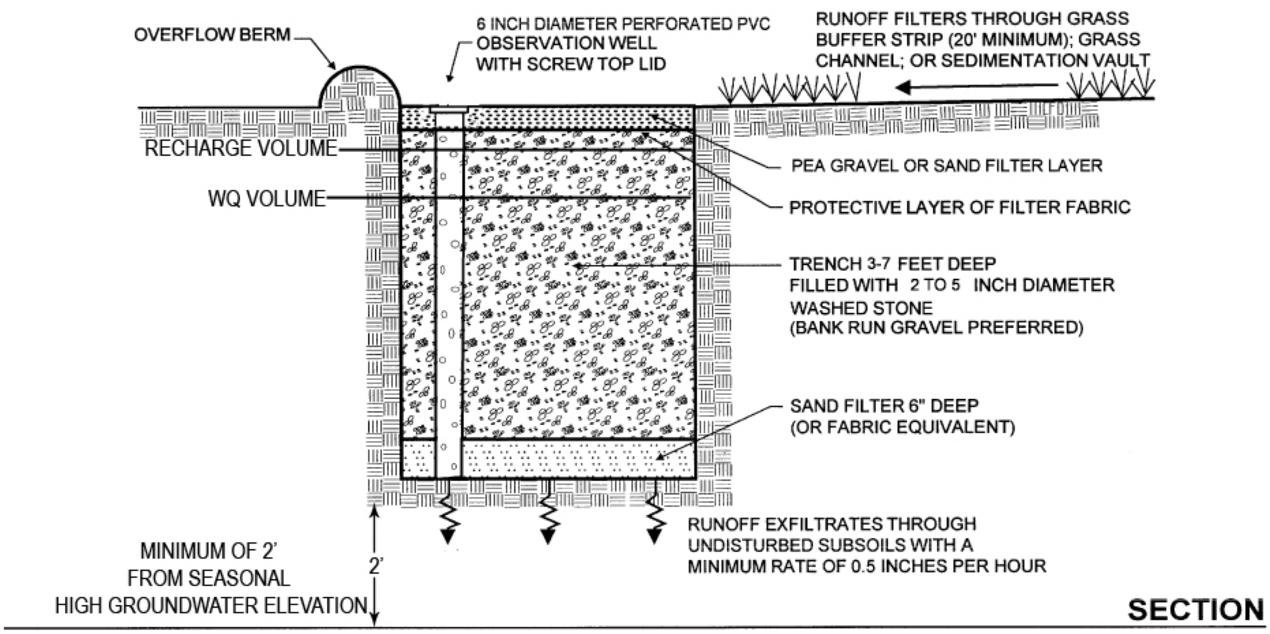
Disadvantages/Limitations:
- High failure rates due to improper siting, inadequate pollution prevention and pretreatment, poor design, construction and maintenance.
- Use restricted to small drainage areas.
- Depending on runoff quality, potential risk of groundwater contamination.
- Requires frequent maintenance.
- Susceptible to clogging with sediment.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Full exfiltration trench systems may be designed for peak rate attenuation
3 - Recharge	Provides groundwater recharge.
4 - TSS Removal	80% TSS removal credit when combined with one or more pretreatment BMPs.
5 - Higher Pollutant Loading	May be used if 44% of TSS is removed with a pretreatment BMP prior to infiltration. For some land uses with higher potential pollutant load an oil grit separator or equivalent must be used prior to discharge to the infiltration structure. Infiltration must be done in compliance with 314 CMR 5.00.
6 - Discharges near or to Critical Areas	Highly recommended with pretreatment to remove at least 44% TSS removal prior to discharge.
7 - Redevelopment	Suitable with pretreatment.

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	80% with pretreatment
• Total Nitrogen	40% to 70%
• Total Phosphorus	40% to 70%
• Metals (copper, lead, zinc, cadmium)	85% to 90%
• Pathogens (coliform, e coli)	Up to 90%



Example of Infiltration Trench

adapted from the University of New Hampshire

Maintenance

Activity	Frequency
Inspect units and remove debris	Every 6 months and after every major storm
Remove sediment from pretreatment BMPs	Every 6 months and after every major storm

Special Features:

High failure rate without adequate pretreatment and regular maintenance

LID Alternative:

Reduce impervious areas
Bioretention areas

Infiltration Trenches

Infiltration trenches can be designed for complete exfiltration or partial exfiltration, where a portion of the runoff volume is directed to the trench and the remainder is conveyed to other BMPs.

Full Exfiltration Trench Systems

Infiltration trenches must be sized to provide storage and exfiltration of the required water quality volume. Full exfiltration systems also provide control of peak discharges and water quality treatment for all storm events equal to or less than the design storm selected. In selecting the design storm, the minimum peak rate attenuation storm event must include the 2- and 10-year 24-hour storm events and may include the 100-year 24-hour storm event, if the runoff from that storm will increase flooding up- or downstream of the site. An emergency overflow channel is required to discharge runoff volumes in excess of the design storm. Economic and physical constraints can restrict the use of full exfiltration systems. Generally, it is not practical to provide storage for large infrequent storms, such as the 100-year storm.

Partial or Water Quality Exfiltration Trench Systems

These systems exfiltrate a portion of the runoff, while the remainder is conveyed to other BMPs. At a minimum, they must be sized to exfiltrate the recharge volume required by Stormwater Management Standard 3. There are two methods of partial infiltration. The first relies on off-line treatment where a portion of the runoff, or the "first-flush," is routed from the main channel to the trench by means of a weir or other diversion structure. The second method is on-line, and uses a perforated pipe at the top of the trench. This underdrain must be placed near the top of the trench. Refer to the design section below. After the trench fills to capacity, excess runoff is discharged through the perforated pipe and directed to other BMPs.

Applicability

Infiltration trenches always require a pretreatment BMP. For sheet flow, pretreatment BMP structures that may be used include vegetated filter strips and pea stone gravel diaphragms. For piped flow, a sediment forebay should be used.

Infiltration trenches are feasible at sites with gentle slopes, permeable soils, and where seasonal high groundwater levels are at least two feet below the bottom of the trench. MassDEP recommends providing greater depths from the bottom of the trench to seasonal high groundwater elevation to reduce the potential for failure. Depth to bedrock will need to be evaluated to determine if use of an infiltration trench is feasible.

Contributing drainage areas must be relatively small and not exceed 5 acres. Infiltration trenches are suitable for parking lots, rooftop areas, local roads, highways, and small residential developments.

Infiltration trenches are adaptable to many sites because of their thin profile. Table IT.1 lists the recommended site criteria. Infiltration trenches can be used in upland areas of larger sites to reduce the overall amount of runoff and improve water quality while reducing the size and costs of downgradient BMPs.

Infiltration trenches are effective at mimicking the natural, pre-development hydrological regime at a site. Full exfiltration systems that have been carefully designed may be capable of controlling peak discharges from the 2-year and 10-year 24-hour storm.

Planning Considerations

MassDEP highly recommends using infiltration trenches near Critical Areas. They may be used to treat stormwater discharges from areas of higher potential pollutant loads, provided 44% of TSS is removed prior to infiltration. For some land uses with higher potential pollutant load, an oil grit separator or equivalent device may be required prior to discharge to the infiltration trench. When an oil/grit separator is used, pipe the runoff to the infiltration trench. Discharges from land uses with higher potential pollutant loads require compliance with 314 CMR 5.00.

Before planning infiltration trenches, carefully evaluate the subsurface of the site including soils, depth to bedrock, and depth to the water table. Make sure soils have a minimum percolation rate of 0.17 inches per hour.

Make the slopes of the contributing drainage area less than 5%. Infiltration trenches have extremely high failure rates, usually due to clogging, so pretreatment is essential. Infiltration trenches are not intended to remove coarse particulate pollutants, and generally are difficult to rehabilitate once clogged. Typical pretreatment BMPs for infiltration trenches

Table IT.1 - Site Criteria for Infiltration Trenches
1. The contributing drainage area to any individual infiltration trench should be restricted to 5 acres or less.
2. The minimum depth to the seasonal high water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the trench.
3. The minimum acceptable soil infiltration rate is 0.17 inches per hour. Infiltration trenches must be sized in accordance with the procedures set forth in Volume 3.
4. A minimum of 2 soil borings should be taken for each infiltration trench. Infiltration trenches over 100 ft. in length should include at least one additional boring location for each 50 ft. increment. Borings should be taken at the actual location of the proposed infiltration trench so that any localized soil conditions are detected.
5. Infiltration trenches should not be used at sites where soils have 30% or greater clay content, or 40% or greater silt clay content. Infiltration trenches will not function adequately in areas with hydrologic soils in group D and infiltration will be limited for hydrologic soils in group C.
6. Infiltration trenches should not be placed over fill materials.
7. The following setback requirements apply to infiltration trench installations: • Distance from any slope greater than 5% to any surface exposed trench: minimum of 100 ft. • Distance from any slope greater than 20% to any underground trench: minimum of 100 ft. • Distance from septic system soil absorption system: minimum of 50 ft. • Distance from any private well: minimum of 100 feet, additional setback distance may be required depending on hydrogeological conditions. • Distance from any public groundwater drinking water supplies: Zone I radius, additional setback distance may be required depending on hydrogeological conditions. • Distance from any surface water supply and its tributaries: Zone A
8. Distance from any surface water of the Commonwealth (other than surface drinking water supplies and their tributaries): minimum of 150 ft downslope and 100 ft upslope.
9. Distance from any building foundations including slab foundations without basements: minimum of 20 ft.

include oil grit separators, deep sump catch basins, vegetated filter strips, pea stone gravel diaphragms, or sediment forebays.

Clogging can be an issue even when infiltrating uncontaminated rooftop runoff as well, so it is important to implement some form of pretreatment to remove sediments, leaf litter, and debris to ensure the proper functioning of the trench and allow for longer periods between maintenance.

Consider the impacts of infiltrating stormwater on nearby resources. Infiltration trenches need to be set back outside Zone Is and Zone As for public drinking water supplies. Finally, avoid creating groundwater mounds near Chapter 21e sites that could alter subsurface flow patterns and spread groundwater pollution.

Design

See the following for complete design references:
Maryland Stormwater Design Manual, Volumes I and II. October 2000. Maryland Department of Environment. Baltimore, MD.

The volume and surface area of an infiltration trench relate to the quantity of runoff entering the trench from the contributing area, the void space, and the infiltration rate. Because the infiltration trench is filled with stone, only the space between the stone is available for runoff storage. Effective designs call for infiltration trenches to be filled with 1.5-inch to 3.0-inch diameter clean washed stone. Conduct a geotechnical study to determine the final soil infiltration rate below the trench. For sizing purposes, assume a void ratio of 0.4.

Take a minimum of two borings or observation pits for each infiltration trench. For trenches over 100 feet long, include at least one additional boring or pit for each 50-foot increment. Take borings or dig observation pits at the actual location of the proposed infiltration trench to determine localized soil conditions.

Base the design of the infiltration trench on the soil evaluation set forth in Volume 3. The minimum acceptable rate is 0.17 inches per hour. Never use the results of a Title 5 percolation test to estimate an infiltration rate, as these tend to greatly overestimate the rate that water will infiltrate into the subsurface.

Place the maximum depth of the trench at least two feet above the seasonal high water table or bedrock, and below the frost line.

Include vegetated buffers (20-foot minimum) around surface trenches. Place permeable filter fabric 6 to 12 inches below the surface of the trench, along the sides, and at the bottom of the trench. Use filter fabric, especially at the surface to prevent clogging; if failure does occur, it can be alleviated without reconstructing the infiltration trench. Another option is to place twelve inches of sand at the bottom of the trench.

Install an observation well at the center of the trench to monitor how quickly runoff is clearing the system. Use a well-anchored, vertical perforated PVC pipe with a lockable above-ground cap.

The visible surface of the trench may either be stone or grassed. Stone is easier to rake out when clogged. If it is vegetated with grasses, use fabric above the stone to keep the soil that serves as the planting medium from clogging the stone. When trenches are designed to accept sheet flow, take into account the grass surface when determining how much of the runoff will exfiltrate into the trench.

A perforated pipe underdrain is sometimes used as part of the design. The purpose of the underdrain is to facilitate exfiltration into the parent soil. Except for underdrains placed between different trench cells, MassDEP does not allow underdrains placed near the bottom of the trench. Placement of an underdrain near the bottom of the trench reduces the amount of treatment and exfiltration, because more water is conveyed through the underdrain to the outlet point when it rains than exfiltrates into the surrounding soils.

Construction

Table IT.2 presents the minimum construction criteria for infiltration trenches. Take precautions before and during construction to minimize the risk of premature failure of the infiltration trench. First, prevent heavy equipment from operating at the locations where infiltration trenches are planned. Heavy equipment will compact soil and adversely affect the performance of the trench. Isolate the areas where the trenches will be located by roping them off and flagging them.

Construct infiltration trenches only after the site has been stabilized. Never use trenches as temporary sediment traps during construction. Use diversion berms or staked and lined hay bales around the perimeter of the trenches during their construction. Excavate and build the trench manually or with light earth-moving equipment. Deposit all excavated material downgradient of the trench to prevent re-deposition during runoff events.

Line the sides and bottom of the trench with permeable geotextile fabric. Twelve inches of sand (clean, fine aggregate) may be substituted or used in addition on the bottom. Place one to three inches of clean, washed stone in the lined trench and lightly compact the stone with plate compactors, to within approximately one foot of the surface. Place fabric filter over the top, with at least a 12-inch overlap on both sides. An underground trench may be filled with topsoil and planted. A surface trench may be filled with additional aggregate stone.

Divert drainage away from the infiltration trench until the contributing drainage area is fully stabilized, including full establishment of any vegetation.

Table IT.2 - Construction Criteria for Infiltration Trenches
1. Infiltration trenches should never serve as temporary sediment traps for construction.
2. Before the development site is graded, the area of the infiltration trench should be roped off and flagged to prevent heavy equipment from compacting the underlying soils.
3. Infiltration trenches should not be constructed until the entire contributing drainage area has been stabilized. Diversion berms should be placed around the perimeter or the infiltration trench during all phases of construction. Sediment and erosion controls should be used to keep runoff and sediment away from the trench area.
4. During and after excavation, all excavated materials should be placed downstream, away from the infiltration trench, to prevent redeposition of these materials during runoff events. These materials should be properly handled and disposed of during and after construction.
Light earth-moving equipment should be used to excavate the infiltration trench. Use of heavy equipment causes compaction of the soils in the trench floor, resulting in reduced infiltration capacity.

Maintenance

Because infiltration trenches are prone to failure due to clogging, it is imperative that they be aggressively maintained on a regular schedule. Using pretreatment BMPs will significantly reduce the maintenance requirements for the trench itself. Removing accumulated sediment from a deep sump catch basin or a vegetated filter strip is considerably less difficult and less costly than rehabilitating a trench. Eventually, the infiltration trench will have to be rehabilitated, but regular maintenance will prolong its operational life and delay the day when rehabilitation is needed. With appropriate design and aggressive maintenance, rehabilitation can be delayed for a decade or more. Perform preventive maintenance at least twice a year.

Inspect and clean pretreatment BMPs every six months and after every major storm event (2 year return frequency). Check inlet and outlet pipes to determine if they are clogged. Remove accumulated sediment, trash, debris, leaves and grass clippings from mowing. Remove tree seedlings, before they become firmly established.

Inspect the infiltration trench after the first several rainfall events, after all major storms, and on regularly scheduled dates every six months. If the top of the trench is grassed, it must be mowed on a seasonal basis. Grass height must be maintained to be no more than four inches. Routinely remove grass clippings leaves and accumulated sediment from the surface of the trench.

Inspect the trench 24 hours or several days after a rain event, to look for ponded water. If there is ponded water at the surface of the trench, it is likely that the trench surface is clogged. To address surface clogging, remove and replace the topsoil or first layer of stone aggregate and the filter fabric. If water is ponded inside the trench, it may indicate that the bottom of the trench has failed. To rehabilitate a failed trench, all accumulated sediment must be stripped from the bottom, the bottom of the trench must be scarified and tilled to induce infiltration, and all of the stone aggregate and filter fabric or media must be removed and replaced.

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Leaching Catch Basins

Description: A leaching catch basin is pre-cast concrete barrel and riser with an open bottom that permits runoff to infiltrate into the ground. There are two configurations:

1. Stand-alone barrel/riser and
2. Barrel/riser combined with a deep sump catch basins that provides pretreatment.

80% TSS removal is awarded to the deep sump catch basin/leaching catch basin pretreatment combination provided the system is off-line.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	May provide some peak rate attenuation if sufficient number of leaching catch basins are provided to control 10-year storm
3 - Recharge	Provides groundwater recharge
4 - TSS Removal	80% TSS removal providing a deep sump catch basin is used for pretreatment and provided it is designed to be off-line
5 - Higher Pollutant Loading	May be used if 44% of TSS is removed with a pretreatment BMP prior to infiltration. For land uses that have the potential to generate runoff with high concentrations of oil and grease, an oil grit separator or equivalent may be required for pretreatment prior to discharge to the leaching catch basin. Infiltration must be done in compliance with 314 CMR 5.00.
6 - Discharges near or to Critical Areas	Not suitable except as terminal treatment for discharges to or near cold-water fisheries.
7 - Redevelopment	May be a good retrofit for sites with existing catch basins

Advantages/Benefits:

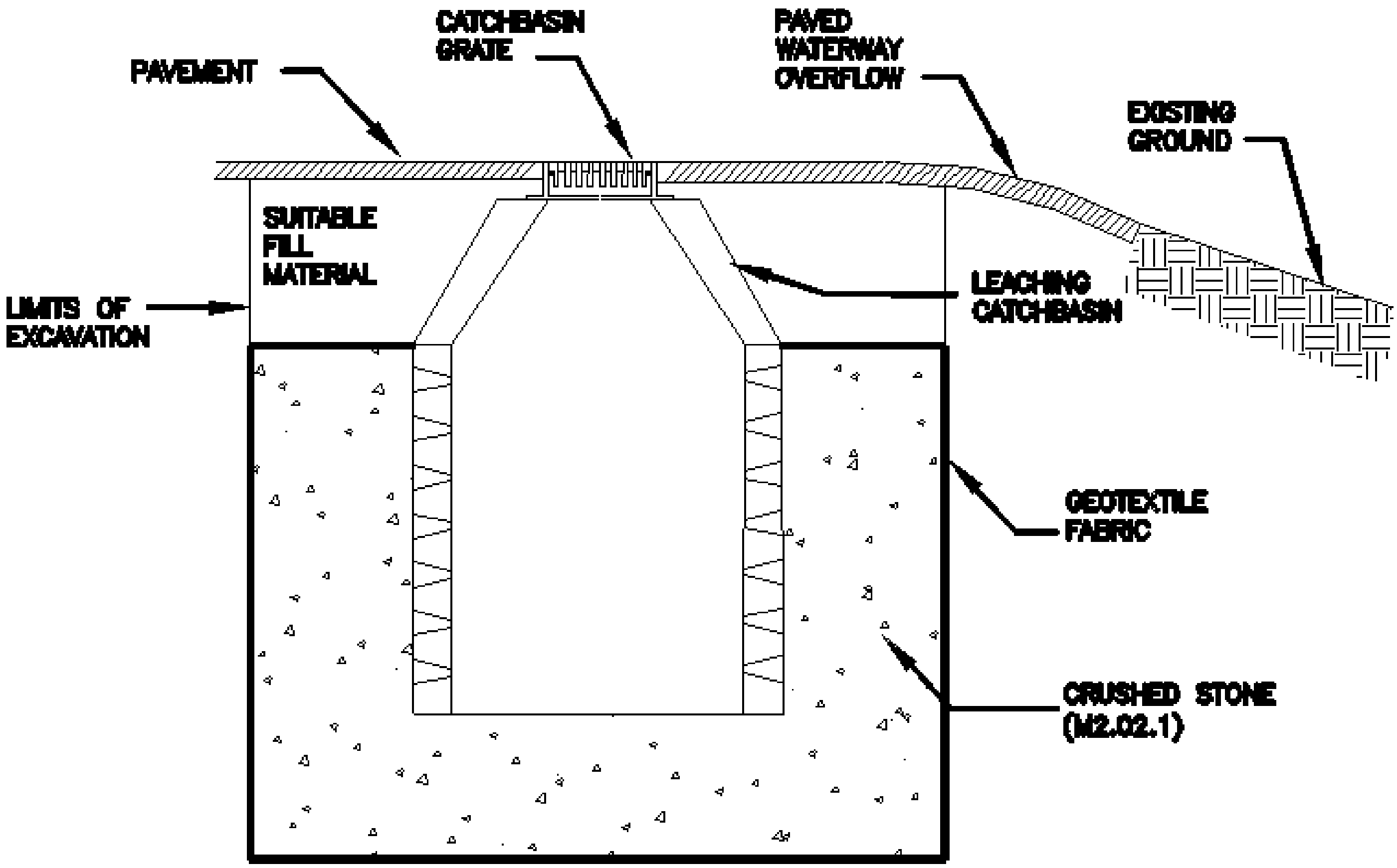
- Provide groundwater recharge.
- Remove coarse sediment

Disadvantages/Limitations:

- Need frequent maintenance. Can become a source of pollutants via resuspension if not properly maintained.
- Cannot effectively remove soluble pollutants or fine particles.
- Do not provide adequate treatment of runoff unless combined with deep sump catch basin
- Entrapment hazard for amphians and other small animals.

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	80% if combined with deep sump catch basin and if designed to be off-line
• Nutrients (Nitrogen, phosphorus)	Insufficient data
• Metals (copper, lead, zinc, cadmium)	Insufficient data
• Pathogens (coliform, e coli)	Insufficient data



adapted from the MassHighway Department

Maintenance

Activity	Frequency
Inspect units and remove debris	Inspect annually or more frequently as indicated by structure performance
Remove sediment	When the basin is 50% filled
Rehabilitate the basin if it fails due to clogging	As needed

Special Features:

Use as off-line device

LID Alternative:

Reduce pervious areas
Bioretention areas and rain gardens

Leaching Catch Basins

Planning Considerations

Use leaching catch basins as off-line devices in areas with highly permeable soils. Provide for the safe overflow from these devices in severe storm events, or in the event of clogging of the soils surrounding the device. Because leaching catch basins discharge runoff to groundwater, do not use them in areas of higher potential pollutant loadings (such as gas stations) without adequate pretreatment such as an oil grit separator.

Design

Leaching catch basins are typically set in an excavation lined with a geotextile liner to prevent fine soil particles from migrating into the void spaces of the stone. The basin is placed on a pad of free-draining crushed stone, with the excavation around the basin back-filled with similar material. The base and barrel of the basin are perforated so that water entering the basin can enter the surrounding stone fill and infiltrate into the ground.

Use stone material with a void ratio of 0.39 or less. Make the depth to groundwater at least 2 feet below the bottom of the leaching catch basin. When designing structural components, design for dead and live loads as appropriate. Include provisions for overflows such as redundant devices and paved chutes.

The basin inlet cover is an important component. The openings must be no larger than 1 inch square to prevent coarse debris larger than 1 inch from entering the basin. The inlet grate must fit tightly into the underlying steel frame to prevent it from being dislodged by traffic. Do not weld the inlet grate to the underlying frame.

The riser section shall be mortared, grouted, gasketed, or otherwise sealed, to prevent exfiltration through the joint. Leaching catch basins shall contain no weep holes. Do not perforate the barrel section.

Make sure leaching catch basins contain no outlet pipes. The only pipe that is allowed in a leaching catch basin is an inlet pipe from an off-line deep sump catch basin paired with that leaching catch basin. Seal all pipe joints.

Construction

Install construction barriers around the excavation area to prevent access by pedestrians. Use diversions and other erosion control practices up-slope of the leaching catch basin to prevent runoff from entering the site before catch basins are complete. Stabilize the surrounding area and any established outlet. Put controls in place to prevent any drainage from being discharged to the leaching catch basin until the contributing drainage area is fully stabilized. Remove all temporary structures after the contributing drainage area and vegetation is stabilized.

Maintenance

- Inspect annually or more frequently as indicated by structure performance
- Remove sediment when the basin is 50% filled.
- Rehabilitate the basin if it fails due to clogging

Adapted from:
MassHighway. Storm Water Handbook for Highways and Bridges. May 2004.

Subsurface Structures

Description: Subsurface structures are underground systems that capture runoff, and gradually infiltrate it into the groundwater through rock and gravel. There are a number of underground infiltration systems that can be installed to enhance groundwater recharge. The most common types include pre-cast concrete or plastic pits, chambers (manufactured pipes), perforated pipes, and galleys.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	N/A
3 - Recharge	Provides groundwater recharge
4 - TSS Removal	80%
5 - Higher Pollutant Loading	May be used if 44% of TSS is removed with a pretreatment BMP prior to infiltration. Land uses with the potential to generate runoff with high concentrations of oil and grease require an oil grit separator or equivalent prior to discharge to the infiltration structure. Infiltration must be done in accordance with 314 CMR 5.00.
6 - Discharges near or to Critical Areas	Highly recommended
7 - Redevelopment	Suitable with pretreatment

Advantages/Benefits:
- Provides groundwater recharge
- Reduces downstream flooding
- Preserves the natural water balance of the site
- Can remove other pollutants besides TSS
- Can be installed on properties with limited space
- Useful in stormwater retrofit applications

Disadvantages/Limitations:
- Limited data on field performance
- Susceptible to clogging by sediment
- Potential for mosquito breeding due to standing water if system fails

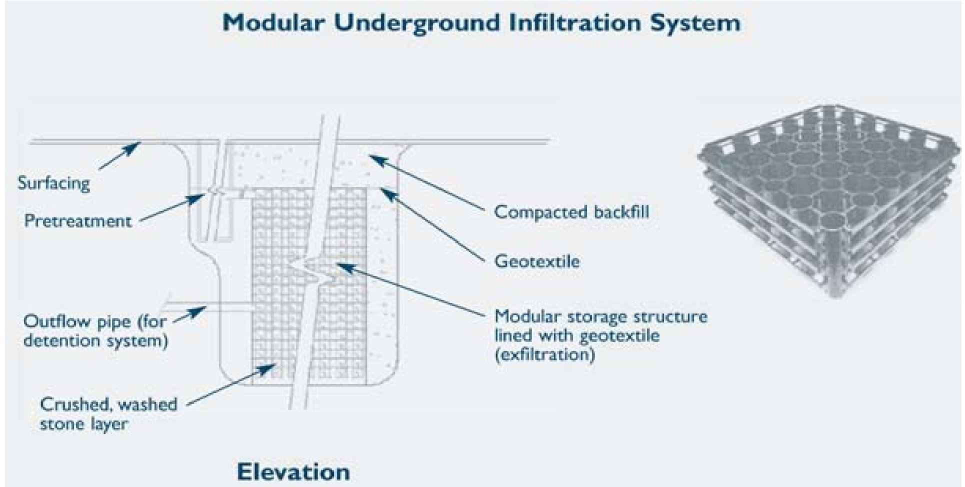
Pollutant Removal Efficiencies

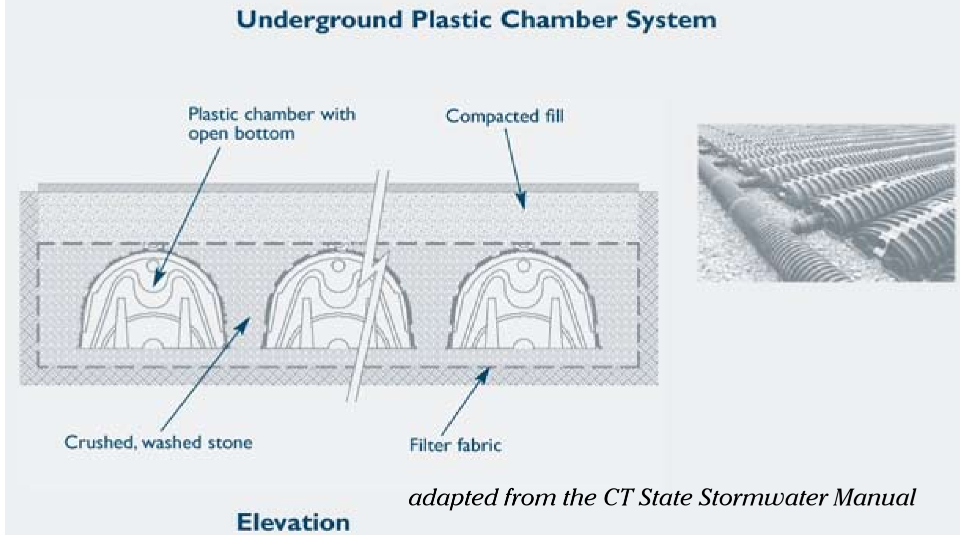
• Total Suspended Solids (TSS)	80%
• Nutrients (Nitrogen, phosphorus)	Insufficient data
• Metals (copper, lead, zinc, cadmium)	Insufficient data
• Pathogens (coliform, e coli)	Insufficient data

Subsurface Structures

There are different types of subsurface structures:

Infiltration Pit: A pre-cast concrete or plastic barrel with uniform perforations. The bottom of the pit should be closed with the lowest row of perforations at least 6 inches above the bottom, to serve as a sump. Infiltration pits typically include an observation well. The pits may be placed linearly, so that as the infiltrative surfaces in the first pit clog, the overflow moves to the second pit for exfiltration. Place an outlet near the top of the infiltration pit to accommodate emergency overflows. MassDEP provides recharge credit for storage below the emergency outflow invert. To make an infiltration pit, excavate the pit, wrap fabric around the barrel, place stone in the bottom of the pit, place the barrel in the pit, and then backfill stone around the barrel. Take a boring or dig an observation trench at the site of each proposed pit.





adapted from the CT State Stormwater Manual

Chambers: These are typically manufactured pipes containing open bottoms and sometimes perforations. The chambers are placed atop a stone bed. Take the same number of borings or observation pits as for infiltration trenches. Do not confuse these systems with underground detention systems (UDS) that use similar chambers. UDS are designed to attenuate peak rates of runoff--not to recharge groundwater.

Perforated Pipes: In this system, pipes containing perforations are placed in a leaching bed, similar to a Title 5 soil absorption system (SAS). The pipes dose the leaching bed. Take the same number of borings or observation pits as for infiltration trenches. Perforated pipes by themselves do not constitute a stormwater recharge system and receive no credit pursuant to Stormwater Standard No. 3. Do not confuse recharge systems that use perforated pipes with perforated pipes installed to lower the water table or divert groundwater flows.

Galleys: Similar to infiltration pits. Some designs consist of concrete perforated rectangular vaults. Others are modular systems usually placed under parking lots. When the galley design consists of a single rectangular perforated vault, conduct one boring or observation trench per galley. When the galleys consist of interlocking modular units, take the same number of borings or observation pits as for infiltration trenches. Do not confuse these galleys with vaults storing water for purposes of underground detention, which do not contain perforations.

Applicability

Subsurface structures are constructed to store stormwater temporarily and let it percolate into the underlying soil. These structures are used for small drainage areas (typically less than 2 acres). They are feasible only where the soil is adequately permeable and the maximum water table and/or bedrock elevation is sufficiently low. They can be used to control the quantity as well as quality of stormwater runoff, if properly designed and constructed. The structures serve as storage chambers for captured stormwater, while the soil matrix provides treatment.

Without adequate pretreatment, subsurface structures are not suitable for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads. Structural pretreatment BMPs for these systems include, but are not limited to, deep sump catch basins, proprietary separators, and oil/grit separators. They are suitable alternatives to traditional infiltration trenches and basins for space-limited sites. These systems can be installed beneath parking lots and other developed areas provided the systems can be accessed for routine maintenance.

Subsurface systems are highly prone to clogging. Pretreatment is always required unless the runoff is strictly from residential rooftops.

Effectiveness

Performance of subsurface systems varies by manufacturer and system design. Although there are limited field performance data, pollutant removal efficiency is expected to be similar to those of infiltration trenches and basins (i.e., up to 80% of TSS removal). MassDEP awards a TSS removal credit of 80% for systems designed in accordance with the specifications in this handbook.

Planning Considerations

Subsurface structures are excellent groundwater recharge alternatives where space is limited. Because infiltration systems discharge runoff to groundwater, they are inappropriate for use in areas with potentially higher pollutant loads (such as gas stations), unless adequate pretreatment is provided. In that event, oil grit separators, sand filters or equivalent BMPs must be used to remove sediment, floatables and grease prior to discharge to the subsurface structure.

Design

Unlike infiltration basins, widely accepted design standards and procedures for designing subsurface structures are not available. Generally, a subsurface structure is designed to store a "capture volume" of runoff for a specified period of "storage time." The definition of capture volume differs depending on the purpose of the subsurface structure and the stormwater management program being used. Subsurface structures should infiltrate good quality runoff only. Pretreatment prior to infiltration is essential.
The composition, configuration and layout of subsurface structures varies considerably depending on the manufacturer. Follow the design criteria specified by vendors or system manufacturers. Install subsurface structures in areas that are easily accessible for routine and non-routine maintenance.

As with infiltration trenches and basins, install subsurface structures only in soils having suitable infiltration capacities as determined through field testing. Determine the infiltrative capacity of the underlying native soil through the soil evaluation set forth in Volume 3. Never use a standard septic system percolation test to determine soil permeability because this test tends to greatly overestimate the infiltration capacity of soils.

Subsurface structures are typically designed to function off-line. Place a flow bypass structure upgradient of the infiltration structure to convey high flows around the structure during large storms.

Design the subsurface structure so that it drains within 72 hours after the storm event and completely dewaters between storms. Use a minimum draining time of 6 hours to ensure adequate pollutant removal. Design all ports to be mosquito-proof, i.e., to inhibit or reduce the number of mosquitoes able to breed within the BMP.

The minimum acceptable field infiltration rate is 0.17 inches per hour. Subsurface structures must be sized in accordance with the procedures set forth in Volume 3. Manufactured structures must also be sized in accordance with the manufacturers' specifications. Design the system to totally exfiltrate within 72 hours.

Design the subsurface structure for live and dead loads appropriate for their location. Provide measures to dissipate inlet flow velocities and prevent channeling of the stone media. Generally, design the system so that inflow velocities are less than 2 feet per second (fps).
All of these devices must have an appropriate number of observation wells, to monitor the water surface elevation within the well, and to serve as a sampling port.

Each of these different types of structures, with the exception of perforated pipes in leaching fields similar to Title 5 systems, must have entry ports to allow worker access for maintenance, in accordance with OSHA requirements.

Construction

Stabilize the site prior to installing the subsurface structure. Do not allow runoff from any disturbed areas on the site to flow to the structure. Rope off the area where the subsurface structures are to be placed. Accomplish any required excavation with equipment placed just outside of this area. If the size of the area intended for exfiltration is too large to accommodate this approach, use trucks with low-pressure tires to minimize compaction. Do not allow any other vehicles within the area to be excavated. Keep the area above and immediately surrounding the subsurface structure roped off to all construction vehicles until the final top surface is installed (either paving or landscaping). This prevents additional compaction. When installing the final top surface, work from the edges to minimize compaction of the underlying soils.

Before installing the top surface, implement erosion and sediment controls to prevent sheet flow or wind blown sediment from entering the leach field. This includes, but is not limited to, minimizing land disturbances at any one time, placing stockpiles away from the area intended for infiltration, stabilizing any stockpiles through use of vegetation or tarps, and placing sediment fences around the perimeter of the infiltration field.

Provide an access port, man-way, and observation well to enable inspection of water levels within the system. Make the observation well pipe visible at grade (i.e., not buried).

Maintenance

Because subsurface structures are installed underground, they are extremely difficult to maintain. Inspect inlets at least twice a year. Remove any debris that might clog the system. Include mosquito controls in the Operation and Maintenance Plan.

Adapted from:
Connecticut Department of Environmental Conservation. Connecticut Stormwater Quality Manual. 2004.
MassHighway. Storm Water Handbook for Highways and Bridges. May 2004.

Other BMPs

Dry Detention Basin

Green Roofs

Porous Pavement

Rain Barrels & Cisterns

Dry Detention Basin

Description: A dry detention basin is an impoundment or excavated basin for the short-term detention of stormwater runoff from a completed development that allows a controlled release from the structure at downstream, pre-development flow rates. Conventional dry detention basins typically control peak runoff for 2-year and 10-year 24-hour storms. They are not specifically designed to provide extended dewatering times, wet pools, or groundwater recharge. Sometimes flows can be controlled using an outlet pipe of the appropriate size but this approach typically cannot control multiple design storms.

Ability to meet specific standards

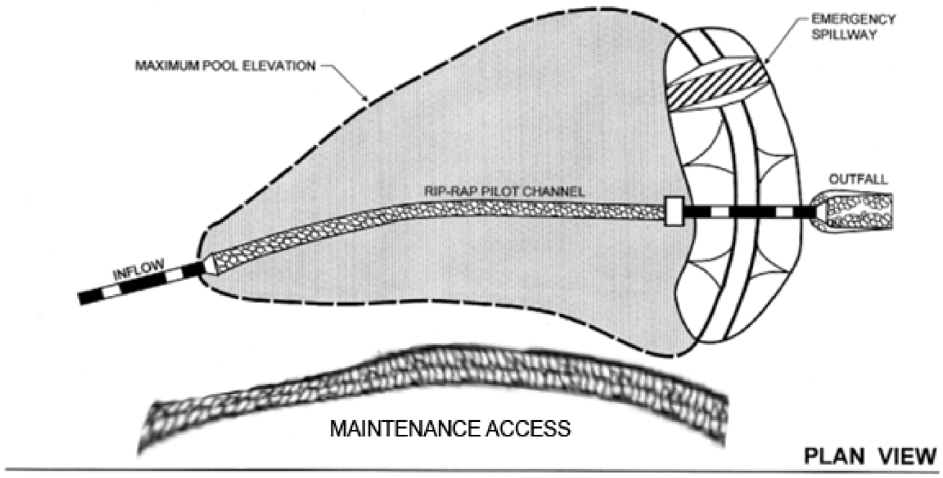
Standard	Description
2 - Peak Flow	Provides peak flow attenuation.
3 - Recharge	Provides no groundwater recharge
4 - TSS Removal	Does not receive any TSS removal credit
5 - Higher Pollutant Loading	May be used if bottom is lined and sealed.
6 - Discharges near or to Critical Areas	Do not use for discharges near or to critical areas
7 - Redevelopment	Not usually suitable

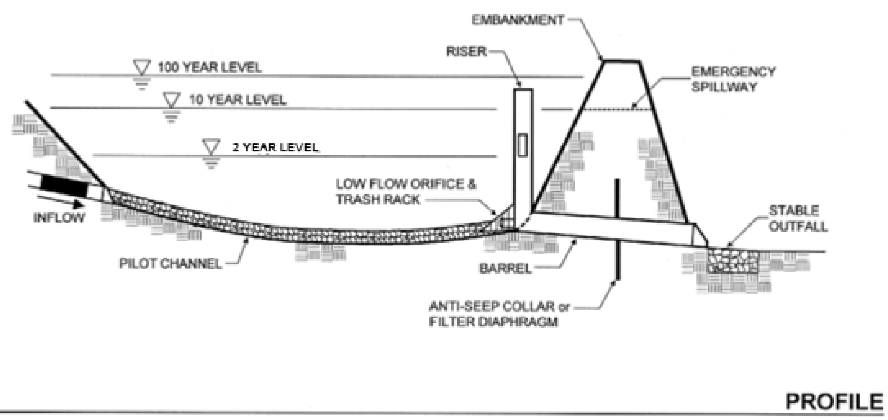
Advantages/Benefits:
- Controls peak runoff flows for 2-year and 10-year storms
- Low cost BMP

Disadvantages/Limitations:
- Provides negligible removal of TSS compared to extended dry detention basins and wet basins.
- Provides negligible groundwater recharge.
- Frequently clogs at inlets and outlets, dramatically affecting retention times and pollutant removal efficiency.
- Cannot be used to control multiple storm events
- Susceptible to resuspension of settled materials by subsequent storms
- Requires large land area
- Cannot be used in watersheds with cold-water fisheries.

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS) — Does not remove TSS.
- Bacteria (coliform, e coli) — Less than 10%
- Total Phosphorus — 10% to 30%
- Total Nitrogen — 5% to 50%
- Metals copper, lead, zinc, cadmium) — 30% to 50%





adapted from the Vermont Stormwater Manual

Maintenance

Activity	Frequency
Inspect wet basins to ensure they are operating as designed	At least once a year.
Mow the upper-stage, side slopes, embankment and emergency spillway.	At least twice a year.
Check the sediment forebay for accumulated sediment, trash, and debris and remove it.	At least twice a year.
Remove sediment from the basin.	As necessary, and at least once every 10 years

Special Features

Include a multiple stage outlet structure to control peak discharges for the 2-year and 10-year storms.

LID Alternative

Consider using a treatment train that includes vegetated filter strips or dry water quality swales and bioretention areas.

Consider decentralized stormwater management systems that direct stormwater runoff from various portions of the site to bioretention areas selectively located across the site.

Dry Detention Basin

Applicability
Because they have a limited capability for removing soluble pollutants, dry detention basins are used solely for water quantity control to attenuate peak flows and limit downstream flooding. Generally, dry detention basins are not practical if the contributing watershed area is less than ten acres. MassDEP recommends at least four acres of drainage area for each acre-foot of storage in the basin.

Dry detention basins may be used as part of a stormwater treatment train in combination with other treatment practices that are effective at removing TSS and providing recharge. The size of a dry detention basin can be substantially reduced if it is placed at the end of a treatment train to take advance of reduced runoff volume resulting from upstream practices that provide infiltration.

Effectiveness
Compared to extended dry detention basins or wet basins, dry detention basins have an extremely limited ability to remove TSS. A dry detention basin is designed to empty out completely in less than 24 hours, resulting in limited settling of sediments and the potential for resuspension of sediments in subsequent storms. Extended dry detention basins provide a minimum 24-hour detention time and incorporate in their design additional features aimed at enhancing pollutant removal, such as a sediment forebay, micropool, or shallow marsh.

Planning Considerations
Consider the following setback requirements when designing a detention basin:

- Distance from a septic system leach field - 50 feet.
- Distance from a septic system tank - 25 feet.
- Distance from a private well - 50 feet
- Distance from the property line -10 feet.

Investigate soils, depth to bedrock, and depth to water table at a site before designing a dry detention basin. At sites where bedrock is close to the surface, high excavation costs may make dry detention basins infeasible. If soils on site are relatively impermeable (such as Soil Group D), a dry detention basin may experience problems with standing water. In this case, building a wet basin may be more appropriate. On the other hand, if the soils are highly permeable, such as well-drained sandy and gravely soils (Soil Group A), it will be difficult to establish a shallow marsh component in the basin.

The maximum depth of dry detention basins typically ranges from 3 to 12 feet. The depth of the basin may be limited by groundwater conditions or by soils. Locate dry detention basins above the normal groundwater elevation (i.e., the basin bottom should not intercept groundwater). Investigate the effects of seepage on the basin if the basin intercepts the groundwater table.

Investigate the effects of a dry detention basin on wetland resources. Mitigate altered wetland resources according to local, state and federal regulations. Like all stormwater BMPs, dry detention basins may not be constructed in wetland resource areas except for bordering land subject to flooding, isolated land subject to flooding, land subject to coastal storm flowage, and riverfront areas. Embankments or dams that store more than 15 acre-feet or that are more than 6 feet high are regulated by the state Office of Dam Safety.

Design
The critical parameters in determining the size of the basin are the storage capacity and the maximum rate of runoff released from the basin. Design dry detention basins to store the volume required to meet the peak rate attenuation requirements of Standard 2 for the 2-year and 10-year 24-hour storms. In some cases, compliance with Standard 2 may require flood storage volume to prevent an increase in off-site flooding from the 100-year 24-hour storm.

Design a multiple stage outlet structure to control peak discharges for the 2-year and 10-year 24-hour storms. Provide an emergency spillway. Build the spillway in the existing ground--not in the embankment. Make the interior embankment slopes no greater than 3:1. To provide drainage, make the minimum slope of the bottom 2%. Provide access for maintenance. Design embankments to meet safety standards. Stabilize the earthern slopes and the bottom of the basins using seed mixes recommended by the NRCS.
[Note: for complete design references, see: Design of Stormwater Pond Systems. 1996. Schueler. Center for Watershed Protection.]

MassDEP recommends using impervious channels because they are simple to construct and easy to maintain. They can be designed to empty completely after a storm. Impervious channels can be undermined by runoff and differential settling if they are not constructed and maintained properly. Locate the top of the impervious channel lining at or below the level of the adjacent grassed areas to ensure thorough drainage of these areas. When designing the channels, consider settlement of the lining and the adjacent areas, the potential for frost impacts on the lining and the potential for erosion or scour along the edges of the lining caused by bank-full velocities. Provide impervious linings with broken stone foundations and weep holes. Design the channel to maintain a low outflow discharge rate at the downstream end of the channel.

Use low-flow underdrains, connected to the principal outlet structure or other downstream discharge point, to promote thorough drying of the channel and the basin bottom. Consider the depth of the low flow channel when preparing the final bottom-grading plan.

Design dry detention basin side slopes to be no steeper than 3:1. Flatter slopes help to prevent erosion of the banks during larger storms, make routine bank maintenance tasks (such as mowing) easier, and allow access to the basin. Include a multi-stage outlet structure to provide an adequate level of flood control. To meet the water quantity control standards, use the required design storm runoff rates as outlet release rates.

Design the outlet to control the outflow rate without clogging. Locate the outlet structure in the embankment for maintenance, access, safety and aesthetics. Design the outlet to facilitate maintenance; the vital parts of the structures should be accessible during normal maintenance and emergency situations. Include a draw-down valve to allow the dry detention basin to completely drain within 24 hours. To prevent scour at the outlet, include a flow transition structure, such as a lined apron or plunge pad, to absorb the initial impact of the flow and reduce the velocity to a level that will not erode the receiving channel or area.

Design embankments and spillways in conformance with the state regulations for Dam Safety (302 CMR 10.00). All dry detention basins must have an emergency spillway capable of bypassing runoff from large storms without damaging the impounding structure. Provide an access for maintenance by public or private right-of-way, using a minimum width of 15 feet and a maximum slope of 5:1. This access should extend to the forebay, safety bench and outflow structure, and should never cross the emergency spillway, unless the spillway has been designed for that purpose. Use vegetative buffers around the perimeter of the basin for erosion control and additional sediment and nutrient removal.

Maintenance

It is critical to provide access for maintenance, especially to the interior of the basin. Inspect dry detention basins at least once per year to ensure that they are operating as intended. Inspect basins during and after storms to determine if the basin is meeting the expected detention times. Inspect the outlet structure for evidence of clogging or outflow release velocities that are greater than design flow. Potential problems that should be checked include: subsidence, erosion, cracking or tree growth on the embankment; damage to the emergency spillway; sediment accumulation around the outlet; inadequacy of the inlet/outlet channel erosion control measures; changes in the condition of the pilot channel; and erosion within the basin and banks. Make any necessary repairs immediately. During inspections, note changes to the detention basin or the contributing watershed because these changes could affect basin performance. Mow the side slopes, embankment, and emergency spillway at least twice per year. Remove trash and debris at this time. Remove sediment from the basin as necessary, and at least once every 10 years or when the basin is 50% full. Provide for an on-site sediment disposal area to reduce the overall sediment removal costs.

Resources:

MassHighway. Stormwater handbook for Highways and Bridges. May 2004.
T.R. Schueler. Center for Watershed Protection. Design of Stormwater Pond Systems. 1996.

Green Roofs

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides peak flow attenuation for small storms
3 - Recharge	Provides no groundwater recharge
4 - TSS Removal	If sized to retain the required water quality volume, the area of the green roof may be deducted from the impervious surfaces used to calculate the required water quality volume for sizing other structural treatment practices.
5 - Higher Pollutant Loading	Not applicable
6 - Discharges near or to Critical Areas	Not applicable
7 - Redevelopment	Highly suitable.

Description: A "Green roof" is a permanent rooftop planting system containing live plants in a lightweight engineered soil medium designed to retain precipitation where the water is taken up by plants and transpired into the air. As a result, much less water runs off the roof compared to conventional rooftops. Green roofs have been in use in Europe for more than 30 years; they are easy to incorporate into new construction, and can be used on many existing buildings. There are two main types:

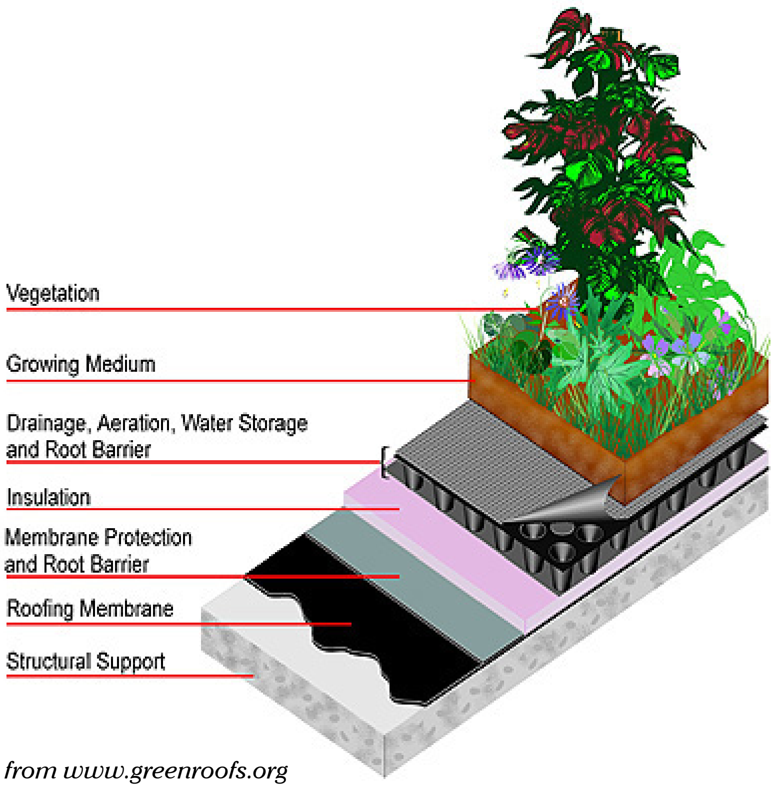
- Extensive: minimal maintenance with restricted variety of plants, resistant to frost, wind and drought: sedum, herbs and grasses, located on almost any flat or low slop roof deck that maximizes water retention;
- Intensive: regular maintenance required (irrigation, fertilizing, pruning, mowing); greater variety of plants (sod grass lawns, perennial, annual flowers, shrubs, small trees); deeper, heavier and richer soil.

Advantages/Benefits:

- Reduces volume and peak rate of runoff from more frequent storms.
- Reduces heating and cooling costs for buildings
- Conserves space
- May extend life expectancies of the roof by shielding the roof from UV and temperature
- Provides sound insulation
- Ideal for redevelopment or in the ultra-urban setting

Disadvantages/Limitations:

- Precipitation captured by green roofs (through interception, storage, plant uptake, evapotranspiration) is not recharged to groundwater.
- If green roofs require irrigation to maintain plants, they may reduce the volume of water available for other purposes.
- May require additional structural strengthening if used for retrofit.



from www.greenroofs.org

Special Features

Runoff from a green roof, like the runoff from non-metal roofs, may be discharged to the ground via a dry well without further treatment.

Runoff from a green roof must be kept separate from the runoff from any land uses with higher potential pollutant loads.

Intensive green roofs that require nutrient-rich fertilizers must not be used where the runoff from such roofs may be discharged to nutrient impaired surface waters.

Green roofs are not appropriate in watersheds where recharge is a high priority.

Pollutant Removal Efficiencies

• Total Suspended Solids (TSS)	No active removal of suspended solids
• Total phosphorus (TP)	Increases TP
• Total Nitrogen	No Removal to Increased TN
• Zinc	Not Reported
• Pathogens (coliform, e. coli)	Not Reported

Maintenance

Activity & Frequency
Green roofs require active maintenance, including irrigating, weeding, mulching, and pruning. For intensive green roofs, use fertilizers containing nitrogen, phosphorus, potassium and micronutrients to support the living plants. Regularly remove any woody plants that become established on the roof.

Green Roofs

Applicability

Green roofs contribute to stormwater management by attenuating the peak rate of runoff for small storms. Green roofs are appropriate for commercial, industrial, and residential structures, especially those with wide roofs. They can be incorporated into new construction or added to existing buildings during renovation or re-roofing. If adding a green roof as part of redevelopment, assess the structural integrity of the roof to determine whether the support structure can withstand the additional loading of the green roof when it is fully saturated. Most green roofs are built on flat or low-angle rooftops, but some have been installed on pitched roofs up to 40% slope, with special design features to prevent slumping and ensure plant survival.

Green roofs are appropriate anywhere it is desirable to reduce the overall amount of stormwater runoff, including areas of chronic flooding or where combined sewer overflows (CSOs) are compromising water quality. Green roofs can incrementally reduce the amount of runoff that contributes to flooding and overflow problems. They are an excellent technique to use in dense urban areas, in areas where infiltration is difficult due to tight soils or shallow bedrock, or on sites where infiltration is undesirable due to existing soil contamination. Because green roofs return rainwater to the atmosphere, they should not be used in situations where groundwater recharge is a priority, such as in stressed basins with chronic low-flow conditions. The roof runoff should be infiltrated instead.

Effectiveness

Many studies indicate that properly designed green roofs are highly effective in intercepting and retaining at least 40% of annual precipitation (e.g., DiNardo, 2003). Green roofs reduce peak discharge rates by retaining runoff and creating longer flow paths. Research indicates that peak flow rates are reduced by 50% to 90% compared to conventional roofs, and that peak discharges are delayed by an hour or more. The main mechanism for peak rate reduction appears to be the depth of the soil media rather than the plants (Forrester, 2007).

Fewer studies have evaluated the water quality of the effluent discharged from green roofs. Berndtsson (2006) indicates that, except for nitrogen, vegetated roofs behave as a source of contaminants. He indicates that while effluent from a green roof contains lower concentrations than those normally found in urban runoff, some metals appear in concentrations that would correspond to moderately polluted natural waters. In addition, the runoff often contains phosphate-phosphorus. Moran (2003) investigated nutrient runoff from a green roof in North Carolina and found that phosphorus increased in the runoff. For this reason, the runoff from green roofs should not be discharged to nutrient-impaired surface waters. If using green roofs in such circumstances, treat the rooftop overflow discharge to remove nutrients prior to discharge to the surface water. Because total phosphorus binds up in most soils, it is preferable to direct the overflow to a stormwater exfiltration treatment system, rather than a surface water body.

Green roofs lower heating and cooling costs, because the trapped air in the underdrain layer and in the root layer help to insulate the roof of the building. During summer, sunlight drives evaporation and plant growth, instead of heating the roof surface. During winter, a green roof can reduce heat loss by 25% or more.

Because green roofs shield roof membranes from intense heat and direct sunlight, the entire roofing system has a longer lifespan than conventional roofs. The presence of a green roof helps to reduce air temperatures around the building, reducing the "heat island" effect and reducing the production of smog and ozone, which forms in the intense heat (175 degrees) created by large conventional roofs. The vegetation on green roofs also consumes carbon dioxide and increases the local levels of oxygen and humidity. Green roofs have demonstrated aesthetic benefits that can increase community acceptance of a high-visibility project; if marketed effectively, they may also increase property values.

Planning Considerations

Carter (2006) recommends using a Runoff Curve Number (RCN) of 86 when performing calculations for peak rate attenuation. Green roof slopes greater than 15% require a wooden lath grid or other retention system to hold substrate in place until plants form a thick vegetative mat. Do not use green roofs where groundwater recharge is a priority, such as in aquifer recharge areas or watersheds experiencing chronic low flows.

Design

Conform to the Massachusetts State Building Code when designing green roofs. In particular, consider structural support requirements, waterproof membranes, and fire resistant materials (some plants such as sedums are flammable). State Plumbing Code requirements must be met for overflow discharge directed to roof leaders.

A green roof must include the following elements:

- A drainage layer;
- A synthetic, high quality waterproof membrane;
- A soil layer;
- Light-weight plants;
- A waterproof membrane.

Drainage Layer:

The drainage layer shall be capable of conveying the storm associated with the water quality volume (one half inch or one inch volume) without ponding on top of the roof cover. It may be constructed of perforated plastic sheets or a thin layer of gravel. Direct runoff from the drainage layer to a roof leader to discharge precipitation that exceeds the storage capacity of the soil.

Membrane:

To prevent the growth medium from clogging the drainage layer, install a geotextile between the drainage layer and the soil layer as well as a root retardant. To prevent leaks, install a waterproof membrane with a root barrier between the drainage layer and the roof sheeting.

Soil Layer:

Type of Soil: Use lightweight soils with good water retention capacity such as perlite, clay shale, pumice or crushed terracotta with no more than 5% organic content. Substrates should not be too rich in organic material such as compost, because of the potential for settling, nutrient export and too rapid plant growth.

Soil Depth: Select the thickness of the soil to store precipitation. Only the void spaces in the soil are credited with storage. Void spaces in the soil shall not exceed 0.4 inch for purposes of sizing. The green roof should be designed to retain the required water quality volume (0.5 inch or 1.0 inch times roof area).

Plants:

Vegetation on green roofs usually consists of hardy, low-growing, drought-resistant, spreading perennials or self-sowing annuals that provide dense cover and are able to withstand heat, cold, and high winds. Appropriate varieties include sedum (stonecrop), delospermum (ice plant), sempervivium, creeping thyme, allium, phloxes, anntenaria, ameria, and abretia. During dry periods, these plants droop but do not die; when it rains, they quickly revive and absorb large amounts of water. Grasses and herbs are less common on green roofs, because they require irrigation or deep substrates that retain more water to survive dry periods.

Vegetation may be planted as vegetation mats, plugs or potted plants, sprigs (cuttings), or seeds. Vegetation mats are the most expensive but achieve immediate full coverage. Potted plants are also expensive and labor-intensive to install. Sprigs are often the most cost effective option, even considering that initial irrigation is necessary and repeat installations may be required due to mortality. Do not use conventional sod, because it requires irrigation, mowing, and maintenance.

Irrigation systems

To maintain plant materials during Massachusetts's summers, consider installing an irrigation system depending on the type of plants selected. For green roofs built with irrigation systems, make sure that the Operation and Maintenance Plan addresses irrigation needs to minimize the amount of water needed for irrigation. Depending on the water source, excessive irrigation during the summer can reduce base flows in nearby wetland resource areas.

Cold Climate Considerations

Green roofs may provide limited peak rate attenuation during winter months when plants are inactive and the soil medium is frozen. Due to changing weather that produces intermittent periods of snow and then rain, design green roofs with an overflow bypass.

Overflow Bypass Connection

Design overflow bypasses to roof leaders in accordance with State Plumbing Code requirements. Never direct the bypass to a wastewater treatment system. Direct the bypass to a drywell to infiltrate the excess rooftop runoff. Although green roofs significantly reduce peak rate of runoff for small storms, they typically do not attenuate the full peak for the 2-year and higher storms (e.g. 10-year and 100-year 24-hour storm). Additional peak rate attenuation measures are usually needed to achieve full compliance with Standard 2.

Construction

Waterproof membranes are made of various materials, such as modified asphalts (bitumens), synthetic rubber (EPDM), hypolan (CPSE), and reinforced PVC. The most common design used in Europe is 60-80 mil PVC single-ply roof systems. Modified asphalts usually require a root barrier, while EPDM and reinforced PVC generally do not. Attention to seams is critical, because some glues and cements are not always root impermeable. The underdrain layer may be constructed of perforated plastic sheets or a thin layer of gravel. Pitched roofs and small flat roofs may not require an underdrain.

A common concern about green roofs is the potential for leaks. The performance of green roofs has improved dramatically since the 1970s, when many leak problems were associated with the first generation of green roofs. Current waterproofing materials, root barriers, and rigorous design and construction standards have largely eliminated these problems. Low-cost electronic grids installed under the membrane during construction can help to pinpoint leaks and minimize repair costs.

Maintenance

Both extensive and intensive green roofs require active maintenance. The vegetation in green roofs requires support during establishment and yearly maintenance thereafter. Plants or sprigs must be irrigated until established, and additional plants or sprigs added to ensure good plant coverage. With drought-resistant vegetation, irrigation of an extensive green roof is rarely necessary after the two-year establishment period. Weeding and mulching may be needed during the establishment period and periodically thereafter throughout the life of the roof.

Regularly remove any woody plants that become established on the roof. Many plants can survive on deposition of airborne nitrogen and biomass breakdown. If necessary, however, apply a slow-release fertilizer once a year to ensure continued vigorous growth of the vegetation. Do not use soluble nitrogen fertilizers and compost due to the potential for nutrient and bacteria export.

If fertilizers containing nitrogen, phosphorus, potassium and micronutrients are necessary to support the living plants, the long-term Operation and Maintenance/Pollution Prevention Plan must include an Integrated Fertilizer Management Plan (IFMP). The IFMP should address fertilizer requirements and ensure that no more than the appropriate amount of fertilizer is used. By reducing the potential for excess nitrogen and phosphorus in the green roof runoff, an Integrated Fertilizer Management Plan is an essential component of the pollution prevention plan.

Resources

- www.greenroofs.org (Green roof industry association; training and design courses)
- www.greenroofs.com (The Green Roof Industry Resource Portal)
- www.bae.ncsu.edu/greenroofs/ (North Carolina State University)
- http://hortweb.cas.psu.edu/research/greenroofcenter/ (Penn State University)
- www.greeninggotham.org/home.php
- www.roofmeadow.com (North American Green Roof Provider)

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Porous Pavement

Description: Porous pavement is a paved surface with a higher than normal percentage of air voids to allow water to pass through it and infiltrate into the subsoil. This porous surface replaces traditional pavement, allowing parking lot, driveway, and roadway runoff to infiltrate directly into the soil and receive water quality treatment. All permeable paving systems consist of a durable, load-bearing, pervious surface overlying a stone bed that stores rainwater before it infiltrates into the underlying soil. Permeable paving techniques include porous asphalt, pervious concrete, paving stones, and manufactured "grass pavers" made of concrete or plastic. Permeable paving may be used for walkways, patios, plazas, driveways, parking stalls, and overflow parking areas.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides peak flow attenuation for small storms.
3 - Recharge	Provides groundwater recharge.
4 - TSS Removal	80% TSS Removal credit if storage bed is sized to hold ½-inch or 1-inch Water Quality Volume, and designed to drain within 72 hours.
5 - Higher Pollutant Loading	Not suitable.
6 - Discharges near or to Critical Areas	Not suitable especially within Zone IIs or Zone A's of public water supplies.
7 - Redevelopment	Suitable.

Advantages/Benefits:

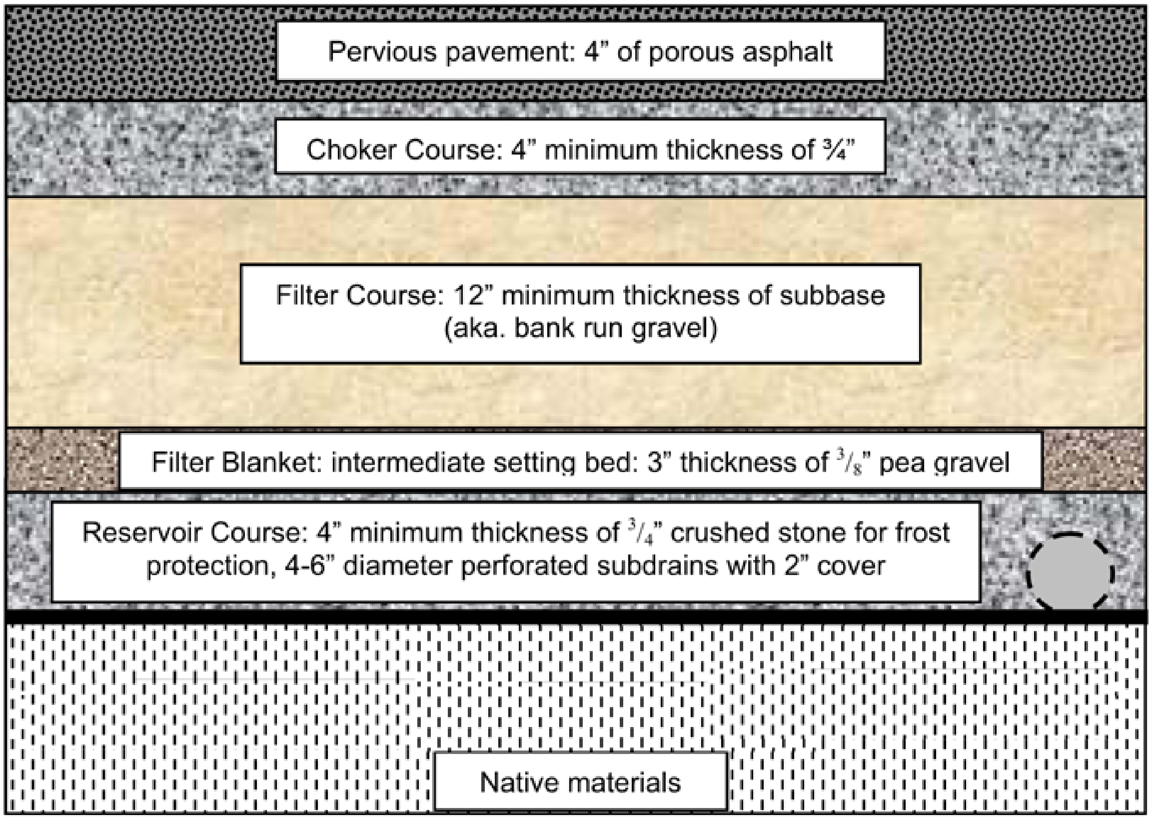
- Reduce stormwater runoff volume from paved surfaces
- Reduce peak discharge rates.
- Increase recharge through infiltration.
- Reduce pollutant transport through direct infiltration.
- Can last for decades in cold climates if properly designed, installed, and maintained
- Improved site landscaping benefits (grass pavers only).
- Can be used as a retrofit when parking lots are replaced.

Disadvantages/Limitations:

- Prone to clogging so aggressive maintenance with jet washing and vacuum street sweepers is required.
- No winter sanding is allowed.
- Winter road salt and deicer runoff concern near drinking water supplies for both porous pavements and impervious pavements.
- Soils need to have a permeability of at least 0.17 inches per hour.
- Special care is needed to avoid compacting underlying parent soils.

Pollutant Removal Efficiencies

- Total Suspended Solids (TSS) — 80%
- Nutrients (Nitrogen, phosphorus) — Insufficient data
- Metals (copper, lead, zinc, cadmium) — Insufficient data
- Pathogens (coliform, e coli) — Insufficient data



adapted from the University of New Hampshire

Maintenance

Activity	Frequency
Monitor to ensure that the paving surface drains properly after storms	As needed
For porous asphalts and concretes, clean the surface using power washer to dislodge trapped particles and then vacuum sweep the area. For paving stones, add joint material (sand) to replace material that has been transported.	As needed
Inspect the surface annually for deterioration	Annually
Assess exfiltration capability at least once a year. When exfiltration capacity is found to decline, implement measures from the Operation and Maintenance Plan to restore original exfiltration capacity.	As needed, but at least once a year
Reseed grass pavers to fill in bare spots.	As needed

Special Features

Most appropriate for pedestrian-only areas and for low-volume, low-speed areas such as overflow parking areas, residential driveways, alleys, and parking stalls.

Porous Pavement

Applicability

Porous pavement, also known as permeable paving, is appropriate for pedestrian-only areas and for low-volume, low-speed areas such as overflow parking areas, residential driveways, alleys, parking stalls, bikepaths, walkways, and patios. It can be constructed where the underlying soils have a permeability of at least 0.17 inches per hour. Porous paving is an excellent technique for dense urban areas, because it does not require any additional land. Porous pavement can be successfully installed in cold climates as long as the design includes features to reduce frost heaving.

Porous paving is not appropriate for high traffic/ high speed areas, because it has lower load-bearing capacity than conventional pavement. Do not use porous pavement in areas of higher potential pollutant loads, because stormwater cannot be pretreated prior to infiltration. Heavy winter sanding will clog joints and void spaces. On some highways, MassHighway Department uses an Open Graded Friction Course (OGF) that has a permeable top coat but an impermeable base course. MassDEP provides no Water Quality or Recharge Credit for OGC, because it does not provide treatment or recharge. The primary benefit of OGF pavements is reductions in noise and hydroplaning.

Effectiveness

Porous pavement provides groundwater recharge and reduces stormwater runoff volume. Depending on design, paving material, soil type, and rainfall, porous paving can infiltrate as much as 70% to 80% of annual rainfall. To qualify for the Water Quality and Recharge Credits, size the storage layer to hold the Required Water Quality or Required Recharge Volume, whichever is larger, using the Static Method, and design the system to dewater within 72 hours. Porous pavement may reduce peak discharge rates significantly by diverting stormwater into the ground and away from pipe-and-basin stormwater management systems, up to the volume housed in the storage layer. Grass pavers can improve site appearance by providing vegetation where there would otherwise be pavement. Porous paving can increase the effective developable area of a site, because the infiltration provided by permeable paving can significantly reduce the need for large stormwater management structures.

Planning considerations

Porous paving must not receive stormwater from other drainage areas, especially any areas that are not fully stabilized.
Use porous paving only on gentle slopes (less than 5%). Do not use it in high-traffic areas or where it will be subject to heavy axle loads.
Consider the setback requirements when considering porous pavement:

Considerations	Setback Requirements
Slope	Less than 5%
Septic system soil absorption system	50 feet
Private well	100 feet
Public well	Outside the Zone 1
Public reservoir	Outside the Zone A
Surface Waters	100 feet
Cellar Foundations	20 feet
Slab Foundations	10 feet
Property Lines	10 feet
Minimum depth	2 feet vertical separation above seasonal high groundwater from bottom of storage layer
Frost Line	Below frost line
Bedrock	As with any stormwater exfiltration system, determine if it is feasible in locations with high bedrock. Presence of bedrock near land surface reduces the ability of soils to exfiltrate to groundwater.

Porous paving reduces the need for other stormwater conveyances and treatment structures, resulting in cost savings.

Permeable paving also reduces the amount of land needed for stormwater management.

Design

There are three major types of permeable paving:

- Porous asphalt and pervious concrete. Although it appears to be the same as traditional asphalt or concrete pavement, it is mixed with a very low content of fine sand, so that it has from 10%-25% void space.

- Paving stones (also known as unit pavers) are impermeable blocks made of brick, stone, or concrete, set on a prepared sand base. The joints between the blocks are filled with sand or stone dust to allow water to percolate to the subsurface. Some concrete paving stones have an open cell design to increase permeability.

- Grass pavers (also known as turf blocks) are a type of open-cell unit paver in which the cells are filled with soil and planted with turf. The pavers, made of concrete or synthetic material, distribute the weight of traffic and prevent compression of the underlying soil.

Each of these products is constructed over a storage bed.

Storage Bed Design

The University of New Hampshire has developed specifications for storage beds used in connection with porous asphalt or pervious concrete. According to UNH, the storage bed should be constructed as indicated in Figure PP 1 with the following components from top to bottom:

- a 4-inch choker course comprised of uniformly graded crushed stone,
- a filter course, at least 12 inches thick, of poorly graded sand or bankrun gravel to provide enhanced filtration and delayed infiltration
- a filter blanket, at least 3 inches thick, of pea stone gravel to prevent material from entering the reservoir course, and
- a reservoir course of uniformly graded crushed stone with a high void content to maximize the storage of infiltrated water and to create a capillary barrier to winter freeze thaw. The bottom of the stone reservoir must be completely flat so that runoff can infiltrate through the entire surface.

The size of the storage bed may have to be increased to accommodate the larger of the Required Water Quality and the Required Recharge Volume.

If paving stones or grass pavers are used, a top course of sand that is one inch thick should be placed above the choker coarse.

Overflow Edge

Some designs incorporate an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the surface of the pavement and acts as a backup in case the surface clogs.

Preparation of Porous Asphalt

Care must be taken in batching and placing porous asphalt. Unless batched and installed properly, porous pavement may have a reduced exfiltration ability. At Walden Pond State Reservation, several of the areas paved with porous asphalt did not meet the target exfiltration rate. Cores were taken and it was found that the batches had more sand and/or asphalt than was specified, and those sections had to be removed and repaved.

It is critical to minimize the amount of asphalt binder. Using greater amounts of asphalt binder could lead to a greater likelihood of "binder" or asphalt drawdown and clogging of voids. Sun light heating can liquefy the asphalt. The liquefied asphalt then drains into the voids, clogging them. Such clogging is not remedied by power washing and vacuuming. The topcoat in such instances needs to be scarified and resurfaced. The University of New Hampshire has prepared detailed specifications for preparing and installing pourous asphalt that are intended to prevent asphalt problems.

Additional Design Considerations

- Provide an open-graded subbase with minimum 40% void space.
- Use surface and stone beds to accommodate design traffic loads
- Generally, do not use porous pavement for slopes greater than 5 %.
- Do not place bottom on compacted fill.
- Provide perforated pipe network along bed bottoms for distribution
- Provide a three-foot buffer between the bed bottom and the seasonal high groundwater elevation, and a two-foot buffer for bedrock.

Cold Weather Design Considerations

Porous pavement performs well in cold climates. Porous pavement can reduce meltwater runoff and avoid excessive water on the road during the snowmelt period.

In cold climates, the major concern is the potential for frost heaving. The storage bed specifications prepared by the University of New Hampshire address this concern.

Maintenance

In most porous pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Consequently, frequent cleaning and maintenance of the pavement surface is critical to prevent clogging. To keep the surface clean, frequent vacuum sweeping along with jet washing of asphalt and concrete pavement is required. No winter sanding shall be conducted on the porous surface.
As discussed, designs that include an "overflow edge" provide a backup in case the surface clogs. If the surface clogs, stormwater will flow over the surface and into the trench, where some infiltration and treatment will occur. For proper maintenance:

- Post signs identifying porous pavement areas.
- Minimize salt use during winter months. If drinking water sources are located nearby (see setbacks), porous pavements may not be allowed.
- No winter sanding is allowed.
- Keep landscaped areas well maintained to prevent soil from being transported onto the pavement.
- Clean the surface using vacuum sweeping machines monthly. For paving stones, periodically add joint material (sand) to replace material that has been transported.
- Regularly monitor the paving surface to make sure it drains properly after storms.
- Never reseal or repave with impermeable materials.
- Inspect the surface annually for deterioration or spalling.
- Periodically reseed grass pavers to fill in bare spots.
- Attach rollers to the bottoms of snowplows to prevent them from catching on the edges of grass pavers and some paving stones.

Adapted from:
MassDEP, Massachusetts Nonpoint Source Pollution Management Manual, 2006.

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University of New Hampshire Center for Stormwater Technology Evaluation and Verification; this research group tests and evaluates stormwater BMPs on the UNH campus.

- An article about the use of permeable pavers at the Westfarms Mall in Connecticut.
- Case Studies from Uni-Group USA, a block paver manufacturer.
- The Nonpoint Education For Municipal Officials program at the University of Connecticut has been involved in numerous permeable paving pilot projects.
- Permeable paver specifications courtesy of the Low Impact Development Center.
- Porous pavement design and operational criteria from the US Environmental Protection Agency, which also publishes a Low Impact Development Page. Also see this report on a Field Evaluation of Permeable Pavements for Stormwater Management (PDF.)
- New Jersey Stormwater Best Management Practices Manual February 2004.

Rain Barrels & Cisterns

Description: Cisterns and rain barrels are structures that store rooftop runoff and reuse it for landscaping and other non-potable uses. Instead of a nuisance to get rid of, consider rooftop runoff as a resource that can be reused or infiltrated. In contrast, conventional stormwater management strategies take rooftop runoff, which is often relatively free of pollutants, and direct it into the stormwater treatment system along with runoff from paved areas.

Ability to meet specific standards

Standard	Description
2 - Peak Flow	Provides peak flow attenuation for small storms.
3 - Recharge	Provides no groundwater recharge.
4 - TSS Removal	The roof surface can be deducted from the impervious area used to calculate the Required Water Quality Volume for sizing other structural treatment BMPs, a) when rain barrel or cistern is sized to store the Required Water Quality Volume for the roof surface (0.5 inch or 1.0 inch), b) stored water is used within 72-hours or discharged to an infiltration BMP, and c) the system is designed to operate year round.
5 - Higher Pollutant Loading	Not applicable.
6 - Discharges near or to Critical Areas	Not applicable.
7 - Redevelopment	Suitable.

Pollutant Removal Efficiencies

- Offers no primary pollutant removal benefits
- Rooftop Runoff presumed to be clean[1]

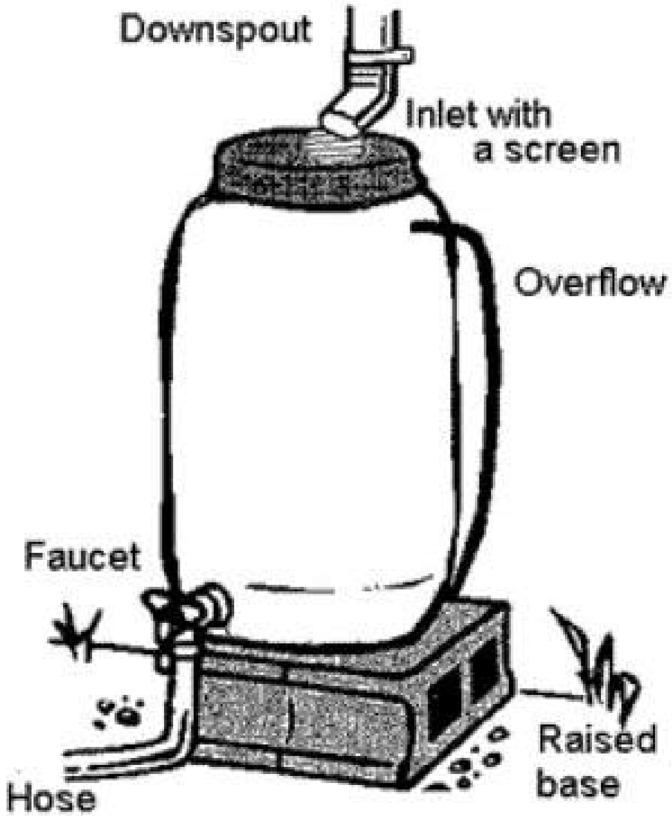
Advantages/Benefits:

- Can reduce water demand for irrigation or other non-potable uses.
- Property owners save money on water bills by using stored water for landscape purposes.
- Public water systems may experience lower peak demand in summer.
- When properly installed, rain barrels and cisterns reduce stormwater runoff volume for small storms.

Disadvantages/Limitations:

- Provides mosquito-breeding habitat unless properly sealed.
- May need to be disconnected and drained in winter to avoid cracking of storage structure

[1]Although MassDEP presumes rooftop runoff to be clean for purposes of the Stormwater Management Standards, research indicates higher PAHs in runoff from asphalt shingled roofs and zinc from metal roofs. USGS research in Texas indicates rooftop runoff contains mercury. Before using rooftop runoff for vegetable gardens, investigate the quality of the runoff, especially when using larvicides in rain barrels or cisterns for mosquito control.



Maintenance

Activity	Frequency
Maintenance requirements for cisterns and rain barrels are minimal. These requirements include the following: Inspecting the unit twice a year, larviciding for mosquito control, disconnecting and draining the system prior to winter to prevent cracking, and replacing or repairing any worn-out pieces.	

Special Features

Direct overflow from rain barrels and cisterns to a dry well, infiltration trench, rain garden, bioretention area, or other infiltration BMP sized to recharge the overflow volume.

Rain Barrels & Cisterns

Applications and Design Principles

The most common approach to roof runoff storage involves directing each downspout to a 55-gallon rain barrel. A hose is attached to a faucet at the bottom of the barrel and water is distributed by gravity pressure. A more sophisticated and effective technique is to route multiple downspouts to a partially or fully buried cistern with an electric pump for distribution. Where site designs permit, cisterns may be quite large, and shared by multiple households, achieving economies of scale. Stored rainwater can be used for lawn irrigation, vegetable and flower gardens, houseplants, car washing, and cleaning windows.

The roof surface can be deducted from the impervious surfaces used to determine the Required Water Quality Volume for sizing other structural treatment practices, only when a) the cistern or barrel can store the required water quality volume for the roof surface, b) the stored water is used or discharged to an infiltration BMP within 72-hours, and c) the system is designed to operate 365 days a year.

Cisterns and rain barrels can provide benefits by reducing the required water quality volume and peak discharge rates depending on the amount of storage available at the beginning of each storm. One rain barrel may provide a useful amount of water for garden irrigation, but it will have little effect on overall runoff volumes, especially if the entire tank is not drained between storms. Improve effectiveness by having more storage volume and by designing the system with a continuous discharge to an infiltration structure, so that there is always storage available for retention. To operate the system year-round, bury or insulate the unit. State Plumbing Code requirements apply to cisterns and rain barrels located within 10 feet of a building. All applicable requirements of the Massachusetts State Plumbing or State Building Codes must be met.

Cisterns and rain barrels are applicable to most commercial and residential properties where there is a gutter and downspout system to direct roof runoff to the storage tank. They take up little room and can be used in dense urban areas. Rain barrels and cisterns are excellent retrofit techniques for almost any circumstance. Rain barrels are covered plastic tanks that can hold from 50 to 100 gallons with a hole in the top for downspout discharge, an overflow outlet, and a valve and hose adapter at the bottom. They are used almost exclusively on residential properties. Plastic rain barrels are typically installed above ground. They must be disconnected prior to the winter, and the barrel drained completely to prevent the barrel from cracking.

Because rain barrels rely on gravity flow, place them near, and slightly higher than, the point of use (whether a garden, flower bed, or lawn). Route the overflow outlet to a dry well, bioretention area, rain garden or other infiltration BMP. It is important for property owners to use the water in rain barrels on a regular basis, otherwise the barrels can fill up and prevent additional roof runoff from being stored. Each house should have the appropriate number of rain barrels or an appropriately sized cistern. A one-inch storm produces over 620 gallons of water from a 1,000 square foot roof. Assuming a rain barrel capacity of 55 gallons, it would take 11 rain barrels to store one inch of runoff from 1,000 square feet of roof.

Cisterns are partially or fully buried tanks with a secure cover and a discharge pump; they provide considerably more storage than barrels, as well as pressurized distribution. They are less susceptible to cracking induced by expansion of freezing water when buried below grade. Cisterns can collect water from multiple downspouts or even multiple roofs, and then distribute this water wherever it needs to go via an electric pump. Property owners may use one large tank or multiple tanks in series. Either way, direct the overflow for the systems to a dry well or other infiltration mechanism so that if the cistern is full, excess roof runoff is infiltrated, and not discharged to the stormwater treatment system. Some cisterns are designed to continuously discharge water into infiltration units at very slow rates, so that the tank slowly empties after a storm, providing more storage for the next storm. The cisterns must also be designed to dewater in 72 hours or less.

Design

Because of the low pressure of the discharge, rain barrels are most effectively used with a drip irrigation system. Secure rain barrels against disturbance by children or animals. Seal any openings with mosquito netting. If present, place the cistern's continuous discharge outlet so that the tank does not empty completely. This ensures water availability at all times, and provides some storage capacity for every storm. A diverter at the cistern inlet can redirect the "first flush" of runoff, which is more likely to have particulates, leaves, and air-deposited contaminants washed off the roof. Keep leaves and debris out of the storage tank by placing a screen at the top of the downspout. Hide rain barrels and cisterns with shrubs or other landscaped features. Direct overflow from rain barrels and cisterns to a dry well, infiltration trench, rain garden, bioretention area, or other infiltration BMP sized to recharge the overflow volume. Use pond routing methods to design cisterns or rain barrels to account for retention of early runoff in the storage tank. Include access ports for any subsurface cisterns. Confined space entry training may be needed to enter large cisterns. MassDEP does not require treatment of runoff from non-metal roofs prior to infiltration.

Maintenance

Maintenance requirements for rain barrels are minimal and consist only of inspecting the unit as a whole and any of its constituent parts and accessories twice a year. The following components should be routinely inspected and either repaired or replaced as needed:

- *Roof catchment,* to ensure that trash and particulate matter are not entering the gutter and downspout to the rain barrel.
- *Gutters,* to ensure that no leaks or obstructions are occurring.
- *Downspouts,* to assure that no leaks or obstructions are occurring.
- *Entrance at rain barrel,* to ensure that there are no obstructions and/or leaks occurring.
- *Rain barrel,* to check for potential leaks, including barrel top and seal.
- *Runoff / overflow pipe,* to check that overflow is draining in non-erosive manner.
- *Spigot,* to ensure that it is functioning correctly.
- *Any accessories,* such as rain diverter, soaker hose, linking kit, and additional guttering.
- *Apply larvicides in strict accordance with all Mass. Department of Agricultural Resources Pesticide Bureau regulations* to prevent mosquitoes from reaching adulthood.
- *Add bleach or other chemicals annually to kill bacteria present in the system.* A qualified professional should determine appropriate treatment.
- *Drain the system before winter* if it is located above ground or partially exposed, to prevent cracking.
- *Disconnect the system from roof leaders in the fall,* if water is not intended to be used during the winter, unless the runoff is directed to a qualifying stormwater infiltration practice.
- *When the cistern or barrel is connected to a stormwater recharge system, remove particulates trapped in the cistern or rain barrel annually to limit clogging of the stormwater infiltration system.*

Adapted from:
MAPC Low Impact Development Toolkit. For more information, go to www.mapc.org/lid and www.arc-of-innovation.org.

Additional Information
http://www.rainwaterrecovery.com/about.html
www.crwa.org (Charles River Watershed Association)

BMP Accessories


Level Spreaders


Check Dams


Outlet Structures


Catch Basin Inserts

BMP Accessories: Level Spreaders, Check Dams, Outlet Structures, Catch Basin Inserts

BMP accessories are not BMPs themselves but are required to facilitate the operation and function of BMPs. This section presents four of the most common and important BMP accessories: level spreaders, check dams, outlet structures, and catch basin inserts.

Level Spreaders

Description

A level spreader receives concentrated flow from channels, outlet structures, or other conveyance structures, and converts it to sheet flow where it can disperse uniformly across a stable slope. A level spreader is not a pollutant reduction device. It improves the efficiency of other BMPs, such as vegetated swales, filter strips, or infiltration systems that depend on sheet flow to operate properly.

Applicability and Planning Considerations

Level spreaders are used in wide, level areas where concentrated runoff occurs. They should be placed on undisturbed soil that has been stabilized with vegetation. Disturbed soils are more erodible. If the spreader is not absolutely level, flow will concentrate at the low point and may worsen erosion problems. Flows to the level spreader should be relatively free of sediment, or the level spreader could be quickly overwhelmed by sediment and lose its effectiveness.

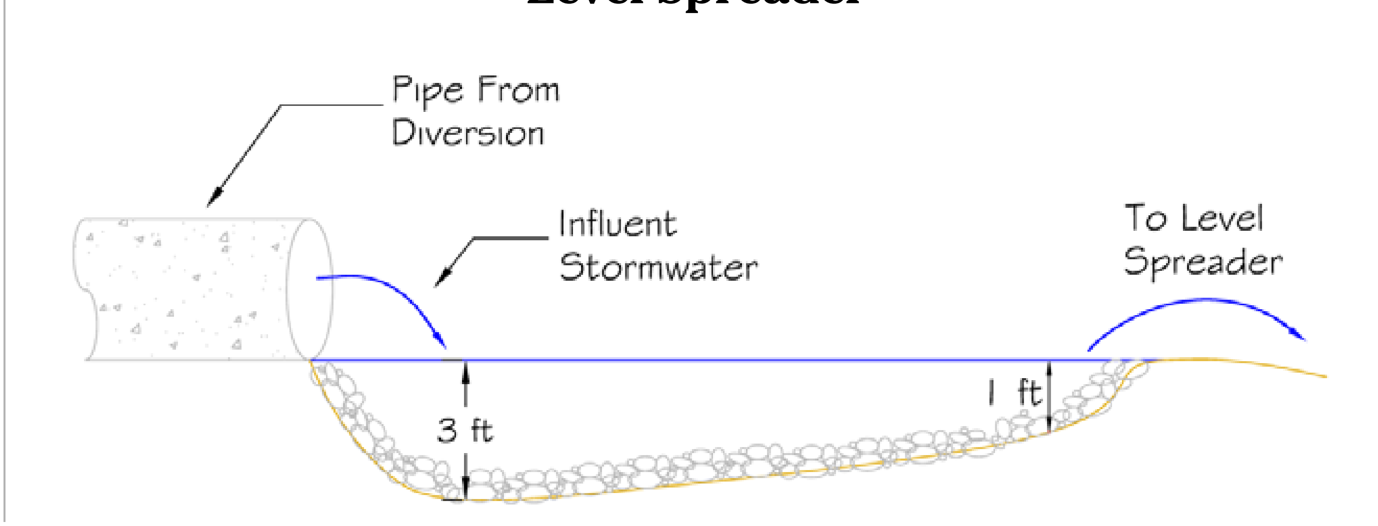
Design and Construction

Level spreaders are usually made of rocks, lumber, or concrete. Typical depths of flow behind each spreader range from 6 to 12 inches.

Construct level spreaders to be absolutely level. Small variations in height of even 0.25 inches can cause water to quickly concentrate and create erosion problems. A 4-inch variation in ground elevation across the entire length of the level spreader can make level construction difficult.

The height of the spreader is based on design flow, allowing for sediment and debris deposition. Design the length of the spreader based on the 10-year design flow for the site or the sheet flow path width, whichever is greater. When designing for the 10-year design flow, use the following table:

Level Spreader



adapted from the North Carolina State University

Drainage Area	Minimum spreader length
1 acre	10 feet
2 acres	10 feet
3 acres	15 feet
4 acres	18 feet
5 acres	20 feet

The slope leading to the level spreader should be less than 1% for at least 20 feet immediately upstream, to keep runoff velocities less than 2 feet per second during the 10-year storm event. The slope at the outlet of the spreader should be 6% or less.

Maintenance

Inspect level spreaders regularly, especially after large rainfall events. Note and repair any erosion or low spots in the spreader.

Adapted from:
Idaho Department of Environmental Quality. Catalog of Stormwater BMPs for Cities and Counties, 209-210.
MassDEP, Massachusetts Nonpoint Source Pollution Management Manual, 2006.
http://www.mass.gov/dep/water/laws/policies.htm#storm
Additional Resources:
Hunt, W.F. et al. Designing Level Spreaders to Treat Stormwater Runoff. North Carolina State University, as presented at North Carolina Department of Transportation Level Spreader Workshop, February 19, 2001, Raleigh, NC.

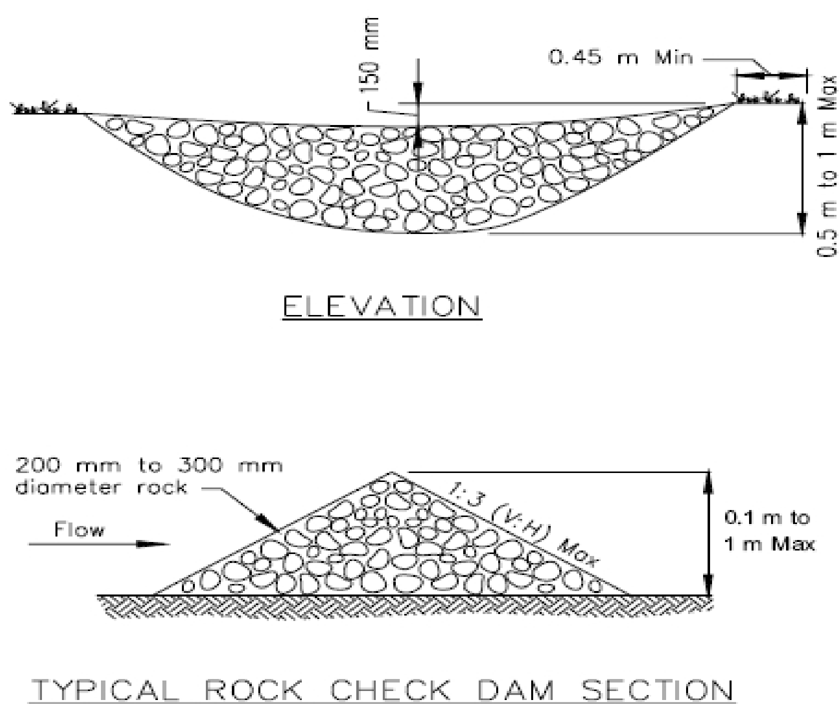
Check Dams

Description

A check dam is a small dam constructed across a drainage ditch, swale, or channel to lower the velocity of flow. Reduced runoff velocity reduces erosion and gullying in the channel and allows sediments to settle out. A check dam may be built from stone, sandbags (filled with pea gravel), logs, or concrete. Check dams are relatively easy and inexpensive to construct. Permanent check dams should be constructed from stone or concrete. Sandbag dams filled with pea gravel or logs are suitable only as temporary practices. Never use a filter fence or a hay bale as a check dam, either on a temporary or permanent basis.

Applicability

Use check dams where temporary channels or permanent channels are not yet vegetated, channel lining is infeasible, where velocity checks are needed, or to induce stormwater exfiltration into the ground within a BMP such as a dry water quality swale. Check dams may also be used as a temporary or emergency measure to limit erosion by reducing flow in small open channels. Other uses for



CHECK DAM
NOT TO SCALE
adapted from Caltrans Stormwater Handbooks

check dams include:

- To reduce flow in small temporary channels that are presently undergoing degradation,
- Where permanent stabilization is impractical due to the temporary nature of the problem,
- To reduce flow in small eroding channels where construction delays or weather conditions prevent timely installation of non-erosive liners.

Check dams can be installed in small open channels that drain 10 acres or less, or channels where stormwater velocities exceed 5 feet per second. Note that some BMPs such as grass channels require flows to not exceed 1 foot per second for the water quality volume. Check dams cause water to pond. Under low-flow situations, water ponds behind the structure and then slowly seeps through the check dam and/or exfiltrates into the underlying soil, depending on the soil permeability. Under high-flow situations, water flows over and/or through the structure.

Advantages

- Inexpensive and easy to install.
- Reduces velocity and may provide aeration of the water.
- Prevents gully erosion from occurring before vegetation is established, and also causes a high proportion of the sediment load in runoff to settle out.
- In some cases, if carefully located and designed, check dams can remain as permanent installations with very minor regrading, etc.
- They may be left as either spillways, in which case accumulated sediment would be graded and seeded, or as check dams to capture sediment coming off that site.
- They must be constructed in dry water quality swales to reduce velocity and induce exfiltration.

Disadvantages

- May kill grass linings in channels if the water level remains high after rainstorms or if there is significant sedimentation.
- Clogging by leaves in the fall may be a problem.
- Should not be used in live streams
- Promotes sediment trapping but resuspension can occur during subsequent storms
- Require extensive maintenance following high velocity flows
- Should not be made from straw bales or silt fences

Design

Install check dams at a distance and a height to allow small pools to form behind them. Install the first check dam about 15 feet from the outfall device and at regular intervals after that, depending on slope and soil type. In multiple check dam installations, design the system so that backwater from the downstream check dam reaches the toe of the next upstream dam. High flows (typically a 2-year or larger storm) should flow over the check dam without increasing upstream flooding or damaging the dam. Form check dams by hand or mechanically. Never dump rock directly into the channel or swale. Rock check dams should consist of well-graded stone consisting of a mixture of rock sizes.

When used in dry water quality swales, the height of the check dam shall be no less than the elevation associated with the Water Quality Volume (1/2 inch or 1-inch times contributing impervious surface).

Exercise care in designing the ends of a check dam to ensure that it is long enough and adequately anchored to prevent ponded water from scouring the soil at the ends, and flowing around the dam.

Some check dam designs may require weirs. For example, if the same check dam is used for water quality treatment (for the water quality volume), and to lag the peak rate of runoff (for the velocity associated with runoff from the 2-year storm), a weir must be included as part of the check dam design. In instances where a permanent check dam is to be used for both water quality treatment and lag peak flows with a weir, use a durable material such as concrete. If the check dam is constructed from stone such as pea gravel, the weir would most likely lose its shape when higher velocities occur.

Maintenance

Inspect check dams after every significant rainfall event. Repair damage as needed. Remove sediment as needed.

Adapted from:
Caltrans, Storm Water Quality Handbooks. Section 4. SC-4 P.
MassDEP, Massachusetts Nonpoint Source Pollution Management Manual, 2006.
http://www.mass.gov/dep/water/laws/policies.htm#storm

OUTLET STRUCTURES

Description

Outlets of BMPs are devices that control the flow of stormwater out of the BMP to the conveyance system.

Outlet Protection Design in Relation to Receiving Wetlands

This section describes the various types of common outlets such as flared end structures, risers, single-stage outlets, and multi-stage outlets. Considerations include setting back the outlet from a brook, providing appropriate energy dissipation, and orientating the outlet to reduce scour effects on the opposite bank.

Alignment of Outlets into Regulatory Streams

The Wetlands and 401 regulations require that stormwater treatment be provided prior to discharge into wetland resource areas such as vegetated wetlands (BVW, IVW, salt marshes), land under water (streams, lakes, rivers, ponds, ocean), and other resource areas, except for Riverfront Areas ILSF, BLSF, and land subject to coastal zone flowage, where such practices may be sited, provided the structures meet the performance standards specified in the Wetland regulations applicable to all projects.

The impact of new pipe outfalls on wetlands can be significantly reduced by locating the outfall point back from the receiving stream, using a flared-end structure, installing riprap or bio-engineered splash pad, and either digging a channel from the outfall to the stream or designing the splash pad to act as a level spreader to sheet the discharged stormwater to the stream.

In addition to not placing the outfall and energy dissipation in a wetland resource area such as a BVW or LUW, care must be exercised in the outlet design to ensure its orientation is such to reduce scour at the entry point and opposite bank. The preferred approach is to end the outlet pipe at a headwall or flared-end structure with a riprap or bio-engineered splash pad, discharging to a manmade drainage swale that is aligned at no more than a 45 degree angle to a stream channel. Design the outlet point and riprap or bio-engineered splash pad to reduce the energy sufficiently to eliminate a need to install riprap on the bank opposite the outfall point to protect it from scour.

References for BMP Accessories:

Note that sections of the Massachusetts Stormwater Update were adapted from a variety of manuals, checklists and other references in the public domain previously developed by other states and federal agencies, including:

Caltrans, Storm Water Quality Handbooks. 2003. (http://www.dot.ca.gov/hq/construc/stormwater/manuals.htm)

Connecticut Department of Environmental Protection. Connecticut Stormwater Quality Manual. 2004. (http://dep.state.ct.us/wtr/stormwater/strmwtrman.htm)

Idaho Department of Environmental Quality. Catalog of Stormwater BMPs for Cities and Counties. March 2003. (http://www.google.com/u/DEQ?q=stormwater&domains=www.deq.idaho.gov&sitesearch=www.deq.idaho.gov)

Maine Department of Environmental Protection. Maine Stormwater Best Management Practices Manual. January 2006. (http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps/index.htm)

Maryland Department of the Environment. Maryland Stormwater Design Manual, Volumes I and II, October 2000. (http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp)

New Jersey Department of Environmental Protection. New Jersey Stormwater Best Management Practices Manual. April 2004. http://www.state.nj.us/dep/stormwater/bmp_manual2.htm

U.S. Department of Transportation. Federal Highway Administration. Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. (Undated). (http://www.fhwa.dot.gov/environment/ultraurb/index.htm)

U.S.Environmental Protection Agency. Office of Research and Development. The Use of Best Management Practices (BMPs) in Urban Watersheds. EPA/600/R-04/184. September 2004.

Vermont Agency of Natural Resources. The Vermont Stormwater Management Manual. April 2002. (http://www.vtwaterquality.org/stormwater.htm)

Catch Basin Inserts

Description

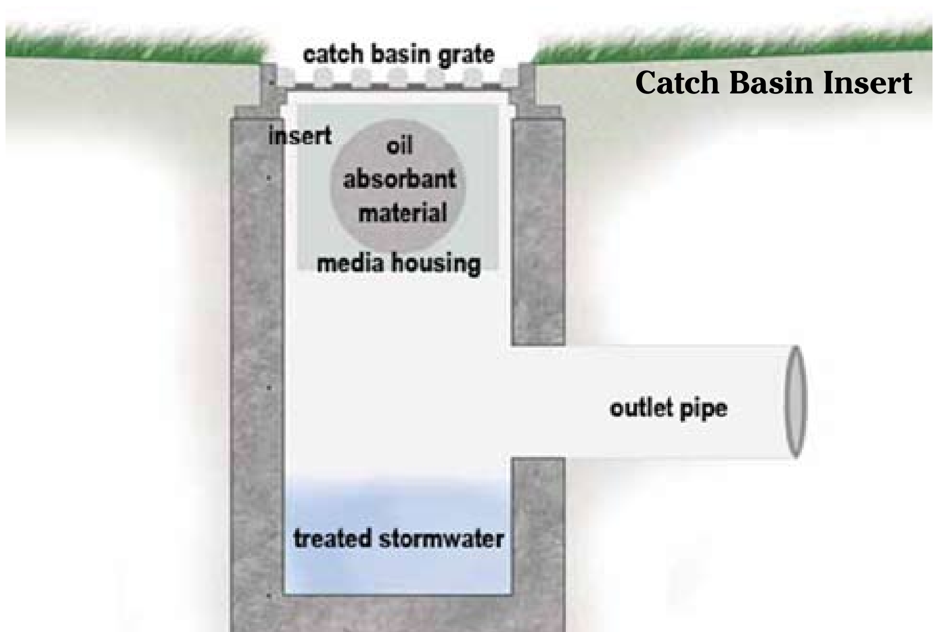
Catch Basin Inserts are a BMP accessory recently developed to add filtering efficiency to traditional catch basins. These proprietary BMPs are capable of removing a range of pollutants, from trash and debris to fine sediments and oil/grease and metals depending upon the filtering medium used. They typically have three components:

- an insert that fits in into the catch basin
- absorbent material (can be a single unit or a series of filters)
- a housing to hold the absorbent material

Applicability and Planning Considerations

Catch Basin Inserts can be useful for specialized applications, such as targeting specific pollutants other than TSS, at Land Uses with Higher Potential Pollution Loads, for oil control at small sites, for retrofits of existing catch basins with no or undersized sumps, to add TSS capability to areas with higher sediment loading, or to improve existing conditions at size-constrained sites (e.g., catch basins near bathing beaches).

If using a proprietary Catch Basin Insert, the manufacturer's specifications must be followed, which may include modifications to the catch basin. Such modifications may include a high flow bypass or other feature to handle clogging or larger storm events.



adapted from the North Carolina State University

Section of catch basin insert

Catch Basin Inserts are typically designed for and used for smaller volume applications. Additionally, larger sized sediment can clog and significantly reduce the effectiveness of some Catch Basin Insert filtering media. Therefore it is important to ensure that flow rates, sediment removal, and the frequency of inspection and maintenance are evaluated.

Design and Construction

Since Catch Basin Inserts are usually proprietary devices, the manufacturer should be asked to ensure that the device will work in the type of catch basin in which it is installed. Flow characteristics and sediment loading should be evaluated and any resulting modifications to the catch basin made before installation of the insert.

Maintenance

Inspect Catch Basin Inserts per the manufacturer's schedule, and especially after large rainfall events. Whoever is responsible for maintenance should explicitly agree to conduct the maintenance per the manufacturer's recommendation and to lawfully dispose of the cleanings or used filtration media.

Chapter 3

Checklist for Redevelopment Projects

Standard 7: A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural stormwater best management practice requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

Redevelopment is defined to include

- Maintenance and improvement of existing roadways, including widening less than a single lane, adding shoulders, correcting substandard intersections, improving existing drainage systems, and repaving;
- Development rehabilitation, expansion and phased projects on previously developed sites, provided the redevelopment results in no net increase in impervious area; and
- Remedial projects specifically designed to provide improved stormwater management, such as projects to separate storm drains and sanitary sewers, and stormwater retrofit projects.

Components of redevelopment projects that include development of previously undeveloped sites do not meet this definition. The portion of the project located in a previously developed area must meet Standard 7, but project components within undeveloped areas must meet all the Standards.

MassDEP recognizes that site constraints often make it difficult to comply with all the Standards at a redevelopment site. These constraints are as follows:

Lack of space. Because of the presence of existing structures, on-site subsurface sewage disposal systems, stormwater best management practices, and water bodies and wetlands, and easements, the space available for the installation of additional stormwater BMPs may be quite limited. On many suites it may be difficult or impossible to use space-intensive BMPs such as wet detention basins.

Soils: The presence of bedrock or clay can limit the effectiveness of infiltration or detention BMPs. Often soils at redevelopment sites have been compacted by buildings and heavy traffic, impairing their ability to infiltrate stormwater into the ground.

Underground utilities. The presence of underground utilities including gas and water mains, sewer pipes and electric cable conduits can greatly reduce the amount of land available for BMPs.

This chapter provides specific guidance and checklists to ensure that the applicant has met his/her obligations under Standard 7. Because it may be difficult for a redevelopment project to comply with all the Stormwater Management Standards, Standard 7 provides that a redevelopment project is required to comply with the following Standards only "to the maximum extent practicable": Standard 2, Standard 3, and the pretreatment and structural stormwater best management practice requirements of Standards 4, 5, and 6. Existing outfalls shall be brought into compliance with Standard 1 only to the maximum extent practicable.

As set forth in Standard 7, the phrase “to the maximum extent practicable” means that:

(1) Proponents of redevelopment projects have made all reasonable efforts to meet the requirements of Standards 2 and 3 and the pretreatment and structural stormwater best management practices requirements of Standards 4, 5, and 6 and to bring existing outfalls into compliance with Standard 1.

(2) They have made a complete evaluation of possible stormwater management measures, including environmentally sensitive site design that minimizes land disturbance and impervious surfaces, low impact development techniques and structural stormwater BMPs; and

(3) If not in full compliance with Standard 1 for existing outfalls, Standards 2 and 3 and the pretreatment and structural stormwater best management practice requirements of Standards 4, 5, and 6, they are implementing the highest practicable level of stormwater management.

Generally, an alternative is practicable if it can be implemented within the site being redeveloped, taking into consideration cost, land area requirements, soils and other site constraints. However, offsite alternatives may also be practicable. Proponents must document the evaluation of practicable alternatives with sufficient information to support the conclusions of the analysis.

At the same time, stormwater runoff from redevelopment projects must be properly managed. To this end, Standard 7 provides that redevelopment projects shall comply with all other requirements of the Stormwater Management Standards, including, without limitation, the pollution prevention requirements of Standards 4, 5, and 6, the erosion and sedimentation control requirements of Standard 8, the operation and maintenance requirements of Standard 9, and the prohibition of illicit discharge set forth in Standard 10. Proponents must also improve existing conditions.

Proponents of redevelopment projects shall document their compliance with these requirements. To assist proponents and reviewers in determining whether a redevelopment project complies with Standard 7, MassDEP has prepared the following redevelopment checklist.

[*Proponents of MassHighway redevelopment projects and Conservation Commissions reviewing such projects may follow the guidelines for redevelopment provided in the MassHighway Stormwater Handbook for Highways and Bridges (May 2004 or latest version) in lieu of the guidance set forth in this chapter.*[1] *The MassHighway Stormwater Handbook was developed by the Massachusetts Highway Department and issued by joint correspondence of May 7, 2004 by MassHighway and MassDEP. It provides detailed guidance on the evaluation and implementation of stormwater management practices for MassHighway road and bridge redevelopment projects, including a methodology for screening and selecting Best Management Practices (BMPs). Proponents and reviewers of other public roadway redevelopment projects may find useful information in the MassHighway Stormwater Handbook*.]

[1] The MassHighway Handbook published in 2004 must be revised to make it consistent with this Handbook.

Redevelopment Checklist

Existing Conditions

- On-site: For all redevelopment projects, proponents should document existing conditions, including a description of extent of impervious surfaces, soil types, existing land uses with higher potential pollutant loads, and current onsite stormwater management practices.
- Watershed: Proponents should determine whether the project is located in a watershed or subwatershed, where flooding, low streamflow or poor water quality is an issue.

The Project

Is the project a redevelopment project?

- Maintenance and improvement of existing roadways
- Development of rehabilitation, expansion or phased project on redeveloped site, or
- Remedial stormwater project

For non-roadway projects, is any portion of the project outside the definition of redevelopment?

- Development of previously undeveloped area
- Increase in impervious surface

If a component of the project is not a redevelopment project, the proponent shall use the checklist set forth below to document that at a minimum the proposed stormwater management system fully meets each Standard for that component. The proponent shall also document that the proposed stormwater management system meets the requirements of Standard 7 for the remainder of the project.

The Stormwater Management Standards

The redevelopment checklist reviews compliance with each of the Stormwater Management Standards in order.

Standard 1: (Untreated discharges)
No new stormwater conveyances (e.g., outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.
Same rule applies for new developments and redevelopments.

Full compliance with Standard 1 is required for new outfalls.

- What BMPs are proposed to ensure that all new discharges associated with the discharge are adequately treated?
- What BMPs are proposed to ensure that no new discharges cause erosion in wetlands or waters of the Commonwealth?
- Will the proposed discharge comply with all applicable requirements of the Massachusetts Clean Waters Act and the regulations promulgated thereunder at 314 CMR 3.00, 314 CMR 4.00 and 314 CMR 5.00?

Existing outfalls shall be brought into compliance with Standard 1 to the maximum extent practicable.

- Are there any existing discharges associated with the redevelopment project for which new treatment could be provided?
- If so, the proponent shall specify the stormwater BMP retrofit measures that have been considered to ensure that the discharges are adequately treated and indicate the reasons for adopting or rejecting those measures. (See Section entitled “Retrofit of Existing BMPs”.)
- What BMPs have been considered to prevent erosion from existing stormwater discharges?

Standard 2: (Peak rate control and flood prevention)
Stormwater management systems must be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates. This Standard may be waived for land subject to coastal storm flowage.
Full compliance for any component that is not a redevelopment

Compliance to the Maximum Extent Practicable:

- Does the redevelopment design meet Standard 2, comparing post-development to pre-development conditions?
- If not, the applicant shall document an analysis of alternative approaches for meeting the Standard. (See Menu of Strategies to Reduce Runoff and Peak Flows and/or Increase Recharge Menu included at the end of this chapter.)

Improvement of existing conditions:

- Does the project reduce the volume and/or rate of runoff to less than current estimated conditions? Has the applicant considered all the alternatives for reducing the volume and/or rate of runoff from the site? (See Menu.)
- Is the project located within a watershed subject to damage by flooding during the 2-year or 10-year 24-hour storm event? If so, does the project design provide for attenuation of the 2-year and 10-year 24-hour storm event to less than current estimated conditions? Have measures been implemented to reduce the volume of runoff from the site resulting from the 2 year or 10 year 24 hour storm event? (See Menu.)
- Is the project located adjacent to a water body or watercourse subject to adverse impacts from flooding during the 100-year 24-hour storm event? If so, are portions of the site available to increase flood storage adjacent to existing Bordering Land Subject to Flooding (BLSF)?
- Have measures been implemented to attenuate peak rates of discharge during the 100-year 24-hour storm event to less than the peak rates under current estimated conditions? Have measures been implemented to reduce the volume of runoff from the site resulting from the 100-year 24-hour storm event?   (See Menu.)

Standard 3: (Recharge to Ground water)
Loss of annual recharge to ground water shall be eliminated or minimized through the use of infiltration measures, including environmentally sensitive site design, low impact development techniques, best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from the pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusettss Stormwater Handbook.
Full compliance for any component that is not a redevelopment

Compliance to the Maximum Extent Practicable:

- Does the redevelopment design meet Standard 3, comparing post-development to pre-development conditions?
- If not, the applicant shall document an analysis of alternative approaches for meeting the Standard?
- What soil types are present on the site? Is the site is comprised solely of C and D soils and bedrock at the land surface?
- Does the project include sites where recharge is proposed at or adjacent to an area classified as contaminated, sites where contamination has been capped in place, sites that have an Activity and Use Limitation (AUL) that precludes inducing runoff to the groundwater, pursuant to MGL Chapter 21E and the Massachusetts Contingency Plan 310 CMR 40.0000; sites that are the location of a solid waste landfill as defined in 310 CMR 19.000; or sites where groundwater from the recharge location flows directly toward a solid waste landfill or 21E site?[2]
- Is the stormwater runoff from a land use with a higher potential pollutant load?
- Is the discharge to the ground located within the Zone II or Interim Wellhead Protection Area of a public water supply?
- Does the site have an infiltration rate greater than 2.4 inches per hour?

Improvements to Existing Conditions:

- Does the project increase the required recharge volume over existing (developed) conditions? If so, can the project be redesigned to reduce the required recharge volume by decreasing impervious surfaces (make building higher, put parking under the building, narrower roads, sidewalks on only one side of street, etc.) or using low impact development techniques such as porous pavement?
- Is the project located within a basin or sub-basin that has been categorized as under high or medium stress by the Massachusetts Water Resources Commission, or where there is other evidence that there are rivers and streams experiencing low flow problems? If so, have measures been considered to replace the natural recharge lost as a result of the prior development? (See Menu.)
- Has the applicant evaluated measures for reducing site runoff? (See Menu.)

<u>Standard 4: (80% TSS Removal)</u>

Stormwater management systems must be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). This standard is met when:

> ***a. Suitable practices for source control and pollution prevention are identified in a long-term pollution prevention plan and thereafter are implemented and maintained;***
> ***b. Stormwater BMPs are sized to capture the required water quality volume determined in accordance with the Massachusetts Stormwater Handbook; and***
> ***c. Pretreatment is provided in accordance with the Massachusetts Stormwater Handbook.***

Full compliance for any component that is not a redevelopment
Full compliance with the long-term pollution plan requirement for new developments and redevelopments.

- Has the proponent developed a long-term pollution plan that fully meets the requirements of Standard 4?
- Does the pollution prevention plan include the following source control measures?
  - Street sweeping

[2] A mounding analysis is needed if a site falls within this category. See Volume 3.

    - Proper management of snow, salt, sand and other deicing chemicals
    - Proper management of fertilizers, herbicides and pesticides
    - Stabilization of existing eroding surfaces

Compliance to the Maximum Extent Practicable for the other requirements:

- Does the redevelopment design provide for treatment of all runoff from existing (as well as new) impervious areas to achieve 80% TSS removal? If 80% TSS removal is not achieved, has the stormwater management system been designed to remove TSS to the maximum extent practicable?
- Have the proposed stormwater BMPs been properly sized to capture the prescribed runoff volume?
    - One inch rule applies for discharge
        - within a Zone II or Interim Wellhead Protection Area,
        - near or to another critical area,
        - from a land use with a higher potential pollutant load
        - to the ground where the infiltration rate is greater than 2.4 inches per hour
- Has adequate pretreatment been proposed?
    - 44% TSS Removal Pretreatment Requirement applies if:
        - Stormwater runoff is from a land use with a higher potential pollutant load
        - Stormwater is discharged
            - To the ground within the Zone II or Interim Wellhead Protection Area of a Public Water Supply
            - To the ground with an infiltration rate greater than 2.4 inches per hour
            - Near or to an Outstanding Resource Water, Special Resource Water, Cold-Water Fishery, Shellfish Growing Area, or Bathing Beach.

- If the stormwater BMPs do not meet all the requirements set forth above, the applicant shall document an analysis of alternative approaches for meeting the these requirements. (See Section on Retrofitting Existing BMPs (the "Retrofit Section").

Improvements to Existing Conditions:

- Have measures been provided to achieve at least partial compliance with the TSS removal standard?
- Have any of the best management practices in the Retrofit Section been considered?
- Have any of the following pollution prevention measures been considered?
    - Reduction or elimination of winter sanding, where safe and prudent to do so
    - Tighter controls over the application of fertilizers, herbicides, and pesticides
    - Landscaping that reduces the need for fertilizer, herbicides and pesticides
    - High frequency sweeping of paved surfaces using vacuum sweepers
    - Improved catch basin cleaning
    - Waterfowl control programs
- Are there any discharges (new or existing) to impaired waters? If so, see TMDL section.

Standard 5 (Higher Potential Pollutant Loads (HPPL)

For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable. If through source control and/or pollution prevention, all land uses with higher potential pollutant loads cannot

be completely protected from exposure to rain, snow, snow melt and stormwater runoff, the proponent shall use the specific stormwater BMPs determined by the Department to be suitable for such use as provided in the Massachusetts Stormwater Handbook. Stormwater discharges from land uses with higher potential pollutant loads shall also comply with the requirements of the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26-53, and the regulations promulgated thereunder at 314 CMR 3.00, 314 CMR 4.00 and 314 CMR 5.00.

Full compliance for any component that is not a redevelopment.
Full compliance with pollution prevention requirements for new developments and redevelopments.

Pollution Prevention

- Has the proponent considered any of the following operational source control measures?
    - Formation of a pollution prevention team,
    - Good housekeeping practices,
    - Preventive maintenance procedures,
    - Spill prevention and clean up,
    - Employee training, and
    - Regular inspection of pollutant sources.

- Has the proponent considered implementation of any of the following operational changes to reduce the quantity of pollutants on site?
    - Process changes,
    - Raw material changes,
    - Product changes, or
    - Recycling.

- Has the proponent considered making capital improvements to protect the land uses with higher potential pollutant loads from exposure to rain, snow, snow melt, and stormwater runoff?

    - Enclosing and/or covering pollutant sources (e.g. placing pollutant sources within a building or other enclosure, placing a roof over storage and working areas, placing tarps under pollutant source)

    - Installing a containment system with an emergency shutoff to contain spills?

    - Physically segregating the pollutant source to prevent run-on of uncontaminated stormwater?

Treatment

- If applicable, compliance with the treatment and pretreatment requirements of Standard 5 only to the Maximum Extent Practicable by directing the stormwater runoff from land uses with higher potential pollutant loads to appropriate stormwater BMPs?

    - Are the BMPs selected capable of removing the pollutants associated with the higher potential pollutant load land (“LUHPPL”) use?

    - Is the land use likely to generate stormwater with high concentrations of oil and grease? If so has an oil grit separator, sand filter, filtering bioretention area or equivalent been proposed for pretreatment?

Improvement of Existing Conditions.

- If the redevelopment converts a site from a non-LUHPPL use to a LUHPPL use, the applicant shall document how the stormwater BMPs shall be modified or replaced to come into compliance with Standard 5.

- What specific measures have been considered to offset the anticipated impacts of land uses with higher potential pollutant loads?

- If the redevelopment proposal is a brownfield project, the applicant shall demonstrate how the stormwater management measures have been designed to prevent mobilization or remobilization of soil and groundwater contamination. (See Brownfield section)

Other Requirements

- Does the discharge comply with all applicable requirements of the Massachusetts Clean Waters Act, 314 CMR 3.00, 314 CMR 4.00 and 314 CMR 5.00?

Standard 6 (Critical Areas)
Stormwater discharges to a Zone II or Interim Wellhead Protection Area of a public water supply and stormwater discharges near or any other critical area require the use of the specific source control and pollution prevention measures and the specific stormwater best management practices determined by the Department to be suitable for managing discharges to such area, as provided in the Massachusetts Stormwater Handbook. A discharge is near a critical area if there is a strong likelihood of a significant impact occurring to said area, taking into account site-specific factors. Stormwater discharges to Outstanding Resource Waters or Special Resource Waters shall be set back from the receiving water and receive the highest and best practical method of treatment. A "stormwater discharge," as defined in 314 CMR 3.04(2)(a)1. or (b), to an Outstanding Resource Water or Special Resource Water shall comply with 314 CMR 3.00 and 314 CMR 4.00. Stormwater discharges to a Zone I or Zone A are prohibited unless essential to the operation of the public water supply.
Full compliance for component of project that is not a redevelopment
Full compliance with pollution prevention requirements for new developments and redevelopments.

If applicable, compliance to the Maximum Extent Practicable with the pretreatment and treatment requirements of Standard 6:

- Does the redevelopment project utilize the pretreatment, treatment and infiltration BMPs approved for discharges near or to critical areas?
- If the redevelopment project does not comply with Standard 6, the applicant shall document an analysis of alternative measures for meeting Standard 6. (See Section on Specific Redevelopment Projects.)

Improvements to Existing Conditions:
- Have measures to protect critical areas been considered, including additional pollution prevention measures and structural and non-structural BMPs?

Other Requirements
- Does the discharge comply with the Massachusetts Clean Waters Act, 314 CMR 3.00, 314 CMR 4.00, and 314 CMR 5.00?

Standard 8: (Erosion, Sediment Control)

A plan to control construction-related impacts, including erosion sedimentation and other pollutant sources during construction and land disturbance activities (construction period erosion, sedimentation, and pollution prevention plan), must be developed and implemented.

All redevelopment projects shall fully comply with Standard 8.

- Has the proponent submitted a construction period erosion, sedimentation and pollution prevention plan that meets the requirements of Standard 8?

Standard 9: (Operation and Maintenance)
A long-term operation and maintenance plan must be developed and implemented to ensure that stormwater management systems function as designed.
All redevelopment projects shall fully comply with Standard 9.

- Has the proponent submitted a long-term Operation and Maintenance plan that meets the requirements of Standard 9?

Standard 10 (Illicit Discharges)
All illicit discharges to the stormwater management system are prohibited.
All redevelopment projects shall fully comply with Standard 10.

- Are there any known or suspected illicit discharges to the stormwater management system at the redevelopment project site?
- Has an illicit connection detection program been implemented using visual screening, dye or smoke testing?
- Have an Illicit Discharge Compliance Statement and associated site map been submitted verifying that there are no illicit discharges to the stormwater management system at the site?

Improvements to Existing Conditions:

- Once all illicit discharges are removed, has the proponent implemented any measures to prevent additional illicit discharges?

Figure 5-1

Menu of Strategies to Reduce Runoff or Peak Flows and/or Increase Recharge

- Rehabilitate the soils
- Plant trees and other vegetation
- Install a green roof
- Maximize naturally vegetated areas
- Reduce impervious surfaces
- Disconnect roof runoff from direct discharge to the drainage system
- Disconnect other existing paved areas from direct discharge to the drainage system, allowing controlled flow over pervious areas or through BMPs providing at least partial recharge
- Install porous pavement and/or other recharge measures (where sustainable and maintainable for promoting infiltration)
- Apply LID techniques for runoff reduction
- Install additional structural BMPs that are appropriate for redevelopment sites including infiltration trenches, subsurface structures, oil-grit separators, proprietary BMPs
- Retrofit existing BMPs

Retrofitting Existing BMPs

Many BMPs can be effectively retrofitted depending on site conditions and the water quantity or quality objectives trying to be achieved.[3] The objective of stormwater retrofitting is to remedy problems associated with, and improve water quality mitigation functions of, older, poorly designed, or poorly maintained stormwater management systems. Prior to the development of the stormwater standards, site drainage design did not require stormwater detention for controlling post-development peak flows. As a result, drainage, flooding, and erosion problems can be common in many older developed areas of the state. Furthermore, a majority of the dry detention basins throughout the state have been designed to control peak flows, without regard to water quality mitigation. Therefore, many existing dry detention basins provide only minimal water quality benefit. Incorporating stormwater retrofits into existing developed sites or into redevelopment projects can reduce the adverse impacts of uncontrolled stormwater runoff.

Bioretention Area Retrofits - can be used as a stormwater retrofit, by modifying existing landscaped areas, or if a parking lot is being resurfaced. In highly urban watersheds, they are one of the few practical retrofit options.

Catch Basin Retrofits or Reconstruction - Older catch basins without sumps can be replaced with catch basins having four foot-deep sumps. Sumps provide storage volume for coarse sediments, assuming that accumulated sediment is removed on a regular basis. Hooded outlets, which are covers over the catch basin outlets that extend below the standing water line, can also be used to trap litter and other floatable materials. Leaching catch basins can be installed adjacent to deep sump catch basins to achieve 80% TSS removal. Be aware, however, that many products are being touted as catch basin inserts, but the effectiveness of these devices can vary significantly.

Dry Detention Basin Retrofits - Traditional dry detention basins can be modified to become extended dry detention basins, wet basins, or constructed stormwater wetlands for enhanced pollutant removal. This is one of the most commonly and easily implemented retrofits, since it typically requires little or no additional land area, capitalizes on an existing facility for which there is already some resident acceptance of stormwater management, and involves minimal impacts to environmental resources (Claytor, Center for Watershed Protection, 2000).

There are numerous retrofit options that will enhance the removal of pollutants in detention basins:

- Excavate the basin bottom to create more permanent pool storage.
- Raise the basin embankment to obtain additional storage for extended detention.
- Modify the outfall structure to create a two-stage release to better control small storms while not significantly compromising flood control detention for large storms.
- Increase the flow path from inflow to outflow and eliminate short-circuiting by using baffles, earthen berms or micro-pond topography to increase residence time.
- Incorporate stilling basins at inlets and outlets.
- Regrade the basin bottom to create a wetland area near the basin outlet or revegetate parts of the basin bottom with wetland vegetation to enhance pollutant removal, reduce mowing, and improve aesthetics.
- Create a wetland shelf along the perimeter of a wet basin to improve shoreline stabilization, enhance pollutant filtering, and enhance aesthetic and habitat functions.
- Create a low maintenance “no-mow” wildflower ecosystem in the drier portions of the basin.

[3] Additional information on retrofitting stormwater BMPs can be found in the Urban Stormwater Retrofit Practices Manual. See http://www.cwp.org/Downloads/ELC_USRM3app.pdf.

- Provide a high flow bypass to avoid resuspension of captured sediments/pollutants during high flows.
- Eliminate low-flow bypasses.

Drainage Channel Retrofits - Existing channelized streams and drainage conveyances such as drainage channels can be modified to reduce flow velocities and enhance pollutant removal. Weir walls or riprap check dams placed across a channel create opportunities for ponding, infiltration, and establishment of wetland vegetation upstream of the retrofit. In-stream retrofit practices include stream bank stabilization of eroded areas and placement of habitat improvement structures (i.e., flow deflectors, boulders, pools/riffles, and low-flow channels) in natural streams and along stream banks. In-stream retrofits may require an evaluation of potential flooding and floodplain impacts resulting from altered channel conveyance, as well as requirements for local, state, or federal approval for work in wetlands and watercourses.

Parking Lots and Roadways- Parking lots offer ideal opportunities for a wide range of stormwater retrofits:

1. Incorporate bioretention areas into parking lot islands and landscaped areas; tree planter boxes can be converted into functional bioretention areas, rain gardens, or treebox filters to reduce and treat stormwater runoff.
2. Remove curbing and add slotted curb stops. Curbs along the edges of parking lots can sometimes be removed or slotted to re-route runoff to vegetated filter strips, water quality swales, grass channels, or bioretention facilities. The capacity of existing swales may need to be evaluated and expanded as part of this retrofit option.
3. Incorporate new treatment practices such as bioretention areas, sand filters, and constructed stormwater wetlands at the edges of parking lots.
4. In overflow parking or other low-traffic areas, asphalt can be replaced with porous pavement.

Sand Filter Retrofits - are suitable where space is limited, because they consume little surface space and have few site restrictions. Since sand filters cannot treat large drainage areas, retrofitting many small individual sites may be the only option. This option may be expensive.

Storm Drain Outfalls - New stormwater treatment practices can be constructed at the outfalls of existing drainage systems. The new stormwater treatment practices are commonly designed as *off-line devices* to treat the first flush volume and bypass larger storms. Water quality swales, bioretention areas, sand filters, constructed stormwater wetlands, and wet basins are commonly used for this type of retrofit. Other stormwater treatment practices may also be used if there is enough space for construction and maintenance.

Specific Redevelopment Projects

Redevelopment projects present unique challenges for controlling stormwater. It is possible that site constraints may prevent a redevelopment project from complying with one or more of the Stormwater Management Standards. Even if a redevelopment project cannot meet all of the Standards, there may be ample opportunity to improve existing site conditions depending on the other water quality or quantity issues in the watershed. The following special considerations provide unique opportunities for identifying how existing conditions may be improved:

A. Groundwater Recharge Areas - Redevelopment projects located within these areas (Zone II, Interim Wellhead Protection Areas (IWPA), aquifer protection districts, etc.) should place a high priority on ground water recharge BMPs.
   1) Disconnecting Rooftop Runoff – In some instances, building roof drains connected to the stormwater drainage system can be disconnected and re-directed to vegetated filter strips, bioretention facilities, or infiltration structures (dry wells or infiltration trenches).
   2) Use of Porous Paving Materials - Existing impermeable pavement in overflow parking or other low-traffic areas can sometimes be replaced with alternative permeable materials such as modular concrete paving blocks, modular concrete or plastic lattice, or cast-in-place concrete grids. Site-specific factors including traffic volumes, soil permeability, maintenance, sediment loads, and land use must be carefully considered prior to selection.

B. Cold-Water Fisheries - Redevelopment projects adjacent to these areas should place a high priority on mitigating potential thermal impacts. Techniques to consider include:

   1) Maintain Time of Concentration - Time of concentration (Tc) is based on the flow path and length, ground cover, slope and channel shape. When development occurs, Tc is often shortened due to the impervious area, causing greater flows to occur over a shorter period of time. Increasing the Tc will help to reduce the thermal impact of stormwater runoff from warm surface areas. Options to consider include:
      - Increasing the length of the runoff flow path
      - Increasing the surface roughness of the flow path
      - Detaining flows on site
      - Minimizing land disturbance
      - Creating flatter slopes.
   2) Disconnecting impervious areas – Breaking up large impervious expanses with vegetated zones will reduce the potential temperature increases of stormwater flowing across hot pavement.

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C. Brownfield Redevelopment – Redeveloping urban and non-urban brownfield sites (which in Massachusetts includes most “disposal sites” under the Massachusetts Contingency Plan [MCP]) are a Commonwealth priority, with ramifications for urban sprawl as well as the remediation of historically contaminated properties. Proponents of brownfield redevelopment projects should evaluate BMPs that will prevent the significant uncontrolled mobilization or remobilization of soil or ground water contamination. BMP considerations at these sites should consider such factors as:
   - The location of stormwater infiltration units with respect to contaminated areas
   - Ground water mounding effects on the rate and direction of migration of ground water contaminants
   - The location of outfalls
   - Water quality BMPs.

D. Runoff to Impaired Water Bodies – If MassDEP has issued a Total Maximum Daily Load (TMDL) that establishes a waste load allocation for stormwater discharge and/or a TMDL Implementation Plan that identifies remedies aimed at reducing the amount of pollutants from stormwater discharges, proponents may be required to install stormwater BMPs that are consistent with the TMDL.

E. Runoff to Areas of Localized Flooding – Project proponents must also understand the potential impacts of stormwater runoff in areas prone to localized flooding. When completing the checklist, proponents should consider the capacity of the receiving water and/or storm drainage system. When evaluating discharges to areas subject to localized flooding, the proponent should evaluate the ability to maintain and/or improve existing site cover and reduce runoff volume.

Chapter 4

Proprietary Stormwater BMPs

Proprietary Stormwater best management practices are manufactured systems that use proprietary settling, filtration, absorption/adsorption, vortex principles, vegetation, and other processes to meet the Stormwater Management Standards. There are two general types of Proprietary BMPs: hydrodynamic separators and filtering systems. Both types may be used for retrofits.

Hydrodynamic separators typically use either chambered systems or swirl concentrators to trap and retain sediment from a designed stormwater flow, and use different methods to help prevent the resuspension of sediment during high flow storm events. The retained sediment is removed through periodic maintenance.

Filtering systems typically use a settling chamber and filtering system that removes specific pollutants. The choice of filtering media or cartridges is typically based on the target pollutants.

Subsurface structures, even those that have manufactured storage chambers, are not proprietary BMPs, since the treatment occurs in the soil below the structure not the structure itself.

The effectiveness of Proprietary BMPs varies with the size of the unit, flow requirements, and specific site conditions. The UMass Stormwater Technologies Clearinghouse database evaluates the quality of proprietary BMP effectiveness studies. MassDEP urges Conservation Commissions to use this database when verifying the effectiveness of Proprietary BMPs: www.mastep.net

Advantages/Benefits:

- Useful for pretreatment/removal of TSS
- Can be an excellent choice in ultra-urban or other constrained sites
- Useful for redevelopments and to improve local conditions
- Longevity can be high with proper maintenance

Disadvantages/Limitations:

- Must be sized carefully to achieve design removal efficiencies
- Efficiency may be affected by size of sediment and rate of sediment loading
- Must ensure regular maintenance to achieve design removal efficiencies
- Not appropriate for terminal treatment for runoff from LUHPPLs or discharges near or to critical areas, unless determined suitable for such use by TARP or STEP.

Two Ways to Approve or Deny the Use of Proprietary Stormwater BMPs

1. MassDEP has reviewed the performance of a technology as determined by TARP or STEP and assigned a TSS removal efficiency.

- If the conditions under which it is proposed to be used are similar to those in the performance testing, presume that the proprietary BMP achieves the assigned TSS removal rate
- Look at sizing, flow and site conditions.

2. Issuing Authority makes a case-by-case assessment of a specific proposed use of a proprietary technology at a particular site and assigns a TSS removal efficiency.

- Proponent must submit reports or studies showing effectiveness of BMP.
- MassDEP strongly recommends using UMass Stormwater Technologies Clearinghouse database to ensure that reports and studies are of high quality (www.mastep.net).
- Look at sizing, flow and site conditions.
- For ultra-urban and constrained sites, proprietary BMPs may be the best choice.

Evaluation of Proprietary Stormwater Systems

Local agencies see a range of proposed stormwater management systems ranging from LID systems that mimic natural hydrology to traditional dry detention basins and manufactured systems.

The Stormwater Management Standards require proponents to consider the use of environmentally sensitive site design and LID techniques *before* selecting the appropriate BMPs for their development or redevelopment projects. After that consideration, the proponents may choose among a variety of stormwater BMPs to provide pretreatment, treatment, peak rate attenuation, and infiltration. These include LID BMPS, the traditional BMPs listed in the BMP charts presented in Volume 1, Chapter One, as well as a number of Proprietary BMPs.

MassDEP encourages proponents to consider proprietary BMPs, particularly where site constraints limit the use of LID techniques or traditional BMPs. If sized properly, manufactured (or "proprietary") BMPs can play a pivotal role in meeting the Stormwater Management Standards, particularly on smaller sites where adequate space for other BMPs is not available.

This Chapter provides the following information:

- Process To Approve or Deny the Use of Proprietary Stormwater Technology
- How to Evaluate the Effectiveness of Proprietary BMPs that Do Not Have a MassDEP TSS Removal Efficiency Rating
- Additional Information about Proprietary BMPs, including sources of information and detailed evaluation guidance for each of the 10 Stormwater Standards

If a developer proposes to include a proprietary BMP as a component of the stormwater management system, the local permitting authority must determine

- whether the proprietary BMP can meet the applicable Stormwater Standards;
- if proposed to meet the TSS removal requirements of Standard 4, whether there is sufficient information available to assess the TSS removal efficiency of the proposed proprietary BMP and, if so;
- assign a TSS removal credit.

This task is not easy. Only a few proprietary technologies have had their TSS removal effectiveness evaluated and approved by the Commonwealth. The overwhelming majority of proprietary technologies have not been evaluated by the state. Those technologies may still be used in Massachusetts, if the Conservation Commission or other local permitting authority determines that they can be used to meet the Stormwater Management Standards at a particular site.

Although MassDEP encourages proponents to consider the use of proprietary technologies to manage stormwater, local permitting agencies have the authority and responsibility to decide how these innovative or manufactured systems may be used, whether they are sized correctly for the intended purpose, and, in most cases, assess the proprietary BMP's ability to remove TSS.

Accordingly, **MassDEP encourages Conservation Commissions** and other local agencies to:

- Evaluate proposed proprietary BMPs by consulting the UMASS Stormwater Technologies Clearinghouse (www.mastep.net) and reviewing the information on the proposed technology.

- Ensure that BMPs described as already having been assessed by Massachusetts (through EEA's legacy STEP program) meet the conditions of those approvals, including model numbers, sizing requirements and site conditions. If such a BMP does not meet all applicable conditions, the TSS removal efficiency number established by the State can be questioned by the local permitting authority.
- Use proprietary systems for specialized situations – like heavily constrained redevelopment sites or other locations - where LID techniques or traditional structural BMPs may not provide needed improvements.

MassDEP encourages manufacturers of proprietary technologies to:

- Have their BMP's operating parameters evaluated though the multi-state Technology Acceptance Reciprocity Partnership (TARP) Program. When a technology completes TARP process, MassDEP will assign a specific TSS removal number or range for the tested use of that technology.
- Submit the results of other studies to the UMASS stormwater technology database clearinghouse (www.mastep.net).
- Promote specialized and niche uses of proprietary technologies to provide Conservation Commissions with more tools to improve the environment.

Ideally the developer of a property proposing these kinds of systems and the local agency evaluating the use of a manufactured or innovative stormwater technology will work cooperatively and agree that the proposed technology is appropriate for its intended use and likely to achieve the results intended.

To do that, developers must provide sufficient analytical information to the local agency (preferably third party analysis) so that it can evaluate the proprietary BMP. The local agency may reasonably deny the use of a proposed technology, if it finds that: (a) there is not sufficient information to assess the effectiveness of the technology; or (b) based on the available information, the proposed use of the technology does not meet all the requirements of the Stormwater Management Standards. In order to perform that analysis, local agencies must evaluate the studies provided to them describing the use and effectiveness of these technologies. Local agencies may not unreasonably deny the use of a proposed technology.

Process To Approve or Deny the Use of Proprietary Stormwater Technology

There are only two ways to evaluate a proposed use of a proprietary BMP in Massachusetts:

1. The Commonwealth has evaluated the performance of the technology and assigned a TSS removal efficiency.

In this case, Conservation Commissions and MassDEP shall presume that the proprietary BMP achieves the assigned TSS removal, provided the conditions under which it is proposed to be used are similar to those in the performance testing. MassDEP reserves the right to change the TSS removal number assigned to a proprietary technology based upon its review of subsequent studies.

The performance of a small number of proprietary BMPs was evaluated through EEA's legacy STEP program. In almost all cases, these STEP approvals were for specific sizing and flow requirements and specific site conditions. Those conditions are listed in the STEP reports. When reviewing this information, Conservation Commissions must analyze the STEP report to verify that the unit being proposed is within the scope of the STEP approval.

Although the STEP program no longer conducts these evaluations, MassDEP will review the performance of and assign a TSS removal efficiency to any proprietary BMPs that successfully complete the multi-state "Technology Acceptance and Reciprocity Partnership" (TARP) assessment process. Currently, MassDEP has not made a similar commitment to assign TSS removal efficiencies based on evaluations conducted under similar programs in other states or third party studies. MassDEP reserves the right to do so in the future.

2. The issuing authority has evaluated the proposed use of a particular proprietary BMP at a specific site and assigned a TSS removal efficiency based upon its own case-by-case review of the effectiveness and intended use of the proprietary BMP.

MassDEP strongly recommends that the issuing authority evaluate proposed BMPs using studies reviewed by the University of Massachusetts and posted on its stormwater database website (www.mastep.net). That database includes information on the relative quality of the studies, and should be used as the basis for a local agency's evaluation of the effectiveness of a proprietary system. Based on this information, the issuing authority may decide to approve or deny the use of any proprietary technology. The issuing authority may not unreasonably deny the use of a proposed technology.

If the operating parameters and performance claims of a proprietary technology have not been fully verified by STEP or TARP and a MassDEP removal efficiency rating has not been assigned, the technology vendor must submit evaluative information to the local agency regarding the technology's effectiveness.

> *Please note that Proprietary BMPs are NOT required to be evaluated by MassDEP to be used in Massachusetts. Only a small number of proprietary BMPs have been evaluated by the Commonwealth, and those evaluations are limited to the specific conditions that were reviewed. In most case in Massachusetts, a proposed use of a particular proprietary BMP at a specific site will be reviewed by the local agency on a case–by-case basis.*

How to Evaluate the Effectiveness of Proprietary BMPs that Do Not Have a MassDEP TSS Removal Efficiency Rating

MassDEP recognizes that the process of reviewing a proposed use of a particular proprietary BMP at a specific site may be daunting. MassDEP has prepared guidance for conducting this review.

Step One: Information that should be submitted as part of the Wetlands NOI.

As more fully set out below, issuing authorities require sufficient information to evaluate proposed uses of proprietary BMPs. If sufficient information is not submitted with the NOI, the Conservation Commission should request additional information as part of the review process.

Specific information that a Conservation Commission may want to request prior to a hearing include:

A A complete description of the proprietary technology or product including a discussion of the advantages of the technology when compared to conventional stormwater treatment systems and LID practices, including:

- Size: What volume is it designed to hold and/or treat? How is the system sized to meet the performance standards in order to handle the required water quality volume, rate of runoff, and types of storms? Standard 4 requires treatment for a required water quality volume, not for a specified design flow rate.
- Technical description, schematic and process flow diagram: How does it work? What are the technical configurations of the unit? Are there any pretreatment requirements? How does it fit in combination with other treatment systems?
- Capital costs and installation process and costs: What does this size system cost? Are there any consumable materials that need to be replaced and if so, how often and how much do they cost? How will the system be installed and who will supervise the installation to ensure that it is done properly? What mistakes can happen during installation? Is any special handling, installation techniques or equipment required?
- Potential disadvantages at this site: Any physical constraints? Weight or buoyancy issues? Durability issues? Energy requirements?
- Operation and maintenance (O&M) requirements and costs: New technologies will not have long-term data on O&M requirements, so it is particularly important that an applicant provide all available information for evaluation.

B. Data on how well the alternative technology works:

- Flow proportional sampling from laboratory testing and full-scale operations that is representative of the potential range of rainfall events (for example, a sufficient number of storms is generally at least 15) and located at sites similar to the conditions of the installation under review.
- Calculation of TSS removal rate should be presented. If there is a removal rating for a similar technology and use posted at http://www.mass.gov/dep/, and the proponent makes a claim for a higher TSS removal rate than for the similar system posted, the applicant must provide sufficient data to support the claim. Removal rates should show removal of various particle sizes across the full range of operating conditions including maximum, minimum and optimal conditions for reliable performance.
- A copy of the site's operation and maintenance plan including operational details on any full-scale installations: e.g., locations, length of time in operation, maintenance logs (logs should record the dates of inspections and cleaning, actions performed, quantities of solids removed, and time required for work).
- Information on any system failures, what those failures were, and how were they corrected.
- Copies of any articles from peer-reviewed, scientific or engineering journals.
- Any approvals or permits from other authorities.
- References along with contact information from other installations.

C. Operation and Maintenance (O&M) Plan:

- To ensure that the system will function as designed, all stormwater management systems must have a written operation and maintenance plan in accordance with Stormwater Management Standard 9. MassDEP stresses the importance of routine maintenance for all stormwater control technologies. A number of alternative technologies perform very well, but only if they are installed and maintained as specified by the manufacturer. For example, some alternative wet vaults may be able to achieve a high TSS removal rate, but only if they are cleaned often enough to prevent re-entrainment of previously trapped sediment.

- The O & M Plan shall
    - Identify access points to all components of the stormwater system;
    - Specify equipment, personnel, and training needed to inspect and maintain system;
    - Include a list of any safety equipment and safety training required for personnel;
    - Set forth a suggested frequency of inspection and cleaning; and
    - Provide a sample inspection checklist and maintenance log.

Please refer to Standard 9 in the Stormwater Technical Handbook (Volume 1, Chapter 1 and Volume 2, Chapter 1) for further guidance about O&M.

Step Two: Evaluate the submitted information.

An issuing authority (Conservation Commission or MassDEP upon appeal) may want to ask the questions set forth below to determine whether a proposed use of an alternative technology, either as a stand-alone product or in combination with other stormwater control practices and technologies, meets all of the Stormwater Management Standards:

A. **Why is this technology being proposed for this site?** Possible reasons are the alternative technology provides a higher level of environmental protection, uses less land area, and is less expensive on a capital or operation and maintenance cost basis. The performance data and other information provided with the application must support these claims. For example, if the applicant proposes an alternative technology, because it is less expensive to maintain than a conventional stormwater control technology system, the applicant must submit information supporting that claim.

B. **How convincing is the performance data?** Applicants must be able to demonstrate that their calculations show satisfactory performance in a laboratory, and preferably, adequate field-testing results. Were performance data (laboratory or field) collected by the technology developer or by independent organizations? Independent data are preferable, but may not always be available. If applicable, do the data and calculations support the claim of a higher TSS removal rate? Is the site similar to other locations where the alternative technology is already properly operating? The greater the similarity in key factors (e.g., soil conditions, climate, sediment loading rates, surficial geography, slopes), the greater the likelihood that the technology will properly work at the proposed site.

C. **Are the data sets complete?** If there are any gaps, why? Are you satisfied with the reasons given as to why there are gaps? For example, if maintenance data are provided for a two-year period, and there is a six-month gap in the record, a reasonable explanation for the gap should be provided. Is there enough information to persuade the issuing authority that the technology will work as proposed?

D. **Technologies may not work all the time or at all locations, and therefore, failures may be expected.** If there have been failures, either in the laboratory or in real settings, is the applicant able to adequately explain the reasons for the failure? Examples could be poor design, improper sizing, and higher sediment loading than anticipated, extreme hydrologic events, poor installation, or poor maintenance. If it was a design problem, has the design of the technology been modified to address the problem? For failures that were not design related, what corrections were made to prevent future failure? Were systems rechecked to see if they were functioning properly after corrections were made?

E. **If only limited data is available, is it possible to assess how the technology will work over its expected life?** If seasonality is an issue, the Commission should see data collected over a full change of seasons that reflect a normal weather year, or at least an estimate of normal annual operations based on available data. Can the technology function well for the full range of storm events that must be controlled? If not, is there a way to address this problem?

F. **Is it possible that a technology may effectively meet one Standard, but hamper compliance with other Standards?** For example, a technology might increase the rate of TSS removal, but limit the annual recharge. The applicant should provide documentation to help the Commission make this evaluation. Do the advantages of the technology potentially outweigh its disadvantages?

G. **Check any references provided by the applicant to find out whether previous installations are properly functioning.** If the information indicates that other Conservation Commissions have previously approved this technology for use in their municipalities, check with those Commissions to verify that the system has performed properly. Were there unexpected operation and maintenance costs? If there were problems, did the vendor assist in resolving them?

See the Detailed Proprietary BMP Evaluation Guidance below for more information.

Step Three: Make a decision on the filings.

If there appears to be sufficient information, the Conservation Commission must issue a decision approving (with or without special conditions) or denying the use of the proposed technology to meet the Stormwater Management Standards. There may be instances where the Conservation Commission may want to add conditions to the Order of Conditions to ensure the proper functioning of the alternative stormwater control technology and, if covered in a local wetlands bylaw, require a bond to be posted to pay for any repairs that may be necessary if the alternative system does not perform as designed. Particular attention to inspection and maintenance is advised and should be included in the conditions.

If a Conservation Commission denies the use of a proprietary technology, it must specify the reasons in writing. Because these decisions are subject to appeal, written documentation is critical.

If insufficient information exists, and the Commission cannot adequately evaluate the proposed technology, the Conservation Commission may either deny the project based on the lack of information (and specify what information is lacking in the denial) or ask the applicant to supply additional information The Conservation Commission may also direct the technology vendor to the TARP contacts listed in the References Section of this Chapter.

Other Proprietary BMP Information

Information about the STEP and TARP programs

The two Massachusetts-accepted evaluation programs - the Massachusetts Strategic Envirotechnology Partnership (STEP) and the multi-state "Technology Acceptance and Reciprocity Partnership" (TARP), were established to ensure rigorous testing and independent analysis of the effectiveness of manufactured or innovative (i.e., "proprietary") stormwater systems. Since each of these programs require significant testing, only a small number of systems have completed the programs and have had their effectiveness officially evaluated.

TARP

TARP was formed by the states of California, Illinois, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, and Virginia to provide reliable performance information about emerging technologies and to reduce the regulatory and permit hurdles that slow down or prevent their use. More information on TARP is available at this web site:
http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/

STEP

Before ending in 2003, the STEP program evaluated a number of different emerging technologies. STEP produced 2 reports and fact sheets on 3 stormwater technologies. Each was assigned a TSS removal efficiency. The reports are located here
http://www.mass.gov/envir/lean_green/documents/techassessments.htm
and the Facts Sheets are located here:
http://www.mass.gov/envir/lean_green/documents/factsheets.htm

Local agencies must note that the STEP verifications are limited to the specific models being used under specific conditions. If the conditions being proposed are significantly different than the conditions under which the units were tested, or the proposed models are different than the model tested, or the flow rates proposed are different than the flow rates tested, the local permitting authority may question whether the evaluations are applicable and may determine that the proposed proprietary technology is not appropriate for the proposed use or may not be able to remove TSS at the proposed rate.

Since the STEP process was less rigorous than the TARP process, and since the conditions under which STEP evaluations occurred were more limited than the TARP's protocol, developers proposing STEP technologies MUST provide the entire STEP Fact Sheet describing the proposed technology. A Conservation Commission may ask to see the entire report, and, upon request, the developer must provide it.

Conservation Commissions and other local agencies shall NEVER rely solely on information contained in STEP-related letters or excerpts from the STEP Fact Sheets or Reports found in vendor-provided literature or advertising when evaluating these systems.

When developers propose a specific use of a particular proprietary stormwater technology that has not been evaluated by the TARP or STEP program, the local agency is responsible for developing a TSS removal number based upon the site conditions, the proposed use of the technology, and information assessing the effectiveness of the technology.

If a proprietary BMP is proposed that has not been evaluated by STEP or TARP, MassDEP strongly encourages local agencies to use third party studies listed on the UMASS Stormwater Technologies Clearinghouse database (www.mastep.net) as the basis for their evaluation of the effectiveness of the proprietary system. While manufactured stormwater technologies are not required to have third party studies to be used in Massachusetts, local agencies in turn are not required to approve the use of these technologies.

The UMASS website (www.mastep.net) grades the quality of the studies evaluating proprietary BMPs. Local agencies must consider this information when deciding whether to approve the use of the proposed technology or what TSS number it will assign to a proposed use of a particular proprietary technology.

If a local agency denies the specific use of a particular alternative technology, the reasons should be specified in writing. This written documentation is important, because denials are subject to appeal and may be overturned, if permission is unreasonably withheld.

Other Sources of Information about Manufactured Stormwater Systems

There are other sources of information about the effectiveness of proprietary BMPs that may be used by local agencies to estimate TSS removal rates.

- ETV: This federal EPA verification program's information can be found at http://www.epa.gov/etv/verifications/vcenter9-9.html. EPA Region I hosts a "virtual trade show" of stormwater technologies with vendor provided information at http://www.epa.gov/ne/assistance/ceitts/stormwater/techs.html.
- New Jersey has a searchable database found at http://www.njcat.org/verification/Verifications.cfm
- Washington Department of Ecology evaluates emerging stormwater treatment technologies, more information and state approvals are found at http://www.ecy.wa.gov/programs/wq/stormwater/newtech
- CSTEV: The University of New Hampshire (UNH) Stormwater Center is evaluating the performance of several stormwater control technology technologies real time and on the ground. Information can be found at http://www.unh.edu/erg/cstev/.
- The American Society of Civil Engineers, EPA and others sponsor an international stormwater best management practices database at http://www.stormwater control technologydatabase.org/.
- MassDEP at http://www.mass.gov/dep/water/wastewater/stormwat.htm has information about stormwater.
- The University of Connecticut: UConn's website at http://nemo.uconn.edu/tools/stormwater/ has information about the interrelationship between increased stormwater runoff and associate pollutants.
- Center for Watershed Protection*:* This national non-profit at http://www.cwp.org/ provides resource information for local officials.

How To Evaluate the Use of Proprietary BMPs in Critical Areas and for Land Uses with Higher Potential Pollution Load: Standards 5 and 6

The Stormwater Management Standards limits the type of stormwater systems that may be used for treatment in **Critical Areas and Land Uses with Higher Potential Pollutant Loads.**

For new development, proprietary stormwater systems[1] may be used in such areas ONLY as a pretreatment device to one of the devices listed in the Stormwater Management Handbook as suitable for such areas or land uses. See Volume 1, Chapter One. For redevelopment sites, these systems may be used for discharges to Critical Areas or from Land Uses with Higher Potential Pollutant Loads ONLY if site constraints prevent use of the devices determined by MassDEP to be suitable for such areas and land uses.

Since the devices listed by MassDEP for discharges to Critical Areas or from Land Uses with Higher Potential Pollutant Loads were selected based on their ability to capture or treat constituents in addition to TSS (such as toxics, pathogens, nutrients, or temperature), proprietary systems proposed for redevelopment projects in these areas must provide similar capabilities.

How Proprietary Stormwater Systems Can Improve Local Conditions

In some cases local agencies will look further than TSS removal in analyzing the effectiveness of proprietary stormwater systems. Removal efficiencies can vary substantially with the size of particles and there are other valid ways than TSS to measure sediment reductions, so local agencies may need to examine closely the system's effectiveness for the specific site at which it is proposed.

Local agencies may be concerned about other contaminants such as toxics (metals such as lead, copper, zinc, or nickel), nutrients, pathogens or physical changes (such as temperature). If a Conservation Commission or other local agency is concerned about any of these parameters, because the receiving water is impaired or the designated use of the receiving water dictates removal of other pollutants, the local agency may want to request and analyze that kind of data.

Detailed Proprietary BMP Evaluation Guidance for each of the 10 Stormwater Standards

The purpose of this detailed guidance is to provide proponents and local agencies with the kinds of questions used by states when verifying the effectiveness of Proprietary BMPs. These questions should be used to address specific questions local agencies may have about the effectiveness of Proprietary BMPs to meet a specific Stormwater Management Standard. This guidance is not intended as a mandatory checklist that every proponent must submit for every Proprietary BMP.

Both proponents and reviewers of proprietary BMPs can use the following questions to determine if the information submitted about a proprietary BMP is sufficient to allow the proposed use.

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[1] Subsurface structures, even if they have manufactured storage chambers, are not proprietary BMPs, since the treatment occurs in the soil below the structure, not in the structure itself.

Using these questions will help proponents and reviewers determine whether a sufficient evaluation of the proprietary BMP has been performed, identify where deficiencies may be present, and reasonably predict the performance of a proprietary BMP at the project site.

General Information

Has the applicant provided a detailed description of the characteristics of the site, described how the proposed proprietary product addresses the unique storm water management requirements of the site, and shown that the proprietary product is in compliance with the Stormwater Management Standards? Has the applicant shown that the BMP is advantageous to the site? Have LID and site design techniques been considered when developing the site design? Items to consider include but are not limited to:

- What is the BMP's proposed use: pretreatment or treatment? Separator, filtration, infiltration or other use?
- Is the project for new development or re-development?
- Are there site constraints that limit what other BMPs can be used?
- Is it in an area of higher potential pollutant loads? (See Standard 5)
- Is there discharge to or near a critical area? (See Standard 6)
- Is there a high flow contribution from off-site?
- Is there a high TSS contribution anticipated from site soils, winter sand application, or other source?
- Are there TMDL requirements or recommendations applicable to the site?
- Are there other reasons that specific pollutants in addition to TSS should be reduced (e.g., Phosphorus, Nitrogen, Bacteria, hydrocarbons)?

Has the applicant provided documentation that the sizing of the device is correct? Is there any reason to allow a smaller size than proposed? Has the applicant demonstrated that the device meets both of the following:

- The Stormwater Management Standards; and
- The sizing procedures and calculations established by the manufacturer and verified through laboratory/field testing.

Has the applicant provided documentation that the product manufacturer's performance claims have been verified through laboratory and/or field-testing? Does the evaluation indicate that the device will work well on this specific site?

- Has the product been approved for use by other agencies in other states; if so, for what pollutants, pollutant levels and/or land use?
- Has the product been listed in the UMASS Stormwater Technologies database, and if so, how have the studies of the product been rated?

Is the product intended for construction period erosion and sedimentation control? If so, has the applicant provided documentation that the product is effective for such use? (See Standard 8 below.)

Did the STEP program evaluate the proposed BMP model and size and assess its TSS removal efficiency? If so, has the applicant:

- provided the complete STEP report (not excerpts or manufacturers' letters)?
- shown that the BMP proposed is one of the models that was evaluated?
- shown that the proposed sizing is the same as the sizing used for the STEP evaluation?

Is the product listed in the UMASS Stormwater Technologies database? If not, has the applicant provided documentation comparable to the studies cited in the database?

> If not, are there compelling site-specific reasons why the proprietary BMP should be used (e.g., severe location or space constraints, need to reduce a specific pollutant, flooding, filter devices proposed)?

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Information Required to Address Specific Stormwater Management Standards

Standard 1: (Untreated discharges): No new stormwater conveyances (e.g., outfalls) may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

No new untreated discharges

- Does the use of the product enable the applicant to provide adequate treatment for its new discharges?
- Does the use of the product enable the applicant to retrofit an existing discharge, achieving an improvement over existing conditions (see Standard 7)?
- Is the system designed to prevent erosion and scour?

Standard 2: (Peak rate control and flood prevention): Stormwater management systems shall be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates. This Standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

Peak rate control

- Does the product have a significant function in managing peak rates of runoff?
- If so, has the applicant documented this function with hydrologic/hydraulic data in lab or field studies?
- How is product performance affected by peak discharges?
- Has the applicant documented its performance with hydrologic/hydraulic in lab or field studies?
- Is the product susceptible to re-suspension and flushing of captured contaminants during a 2 -year or 10-year storm?
- Is the product designed to prevent such re-suspension and flushing? Is this documented in the laboratory/field studies? Was the particle size in those studies comparable to that used to calculate the performance and size of the proprietary BMP?
- If the product is not designed to address re-suspension and flushing, does the project design provide for “off-line” placement of the device?
- Is the product subject to damage or filling by sediment during a flood event or a coastal storm event?

Standard 3: (Recharge): Loss of annual recharge to ground water shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

Recharge

- Is the product proposed as part of a recharge system? If so,
- Is it a pre-treatment device intended to remove particulates and/or other pollutants prior to discharge to a recharge BMP?
- Is it a recharge BMP that requires protection by another pre-treatment BMP?
- Does it provide both pre-treatment and recharge?

Standard 4: (80% TSS Removal): Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS). This standard is met when:

a. Suitable practices for source control and pollution prevention are identified in a long-term pollution prevention plan and thereafter are implemented and maintained;

b. Stormwater best management practices are sized to capture the prescribed runoff volume; and

c. Pretreatment is provided in accordance with the Massachusetts Stormwater Handbook.

Water Quality Treatment

- Does the product remove TSS?
- Has the applicant provided documentation that the TSS removal capability of the device is based on a particle size distribution meeting accepted evaluation protocols? (See www.mastep.net)
- Does the product provide for control or prevention of re-suspension, scour, and/or flushing of captured solids or other contaminants treated by the product?
- Has the product been sized per manufacturer's standards, as verified by laboratory/filed testing?
- Does the product treat other pollutants, and if so, has applicant provided performance documentation (with verification documented by or consistent with the MassSTEP Database)?
- Is the proposed use of the product in the correct sequence in the "treatment train"?

    - Pretreatment (e.g., coarse particle separation, e.g., sand sized particles such as OK-110 floatables removal)
    - Terminal treatment (e.g. fine particle settling, e.g., silt and fine sand particles such as NJDEP PSD)
    - Polishing treatment (e.g., filtration, bacteria absorption or adsorption)
    - Infiltration

- How will the future use of the site influence the kinds of pollutants to be treated and loading rates of those pollutants (e.g., residential may mean more nutrients, a roadway may mean more coarse TSS)?

Standard 5 (Land Use with Higher Potential Pollutant Loads (LUHPPL)): For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable. If through source control and/or pollution prevention all land uses with higher potential pollutant loads cannot be completely protected from exposure to rain, snow, snow melt, and stormwater runoff, the proponent shall use the specific structural stormwater BMPs determined by the Department to be suitable for such uses as provided in the Massachusetts Stormwater Handbook. Stormwater

discharges from land uses with higher potential pollutant loads shall also comply with the requirements of the Massachusetts Clean Waters Act, M.G.L. c. 21, §§ 26-53 and the regulations promulgated thereunder at 314 CMR 3.00, 314 CMR 4.00 and 314 CMR 5.00.

Land Uses with Higher Potential Pollutant Loads (LUHPPL)

Does this standard apply to the site? If so,

- Is the product used consistent with the source control requirements of the Stormwater Management Standards?
- Does the technology provide pretreatment prior to discharge to a technology that has been determined to be suitable for runoff LUHPPL? ?
- What pollutants are associated with the LUHPPL? What demonstration can be provided that shows that the proposed BMP is capable of removing and/or treating those pollutants?
- Does the LUHPPL have the potential to generate stormwater runoff that has high concentrations of oil and grease? If so, has the technology been proposed in addition to an oil grit separator or sand filter or as an alternative method of achieving oil and grease removal in place of an oil grit separator or sand filter? If the technology is proposed in place of an oil grit separator or sand filter, what evidence is there that the technology is effective in removing oil and grease?

Standard 6 (Critical Areas): Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply and stormwater discharges near or to any other critical area require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined by the Department to be suitable for managing discharges to such areas as provided in the Massachusetts Stormwater Handbook. A discharge is near a critical area, if there is a strong likelihood of a significant impact occurring to said area, taking into account site-specific factors. Stormwater discharges to Outstanding Resource Waters and Special Resource Waters shall be removed and set back from the receiving water or wetland and receive the highest and best practical method of treatment. A "storm water discharge" as defined in 314 CMR 3.04(2)(a)1 or (b) to an Outstanding Resource Water or Special Resource Water shall comply with 314 CMR 3.00 and 314 CMR 4.00. Stormwater discharges to a Zone I or Zone A are prohibited unless essential to the operation of a public water supply.

Critical Areas

Does this standard apply to the site? If so,

- Is the product used for pretreatment prior to discharge to a technology that the Department has determined is suitable for the particular critical area?
- Does the product have any operating characteristics that could adversely affect the critical area, such as
  - Thermal impacts to coldwater fisheries
  - Release of bacteria to shellfish growing areas, bathing beaches
  - Release of previously captured pollutants (scour)

Standard 7 (Redevelopment): A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural best management practice

requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

Redevelopment

- Do site constraints make a proprietary BMP a better choice than a traditional BMP?
- Does the product performance documentation enable the Conservation Commission to determine a quantitative rating of the product for achieving one or more of Standards 2-6?
- If the answers to both b and c are "no", does the product documentation enable the Commission to qualitatively determine that the product improves existing conditions relative to one or more of Standards 2-6?

Standard 8: (Erosion, Sediment Control): A plan to control construction related impacts including erosion, sedimentation and other pollutant sources during construction and land disturbance activities (construction period erosion, sedimentation, and pollution prevention plan) shall be developed and implemented.

Erosion and Sediment Control

- Is the product intended to control erosion and sedimentation during the construction process?
- If so, has the applicant documented this function? How does it fit into the construction period erosion, sedimentation and pollution prevention plan?
- Is the product susceptible to adverse impact by erosion and sedimentation during construction, and if so, has the applicant documented how the product will be protected from such impact?

Standard 9: (Operation and Maintenance): A long-term operation and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed.

Operation and Maintenance

- Has the applicant completely described the installation, operation, and maintenance of the device? Has the applicant documented how the required maintenance will be done and who will do it?
- Has the applicant included a copy of the manufacturer's installation, inspection, operation, and maintenance procedures in the project O&M plan?
- Is the proposed BMP included in the project's O&M plan?
- Does the product require special materials or equipment for cleaning? If so, what materials or equipment are necessary?
- Has the O&M plan funding accounted for such equipment and materials?
- Does the inspection or maintenance of the device require confined space entry protocols?
- Is the frequency of maintenance and cleaning documented by pollutant loading/removal estimates, experience at other installations, or other information demonstrating that the proposed frequency is adequate?
- How will the future use of site influence O&M needs? More frequent? Less frequent?

Standard 10 (Illicit Discharges): All illicit discharges to the stormwater management system are prohibited.

Have steps been taken to prevent illicit discharges from entering the proprietary BMP?

Chapter 5
Miscellaneous Stormwater Topics

Mosquito Control in Stormwater Management Practices

Both aboveground and underground stormwater BMPs have the potential to serve as mosquito breeding areas. Good design, proper operation and maintenance and treatment with larvicides can minimize this potential.

EPA recommends that stormwater treatment practices dewater within 3 days (72 hours) to reduce the number of mosquitoes that mature to adults, since the aquatic stage of many mosquito species is 7 to 10 days. Massachusetts has had a 72-hour dewatering rule in its Stormwater Management Standards since 1996. The 2008 technical specifications for BMPs set forth in Volume 2, Chapter 2 of the Massachusetts Stormwater Handbook also concur with this practice by requiring that all stormwater practices designed to drain do so within 72 hours.

Some stormwater practices are designed to include permanent wet pools. These practices – if maintained properly – can limit mosquito breeding by providing habitat for mosquito predators. Additional measures that can be taken to reduce mosquito populations include increasing water circulation, attracting mosquito predators by adding suitable habitat, and applying larvicides.

The Massachusetts State Reclamation and Mosquito Control Board (SRMCB), through the Massachusetts Mosquito Control Districts, can undertake further mosquito control actions specifically for the purpose of mosquito control pursuant to Massachusetts General Law Chapter 252. The Mosquito Control Board, http://www.mass.gov/agr/mosquito/, describes mosquito control methods and is in the process of developing guidance documents that describe Best Management Practices for mosquito control projects.

The SRMCB and Mosquito Control Districts are not responsible for operating and maintaining stormwater BMPs to reduce mosquito populations. The owners of property that construct the stormwater BMPs or municipalities that "accept" them through local subdivision approval are responsible for their maintenance.[1] The SRMCB is composed of officials from MassDEP, Department of Agricultural Resources, and Department of Conservation and Recreation. The nine (9) Mosquito Control Districts overseen by the SRMCB are located throughout Massachusetts, covering 176 municipalities.

<u>Construction Period Best Management Practices for Mosquito Control</u>

To minimize mosquito breeding during construction, it is essential that the following actions be taken to minimize the creation of standing pools by taking the following actions:

- ***Minimize Land Disturbance:*** Minimizing land disturbance reduces the likelihood of mosquito breeding by reducing silt in runoff that will cause construction period controls to clog and retain standing pools of water for more than 72 hours.
- ***Catch Basin inlets:*** Inspect and refresh filter fabric, hay bales, filter socks or stone dams on a regular basis to ensure that any stormwater ponded at the inlet drains within 8 hours after precipitation stops. Shorter periods may be necessary to avoid hydroplaning in roads

[1] MassDEP and MassHighway understand that the numerous stormwater BMPs along state highways pose a unique challenge. To address this challenge, the 2004 MassHighway Stormwater Handbook will provide additional information on appropriate operation and maintenance practices for mosquito control when the Handbook is revised to reflect the 2008 changes to the Stormwater Management Standards..

caused by water ponded at the catch basin inlet. Treat catch basin sumps with larvicides such as *Bacillus sphaericus* (*Bs*) using a licensed pesticide applicator.

- ***Check Dams:*** If temporary check dams are used during the construction period to lag peak rate of runoff or pond runoff for exfiltration, inspect and repair the check dams on a regular basis to ensure that any stormwater ponded behind the check dam drains within 72 hours.
- ***Design construction period sediment traps*** to dewater within 72 hours after precipitation. Because these traps are subject to high silt loads and tend to clog, treat them with the larvicide *Bs* after it rains from June through October, until the first frost occurs.
- ***Construction period open conveyances:*** When temporary manmade ditches are used for channelizing construction period runoff, inspect them on a regular basis to remove any accumulated sediment to restore flow capacity to the temporary ditch.
- ***Revegetating Disturbed Surfaces:*** Revegetating disturbed surfaces reduces sediment in runoff that will cause construction period controls to clog and retain standing pools of water for greater than 72 hours.
- ***Sediment fences/hay bale barriers:*** When inspections find standing pools of water beyond the 24-hour period after a storm, take action to restore barrier to its normal function.

Post-Construction Stormwater Treatment Practices

- Mosquito control begins with the environmentally sensitive site design. Environmentally sensitive site design that minimizes impervious surfaces reduces the amount of stormwater runoff. Disconnecting runoff using the LID Site Design credits outlined in the Massachusetts Stormwater Handbook reduces the amount of stormwater that must be conveyed to a treatment practice. Utilizing green roofs minimizes runoff from smaller storms. Storage media must be designed to dewater within 72 hours after precipitation.
- Mosquito control continues with the selection of structural stormwater BMPs that are unlikely to become breeding grounds for mosquitoes, such as:
  - ***Bioretention Areas/Rain Gardens/Sand Filter:*** These practices tend not to result in mosquito breeding. If any level spreaders, weirs or sediment forebays are used as part of the design, inspect them and correct them as necessary to prevent standing pools of water for more than 72 hours.
  - ***Infiltration Trenches:*** This practice tends not to result in mosquito breeding. If any level spreaders, weirs, or sediment forebays are used as part of the design, inspect them and correct them as necessary to prevent standing pools of water for more than 72 hours.
- Another mosquito control strategy is to select BMPs that can become habitats for mosquito predators, such as:
  - ***Constructed Stormwater Wetlands:*** Habitat features can be incorporated in constructed stormwater wetlands to attract dragonflies, amphibians, turtles, birds, bats, and other natural predators of mosquitoes.
  - ***Wet Basins:*** Wet basins can be designed to incorporate fish habitat features, such as deep pools. Introduce fish in consultation with Massachusetts Division of Fisheries and Wildlife. Vegetation within wet basins designed as fish habitat must be properly managed to ensure that vegetation does not overtake the habitat. Proper design to ensure that no low circulation or "dead" zones are created may reduce the potential for mosquito breeding. Introducing bubblers may increase water circulation in the wet basin.

Effective mosquito controls require proponents to design structural BMPs to prevent ponding and facilitate maintenance and, if necessary, the application of larvicides. Examples of such design practices include the following:

- ***Basins:*** Provide perimeter access around wet basins, extended dry detention basins and dry detention basins for both larviciding and routine maintenance. Control vegetation to ensure that access pathways stay open.
- ***BMPs without a permanent pool of water:*** All structural BMPs that do not rely on a permanent pool of water must drain and completely dewater within 72 hours after precipitation. This includes dry detention basins, extended dry detention basins, infiltration basins, and dry water quality swales. Use underdrains at extended dry detention basins to drain the small pools that form due to accumulation of silts. Wallace indicates that extended dry extended detention basins may breed more mosquitoes than wet basins. It is, therefore, imperative to design outlets from extended dry detention basins to completely dewater within the 72-hour period.
- ***Energy Dissipators and Flow Spreaders:*** Currier and Moeller, 2000 indicate that shallow recesses in energy dissipators and flow spreaders trap water where mosquitoes breed. Set the riprap in grout to reduce the shallow recesses and minimize mosquito breeding.
- ***Outlet control structures:*** Debris trapped in small orifices or on trash racks of outlet control structures such as multiple stage outlet risers may clog the orifices or the trash rack, causing a standing pool of water. Optimize the orifice size or trash rack mesh size to provide required peak rate attenuation/water quality detention/retention time while minimizing clogging.
- ***Rain Barrels and Cisterns:*** Seal lids to reduce the likelihood of mosquitoes laying eggs in standing water. Install mosquito netting over inlets. The cistern system should be designed to ensure that all collected water is drained into it within 72 hours.
- ***Subsurface Structures, Deep Sump Catch Basins, Oil Grit Separators, and Leaching Catch Basins:*** Seal all manhole covers to reduce likelihood of mosquitoes laying eggs in standing water. Install mosquito netting over the outlet (CALTRANS 2004).

The Operation and Maintenance Plan should provide for mosquito prevention and control.

- ***Check dams:*** Inspect permanent check dams on the schedule set forth in the O&M Plan. Inspect check dams 72 hours after storms for standing water ponding behind the dam. Take corrective action if standing water is found.
- ***Cisterns:*** Apply *Bs* larvicide in the cistern if any evidence of mosquitoes is found. The Operation and Maintenance Plan shall specify how often larvicides should be applied to waters in the cistern.
- ***Water quality swales:*** Remove and properly dispose of any accumulated sediment as scheduled in the Operation and Maintenance Plan.
- ***Larvicide Treatment:*** The Operation and Maintenance Plan must include measures to minimize mosquito breeding, including larviciding.
- The party identified in the Operation and Maintenance Plan as responsible for maintenance shall see that larvicides are applied as necessary to the following stormwater treatment practices: catch basins, oil/grit separators, wet basins, wet water quality swales, dry extended detention basins, infiltration basins, and constructed stormwater wetlands. The Operation and Maintenance Plan must ensure that all larvicides are applied by a licensed pesticide applicator and in compliance with all pesticide label requirements.
- The Operation and Maintenance Plan should identify the appropriate larvicide and the time and method of application. For example, *Bacillus sphaericus (Bs*), the preferred

larvicide for stormwater BMPs, should be hand-broadcast.[2] Alternatively, Altosid, a Methopren product, may be used. Because some practices are designed to dewater between storms, such as dry extended detention and infiltration basins, the Operation and Maintenance Plan should provide that larviciding must be conducted during or immediately after wet weather, when the detention or infiltration basin has a standing pool of water, unless a product is used that can withstand extended dry periods.

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[2] *Bacillus thuringienis israelensis* or *Bti* is usually applied by helicopter to wetlands and floodplains

Roads and Stormwater BMPs

In general, the stormwater BMPs used for land development projects can also be used for new roadways and roadway improvement projects. However, for improvement of existing roads, there are often constraints that limit the choice of BMP. These constraints derive from the linear configuration of the road, the limited area within the existing right-of-way, the structural and safety requirements attendant to good roadway design, and the long-term maintainability of the roadway drainage systems. The MassHighway Handbook provides strategies for dealing with the constraints associated with providing stormwater BMPs for roadway redevelopment projects.

Roadway design can minimize impacts caused by stormwater. Reducing roadway width reduces the total and peak volume of runoff. Designing a road with country drainage (no road shoulders or curbs) disconnects roadway runoff. Disconnection of roadway runoff is eligible for the Low Impact Site Design Credit provided the drainage is disconnected in accordance with specifications outlined in Volume 3.

Like other parties, municipalities that work within wetlands jurisdictional areas and adjacent buffer zones must design and implement structural stormwater best management practices in accordance with the Stormwater Management Standards and the Stormwater Management Handbook. In addition, in municipalities and areas where state agencies operate stormwater systems, the DPWs (or other town or state agencies) must meet the "good housekeeping" requirement of the municipality's or agency's MS4 permit.

MassHighway has taken stormwater management one step further by working with MassDEP to develop the MassHighway Storm Water Handbook for Highways and Bridges. The purpose of the MassHighway Handbook is to provide guidance for persons involved in the design, permitting, review and implementation of state highway projects, especially those involving existing roadways where physical constraints often limit the stormwater management options available. These constraints, like those common to redevelopment sites, may make it difficult to comply precisely with the requirements of the Stormwater Management Standards and the Massachusetts Stormwater Handbook.[3] In response to these constraints, MassDEP and MHD developed specific design, permitting, review and implementation practices that meet the unique challenges of providing environmental protection for existing state roads. The information in the MassHighway Handbook may also aid in the planning and design of projects to build new highways and to add lanes to existing highways, since they may face similar difficulties in meeting the requirements of the Stormwater Management Standards.

Although it is very useful, the MassHighway Handbook does not allow MassHighway projects to proceed without individual review and approval by the issuing authority when subject to the Wetlands Protection Act Regulations, 310 CMR 10.00, or the 401 Water Quality Certification Regulations, 314 CMR 9.00. For example, MassHighway must provide a Conservation Commission with a project-specific Operation and Maintenance Plan in accordance with Standard 9 that documents how the project's post-construction BMPs will be operated and maintained.[4]

[3] The 2004 MassHighway Handbook outlines standardized methods for dealing with these constraints as they apply to highway redevelopment projects. MassDEP and MassHighway intend to work together to provide guidance for add a lane projects when the 2004 Handbook is revised to reflect the 2008 changes to the Stormwater Management Standards.

[4] The general permit for municipal separate storm sewer systems (the MS4 Permit) requires MassHighway to develop and implement procedures for the proper operation and maintenance of stormwater BMPs. To

Some municipalities have asked if the MassHighway Handbook governs municipal road projects. The answer is no.[5] The MassHighway Handbook was developed in response to the unique problems and challenges arising out of the management of the state highway system. Like other project proponents, cities and towns planning road or other projects in areas subject to jurisdiction under the Wetlands Protection Act must design and implement LID, non-structural and structural best management practices in accordance with the Stormwater Management Standards and the Massachusetts Stormwater Handbook.

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avoid duplication of effort, MassHighway may be able rely on the same procedures to fulfill the operation and maintenance requirements of Standard 9 and the MS 4 Permit.

[5] Although the MassHighway Handbook does not govern municipal road projects, cities and towns may find some of the information presented in the Handbook useful.

Appendix Operating and Source Control BMPs

This appendix identifies specific pollution prevention measures for use at certain industrial and commercial facilities. Implementation of these measures can help the operators of these facilities prevent the pollutants generated by their operations from entering surface waters or groundwater.[1]

Pollution prevention measures are identified for the following facilities:

- Auto Salvage Yards (Auto recycling facilities)
- Auto Fueling Facilities (Gas stations)
- Building, Repair, and Maintenance of Boats and Ships
- Commercial Animal Handling Areas
- Commercial Composting
- Commercial Printing Operations
- Loading and Unloading Areas for Liquid or Solid Material
- Painting/Finishing/ Coating of Vehicles/Boats/ Buildings/ Equipment
- Railroad Yards

[1] For additional information on pollution prevention at commercial and industrial sites. See Volume IV of the Stormwater Manual for Western Washington at http://www.ecy.wa.gov/pubs/0510032.pdf.
See also the EPA web site at http://cfpub.eap.gov/npdes/stormwater/swppp-msgp.cfm

BMPs for Auto Salvage Yards

The auto salvage business offers great opportunities for recycle / reuse. The dismantling of vehicles for reusable parts and fluids and the sale of remaining materials as scrap has gone a long way toward lessening the burden on our landfills. Unfortunately, the methods used in dismantling and storage can, and often have, resulted in serious negative impacts on the environment.

Fluids Handling

Properly remove and handle automobile fluids. Fluids associated with auto salvage include:

□ Drained motor oil
□ Antifreeze
□ Hydraulic oil/fluid
□ Transmission fluid
□ Brake fluid
□ Window cleaner
□ Oil recovered from steam cleaning
□ Water recovered from steam cleaning
□ Storm water run off from storage area

Drained Motor Oil: An accepted practice is to allow oil to remain in the engine. It and the associated filters are sold with the engine. However, this is not true of all salvage yards. Used motor oil can be stored and sold to a processor or re-refiner or used as a fuel or energy source. Store used oil inside under cover or in covered containers on an impervious pad with adequate containment.

Antifreeze: Most salvaged vehicles have antifreeze in their systems. Due to heavy metal accumulation in the antifreeze and chemical makeup of antifreeze (ethylene-glycol), it is not recommended to use the sewer for disposal. Reclaim and reuse antifreeze. Store used antifreeze inside under cover or in covered containers on an impervious pad with adequate containment.
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Other Vehicle Fluids: Brake fluid, transmission fluid, and hydraulic oils are not considered financially feasible for recovery. Store these fluids under cover or in covered containers on an impervious pad with adequate containment. Dispose of these fluids as a hazardous waste.

Wastewater and Stormwater Runoff: Steam-cleaning of engines and parts results in oil-contaminated wastewater. Segregate this water from domestic-type wastewater. Steam clean engines and parts inside and under cover to prevent exposure to rain, snow, snowmelt and runoff.

This wastewater should be given time to allow for solids settlement. If possible, separate the used oil for recycling and collection by a permitted used-oil transporter.
Dispose of the remaining sludge as a hazardous waste.

Other Recyclable Materials: Other salvage yard materials that can be recycled include:
□ Lead Acid Batteries (State law prohibits disposal in a landfill)

- Radiators, Engines, Air Conditioning Coils, Catalytic Converters
- Scrap Metals and Plastic
- Rubber-Related Materials

All of these materials are recyclable and whenever possible, they should be recycled instead of being disposed of in landfills.

BMPs for Auto Fueling Facilities (Gas stations)

Description of Pollutant Sources: A fueling station is a facility dedicated to the transfer of fuels from a stationary pumping station to mobile vehicles or equipment. It includes above- or under-ground fuel storage facilities. In addition to general service gas stations, fueling may also occur at 24-hour convenience stores, construction sites, warehouses, car washes, manufacturing establishments, port facilities, and businesses with fleet vehicles. Typically, stormwater contamination at fueling stations is caused by leaks/spills of fuels, lube oils, radiator coolants, and vehicle washwater.

Pollutant Control Approach: Construct new or substantially remodeled fueling stations on an impervious concrete pad under a roof to keep out rainfall and stormwater run-on. Use a treatment BMP such as an oil grit separator, sand filter or equivalent for contaminated stormwater and wastewaters in the fueling containment area.

Applicable Operational BMPs:

- Prepare an emergency spill response and cleanup plan and have designated trained person(s) available either on-site or on call at all times to promptly and properly implement that plan and immediately cleanup all spills. Keep suitable cleanup materials, such as dry adsorbent materials, on-site to allow prompt cleanup of a spill.
- Train employees on the proper use of fuel dispensers. Post “No Topping Off” signs (topping off gas tanks causes spillage and vents gas fumes to the air). Make sure that the automatic shutoff on the fuel nozzle is functioning properly.
- The person conducting the fuel transfer must be present at the fueling pump during fuel transfer, particularly at unattended or self-serve stations.
- Keep drained oil filters in a suitable container or drum. Drums should be closed on an impervious pad with adequate containment.
- For more information about when you need to report a spill to MassDEP and how quickly you need to report it (in many instances a spill must be reported within 2 hours), go to this MassDEP web page: http://mass.gov/dep/cleanup/dealin01.htm

Applicable Structural Source Control BMPs:

• Design the fueling island to control spills (e.g., use dead-end sumps or spill-control separators) and to treat collected stormwater and/or wastewater to required levels. Slope the concrete containment pad around the fueling island toward drains; either trench drains, catch basins and/or a dead-end sump. Drains to treatment should have a shutoff valve, which must be closed in the event of a spill.
• Alternatively, design the fueling island as a spill-containment pad with a sill or berm raised to a minimum of four inches to prevent the runoff of spilled liquids and to prevent run-on of stormwater from the surrounding area.
• The fueling pad should be paved with Portland cement concrete, or equivalent.
• The fueling island should have a roof or canopy to prevent the direct entry of precipitation onto the spill containment pad. The roof or canopy should, at a minimum,

cover the spill containment pad (within the grade break or fuel dispensing area) and preferably extend several additional feet to reduce the introduction of windblown rain. Convey all roof drains to storm drains outside the fueling containment area.

• Convey the stormwater collected on the fuel island containment pad to a sanitary sewer system, if approved by the sanitary authority; or to an approved treatment system such as an oil/grit separator, sand filter or equivalent. Alternatively, a lined vegetated filter strip can also convey the stormwater from the fuel island to a bioretention area with an under-drain. Discharges from treatment systems to storm drains or surface waters or to the ground must not display ongoing or recurring visible sheen and must meet the requirements of the permit under which they are discharged.

• Alternatively, stormwater collected on the fuel island containment pad may be collected and held for proper off-site disposal.

• Transfer the fuel from the delivery tank trucks to the fuel storage tank in impervious contained areas and ensure that appropriate overflow protection is used. Alternatively, cover nearby storm drains during the filling process and use drip pans under all hose connections.

Additional BMPs for Vehicles 10 feet high or greater:

A roof or canopy may not be practicable at fueling stations that regularly fuel vehicles that are 10 feet high or taller. At those types of fueling facilities, consider using the following additional BMPs:

• If a roof or canopy is impractical, equip the concrete fueling pad with emergency spill controls, including a shutoff valve for the drainage from the fueling area. The valve must be closed in the event of a spill. An electronically actuated valve is preferred to minimize the time lapse between spill and containment. Spills must be cleaned up and contaminated materials disposed off-site in accordance with MassDEP policies and regulations: http://mass.gov/dep/cleanup/dealin01.htm

• The valve may be opened to convey contaminated stormwater to a sanitary sewer, if approved by the sewer authority, or to oil removal treatment such as an API oil/grit separator, sand filter or equivalent treatment, and then to a basic treatment BMP. Discharges from treatment systems to storm drains or surface water or to the ground must not display ongoing or recurring visible sheen and must not contain a significant amount of oil and grease.

An explosive or flammable mixture is defined under state and federal regulations, based on a flash point determination of the mixture. See Appendix B IV for sources of information for flammability and other chemical risks: http://www.osha.gov/dsg/hazcom/ghd053107.html If contaminated stormwater is determined not to be explosive or flammable, then it could be conveyed to a sanitary sewer system.

BMPs for the Building, Repair, and Maintenance of Boats and Ships

Description of Pollutant Sources: Sources of pollutants at boat and shipbuilding, repair, and maintenance at boatyards, shipyards, ports, and marinas include pressure washing, surface preparation, paint removal, sanding, painting, engine maintenance and repairs, and material handling and storage, if conducted outdoors. If feasible, these activities should be done inside under cover. If done outside, use an impervious surface with adequate containment. Potential pollutants include spent abrasive grits, solvents, oils, ethylene glycol, wash water, paint over-spray, cleaners/ detergents, anti-corrosive compounds, paint chips, scrap metal, welding rods, resins, glass fibers, dust, and miscellaneous trash. Pollutant constituents include TSS, oil and grease, organics, copper, lead, tin, and zinc.

Pollutant Control Approach: Apply good housekeeping, preventive maintenance and cover and containment BMPs in and around work areas. See http://mass.gov/dep/recycle/boatyard.htm

Applicable Operational BMPs: Applicable operational BMPs are:

• Regularly clean all accessible work, service and storage areas to remove debris, spent sandblasting material, and any other potential stormwater pollutants.
• Sweep rather than hose debris on the dock. If hosing is unavoidable, collect and convey the hose water to a wastewater treatment system or facility.
• Collect spent abrasives regularly and store under cover to await proper disposal.
• Dispose of greasy rags, oil filters, air filters, batteries, spent coolant, and degreasers properly.
• Drain oil filters before disposal or recycling.
• Immediately repair or replace leaking connections, valves, pipes, hoses and equipment that causes the contamination of stormwater.
• Use drip pans, drop cloths, tarpaulins or other protective devices in all paint mixing and solvent operations unless carried out in impervious contained and covered areas.
• Convey sanitary sewage to pump-out stations, portable on-site pump-outs, or commercial mobile pump-out facilities or other appropriate onshore facilities.
• Maintain automatic bilge pumps in a manner that will prevent waste material from being pumped automatically into surface water.
• Prohibit uncontained spray painting, blasting or sanding activities over open water or in any area where these activities may be exposed to rain, snow, snow melt or runoff.
• Do not dump or pour waste materials down floor drains, sinks, or outdoor storm drain inlets that discharge to surface water or groundwater. Plug floor drains that are connected to storm drains or to surface water. If necessary, install a sump that is pumped regularly.
• Prohibit outside spray painting, blasting or sanding activities during windy conditions that render containment ineffective.
• Do not paint and/or use spray guns on topsides or above decks.
• Immediately clean up any spillage on dock, boat or ship deck areas and dispose of the wastes properly.

Applicable Structural Source Control BMPs:

• Use fixed platforms with appropriate plastic or tarpaulin barriers as work surfaces and for containment when performing work on a vessel in the water to prevent blast material or paint overspray from contacting stormwater or the receiving water. Use of such platforms will be kept to a minimum and at no time be used for extensive repair or construction (anything in excess of 25 percent of the surface area of the vessel above the waterline).
• Use plastic or tarpaulin barriers beneath the hull and between the hull and dry dock walls to contain and collect waste and spent materials. Clean and sweep regularly to remove debris.
• Enclose, cover, or contain blasting and sanding activities to the maximum extent practicable to prevent abrasives, dust, and paint chips from reaching storm sewers or receiving waters. Use plywood and/or plastic sheeting to cover open areas between decks when sandblasting (scuppers, railings, freeing ports, ladders, and doorways).
• Direct deck drainage to a collection system sump for settling and/or additional treatment.
• Store cracked batteries in a covered secondary container.
• Apply source control BMPs provided in this chapter for other activities conducted at the marina, boat yard, shipyard, or port facility (BMPs for Fueling at Dedicated Stations, BMPs for Washing and Steam Cleaning Vehicle/Equipment/Building Structures, and BMPs for Spills of Oil and Hazardous Substances).

Recommended Additional Operational BMPs:

• Consider recycling paint, paint thinner, solvents, used oils, oil filters, pressure wash wastewater and any other recyclable materials.
• Perform activities like paint mixing, solvent mixing, fuel mixing on shore inside or under cover or on an impervious area with adequate containment.

BMPs for Commercial Animal Handling Areas

Description of Pollutant Sources: Animals at racetracks, kennels, fenced pens, veterinarians, and businesses that provide boarding services for horses, dogs, cats, and other animals, can generate pollutants from the following activities: manure deposits, animal washing, grazing and any other animal handling activity that could contaminate stormwater. Pollutants can include coliform bacteria, nutrients, and total suspended solids.

Pollutant Control Approach: To prevent, to the maximum extent practicable, the discharge of contaminated stormwater from animal handling and keeping areas.

Applicable Operational BMPs:

• Regularly sweep and clean animal keeping areas to collect and properly dispose of droppings, uneaten food, and other potential stormwater contaminants
• Do not hose down to storm drains or to receiving water those areas that contain potential stormwater contaminants
• Do not allow any wash waters to be discharged to storm drains. Wash water is wastewater that must not be discharged to the stormwater management system.
• If animals are kept in unpaved and uncovered areas, the ground should either have vegetative cover or some other type of ground cover such as mulch
• If animals are not leashed or in cages, surround the area where animals are kept with a fence or other means that prevents animals from moving away from the controlled area where BMPs are used.

BMPs for Commercial Composting

Description of Pollutant Sources: Commercial compost facilities, operating outside without cover, require large areas to decompose wastes and other feedstocks. Design these facilities so as to separate stormwater from leachate (i.e., industrial wastewater) to the greatest extent practicable. When stormwater is allowed to contact any active composting areas, including waste receiving and processing areas, it becomes leachate.

Pollutants in leachate include nutrients, biochemical oxygen demand (BOD), organics, coliform bacteria, acidic pH, color, and suspended solids. Stormwater at a compost facility consists of runoff from areas at the facility that are not associated with active processing and curing, such as product storage areas, vehicle maintenance areas, and access roads.

Applicable Operational BMPs:

• Ensure that the compost feedstocks do not contain dangerous or hazardous wastes, or solid wastes that are not beneficial to the composting process. Train employees to screen these materials in incoming wastes.
• Store finished compost properly, such as in a covered area, to prevent contamination of stormwater.

Applicable Structural Source Control BMPs:

• Provide curbing for all compost pads to prevent stormwater run-on and leachate run-off.
• Slope all compost pads sufficiently to direct leachate to collection devices.
• Provide one or more sumps or catch basins capable of collecting leachate and conveying it to the leachate holding structure for all compost pads.

Applicable Treatment BMPs:

• Convey all leachate from composting operations to a sanitary sewer, holding tank, or on-site treatment systems designed to treat the leachate and TSS.
• Line the ponds used to collect, store, or treat leachate and other contaminated waters associated with the composting process to prevent groundwater contamination.

Recommended Additional BMPs:
• Regularly clean up debris from yard areas.
• Locate stored residues in areas designed to collect leachate.
• Limit storage times of residues to prevent degradation and generation of leachate.
• Consider using leachate as make-up water in early stages of the composting process. Because leachate can contain pathogenic bacteria, take care to avoid contaminating finished product or nearly finished product with leachate.
• In areas of the state with dry climates, consider using evaporation as a means of reducing the quantity of leachate.

BMPs for Commercial Printing Operations

Description of Pollutant Sources: Materials used in the printing process include inorganic and organic acids, resins, solvents, polyester film, developers, alcohol, vinyl lacquer, dyes, acetates, and polymers. Waste products may include waste inks and ink sludge, resins, photographic chemicals, solvents, acid and alkaline solutions, chlorides, chromium, zinc, lead, spent formaldehyde, silver, plasticizers, and used lubricating oils. As the printing operations are conducted indoors, the only likely points of potential contact with stormwater are the outside temporary storage of waste materials and offloading of chemicals at external unloading bays. Pollutants can include TSS, pH, heavy metals, oil and grease, and COD.

Pollutant Control Approach: Ensure appropriate disposal of process wastes. Cover and contain stored raw and waste materials.

Applicable Operational BMPs:

- Discharge process wastewaters to a sanitary sewer, if approved by the local sewer authority, or to an approved process wastewater treatment system.
- Do not discharge process wastes or wastewaters into storm drains, groundwater or surface water.
- Determine whether any of these wastes qualify for regulation as dangerous wastes and dispose of them accordingly.

Applicable Structural Source Control BMP: Store raw materials or waste materials that could contaminate stormwater in covered and contained areas.

Recommended Additional BMPs:

- Train all employees in pollution prevention, spill response, and environmentally acceptable materials-handling procedures.
- Store materials in proper, appropriately labeled containers. Identify and label all chemical substances.
- Regularly inspect all stormwater management devices and maintain them as necessary.
- Try to use press washes without listed solvents, and with the lowest VOC content possible. Don't evaporate ink cleanup trays to the outside atmosphere.
- Place cleanup sludges into a container with a tight lid and dispose of as hazardous waste. Do not dispose of cleanup sludges in the garbage or in containers of soiled towels.

BMPs for Loading and Unloading Areas for Liquid or Solid Material

Description of Pollutant Sources: Loading/unloading of liquid and solid materials at industrial and commercial facilities are typically conducted at shipping and receiving, outside storage, and fueling areas. Materials transferred can include products, raw materials, intermediate products, waste materials, fuels, scrap metals, etc. Leaks and spills of fuels, oils, powders, organics, heavy metals, salts, acids, and alkalis during transfer are potential causes of stormwater contamination. Spills from hydraulic line breaks are a common problem at loading docks.

Pollutant Control Approach: Cover and contain the loading/ unloading area where necessary to prevent run-on of stormwater and runoff of contaminated stormwater.

Applicable Operational BMPs:

At All Loading/ Unloading Areas:

• A significant amount of debris can accumulate outside uncovered loading/unloading areas. Sweep these surfaces frequently to remove material that could otherwise be washed off by stormwater. Sweep outside areas that are covered for a period of time by containers, logs, or other material after the areas are cleared.
• Place drip pans, or other appropriate temporary containment device, at locations where leaks or spills may occur, such as hose connections, hose reels and filler nozzles. Always use drip pans when making and breaking connections. Check loading and unloading equipment such as valves, pumps, flanges, and connections regularly for leaks and repair as needed.

At Tanker Truck and Rail Transfer Areas to Above/Below-ground Storage Tanks:

• To minimize the risk of accidental spillage, prepare an "Operations Plan" that describes procedures for loading/unloading. Train employees, especially forklift operators, in its execution and post it or otherwise have it readily available to employees.
• Prepare and implement an Emergency Spill Cleanup Plan for the facility that includes the following BMPs:
- Ensure the cleanup of liquid/solid spills in the loading/ unloading area immediately, if a significant spill occurs, and, upon completion of the loading/unloading activity, or at the end of the working day.
- Retain and maintain an appropriate oil spill cleanup kit on-site for rapid cleanup of material spills
    - Ensure that an employee trained in spill containment and cleanup is present during loading/unloading.
    - Notify MassDEP as required: http://mass.gov/dep/cleanup/dealin01.htm

At Rail Transfer Areas to Above/below-ground Storage Tanks: Install a drip pan system within the rails to collect spills/leaks from tank cars and hose connections, hose reels, and filler nozzles.

Applicable Structural Source Control BMPs:

At All Loading/ Unloading Areas:

• To the extent practicable, conduct unloading or loading of solids and liquids in a manufacturing building, under a roof, or lean-to, or other appropriate cover.
• Berm, dike, and/or slope the loading/unloading area to prevent run-on of stormwater and to prevent the runoff or loss of any spilled material from the area.
• Large loading areas frequently are not curbed along the shoreline. As a result, stormwater passes directly off the paved surface into surface water. Place curbs along the edge, or slope the edge such that the stormwater can flow to an internal storm drain system that leads to a treatment BMP.
• Pave and slope loading/unloading areas to prevent the pooling of water. The use of catch basins and drain lines within the interior of the paved area must be minimized as they will frequently be covered by material, or they should be placed in designated "alleyways" that are not covered by material, containers or equipment.

Recommended Structural Source Control BMP: For the transfer of pollutant liquids in areas that cannot contain a catastrophic spill, install an automatic shutoff system in case of unanticipated off-loading interruption (e.g. coupling break, hose rupture, overfill, etc.).

At Loading and Unloading Docks:

• Install/maintain overhangs, or door skirts that enclose the trailer end, to prevent contact with rainwater.
• Design the loading/unloading area with berms and grading to prevent the run-on of stormwater.
• Retain on-site the necessary materials for rapid cleanup of spills.

At Tanker Truck Transfer Areas to Above/Below-Ground Storage Tanks:

• Pave the area on which the transfer takes place. If any transferred liquid, such as gasoline, is reactive with asphalt, pave the area with Portland cement concrete.
• Slope, berm, or dike the transfer area to a dead-end sump, spill containment sump, an oil/grit separator, or other spill control device.

BMPs for Painting/Finishing/ Coating of Vehicles/Boats/ Buildings/ Equipment

Description of Pollutant Sources: Surface preparation and the application of paints, finishes and/or coatings to vehicles, boats, buildings, and/or equipment outdoors can be sources of pollutants. Potential pollutants include organic compounds, oils and greases, heavy metals, and suspended solids.

Pollutant Control Approach: Cover and contain painting and sanding operations and apply good housekeeping and preventive maintenance practices to prevent the contamination of stormwater with painting oversprays and grit from sanding.
http://www.dtsc.ca.gov/PollutionPrevention/ABP/upload/IntroAuto_Body_and_Paint.pdf

Applicable Operational BMPs:

• Train employees in the careful application of paints, finishes, and coatings to reduce misuse and over spray. Use ground- or drop-cloths underneath outdoor painting, scraping, sandblasting work, and properly clean and temporarily store collected debris daily.
• Do not conduct spraying, blasting, or sanding activities over open water or where wind may blow paint into water.
• Wipe up spills with rags and other absorbent materials immediately. Do not hose down the area to a storm drain or receiving water or conveyance ditch to receiving water.
• On marine dock areas, sweep rather than hose down debris. Collect any hose water generated and convey to appropriate treatment and disposal.
• Use a storm drain cover, filter fabric, or similarly effective runoff control device if dust, grit, washwater, or other pollutants may escape the work area and enter a catch basin. The containment device(s) must be in place at the beginning of the workday. Collect contaminated runoff and solids and properly dispose of such wastes before removing the containment device(s) at the end of the workday.
• Use a ground cloth, pail, drum, drip pan, tarpaulin, or other protective device for activities such as paint mixing and tool cleaning outside or where spills can contaminate stormwater.
• Properly dispose of all wastes and prevent all uncontrolled releases to the air, ground or water.
• Clean brushes and tools covered with non-water-based paints, finishes, or other materials in a manner that allows collection of used solvents (e.g., paint thinner or turpentine) for recycling or proper disposal.
• Store toxic materials under cover during precipitation events and when not in use to prevent contact with stormwater.

Applicable Structural Source Control BMPs: Enclose and/or contain all work while using a spray gun or conducting sand blasting. Do not conduct outside spraying, grit blasting, or sanding activities during windy conditions that render containment ineffective.

Recommended Additional Operational BMPs:

- Clean paintbrushes and tools covered with water-based paints in sinks connected to sanitary sewers or in portable containers that can be dumped into a sanitary sewer drain.
- Recycle paint, paint thinner, solvents, pressure washwater, and any other recyclable materials.
- Use efficient spray equipment such as electrostatic, air-atomized, high-volume/low-pressure, or gravity feed spray equipment.
- Purchase recycled paints, paint thinner, solvents, and other products if feasible.

BMPs for Railroad Yards.

Note: MassDEP requires an oil grit separator, sand filter or equivalent to manage stormwater runoff from this land use.

Description of Pollutant Sources: Pollutant sources can include drips/leaks of vehicle fluids onto the railroad bed, human waste disposal, litter, locomotive/railcar/equipment cleaning areas, fueling areas, outside material storage areas, the erosion and loss of soil particles from the railroad bed, maintenance and repair activities at railroad terminals, switching yards, and maintenance yards, and herbicides used for vegetation management. Waste materials can include waste oil, solvents, degreasers, antifreeze solutions, radiator flush, acids, brake fluids, soiled rags, oil filters, sulfuric acid and battery sludges, and machine chips with residual machining oil and toxic fluids/solids lost during transit. Potential pollutants include oil and grease, TSS, BOD, organics, pesticides, and metals.

Pollutant Control Approach: Apply good housekeeping and preventive maintenance practices to control leaks and spills of liquids in railroad yard areas.

Applicable Operational and Structural Source Control BMPs:

• Do not allow discharge to outside areas from toilets while a train is in transit. Pump out facilities should be used to service these units.
• Use drip pans at hose/pipe connections during liquid transfer and other leak-prone areas.
• During maintenance, do not discard debris or waste liquids along the tracks or in railroad yards.

Applicable Treatment BMPs: In areas subjected to leaks/spills of oils or other chemicals, convey the contaminated stormwater to appropriate treatment such as a sanitary sewer, if approved by the appropriate sewer authority, or to an oil/grit separator for floating oils, or other treatment, as approved by the local jurisdiction.

Retail and Wholesale.

- **Restaurants/Fast Food (SIC: 5800*)***

Description**:** Businesses that provide food service to the general public, including drive-through facilities.

Potential Pollutant Generating Sources**:** Potential pollutant sources include high-use customer parking lots and garbage dumpsters. The cleaning of roofs and other outside areas of restaurant and cooking vent filters in the parking lot can cause cooking grease to be discharged to the storm drains. MassDEP prohibits discharging wash water or grease to storm drains or surface water.

- **Retail/General Merchandise (SIC: 5300, 5600, 5700, 5900, and 5990*)***

Description**:** This group includes general merchandising stores such as department stores, shopping malls, variety stores, 24-hour convenience stores, and general retail stores that focus on a few product types such as clothing and shoes. It also includes furniture and appliance stores.

Potential Pollutant Generating Sources**:** Of particular concern are the high-use parking lots of shopping malls and 24-hour convenience stores. Furniture and appliance stores may provide repair services in which dangerous wastes may be produced.

- **Retail/Wholesale Vehicle and Equipment Dealers (SIC: 5010, 5080, and 5500, 7510 excluding fueling stations)**

Description: This group includes all retail and wholesale businesses that sell, rent, or lease cars, trucks, boats, trailers, mobile homes, motorcycles and recreational vehicles. It includes both new and used vehicle dealers. It also includes sellers of heavy equipment for construction, farming, and industry. With the exception of motorcycle dealers, these businesses have large parking lots. Most retail dealers that sell new vehicles and large equipment also provide repair and maintenance services.

Potential Pollutant Generating Sources: Oil and other materials that have dripped from parked vehicles can contaminate stormwater at high-use parking areas. Vehicles are washed regularly, generating vehicle grime and detergent pollutants. The storm- or washwater runoff will contain oils and various organics, metals, and phosphorus. Repair and maintenance services generate a variety of waste liquids and solids including used oils and engine fluids, solvents, waste paint, soiled rags, and dirty used engine parts. Many of these materials are hazardous wastes.

- **Retail/Wholesale Nurseries and Building Materials (SIC: 5030, 5198, 5210, 5230, and 5260*)***

Description**:** These businesses are placed in a separate group because they are likely to store much of their merchandise outside of the main building. They include nurseries, and businesses that sell building and construction materials and equipment, paint, and hardware.

Potential Pollutant Generating Sources**:** Some businesses may have small fueling capabilities for forklifts and may also maintain and repair their vehicles and equipment. Some businesses may have unpaved areas, with the potential to contaminate stormwater by leaching of nutrients, pesticides, and herbicides. Storm runoff from exposed storage areas can contain suspended solids, and oil and grease from vehicles and forklifts and high-use customer parking lots, and other pollutants. Runoff from nurseries may contain nutrients, pesticides and/or herbicides.

- **Retail/Wholesale Chemicals and Petroleum (SIC: 5160, 5170*)***

Description**:** These businesses sell plastic materials, chemicals and related products. This group also includes the bulk storage and selling of petroleum products such as diesel oil and automotive fuels.

Potential Pollutant Generating Sources**:** The general areas of concern are the spillage of chemicals or petroleum during loading and unloading, and the washing and maintenance of tanker trucks and other vehicles. Also, the fire code requires that vegetation be controlled within a tank farm to avoid a fire hazard. Herbicides are typically used. The concentration of oil in untreated stormwater is known to exceed the water quality effluent guideline for oil and grease. Runoff is also likely to contain significant concentrations of benzene, phenol, chloroform, lead, and zinc.

- **Retail/Wholesale Foods and Beverages (SIC 5140, 5180, 542, 54)**

Description: Included are businesses that provide retail food stores, including general groceries, fish and seafood, meats and meat products, dairy products, poultry, soft drinks, and alcoholic beverages.

Potential Pollutant Generating Sources**:** Vehicles may be fueled, washed and maintained at the business. Spillage of food and beverages may occur. Waste food and broken contaminated glass may be temporarily stored in containers located outside. High-use customer parking lots may be sources of oil and other contaminants.

- **Other Retail/Wholesale Businesses (SIC: 5010 (not 5012), 5040, 5060,5070, 5090)**

Description: Businesses in this group include sellers of vehicle parts, tires, furniture and home furnishings, photographic and office equipment, electrical goods, sporting goods and toys, paper products, drugs, and apparel.

Potential Pollutant Generating Sources**:** Pollutant sources include high-use parking lots, and delivery vehicles that may be fueled, washed, and maintained on premises.

BMPs for Road Salt Storage and Snow Disposal
Description:
The application and storage of deicing materials, most commonly salts such as sodium chloride, can lead to water quality problems for surrounding areas. Salts, gravel, sand, and other materials are applied to highways and roads to reduce the amount of ice during winter storm events. Salts lower the melting point of ice, allowing roadways to stay free of ice buildup during cold winters. Sand and gravel increase traction on the road, making travel safer.

MassDEP has developed a guidance document for communities regarding snow disposal, available on the web at: http://www.mass.gov/dep/water/laws/snowdisp.htm. This guidance document recommends the following to establish a snow disposal site. The key to selecting effective snow disposal sites is to locate them adjacent to or on pervious surfaces in upland areas away from water resources and wells. At these locations, the snow meltwater can filter in to the soil, leaving behind sand and debris which can be removed in the springtime. Snow dumping prohibitions include:

- Avoid dumping snow into any waterbody, including rivers, the ocean, reservoirs, ponds, or wetlands. In addition to water quality impacts and flooding, snow disposed of in open water can cause navigational hazards when it freezes into ice blocks.
- Do not dump snow within a Zone II or Interim Wellhead Protection Area (IWPA) of a public water supply well or within 75 feet of a private well, where road salt may contaminate water supplies.
- Avoid dumping snow on MassDEP-designated high- and medium-yield aquifers where it may contaminate groundwater (see the next page for information on ordering maps from MassGIS showing the locations of aquifers, Zone II's, and IWPAs in your community).
- Avoid dumping snow in sanitary landfills and gravel pits. Snow meltwater will create more contaminated leachate in landfills, posing a greater risk to groundwater, and in gravel pits there is little opportunity for pollutants to be filtered out of the meltwater because groundwater is close to the land surface.
- Do not place snow on top of storm drain catch-basins or in stormwater drainage swales or ditches. Snow combined with sand and debris may block a storm drainage system, causing localized flooding. A high volume of sand, sediment, and litter released from melting snow also may be quickly transported through the system into surface water.

In addition to carefully selecting disposal sites before the winter begins, it is important to prepare and maintain these sites to maximize their effectiveness. The following maintenance measures should be undertaken for all snow disposal sites:

- Securely place a silt fence or equivalent barrier on the downgradient side of the snow disposal site.
- To filter pollutants out of the meltwater, maintain a 50-foot vegetative buffer strip during the growth season between the disposal site and adjacent waterbodies.

- Clear debris from the site prior to using the site for snow disposal.
- Clear debris from the site and properly dispose of it at the end of the snow season.

Applicability:

This practice is applicable to areas that receive snowfall in winter months and require deicing materials. Municipalities in these areas must ensure proper storage and application for equipment and materials and identify appropriate areas for snow disposal.

Siting and Design Considerations:

Many of the problems associated with contamination of local waterways stem from the improper storage of deicing materials. Salts are very soluble when they come into contact with storm water. They can migrate into groundwater used for public water supplies and also contaminate surface waters.

More information about road deicing materials can be found at the American Association of State Highway and Transportation Officials web page at:
http://www.transportation.org/

Limitations:

Road salt is the least expensive material for deicing operations; however, once the full social costs are taken into account, alternative products and better management and application of salts become increasingly attractive options.

Maintenance Considerations:

Covering stored road salts may be costly; however, the benefits are greater than the perceived costs. Storing road salts correctly prevents the salt from lumping together, which makes it easier to load and apply. In addition, covering salt storage piles reduces salt loss from storm water runoff and potential contamination to streams, aquifers, and estuarine areas. Salt storage piles should be located outside the 100-year floodplain for further protection against surface water contamination.

During road salt application, certain best management practices can produce significant environmental benefits. Regulate the amount of road salt applied to avoid over-salting motorways and increasing runoff concentrations. Many drinking water supply watersheds in Massachusetts use lower amounts of road salt to protect the resource.

The amount of salt applied should be varied to reflect site-specific characteristics, such as road width and design, traffic concentration, and proximity to surface waters. Calibration devices for spreaders in trucks aid maintenance workers in the proper application of road salts. Use alternative materials, such as sand or gravel, in especially sensitive areas.

MassHighway and the Executive Office of Energy & Environmental Affairs have developed a Generic Environmental Impact Report on Snow and Ice Control that contains many suggestions to reduce road salt impacts on water resources. The Massachusetts DEP has issued the Massachusetts Guidelines on Deicing Chemical (Road Salt) Storage (1997), available on the web at:
http://www.mass.gov/dep/water/laws/policies.htm#snowsalt

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BMPs for Service Industries

- **Animal Care Services (SIC: 0740, 0750)**

Description: This group includes racetracks, kennels, fenced pens, veterinarians and businesses that provide boarding services for animals including horses, dogs, and cats.

Potential Pollutant Generating Sources: The primary sources of pollution include animal manure, wash waters, waste products from animal treatment, runoff from pastures where larger livestock are allowed to roam, and vehicle maintenance and repair shops. Pastures may border streams and direct access to the stream may occur. Both surface water and groundwater may be contaminated. Potential stormwater contaminants include fecal coliform, oil and grease, suspended solids, BOD, and nutrients.

- **Commercial Car and Truck Washes (SIC: 7542)**

Description**:** Facilities include automatic systems found at individual businesses or at gas stations and 24-hour convenience stores, as well as self-service car washes. There are three main types: tunnels, rollovers and hand-held wands. The tunnel wash, the largest, is housed in a long building through which the vehicle is pulled. At a rollover wash, the vehicle remains stationary while the equipment passes over. Wands are used at self-serve car washes. Some car washing businesses also sell gasoline.

Potential Pollutant Generating Sources: Wash wastewater may contain detergents and waxes. Wastewater should be discharged to sanitary sewers. In self-service operations a drain is located inside each car bay. Although these businesses discharge the wastewater to the sanitary sewer, some washwater can find its way to the storm drain, particularly with the rollover and wand systems. Rollover systems often do not have air-drying. Consequently, as it leaves the enclosure the car sheds water to the pavement. With the self-service system, washwater with detergents can spray outside the building and drain to storm sewer. Users of self-serve operations may also clean engines and change oil, dumping the used oil into the storm drain. Potential pollutants include oil and grease, detergents, soaps, BOD, and TSS.

- **Equipment Repair (SIC: 7353, 7600)**

Description**:** This group includes several businesses that specialize in repairing different equipment including communications equipment, radio, TV, household appliances, and refrigeration systems. Also included are businesses that rent or lease heavy construction equipment, as miscellaneous repair and maintenance may occur on-site.

Potential Pollutant Generating Sources: Potential pollutant sources include storage and handling of fuels, waste oils and solvents, and loading/unloading areas. Potential pollutants include oil and grease, low/high pH, and suspended solids.

- **Laundries and Other Cleaning Services (SIC: 7211 through 7217)**

<u>Description:</u> This category includes all types of cleaning services such as laundries, linen suppliers, diaper services, coin-operated laundries and dry cleaners, and carpet and upholstery services. Wet washing may involve the use of acids, bleaches and/or multiple organic solvents. Dry cleaners use an organic-based solvent, and sometimes small amounts of water and detergent. Solvents may be recovered and filtered for further use. Carpets and upholstery may be cleaned with dry materials, hot water extraction processes, or in-plant processes using solvents followed by a detergent wash.

<u>Potential Pollutant Generating Sources:</u> Wash liquids are discharged to sanitary sewers. Stormwater pollutant sources include: loading and unloading of liquid materials, particularly at large commercial operations, disposal of spent solvents and solvent cans, high-use customer parking lots, and outside storage and handling of solvents and waste materials. Potential stormwater contaminants include oil and grease, chlorinated and other solvents, soaps and detergents, low/high pH, and suspended solids.

- **Marinas and Boat Clubs (SIC: 7999)**

<u>Description:</u> Marinas and yacht clubs provide moorage for recreational boats. Marinas may also provide fueling and maintenance services. Other activities include cleaning and painting of boat surfaces, minor boat repair, and pumping of bilges and sanitary holding tanks. Not all marinas have a system to receive pumped bilge water.

<u>Potential Pollutant Generating Sources:</u> Both solid and liquid wastes are produced as well as stormwater runoff from high-use customer parking lots. Waste materials include sewage and bilge water. Maintenance by the tenants will produce used oils, oil filters, solvents, waste paints and varnishes, used batteries, and empty contaminated containers and soiled rags. Potential stormwater contaminants include oil and grease, suspended solids, heavy metals, and low/high pH.

- **Golf and Country Clubs (SIC: 7992, 7997)**

<u>Description:</u> Public and private golf courses and parks are included.

<u>Potential Pollutant Generating Sources:</u> Maintenance of grassed areas and landscaped vegetation has historically required the use of fertilizers and pesticides. Golf courses contain small lakes that are sometimes treated with algaecides and/or mosquito larvicides. The fertilizer and pesticide application process can lead to inadvertent contamination of nearby surface waters by overuse, misapplication, or the occurrence of storms shortly after application. Heavy watering of surface greens in golf courses may cause pesticides or fertilizers to migrate to surface and shallow groundwater resources. The use of pesticides and fertilizers generates waste containers. Equipment must be cleaned and maintained.

- **Miscellaneous Services (SIC: 4959, 7260, 7312, 7332, 7333, 7340, 7395, 7641, 7990, 8411)**

Description: This group includes photographic studios, commercial photography, funeral services, amusement parks, furniture and upholstery repair and pest control services, and other professional offices. Pollutants from these activities can include pesticides, waste solvents, heavy metals, pH, and suspended solids, soaps and detergents, and oil and grease.

Potential Pollutant Generating Sources**:** Leaks and spills of materials from the following businesses can be sources of stormwater pollutants:
1. Building maintenance produces wash and rinse solutions, oils, and solvents.
2. Pest control produces rinse water with residual pesticides from washing application equipment and empty containers.
3. Outdoor advertising produces photographic chemicals, inks, waste paints, and organic paint sludges containing metals.
4. Funeral services produce formalin, formaldehyde, and ammonia.
5. Upholstery and furniture repair businesses produce oil, stripping compounds, wood preservatives and solvents.

- **Professional Services (SIC: 6000, 7000 and 8000, 806, 807)**

Description: The remaining service businesses include theaters, hotels/motels, finance, banking, hospitals, medical/dental laboratories, medical services, nursing homes, schools/universities, and legal, financial and engineering services. Stormwater from parking lots will contain undesirable concentrations of oil and grease, suspended particulates, and metals such as lead, cadmium and zinc. Dangerous wastes might be generated at hospitals, nursing homes and other medical services.

Potential Pollutant Generating Sources: The primary concern is runoff from high-use parking areas, maintenance shops, and storage and handling of dangerous wastes.

- **Vehicle Maintenance and Repair (SIC: 4000, 7530, 7600)**

Description**:** This category includes businesses that paint, repair and maintain automobiles, motorcycles, trucks, and buses and battery, radiator, muffler, lube, tune-up and tire shops, excluding those businesses listed elsewhere in this manual.

Potential Pollutant Generating Sources**:** Pollutant sources include storage and handling of vehicles, solvents, cleaning chemicals, waste materials, vehicle liquids, batteries, and washing and steam-cleaning of vehicles, parts, and equipment. Potential pollutants include waste oil, solvents, degreasers, antifreeze, radiator flush, acid solutions with chromium, zinc, copper, lead and cadmium, brake fluid, soiled rags, oil filters, sulfuric acid and battery sludge, and machine chips in residual machining oil.

- **Construction Businesses (SIC: 1500, 1600, and 1700)**

Description: This category includes builders of homes, commercial and industrial buildings, and heavy equipment as well as plumbing, painting and paper hanging, carpentry, electrical, roofing and sheet metal, wrecking and demolition, stonework, drywall, and masonry contractors. It does not include construction sites.

Potential Pollutant Generating Sources**:** Potential pollutant sources include leaks/spills of used oils, solvents, paints, batteries, acids, strong acid/alkaline wastes, paint/varnish removers, tars, soaps, coatings, asbestos, lubricants, anti-freeze compounds, litter, and fuels at the headquarters, operation, staging, and maintenance/repair locations of the businesses. Demolition contractors may store reclaimed material before resale.
Roofing contractors generate residual tars and sealing compounds, spent solvents, kerosene, and soap cleaners, as well as non-hazardous-waste roofing materials. Sheet metal contractors produce small quantities of acids and solvent cleaners such as kerosene, metal shavings, adhesive residues and enamel coatings, and asbestos residues that have been removed from buildings. Asphalt paving contractors are likely to store application equipment such as dump trucks, pavers, tack coat tankers and pavement rollers at their businesses. Stormwater passing through this equipment may be contaminated by the petroleum residuals. Potential pollutants include oil and grease, suspended solids, BOD, heavy metals, pH, COD, and organic compounds.

Documenting Compliance

A Stormwater Report must be submitted to document compliance with the Stormwater Management Standards. For projects that are subject to the Stormwater Management Standards and regulated by the Wetlands Protection Act Regulations, 310 CMR 10.00, and or the 401 Water Quality Certification Regulations, the Stormwater Report must accompany the permit application. For each Standard, this Chapter describes the calculations that must be performed and the other information that must be submitted to document compliance. References that may be useful in conducting each computation are listed at the end of the section dealing with each Standard.

Who Prepares The Stormwater Report: The Stormwater Report must be prepared under the direction of a Registered Professional Engineer (RPE) licensed to do business in the Commonwealth pursuant to MGL Chapter 112 Section 81R. The RPE must perform the required calculations. The Stormwater Report Certification and Checklist must be stamped and signed by the RPE.

Who Reviews the Stormwater Report: For projects subject to jurisdiction under the Wetlands Protection Act, Conservation Commissions have the opportunity to review the Stormwater Report when Wetland NOIs are submitted for new development and redevelopment in wetland resource areas and buffer zones. MassDEP has the opportunity to review Report for 401 Water Quality Certification Applications or when there is an appeal of a decision issued by a Conservation Commission.

As more fully set forth below, the Stormwater Report must include the computations required to document compliance with many of the Standards. The required computations described in this chapter include the following:

- Standard 1 - Computations to show that discharge does not cause scour or erosion.
- Standard 2 - Peak Rate Attenuation (see Hydrology Handbook).
- Standard 3 - Recharge
    - Soil Evaluation
    - Required Recharge Volume
    - Sizing
        - "*Static*" Method
        - "*Simple Dynamic*" Method
        - "*Dynamic Field*" Method
    - 72-hour Drawdown Analysis
    - Capture Area Adjustment
    - Mounding Analysis
- Standard 4 - Required Water Quality Volume.
- Standard 5 – 6: Computations used to demonstrate compliance with Standard 4.
- Standard 7: Computations demonstrating that peak rate attenuation, recharge, and water quality treatment is provided to maximum extent practicable
- Standard 8: Computations related to sizing of erosion and sediment controls

REQUIRED DOCUMENTATION INCLUDING COMPUTATIONS FOR EACH STORMWATER STANDARD

STANDARD 1. NO UNTREATED DISCHARGES OR EROSION TO WETLANDS

Applicants must demonstrate that there are no new untreated discharges. To demonstrate that all new discharges are adequately treated, applicants may rely on the computations required to demonstrate compliance with Standards 4 through 6. No additional computations are required.

To demonstrate that new discharges do not cause or contribute to erosion in wetlands or waters of the Commonwealth, the following computations are required.

To evaluate whether the discharge will cause erosion or scour, the first step is to determine the stormwater discharge velocity at each outlet. The second step is to perform computations and select materials or practices to reduce that velocity or armor the ground to withstand the shearing force caused by the discharged stormwater. Computations must be conducted for both point sources and sheet flow.

Stormwater Discharge Velocity: Determine maximum discharge or velocity at each outlet for all conveyances. The maximum discharge or velocity is dependent on the size of the conveyance. Include gravitational forces in the computations when proposing to discharge stormwater above the receiving practice. Tailwater conditions in the receiving wetland must also be factored into the analysis. For sheet flow, the maximum velocity to evaluate is the runoff from the 2-year 24-hour storm. Engineers shall select an accepted method to determine maximum velocity.

Ability of Ground Surface to Resist Erosion: Determine ability of ground or lining materials to resist erosion from the velocity computed in part (a). Banks opposite a stormwater discharge point may need to be evaluated to assess their ability to resist scour when banks are close to the outlets (e.g., a narrow stream channel). This may be done by performing computations to estimate the size/weight of stone or bioengineered materials needed to resist the force of water or comparing the discharge velocity against a “permissible velocity table” that provides information on the ability of different types of materials/vegetation to resist shear.

The references that follow include several different computational methods and permissible velocity tables that are acceptable.

Channel Slope	Lining [1]	Permissible Velocity (feet/second)
0 - 5%	Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Sericea lespedeza Annual lespedeza Small grains	2.5
5 - 10%	Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater Than 10%	Tall fescue Kentucky bluegrass	3

Table 2.3.1: Example of Permissible Velocity Table, Modified from Soil and Water Conservation Engineering, 1992, Schwab et al, John Wiley and Sons

REFERENCES FOR STANDARD 1

Fletcher, B.P. and Grace, J.L., Jr., 1974, Practical Guidance for Design of Lined Channel Expansions at Culvert Outlets, Technical Report H-74-9, U.S. Army Engineer Experiment Station, Vicksburg, MS., page A12 (specifies methods for sizing riprap blanket dimensions from discharges from circular, square, rectangular and other shaped outlets)

Fangmeier, D.A., Elliot, W.J., Workman, S.R., Huffman, R.L., and Schwab, G.O., 2006, Soil and Water Conservation Engineering, 5th Edition, Thomson – Delmar Learning, Clifton Park, NY (permissible velocity table – page 119)

Gribbon, John E., 1997, Hydraulics and Hydrology for Stormwater Management, Chapter 5.5, Storm Sewer Outfalls, Delmar Publishers, Albany, NY (computation methods)

Lindeburg, Michael R., 2005, Civil Engineering Reference Manual for the PE Exam, 10th Edition (general reference, computational methods)

[1] Before selecting a vegetated lining, consult the list of plants banned for sale, trade, purchase, or distribution in Massachusetts by the Department of Agricultural Resources, pursuant to M.G.L. Chapter 128 Section 2 and Sections 16 through 31A. See http://www.mass.gov/agr/farmproducts/proposed_prohibited_plant_list_v12-12-05.htm

Schwab, G. O., Fangmeier, D.A., Elliot, W.J., and Frevert, R.K., 1992, Soil and Water Conservation Engineering, 4th Edition, John Wiley and Sons (permissible velocity table)

U.S. Agricultural Research Service, 1987, Stability Design of Grass-Lined Open Channels, Agricultural Handbook No. 667. Online at: http://www.info.usda.gov/CED/ftp/CED/AH-667.pdf (computational methods)

U.S. Army Corps of Engineers, Engineering and Design - Hydraulic Design of Flood Control Channels, Engineering Manual (EM) 1110-2-1601. Online at: http://www.usace.army.mil/publications/eng-manuals/em1110-2-1601/toc.htm (computational methods)

U.S. Army Corps of Engineers, Drainage and Erosion-Control Structures for Airfields and Heliports, Technical Manual (TM) 5-820-3/AFM 88-5, Chapter 5. Online at: http://www.usace.army.mil/publications/armytm/tm5-820-3/chap5.pdf (computation methods)

U.S. Army Corps of Engineers, Hydraulic Design Criteria, Sheets 722-1 to 722-7. Online at: http://chl.erdc.usace.army.mil/Media/2/8/4/700.pdf (computational methods)

U.S. Federal Highway Administration, 2006, Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Center Circular No. 14 (HEC-14). Online at: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14.pdf (computational methods)

U.S. Federal Highway Administration, 2005, Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular Number 15 (HEC-15), Third Edition. Online at: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/05114/05114.pdf (computational methods)

U.S. Federal Highway Administration, 2001, Urban Drainage Design Manual, Hydraulic Engineering Circular Number 22 (HEC-22), Second Edition, Storm Drain Outfalls, Section 7.1.5. Online at: http://isddc.dot.gov/OLPFiles/FHWA/010593.pdf (general reference)

U.S. Natural Resources and Conservation Service (NRCS), National Handbook of Conservation Practices. Online at http://www.nrcs.usda.gov/Technical/Standards/nhcp.html (practices to reduce erosion)

U.S. Soil Conservation Service (SCS). 1966. Handbook of Channel Design for Soil and Water Conservation (SCS-TP-61). Online at: http://www.info.usda.gov/CED/ftp/CED/tp-61.pdf (permissible velocity table)

U.S. Soil Conservation Service (SCS). 1979. Engineering Field Manual for Conservation Practices, (Structures – Chapter 6, Grassed Waterways - Chapter 7). Washington, D.C., Chapter 7. Online at: http://www.info.usda.gov/CED/Default.cfm?xSbj=53&xAud=24 (computation methods, permissible velocity table, practices)

Young, G.K., et al, 1996. HYDRAIN – Integrated Drainage Design Computer System: Version 6.0 – Volume VI: HYCHL, FHWA-SA-96-064 (computational methods)

STANDARD 2. PEAK RATE ATTENUATION

Required Computations or Demonstrations:

See Hydrology Handbook for Conservation Commissioners:
http://www.mass.gov/dep/water/laws/hydrol.pdf

REFERENCES FOR STANDARD 2

Nyman, David, 2002, Hydrology Handbook for Conservation Commissions, Massachusetts Department of Environmental Protection. Online at:
http://www.mass.gov/dep/water/laws/hydrol.pdf

U.S. NRCS, 1986, Urban Hydrology for Small Watersheds Technical, Release 55. Online at:
http://www.info.usda.gov/CED/ftp/CED/tr55.pdf

U.S. NRCS, 2005, Win Technical Release 20. Online at:
http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR20.html

U.S. NRCS, Win Technical Release 55. Online at:
http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html

U.S. ACOE, HEC-HMS (Hydrologic Modeling System). Online at:
http://www.hec.usace.army.mil/software/hec-hms/

STANDARD 3. STORMWATER RECHARGE

Required Computations or Demonstrations:

Multiple computations are necessary:

a. Impervious Area
b. Required Recharge Volume
c. Bottom Area Sizing for Infiltration Structures

See below and MassDEP *Hydrology Handbook for Conservation Commissioners*, Chapter 8.

RECHARGE REQUIREMENTS

The following requirements apply to the design of recharge structures. These requirements affect design computations so the following brief synopsis is provided. The "*Static"*, "*Simple Dynamic"*, and "*Dynamic Field"* methods for sizing are explained later in this Section.

- Minimum infiltration rate: Must be at least 0.17 inches/hour at the actual location where infiltration is proposed on site soil. No stormwater recharge systems shall be sited in soils that infiltrate lower than 0.17 inches/hour[2] due to the potential for failure.
  - When "*Static*" or " *Simple Dynamic"* Methods are used to size the recharge practice: whether the soils exfiltrate faster than 0.17 inches/hour is determined based on a soil textural analysis (see Soil Evaluation Section in this Chapter) and the rates specified by Rawls 1982 (See Table 2.3.3).
  - When the "*Dynamic Field*" method is used: whether the soils exfiltrate faster than 0.17 inches/hour is based on 50% of the actual in-situ *saturated hydraulic conductivity* rate. (See Soil Evaluation Section in this Chapter).
- Rapid Infiltration Rate: Rapid infiltration rate for purposes of stormwater infiltration is considered to be *saturated hydraulic conductivity* greater than 2.4 inches/hour at the specific location(s) where infiltration is proposed.
  - When "*Static*" or " *Simple Dynamic*" Methods are used for design, use rate specified by Rawls 1982 (see Table 2.3.3) for the soil type at the location where infiltration is proposed based on a soil textual analysis (see Soil Evaluation Section of this Chapter) to determine whether soil is classified as having a rapid infiltration rate.
  - When the "*Dynamic Field"* Method is used for design: 50% of the actual *in-situ saturated hydraulic conductivity* rate is used to determine whether the soil has a rapid infiltration rate.
    - *Example*: If the *in-situ* rate established by field-testing is 5.1 inches/hour, 50% of that rate = 2.55 inches/hour. The soil has a rapid infiltration rate, since 2.55 inches/hour>2.4 inches/hour.
- TSS Pretreatment: Stormwater Infiltration BMPs are infiltration basins, infiltration trenches, dry wells, subsurface infiltration structures and bioretention cells configured specifically to exfiltrate.
  - At least 44% TSS pretreatment is required prior to discharge to the stormwater infiltration BMP when:
    - The infiltration BMP is located within an area with a rapid infiltration
    - Runoff from a land use with a higher potential pollutant load (LUHPPL) is directed to the infiltration BMP.
    - The infiltration BMP is located within a Zone II or an Interim Wellhead Protection Area (IWPA) of a Public Drinking Water Source/Supply.
    - The discharge from the infiltration BMP is to or near another *critical area.* These critical areas are Outstanding Resource Waters, Special Resource Waters, shellfish growing areas, bathing beaches, and cold-water fisheries.

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[2] According to Rawls 1982, the lower end of soils assigned to Hydrologic Soil Group C have an average infiltration rate of 0.17 inches per hour. See Table 2.3.3. Hydrologic Soil Groups A and B are more conducive to stormwater recharge than "C" soils, so care must be exercised when designing stormwater recharge system in "C" soils.

- At least 80% TSS pretreatment is required prior to discharge to stormwater infiltration BMP when:
  - The "*Dynamic Field"* method is proposed for sizing purposes.

SOIL EVALUATION

An evaluation must be undertaken to classify the Hydrologic Soil Groups (HSG) soils on site using classification methodologies developed by U.S. Natural Resources Conservation Service (NRCS). The Hydrologic Soil Groups are used in conjunction with impervious areas on a site to calculate the *Required Recharge Volume*.

The following steps are required to identify the Hydrologic Soil Groups on a site:

STAGE 1) Review NRCS (formerly SCS) Soil Surveys

NRCS soil surveys are to be used as the first step in identifying soils and soil hydrologic groups present at the site. All counties in Massachusetts have been mapped by NRCS. NRCS Soil Survey information is available online at:
http://www.ma.nrcs.usda.gov/technical/soils/index.html or
http://nesoil.com/massachusetts_soil_survey.htm. Locate the site using the electronic Soil Survey or on plans included in a hard copy of the Soil Survey. Identify the NRCS soil type and associated Hydrologic Soil Group by consulting the Soil Survey lists for the site.

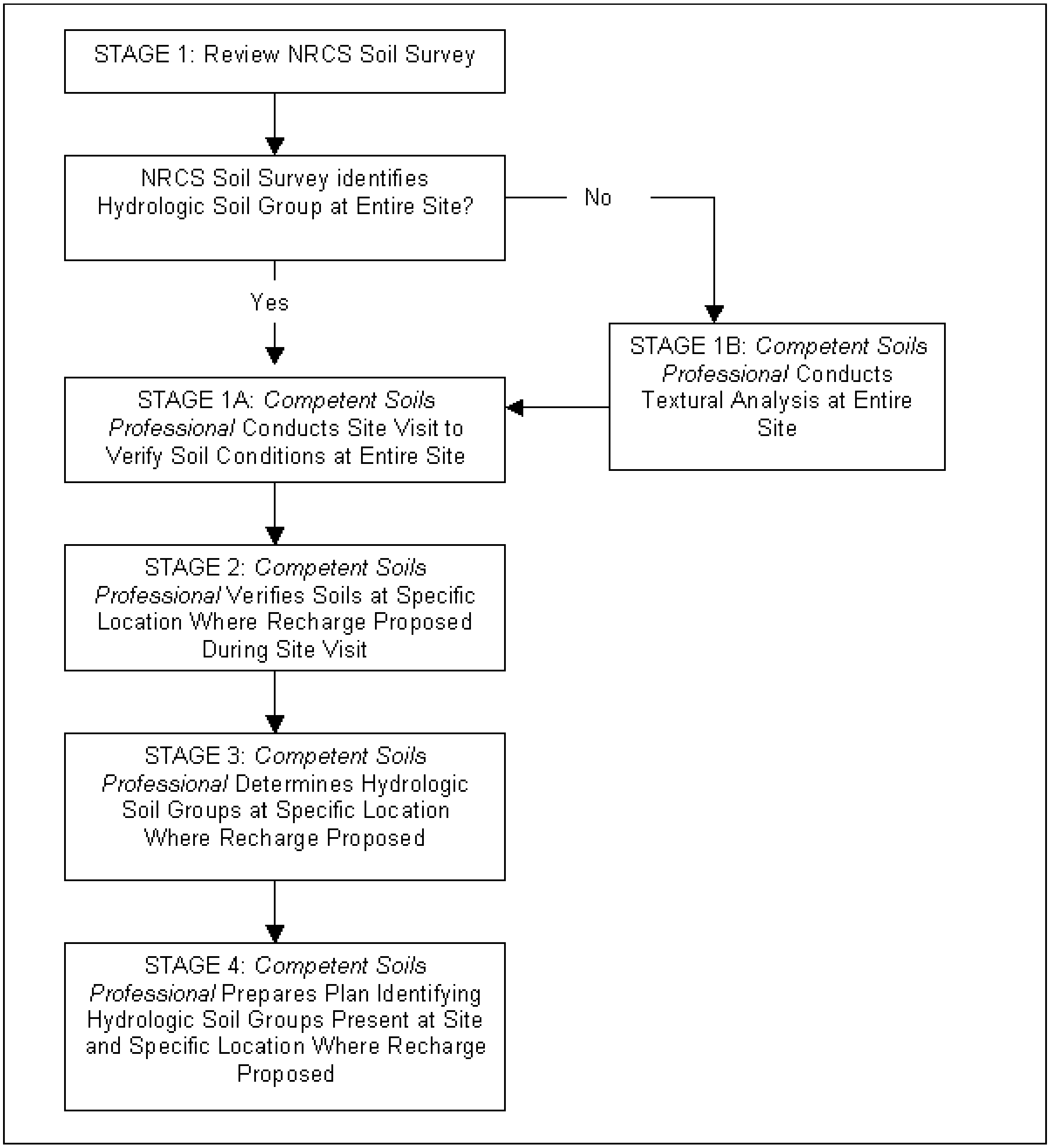


Figure 2.3.1: Determining Hydrologic Soil Group(s)

STAGE 1A) Site Visit

After completion of STAGE 1, a "*Competent Soils Professional*[3]" must conduct a site visit to confirm the NRCS soil survey. The site visit will allow for observation of noticeable deviations in site conditions (i.e., bedrock outcrops, open gravel/sand areas, recent filling). The site visit

[3] A *Competent Soils Professional* is an individual with demonstrated expertise in soil science, including, but not limited to, a Massachusetts Registered Professional Engineer, Engineer in Training (EIT certificate) with a concentration in civil, sanitary or environmental engineering, or Bachelor of Arts or Sciences degree or more advanced degree in Soil Science, Geology, or Groundwater Hydrology from an accredited college or university.

must establish whether the on-site soils have been disturbed, filled, or altered in a way that affects the natural drainage of the site.

The "*Competent Soils Professional*" shall perform the following tasks:

a. Conduct site visit. Determine whether any noticeable deviations on site exist from the NRCS Soil Survey (i.e., bedrock outcrops, open gravel/sand areas, recent filling). Determine whether the on-site soils have been disturbed, filled, or altered in any way.

b. Review any existing field test pit data and available boring logs and compare with NRCS information published in the Soil Survey. Boring logs and test pit data often indicate the soil textural class and varying soil strata (i.e., restrictive layers) and may assist in further refinements of soil delineations.

c. Review any existing USGS geologic maps for general rock types and bedrock depths. The presence of bedrock, including rock outcrops, is a significant factor in the potential for groundwater recharge. Knowledge of the bedrock and rock type at the site will be beneficial in further characterizing existing recharge conditions.

d. Review available aerial photographs. If a detailed site map is not available at the time of the initial investigation, an aerial photograph may provide additional information for delineating impervious and pervious areas.

e. When the Soil Survey does not identify the Hydrologic Soil Group(s) at the site or when the site conditions are not consistent with the NRCS Soil Survey, the *Competent Soils Professional* shall complete STAGE 1B. When the NRCS Soil Survey identifies the Hydrologic Soil Group(s) at the site, and the STAGE 1A investigation indicates site conditions are consistent with the NRCS Soil Survey, proceed to STAGE 2.

STAGE 1B) Additional Measures When the NRCS Soil Survey Does Not Identify Hydrologic Soil Group(s) At the Site or When Site Conditions Are Found That Are Inconsistent with the NRCS Soil Survey

Where the NRCS Soil Survey does not identify the Hydrologic Soil Group or when the site conditions are inconsistent with the NRCS Soil Survey, the site visit in STAGE 1A must include a soils textural analysis of the soils present throughout the entire site to determine the Hydrologic Soil Group(s). This investigation is needed to calculate the *Required Recharge Volume*. STAGE 1B is conducted for the entire site whereas the STAGE 2 investigation is conducted only at the actual location(s) where stormwater recharge is proposed.

The NRCS Soil Surveys may not identify the Hydrologic Soil Group(s) at sites located in urban areas. Most counties in Massachusetts have areas that have been mapped by NRCS as urban land or complexes of urban land and a soil series. When soils are mapped as urban land or complexes of urban land, the NRCS does not assign the soils to a Hydrologic Soil Group. Further, the NRCS does not typically identify the Hydrologic Soil Group(s) for soils mapped as Udorthents, udipsamments, nomans land, pits, gravels and quarries. The total area of urban complex soils in Massachusetts is approximately 150,000 acres or 3 % of the mapped area in the state. Soils mapped as urban and other soils comprise approximately 255,000 acres or 5.5% of the total mapped area.

For sites with soils that have not been assigned to a Hydrologic Soil Group by NRCS, the *Competent Soils Professional* must conduct a *Soil Textural Analysis* (see STAGE 2 for description) to identify the Hydrologic Soil Group(s) at the site (see STAGE 3), using test pits or soil borings. For a typical site, it is recommended that one test pit or boring be completed per acre with a minimum of 4 test pits or borings per site. The *Soil Textural Analysis* must be completed using standard USDA soil physical analyses (Black, et. al., 1965), i.e., particle size analyses. Classification of soil texture shall be consistent with the USDA Textural Triangle. The soil textural analysis for STAGE 1B must be conducted in the surface soil horizons. NRCS Soil Survey evaluations typically cover the first 60-inch soil depth. The field investigation for STAGE 2 must occur in the actual soil layer where recharge is proposed.

Stormwater recharge is not permitted through fill materials composed of asphalt, brick, concrete, construction debris, and materials classified as solid or hazardous waste. When the STAGE 1B field investigation indicates fill is present, the *Competent Soils Professional* must conduct a soil textural analysis of the parent material below the fill layer.

STAGE 2) Determine Site Conditions at Specific Location Where Recharge is Proposed

The following actions shall be performed to determine soil conditions at actual location on the site where recharge is proposed:

a. Conduct tests at the point where recharge is proposed. The tests are a field evaluation conducted in the actual location and soil layer where stormwater infiltration is proposed (e.g., if the O, A and B soil horizons are proposed to be removed, the tests need to be conducted in the C soil layer below the bottom elevation of the proposed recharge system). The tests shall be conducted by the *Competent Soils Professional*. The tests shall evaluate the following:

   - ❑ *Soil Textural Analysis* using NRCS methods
   - ❑ Depth to seasonal high groundwater
   - ❑ When *"Dynamic Field"* Method is proposed for sizing a field-derived *saturated hydraulic conductivity* must be determined as part of the site investigation.
   - ❑ When the "*Static*" or "*Simple Dynamic"* Methods or LID Site Design Credits are proposed for sizing stormwater recharge BMPs, in-situ tests for *saturated hydraulic conductivity* are not required for purposes of the Stormwater Standards and the *saturated hydraulic conductivities* listed by Rawls 1982 (see Table 2.3.3) shall be used.[4]

[4] When NRCS Soil Surveys indicate a lower saturated hydraulic conductivity than Rawls 1982, care must be exercised in the design process. NRCS Soil Surveys may indicate multiple saturated conductivities for the same soil, depending on the soil depth.

Soil Textural Analysis (For STAGES 1B and 2)

Soil texture represents the relative composition of sand, silt and clay in soil. Soil texture is determined using procedures described in the USDA, 2007, National Soil Survey Handbook, Section 618.67 (Texture Class, Texture Modifier, and Terms Used in Lieu of Texture). See http://soils.usda.gov/technical/handbook/contents/part618.html#67. Soils must not be composited from one test pit or bore hole with soils from another test pit or bore hole for purposes of the textural analysis.

The NRCS also has online tools to assist in soil texture analysis, once the relative proportions of sand, silt, and clay have been determined. See http://soils.usda.gov/technical/aids/investigations/texture/

Soil textual analysis may also be completed using the methods described by MassDEP Soil Evaluator Course Chapter 2. These methods are based on the USDA NRCS methods http://170.68.97.68/dep/water/compliance/sech2.pdf

The number of locations where the soil textural analysis must be conducted at the actual point(s) where stormwater recharge is proposed depends on the type and size of the infiltration BMP. The BMP Specifications in Volume 2, Chapter 2 list the number of test locations needed for specific infiltration BMPs.

Determining Saturated Hydraulic Conductivity for Design Purposes (for STAGE 2)

Saturated hydraulic conductivity rates must be determined at the actual location and soil layer where recharge is proposed when the "*Dynamic Field"* method is proposed. When the "*Static"* or "*Simple Dynamic"* methods are proposed, the Rawls Rates at the location and soil depth where recharge is proposed shall be presumed to represent the *saturated hydraulic conductivity*, and no field evaluation is required.

a. Field test methods to assess *saturated hydraulic conductivity* for the "*Dynamic Field"* method must simulate the "field-saturated" condition. See ASTM D5126-90 (2004) Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone. The *saturated hydraulic conductivity* analysis must be conducted by the *Competent Soils Professional*. Acceptable tests include:
   i. Guelph permeameter - ASTM D5126-90 Method
   ii. Falling head permeameter – ASTM D5126-90 Method
   iii. Double ring permeameter or infiltrometer - ASTM D3385-03[5], D5093-02[6], D5126-90 Methods
   iv. Amoozemeter or Amoozegar permeameter – Amoozegar 1992

c. A Title 5 percolation test is not an acceptable test for *saturated hydraulic conductivity*. Title 5 percolation tests overestimate the *saturated hydraulic conductivity* rate.

[5] ASTM D3385-03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer

[6] ASTM D5093-02 Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.

d. The number of test locations is dependent on the type and size of the infiltration BMP. The BMP Section in Volume 2, Chapter 2 lists the number of test locations needed for specific infiltration BMPs.
e. For the "*Dynamic Field"* method, the tests results for *saturated hydraulic conductivity* measured in the field must use the lowest of the values recorded for sizing the stormwater recharge BMP, and not an average.
f. For the "*Static"* and "*Simple Dynamic"* Methods, the *saturated hydraulic conductivity* is determined using the Rawls Rate associated with the slowest of the Hydrologic Soil Groups determined to exist at the point where recharge is actually proposed.

    Example: Assume three samples are taken at a proposed infiltration basin in the actual soil layer where recharge is proposed. Two samples indicate sandy soils. The last sample indicates a sandy loam soil. The Rawls Rates used for the exfiltration analysis must use the sandy loam rate and not the sandy soil rate. Soils must not be composited for purposes of the soil textural analysis.

Determining Seasonal High Groundwater

Seasonal high groundwater represents the highest groundwater elevation. Depth to seasonal high groundwater may be identified based on redox features in the soil (see Fletcher and Venneman listed in References). When redox features are not available, installation of temporary push point wells or piezometers should be considered. Ideally, such wells should be monitored in the spring when groundwater is highest and results compared to nearby groundwater wells monitored by the USGS to estimate whether regional groundwater is below normal, normal or above normal (see: http://ma.water.usgs.gov). Procedures identified by MassDEP Title 5 Soil Evaluator Course, Chapter 4 may also be used. See: http://www.mass.gov/dep/water/compliance/sech4.pdf.

When Fill Materials Are Determined To Be Present

When fill materials are present or are added prior to construction of the system, a soil textural analysis must be conducted in both the fill material and the underlying parent materials, and the Hydrologic Soil Group of the more restrictive layer shall be used to size the infiltration BMP. If fill is present that is composed of asphalt, brick, concrete, construction debris, or if materials classified as solid or hazardous waste are identified at the specific location where recharge is proposed, recharge elsewhere on site must be considered. Alternatively, the debris or waste may be removed in accordance with all applicable Solid and Hazardous Waste Regulations (see 310 CMR 19.000 and 40.0000) and replaced with clean material suitable for infiltration. Any solid or hazardous wastes present on the site must be managed in strict accordance with MassDEP Solid Waste Regulations, 310 CMR 19.000, Hazardous Waste Regulations, 310 CMR 30.00, and the Massachusetts Contingency Plan Regulations, 310 CMR 40.000.

STAGE 3: Identify Hydrologic Soil Groups On-site and At Location Where Recharge Proposed

The *Competent Soils Professional* shall use the information collected in STAGES 1 and 2 to identify the Hydrological Soil Group(s) throughout the entire site (for purposes of a Registered

Professional Engineer calculating the *Required Recharge Volume*) and in the actual location and soil horizon and/or layer where stormwater infiltration is proposed (for purposes of a Registered Professional Engineer sizing the Recharge BMP).

In making the determination of the Hydrologic Soil Group at the location where recharge is proposed, the *Competent Soils Professional* may not be able to rely on the classification by NRCS. For undisturbed soils in Massachusetts, NRCS has assigned each soil type to a Hydrologic Soil Group. However, that classification is based on the upper and not lower soil horizons. When the lower soil horizons or layers are proposed for stormwater infiltration, the soils must be assigned to a Hydrologic Soil Group by the *Competent Soils Professional*. USDA NRCS, 2007, Part 630 Hydrology National Engineering Handbook, Chapter 7, Hydrologic Soil Groups, and USDA NRCS 2007 National Soil Survey, Part 618.36, describe this process. See: http://policy.nrcs.usda.gov/media/pdf/H_210_630_7.pdf and http://soils.usda.gov/technical/handbook/contents/part618.html#36

After determination of the Hydrologic Soil Group(s) on site and at the actual points(s) where recharge is proposed, Registered Professional Engineers shall use Table 2.3.2 to calculate the volume of stormwater required to be recharged.

When the *"Static"* or *"Simple Dynamic"* Methods are used, the Rawls Table (Table 2.3.3) must be used to establish the exfiltration rate associated with the soil textures determined at the actual location on site where infiltration is proposed. When the "*Dynamic Field"* Method is used, the exfiltration rate for design purposes must be assumed to be no more than 50% of the *in-situ saturated hydraulic conductivity* rate at the actual location on site where infiltration is proposed.

STAGE 4: Prepare a Plan identifying Hydrologic Soil Groups for the Site

After review of the available data, prepare a plan of the site clearly delineating the Hydrologic Soil Groups throughout the entire site and the specific point(s) where recharge is proposed. Deviations from the NRCS Soil Surveys and special conditions discovered during additional investigations (relative to recharge potential) must be noted on the plan and described. The plan shall identify the location of all borings and test pits, including the location of any known prior test pits or borings. Test pit or boring logs shall be appended to the plan, identifying in cross section the soil types, seasonal high groundwater elevation, confining layers, and other appropriate information.

Note that many areas with Hydrologic Soil Group “D” soils (as well as other areas mentioned above) may be within wetland resource areas that are subject to the Wetlands Protection Act Regulations (310 CMR 10.00).

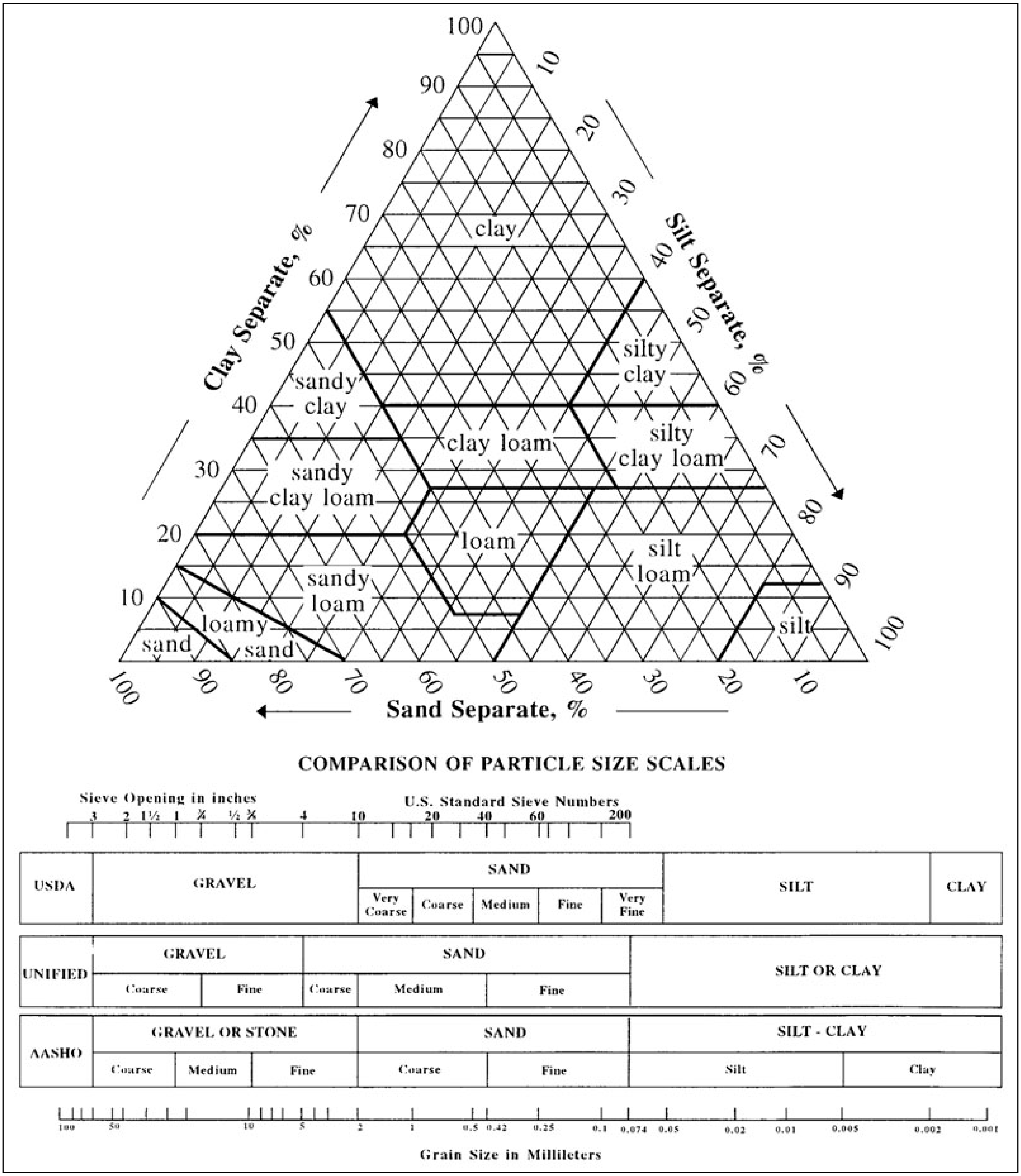


Figure 2.3.2: USDA, NRCS, 2007 National Soil Survey Handbook, Part 618, Exhibit 8,
http://soils.usda.gov/technical/handbook/contents/part618ex.html#ex8

CONTRIBUTING DRAINAGE AREA

The contributing drainage area must be determined for purposes of determining compliance with Standards 2, 3, and 4. The contributing drainage area for Standard 2 includes all areas contributing drainage to a site, including off-site locations. For purposes of Standards 3 and 4, only the impervious areas on the project site are used for purposes of calculating the *Required Recharge Volume* and the *Required Water Quality Volumes.*

IMPERVIOUS AREA

Impervious area must be determined in order to calculate the *Required Recharge Volume* and the *Required Water Quality Volume.* The impervious area is a subset of the contributing drainage area. For purposes of Standards 3 and 4, impervious surfaces include roads, rooftops, parking lots, and sidewalks, when they are paved with concrete, asphalt, or brick pavers. Various credits can be used to reduce the *Required Recharge Volume* and the *Required Water Quality Volume,* for Standards 3 and 4. See LID Site Design Credit Section of this Chapter.

Porous pavement is considered to be an impervious surface for purposes of calculating the *Required Water Quality Volume* and the *Required Recharge Volume.* When using porous pavement, the larger of the *Required Water Quality Volume* or *Required Recharge Volume* must be used to size the storage media under the porous pavement.

Similarly, a green roof is considered to be an impervious surface for purposes of sizing the growing media that treats the *Required Water Quality Volume* and determining the total *Required Recharge Volume* for the site. A green roof is a treatment device and does not recharge the groundwater.

RECHARGE VOLUME

STEP 1) REQUIRED RECHARGE VOLUME

Calculate *Required Recharge Volume*.[7] The *Required Recharge Volume* equals a depth of runoff corresponding to the soil type times the impervious areas covering that soil type at the post-development site.

$$Rv = F \times \text{impervious area} \qquad \textbf{Equation (1)}$$

Rv = *Required Recharge Volume,* expressed in Ft^3, cubic yards, or acre-feet
F = Target Depth Factor associated with each Hydrologic Soil Group
Impervious Area = pavement and rooftop area on site

7 MassDEP recognizes that along MassHighway Projects, because of right-of-way limitations it may be difficult to recharge the *Required Recharge Volume* at every point along redevelopment and add-a-lane projects. MassHighway may use a macro approach to meet this requirement by recharging more than the *Required Recharge Volume* at certain locations within a subwatershed (rest stops, exit ramps, median strips) to compensate for other locations within the same subwatershed where it is not able to infiltrate the *Required Recharge Volume*. MassDEP and MassHighway intend to work together to revise the 2004 MassHighway Handbook for Highways and Bridges to elaborate on this approach as it applies to redevelopment and add-a-lane projects and to reflect the 2008 changes to the Stormwater Management Standards.

Attention must be given to ensure consistency in units. In particular, the Target Depth Factors must be converted to feet.

NRCS HYDROLOGIC SOIL TYPE	APPROX. SOIL TEXTURE	TARGET DEPTH FACTOR (F)
A	sand	**0.6-inch**
B	loam	**0.35-inch**
C	silty loam	**0.25-inch**
D	clay	**0.1-inch**

Table 2.3.2: Recharge Target Depth by Hydrologic Soil Group

When a site contains multiple Hydrologic Soil Groups, determine the *Required Recharge Volume* for each impervious area by Hydrologic Soil Group and then add the volumes together.

Example: Assume a ten (10) acre site. 5.0 acres are proposed to be developed for a retail use. A section of the entrance roadway is to be bridged over a stream that is classified as land under water. As such, the bridging is subject to the Wetlands Protection Act Regulations, and the Stormwater Management Standards apply to stormwater runoff from all proposed roads, parking areas, and rooftops. Of the 5.0 acres proposed to be developed, 2 acres of impervious surfaces are proposed atop Hydrologic Soil Group (HSG) "A" soils, 1 acre of impervious surfaces atop HSG "B" soil, 1.5 acres of impervious surfaces atop HSG "C" soil, and 0.5 acres are proposed to be landscaped area. The remaining 5.0 acres, located on HSG "A" soil, are proposed to remain forested. Determine the *Required Recharge Volume*.

Solution: The *Required Recharge Volume* is determined only for the impervious surfaces. The 5.0-acre forested area and the 0.5-acre landscaped area are not impervious areas. Although converted from forest, landscaped area is pervious area for purposes of Standard 3. Use *Equation (1)* to determine the *Required Recharge Volume* for each Hydrologic Soil Group covered by impervious area. Add together the *Required Recharge Volumes* determined for each HSG.

Rv = F x impervious area

$Rv = [(F_{HSG\ \text{"A"}})(Area_1)] + [(F_{HSG\ \text{"B"}})(Area_2)] + [(F_{HSG\ \text{"C"}})(Area_3)] + [(F_{HSG\ \text{"D"}})(Area_4)]$ ***Equation (2)***

Rv = [(0.6-in/12)(2 acres)] + [(0.35-in/12)(1 acre)] + [(0.25-in/12)(1.5 acres)] + [(0.1-in/12)(0 acres)]

Rv = 0.1605 acre-feet

Rv = 0.1605 acre-feet x 43560 square feet/acre-feet = 6,991 cubic feet or *258.9 cubic yards*

Evaluate Where Recharge Is Directed

The infiltration BMP must be evaluated to determine if the proposed recharge location will alter a Wetland Resource Area by causing changes to the hydrologic regime. For example, if Watershed "A" contains a vernal pool within a Bordering Vegetated Wetland, and the vernal pool is fed by groundwater, and runoff from Watershed "A" is proposed to be directed to Watershed "B" for infiltration, an evaluation is necessary to determine if redirecting the runoff will cause an alteration to the vernal pool. In such instances, Water Budgeting using the Thornthwaite method or equivalent must be employed. TR-20/TR-55 methods are not sufficient for water budgeting purposes. Water budgeting analysis is not required, if the recharge is directed to the same subwatershed where the impervious surfaces are proposed.

STEP 2) SIZING STORAGE VOLUME

Determine the Storage Volume. The Storage Volume is the volume of the basin, chamber, or voids that must be constructed in order to hold the *Required Recharge Volume*. Three methods may be used to determine the Storage Volume:

1. The "*Static" Method;*
2. The "*Simple Dynamic" Method;* or the
3. The "*Dynamic Field" Method.*

The "*Static*" Method assumes that there is no exfiltration until the entire recharge device is filled to the elevation associated with the *Required Recharge Volume*. The two "*Dynamic"* Methods assume stormwater exfiltrates into the groundwater as the storage chamber is filling. [8] The *"Simple Dynamic"* Method assumes that the *Required Recharge Volume* is discharged to the infiltration BMP over 2 hours and exfiltrates over the 2-hour period at the Rawls Rate. The "*Dynamic Field"* Method assumes that the *Required Recharge Volume* discharges to the infiltration BMP over 12 hours and infiltrates at no more than 50% of the *in-situ saturated hydraulic conductivity rate*.[9] The "*Static"* Method produces a larger storage volume than either *Dynamic* Method and produces the most conservative result. The "*Dynamic Field"* Method may be used only for sizing an infiltration BMP that is used solely for disposal of stormwater (i.e., 80% TSS removal must occur prior to directing runoff to the infiltration BMP)[10].

When using the "*Static"* or "*Simple Dynamic"* Methods, only a textural soil analysis is required to determine the corresponding Hydrologic Soil Group. Textural soil analysis is explained in the Hydrologic Soil Group Section above. The "*Dynamic Field"* Method requires more soil testing to determine the *in-situ saturated hydraulic conductivity.*

[8] Rich Claytor, Bethany Eisenberg, and Tom Maguire were instrumental in the development of the two *Dynamic* Methods.

[9] 50% is used as a factor of safety to represent the anticipated long-term exfiltration rate due to clogging of the underlying media/soil that occurs over time.

[10] Even if 80 % TSS removal is not required because the *"Dynamic Field"* Method has been used to size the infiltration BMP, 44% TSS removal may be required prior to discharge to the infiltration BMP. 44% TSS removal is required prior to discharge to an infiltration BMP if the *saturated hydraulic conductivity* is greater than 2.4 inches/hour based on the Rawls Rate for the "*Static"* and "*Simple Dynamic"* Methods. 44% TSS removal is also required prior to discharge to the infiltration BMP if runoff is from a LUHPPL or directed to a Zone II or IWPA, or near or to another critical area.

If using the "*Static"* Method, go to STEP 3. If using either *Dynamic* Method, skip STEP 3 and go to STEP 4.

STEP 3) *STATIC* METHOD:

a. Assume the entire *Required Recharge Volume* determined by following the procedures set forth in STEP 1 is discharged to infiltration device before infiltration begins.
b. Size the volume of the basin, chamber or total voids to hold the *Required Recharge Volume* determined under STEP 1.
c. Go to STEP 5 to confirm that the bottom of the infiltration BMP is large enough to ensure that the system will completely drain in 72 hours or less.

Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group "A." An infiltration structure is proposed to meet Stormwater Standard 3. Use the *"Static"* Method to determine the storage volume of the infiltration structure.

Solution: The *Required Recharge Volume* is based on 0.60 inches (see Table 2.3.2) of runoff. Using *Equation (1):*

$$Rv = F \times \textit{impervious area}$$
$$Rv = (F_{\text{HSG "A"}}) \times (\textit{impervious area})$$
$$Rv = [(0.6 \text{ inches}/12 \text{ inches/foot})][(0.75 \text{ acre})(43{,}560 \text{ square feet/acre})]$$
$$Rv = 1{,}633.5 \text{ cubic feet or } 60.5 \text{ cubic yards}$$

Assuming that the stored runoff will exfiltrate completely into the ground within 72 hours, the infiltration structure must have a storage volume of 1,633.5 cubic feet.[11]

STEP 4) *"SIMPLE DYNAMIC"* AND "*DYNAMIC FIELD"* METHODS

[11] If the infiltration structure is a trench filled with stone, the excavated volume of the trench must be determined to account for the stone in the trench**.** . The minimum excavated *infiltration trench* volume is determined as follows:

$$\textit{Infiltration Trench Excavated Volume} = \frac{Rv}{n}$$

Where:
Rv = Required Recharge Volume
n = porosity or percentage of void space between the stone

Assuming n = 0.35 (35% voids) between the stone, the minimum Infiltration Trench Excavated Volume for design purposes would be:

$$\textit{Infiltration Trench Excavated Volume} = \frac{1633.5 \textit{ cubic feet}}{0.35} = 4668 \textit{ cubic feet}$$

Where an applicant chooses to size the recharge practice to take into account the fact that stormwater is exfiltrating from the recharge practice at the same time that the storage chamber is filling, one of the two methods specified in this Handbook must be used. These methods are referred to as the "*Simple Dynamic"* and "*Dynamic Field"* Methods. They result in smaller storage volumes than would otherwise be required by the "*Static"* Method. In Hydrologic Soil Group B, C, and D soils, all three methods produce similar sized storage. However, in sandy soils (Hydrologic Soil Group A), the "*Simple Dynamic"* and "*Dynamic Field"* Methods can produce smaller storage requirements. Since the "*Simple Dynamic"* and "*Dynamic Field"* Methods are less conservative than the *"Static"* Method, maintenance over the life of the recharge practice is especially critical to ensure that the recharge practice will function as designed over the long-term.

"Simple Dynamic"

Of the two "*Dynamic"* Methods, the "*Simple"* Method requires less time to complete. *Saturated hydraulic conductivity* is based on a soil textural analysis[12] performed at the location (actual depth/elevation) where the exfiltration is proposed to confirm or determine the Hydrologic Soil Group classification and the associated Rawls Rate. The "*Simple Dynamic"* Method is more conservative than the *"Dynamic Field"* Method, because it limits the allowable infiltration time that is used to reduce size of the infiltration BMP to the peak two hour period of a "typical storm". The *"Simple Dynamic"* Method can be performed by using the formulas set forth below.

Rv = F *x* impervious area
A =Rv ÷ (D+KT)
V=A*x*D
Rv is the *Required Recharge Volume*
F=Target Depth Factor. See Table 2.3.2.
A is the minimum required surface area of the bottom of the infiltration structure
V is the Storage Volume determined in accordance with the *"Simple Dynamic"* Method
D is a depth of the infiltration facility[13]
K is the saturated hydraulic conductivity. For " *Simple Dynamic"* Method, use Rawls Rate (See Table 2.3.3), and
T is the allowable drawdown during the peak of the storm (use 2 hours)

Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group "A." An infiltration structure that is 4 feet deep is proposed to meet Standard 3. Determine the storage volume of the infiltration structure, using the "*Simple Dynamic"* Method.

Rv= F *x* impervious area
Rv= [(0.6 inches/12 inches/foot)][(0.75 acre)(43,560 square feet/acre)]
Rv =1,633.5 cubic ft or 60.5 cubic yards

[12] See Hydrologic Soil Group section above for information related to soil textural analysis.
[13] If the infiltration facility is a practice that uses stone or another media such as a dry well, only the void spaces must be considered. In those circumstances, use nd instead of d, where n is the percent porosity of the stone or other media. See footnote 11.

A=Rv÷(d+Kt)
A=1633.5cubic ft ÷[4 ft +(8.3"/hr/12"/ft *x* 2hr)]
A=303.4 sq. ft.
V=A *x* D
V=303.4 square ft *x* 4 ft
V=1203.6 cubic ft.[14]

To size an infiltration BMP using the "*Simple Dynamic*" Method, applicants may also use a computer model based on TR-20 as described below. As more fully set forth below, this computer model assumes that the *Required Water Quality Volume* is entering the infiltration BMP during the peak two hours of the storm and that runoff is being discharged from the BMP during the same two hour period at the Rawls Rate. This contemporaneous exfiltration allows a proponent to reduce the size of the infiltration BMP.

a. Use Equation 1 to determine the *Required Recharge Volume*
b. Select a 24-hour rainfall event that generates the *Required Recharge Volume* during the peak 2 hours. Use only the Site's impervious drainage area and the default NRCS Initial Abstraction of 0.2S and Type III storm. Set the storm duration for 24 hours, but use a start time of 11 hours and an end time of 13 hours. This creates a truncated hydrograph where most of the rainfall typical of a 24-hour Type III Storm occurs in just 2 hours. Selecting the correct precipitation depth is an iterative process. Various precipitation depths must be tested to determine which depth generates the *Required Recharge Volume*, using the Win TR-20 method (or other software based on TR-20). Each precipitation depth evaluated generates a runoff hydrograph. The area under the hydrograph is a volume. The correct result is achieved when the volume under the inflow hydrograph equals the *Required Recharge Volume.*
c. Using the resulting inflow hydrograph, choose an appropriate exfiltration structure with an appropriate bottom area and storage volume.[15]
d. Use recharge system bottom as maximum infiltrative surface area. Do not use sidewalls.[16]
e. Assume stormwater exfiltrates from the device over the peak 2-hour period of the rainfall event determined in step b above
f. Set exfiltration rates no higher than the Rawls Rates for the corresponding soil at the specific location where infiltration is proposed (see Table 2.3.3).
g. Assume exfiltration rate is constant.
h. Using the computer model, confirm adequate *Storage Volume*.
i. Go to STEP 5 to confirm that the bottom of the proposed infiltration BMP is large enough to ensure that the practice will drain completely in 72 hours or less. For purposes of the STEP 5 evaluation, assume the exfiltration rates are no higher than the Rawls Rates.

[14] The storage volume calculated using this "*Simple Dynamic*" Method is measurably less than the 1633.5 cubic feet that resulted from the "*Static*" Method.
[15] An applicant may have to select several different size infiltration structures before s/he identifies a structure that is adequately sized.
[16] If the recharge system includes stone or other media, remember that the effective storage volume only includes the voids between the stone or other media. See footnote 11.

Example Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group “A.” To meet Standard 3, an infiltration structure is proposed with a bottom that has a surface area of 303 square feet and a storage volume of 1212 cubic feet. Use the *“Simple Dynamic”* Method to confirm that this storage volume is adequate.

Solution using the computer model

The *Required Recharge Volume* is calculated using Equation 1 as follows:
Rv=F *x* impervious area
Rv= [(0.6 inches/12 inches/foot)][(0.75 acre)(43,560 square feet/acre)]
Rv =1,633.5 cubic feet or 60.5 cubic yards

The amount of precipitation is determined iteratively by developing a hydrograph that generates the 1,633.5 cubic feet, the *Required Recharge Volume*, during the peak two hours of the storm. A hydrograph is generated for a storm that produces 1.29" of precipitation and indicates the runoff is entering the infiltration structure at a maximum rate of 0.87 cfs during the most intense two hours of the storm. An exfiltration system is sized to store the difference between the inflow volume and the outflow volume using an infiltration rate of 8.3 inches/hour for HSG “A” soil (based on the Rawls Rates) over the 2-hour period. The outflow hydrograph reveals that runoff will leave the infiltration structure at a constant rate of 0.06 cfs during the peak two hours of the storm. The results yield an infiltration structure with a surface a ponding depth of 4.0 feet and a storage volume of 1,212 cubic feet. [17]

Type III 24-hr Rainfall=1.29"

Subcatchment 1S: Sample Site

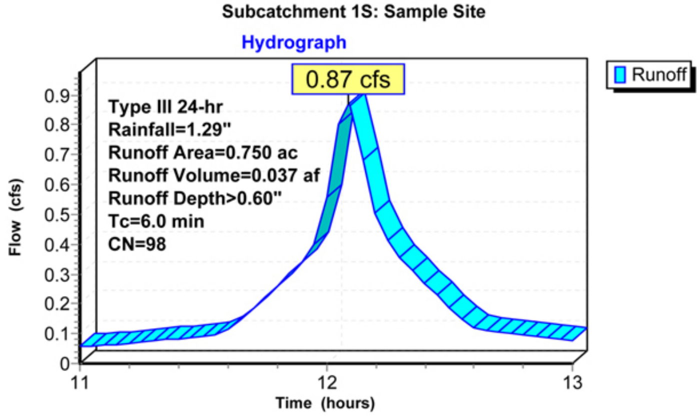
Runoff = 0.87 cfs @ 12.09 hrs, Volume= 0.037 af, Depth> 0.60"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 11.00-13.00 hrs, dt= 0.05 hrs
Type III 24-hr Rainfall=1.29"

Area (ac)	CN	Description
0.750	98	Paved roads w/curbs & sewers

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
6.0					**Direct Entry, Minimum**

Subcatchment 1S: Sample Site



[17] The storage volume calculated using software based on TR-20 is 1216 cubic feet, is nearly identical to the storage volume using the formula set forth herein.

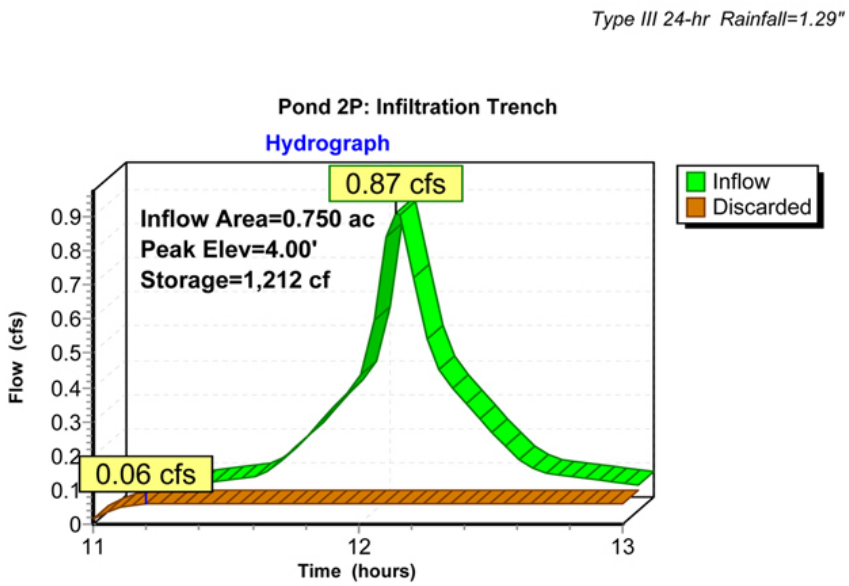


Table 2.3.3. 1982 Rawls Rates[18]

Texture Class	NRCS Hydrologic Soil Group (HSG)	Infiltration Rate Inches/Hour
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	B	1.02
Loam	B	0.52
Silt Loam	C	0.27
Sandy Clay Loam	C	0.17
Clay Loam	D	0.09
Silty Clay Loam	D	0.06
Sandy Clay	D	0.05
Silty Clay	D	0.04
Clay	D	0.02

18 Rawls, Brakensiek and Saxton, 1982

"Dynamic Field"

The "*Dynamic Field"* method may be used only for sizing infiltration structures that are used solely for disposal of stormwater (i.e., 80% TSS removal has been achieved prior to directing runoff to the infiltration BMP). *Saturated hydraulic conductivity* testing is required at the actual location where exfiltration is proposed.

a. Use Equation 1 to determine *Required Recharge Volume*
b. Select a 24-hour rainfall event that generates the *Required Recharge Volume* over 12 hours. Use only the Site's impervious drainage area and the default NRCS Initial Abstraction of 0.2S and Type III storm. Set the storm duration for 24 hours, but use a start time of 6 hours and an end time of 18 hours. This creates a truncated hydrograph where most of the rainfall typical of a 24-hour Type III storm occurs in just 12 hours. Selecting the correct rainfall depth is an iterative process. Various precipitation depths must be tested to determine which depth generates the *Required Recharge Volume*, using the Win TR-20 method (or other software based on TR-20). Each precipitation depth evaluated generates a runoff hydrograph. The area under the hydrograph is a volume. The correct result is achieved when the volume under the inflow hydrograph equals the *Required Recharge Volume.*
c. Using the resulting inflow hydrograph, choose an appropriate infiltration structure with an appropriate bottom area and storage volume.[19]
d. Use recharge system bottom as maximum infiltrative surface area. Do not use sidewalls.
e. Assume that exfiltration begins immediately at 6 hours and continues for 12 hours. Infiltration of the *Required Recharge Volume* may take more than 12 hours.
f. Set exfiltration rate used in the analysis to no higher than 50% of the *in-situ saturated hydraulic conductivity* rate in the soil layer where infiltration is proposed (e.g., if the *in-situ* rate is 10 inches/hour, 50% x 10 in/hr = 5 inches/hour).
g. Assume exfiltration rate is constant
h. Using computer model confirm adequate STORAGE VOLUME.
i. Go to STEP 5 to ensure that the bottom of the infiltration BMP is large enough to ensure that the system will completely drain in 72 hours using 50% of the *in-situ saturated hydraulic conductivity* rate determined using field-testing.

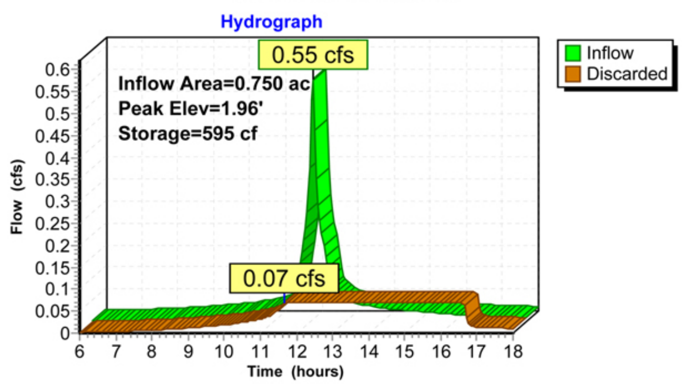
Example: Assume a one (1) acre undeveloped site. Assume 75% of the site is proposed to be impervious area (0.75 acre). The soils are classified as Hydrologic Soil Group "A." An *in-situ* field evaluation reveals a *saturated hydraulic conductivity* rate of 20" per hour. An infiltration structure with a bottom surface area of 303 square feet is proposed to meet Standard 3. Use the *"Dynamic Field"* Method to determine the storage volume of the infiltration basin.

Solution: The *Required Recharge Volume* is calculated using Equation 1 as follows.
Rv=F *x* impervious area
Rv= [(0.6 inches/12 inches/foot)][(0.75 acre)(43,560 square feet/acre)]
Rv =1,633.5 cubic feet or 60.5 cubic yards

[19] An applicant may have to try different size infiltration structures before an infiltration structure that is adequately sized is identified.

The amount of precipitation is determined iteratively by developing a hydrograph that generates the *Required Water Quality Volume* over a 24-hour period. Based on this process, a hydrograph that generates 0.6 inches of runoff (this is the Target Depth Factor for HSG A soils in Table 2.3.2) during the peak 12 hours of a storm. A hydrograph is generated for a storm that produces 0.87 inches of precipitation over 24 hours with runoff entering the infiltration structure at a maximum rate of 0.55 cfs during the most intense period of the storm. Assume the bottom has a surface area of 303 square feet and that runoff exfiltrates at 10 inches per hour (50% of the *in-situ saturated hydraulic conductivity* rate determined by field-testing). Based on the hydrograph, runoff leaves the infiltration structure at 0.07 cfs. The model calculates a storage capacity of 595 cubic feet. Note: the peak elevation calculated by the model is 1.96 feet, approximately half of the ponding depth produced by the "*Simple Dynamic*" Method. The smaller peak elevation arises, because infiltration is assumed to occur over a longer period in the "*Dynamic Field*" Method than the "*Dynamic Simple*" Method, i.e., 12 hours instead of two hours, and the infiltration rate for the *"Dynamic Field"* Method is 10 inches per hour instead of the 8.3 inches per hour (Rawls Rate) for the "*Dynamic Simple*" Method.

Type III 24-hr Rainfall=0.87"



Type III 24-hr Rainfall=0.87"

Subcatchment 1S: Sample Site

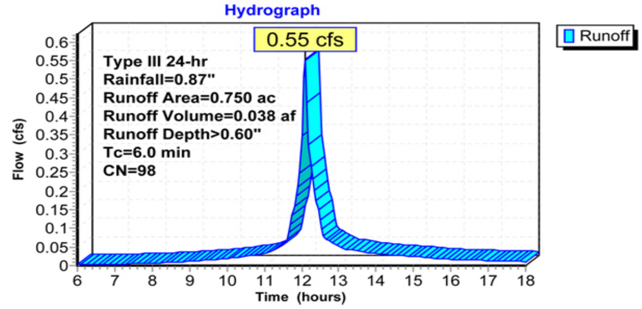
Runoff = 0.55 cfs @ 12.09 hrs, Volume= 0.038 af, Depth> 0.60"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 6.00-18.00 hrs, dt= 0.05 hrs
Type III 24-hr Rainfall=0.87"

Area (ac)	CN	Description
0.750	98	Paved roads w/curbs & sewers

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
6.0					Direct Entry, Minimum

Subcatchment 1S: Sample Site



STEP 5) DRAWDOWN WITHIN 72 HOURS

Use the same infiltration rate that is used for sizing the infiltration BMP to confirm that the infiltration BMP will drain completely within 72 hours. For the "*Static"* and "*Simple Dynamic"* Methods, the Rawls Rates associated with the slowest of the Hydrologic Soil Groups determined to exist at the point where recharge is actually proposed shall be used. For the "*Dynamic Field"* Method, 50% of the lowest value obtained from the test results for *saturated hydraulic conductivity* measured in the field at the actual location and soil layer where recharge is proposed shall be used.

a. For infiltration BMPs sized using the "*Static"* Method or the "*Simple Dynamic*" Method, the drawdown analysis is based on the *Required Recharge Volume* exfiltrating at the Rawls Rates based on the soil textural analysis conducted at the proposed exfiltration location. The slowest Rawls Rate (1982) at the actual location where the recharge is proposed is used for purposes of the drawdown analysis.
b. For infiltration BMPs sized using the "*Dynamic Field"* Method, the drawdown analysis must be based on the *Required Recharge Volume* infiltrating at 50% of the lowest *in-situ saturated hydraulic conductivity* rate at the location and specific soil layer where exfiltration is proposed.
c. The infiltration rate shall be assumed to be constant for purposes of the drawdown analysis. [20]
d. Only the bottom surface shall be considered. No credit shall be afforded to sidewall exfiltration.
e. If the drawdown analysis indicates the entire volume cannot be drawn down within 72 hours, the bottom area of the infiltration BMP must be increased or the *Required Recharge Volume* must be reduced. The *Required Recharge Volume* may be reduced by reducing the amount of impervious surfaces on the site or by taking advantage of the Low Impact Development Site Design Credits.

To determine whether an infiltration BMP will drain within 72 hours, the following formula must be used[21]:

$$Time_{drawdown} = \frac{Rv}{(K)(Bottom\ Area)}$$

Where:
Rv = Storage Volume
K = Saturated Hydraulic Conductivity For "Static" and "Simple Dynamic" Methods, use Rawls Rate (see Table 2.3.3). For "Dynamic Field" Method, use 50% of the in-situ saturated hydraulic conductivity.
Bottom Area = Bottom Area of Recharge Structure[22]

[20] The drawdown analysis also assumes that the water table does not fluctuate during the draw down period.

[21] In some cases, the infiltration structure may be designed to treat the *Required Water Quality Volume* and/or to attenuate peak discharges in addition to infiltrating the *Required Recharge Volume*. In that event, the storage volume of the structure must be used in the formula for determining drawdown time in place of the *Required Recharge Volume*.

Drawdown Analysis Example for "Static" and "Simple Dynamic" Methods: Assume a one-acre site. An area that is 0.75 acre is proposed to be developed as impervious area. The soils are Hydrologic Soil Group "A" soils. An infiltration structure is proposed to meet Standard 3. Using Equation 1, the *Required Recharge Volume* is determined to be 1633.5 cubic feet. The soil textural analysis determined the soil layer for the proposed infiltration basin bottom is "sand," which is classified by the NRCS as Hydrologic Soil Group "A". The bottom area of the proposed basin is 303 square feet. Determine whether the proposed infiltration structure will draw down the 1633.5 cubic feet of water within 72 hours.

$$Time_{drawdown} = \frac{1633.5\ cubic\ \ feet}{(8.3\ inches/hour)(1\ ft/12\ inches)(303\ square\ \ feet)}$$

$Time_{drawdown}$ = 7.8 hours

7.8 hours < 72 hours so result is satisfactory for design purposes

The infiltration structure as designed is estimated to drawdown in 7.8 hours, well within the 72-hour requirement. If the analysis indicated that the recharge took longer than 72 hours, the bottom area of the infiltrative surface would need to be increased (e.g., instead of an infiltration structure with 303 square foot bottom area, evaluate a structure with a bottom area of 350 square feet, etc.) or the *Required Recharge Volume* would have to be reduced. The *Required Recharge Volume* could be reduced by reducing the amount of impervious surfaces or by taking advantage of the Low Impact Design Site Design Credits.

Drawdown Analysis Example for "Dynamic Field" Method: Assume a one-acre site. 0.75 acres is proposed to be developed. The soils are classified in the NRCS County Soil Survey as Hydrologic Soil Group "A" soils. An infiltration structure is proposed to meet Standard 3. Although the *Required Recharge Volume* is 1633.5 cubic feet, the *Storage Volume* of the infiltration basin was determined to be 595 cubic feet using the "*Dynamic Field*" Method. The saturated hydraulic conductivity tests in the actual soil horizon where infiltration is proposed indicates that the lowest rate is 20 inches/hour. The bottom area of the proposed basin is 303 square feet (sized approximately 30 long by 10 feet wide). Determine whether the proposed infiltration basin will draw down the *Required Recharge Volume* for design purposes within 72 hours.

Solution: The exfiltration rate used for purposes of design is 50% of the in-situ rate. Assuming the infiltration rate is constant, the time to drawdown the *Required Recharge Volume* for design purposes would be:

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[22] To account for the porosity of the stone, a different formula is required to determine whether the Required Recharge Volume drains within 72 hours if the infiltration structure is a trench filled with stone. In that event, the drawdown time would be calculated as follows with n = porosity of the stone:

$$Time_{drawdown} = \frac{Rv}{(K)(Trench\ \ Bottom\ \ Area)(n)}$$

$$Time_{drawdown} = \frac{Rv}{(K)(Bottom\ \ Area)}$$

Where
Rv= Required Recharge Volume
K = 50% of the in-situ Saturated Hydraulic Conductivity
Bottom Area = Bottom Area of Recharge Structure

$$Time_{drawdown} = \frac{1633.5\ cubic\ \ feet}{(10\ inches\ /\ hour)(1\ \ ft\ /\ 12\ \ inches(303\ \ square\ \ feet)}$$

$Time_{drawdown}$ = 6.5 hours

6.5 hours < 72 hours so result is satisfactory for design purposes.

OTHER CONSIDERATIONS FOR STANDARD 3
CAPTURE AREA ADJUSTMENT: DETERMININING IF ENOUGH RUNOFF IS DIRECTED TO THE RECHARGE PRACTICE[23]

Sufficient runoff must be directed to the infiltration BMPs to ensure infiltration of the *Required Recharge Volume*. In some cases, designers size exfiltration practices based on the *Required Recharge Volume*, but then direct only a portion of the site's impervious area to the practice. As a result, the infiltration BMPs may not be able to capture sufficient rainfall on an average annual basis to meet the *Required Recharge Volume*. In this case, designers and reviewers have two options: either redesign the site so that runoff from more of the impervious areas located on the site is directed to the infiltration BMPs, or increase the storage capacity of the infiltration BMPs so that they may capture more of the runoff from the impervious surfaces located within the contributing drainage area. The following procedure describes the method that must be used where runoff from only a portion of the impervious area on a site is directed to one or more infiltration BMPs. This procedure is required to ensure that the infiltration BMPs are able to capture sufficient runoff from the impervious surfaces within the contributing drainage area to infiltrate the *Required Recharge Volume*. This procedure is not required for those sites where all impervious surfaces drain to an infiltration BMP. In no case shall runoff from less than 65% of the site's impervious cover be directed to the BMPs intended to infiltrate the *Required Recharge Volume.* When less than 65% of impervious surfaces on a site are directed to infiltration BMPs, the system cannot capture sufficient runoff to infiltrate the *Required Recharge Volume.*

1) Calculate the *Required Recharge Volume* based on total site impervious cover and underlying soil classification and size the infiltration BMP using the "*Static*" Method or one of the "*Dynamic*" Methods

2) Calculate the site's impervious area that drains to proposed recharge facilities.

[23] A similar adjustment must be made if runoff from all impervious surfaces is not directed to the treatment BMPs.

3) Divide the total site impervious area by the impervious area draining to the proposed recharge facilities.

4) Multiply the resulting quotient from Step 3 by the original *Required Recharge Volume* calculated under Step 1 to determine the adjusted minimum storage volume needed to meet the recharge volume requirement. The *"Static"* Method or either of the *Dynamic* Methods may be used to determine the storage volume.

Example:

A 1.5-acre site with 1 acre of impervious cover overlays Hydrologic Soil Group "A" soils. Based on site and topographic constraints, runoff from only 0.7 acres of the impervious cover will be discharged to one or more recharge facilities. Find the minimum recharge storage volume needed for the site, assuming the *"Static"* Method.

Solution:

1) *Rv = F x impervious area*
2) *Rv = [(0.6 inches/12 inches/foot)(1.0 acre)(43,560 sq. ft./acre)]*
   Rv = 2,178 cubic feet
3) *Site area draining to recharge facilities = 0.70 (1.0 acre) = 0.7 acres*
4) *Ratio of total site area to site area draining to recharge facilities = 1.0 acre/0.7 acre = 1.43*
5) *Adjusted minimum required recharge volume = [(1.43)(2,178 cubic feet)] = 3,1154 cu. ft.*

Assuming that the analysis indicates that the stored runoff will exfiltrate completely into the ground within 72 hours, the recharge facility needs to be sized, at a minimum, to hold 3,114 cubic feet of runoff.

MOUNDING ANALYSIS

Mounding analysis is required when the vertical separation from the bottom of an exfiltration system to seasonal high groundwater is less than four (4) feet *and* the recharge system is proposed to attenuate the peak discharge from a 10-year or higher 24-hour storm (e.g., 10-year, 25-year, 50-year, or 100-year 24-hour storm). In such cases, the mounding analysis must demonstrate that the *Required Recharge Volume* (e.g., infiltration basin storage) is fully dewatered within 72 hours (so the next storm can be stored for exfiltration). The mounding analysis must also show that the groundwater mound that forms under the recharge system will not break out above the land or water surface of a wetland (e.g., it doesn't increase the water sheet elevation in a Bordering Vegetated Wetland, Salt Marsh, or Land Under Water within the 72-hour evaluation period).

The Hantush[24] or other equivalent method may be used to conduct the mounding analysis. The Hantush method predicts the maximum height of the groundwater mound beneath a rectangular or circular recharge area. It assumes unconfined groundwater flow, and that a linear relation exists between the water table elevation and water table decline rate. It results in a water table recession hydrograph depicting exponential decline. The Hantush method is available in proprietary software and free on-line calculators on theWeb in automated format. If the analysis indicates the mound will prevent the infiltration BMP from fully draining within the 72-hour period, an iterative process must be employed to determine an alternative design that drains within the 72-hour period.

Mounding analysis is also needed when recharge is proposed at or adjacent to a site classified as contaminated, was capped in place, or has an Activity and Use Limitation (AUL) that precludes inducing runoff to the groundwater, pursuant to MGL Chapter 21E and the Massachusetts Contingency Plan 310 CMR 40.0000; or is a solid waste landfill pursuant to 310 CMR 19.000; or groundwater from the recharge location flows directly toward a solid waste landfill or 21E site. In this case, the mounding analysis must determine whether infiltration of the *Required Recharge Volume* will cause or contribute to groundwater contamination.

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STANDARD 4. WATER QUALITY

Required Computations or Demonstrations:

Source Control and Pollution Prevention Measures must be identified in the Pollution Prevention Plan[25]

Computations that are or may be necessary:

a. *Required Water Quality Volume*
b. TSS removal rate
c. Weight determination

WATER QUALITY TREATMENT VOLUME[26]

$$V_{WQ} = (D_{WQ}/12 \text{ inches/foot}) * (A_{IMP} * 43{,}560 \text{ square feet/acre}) \qquad \textbf{Equation (3)}$$

V_{WQ} = *Required Water Quality Volume* (in cubic feet)
D_{WQ} = Water Quality Depth: one-inch for discharges within a Zone II or Interim Wellhead Protection Area, to or near another critical area, runoff

[25] See Volume 1, Chapter 1 and Volume 2, Chapter 1.

[26] Some proprietary BMPs are sized based on a flow rate. Applicants proposing such BMPs must provide documentation that the BMPs have been sized to treat the *Required Water Quality Volume.* MassDEP intends to provide detailed guidance on how to convert a flow rate to the *Required Water Quality Volume.*

from a LUHPPL, or exfiltration to soils with infiltration rate greater than 2.4 inches/hour or greater; ½-inch for discharges near or to other areas.

A_{IMP} = Impervious Area (in acres)

Example for ½-inch D_{WQ}: Assume a two (2) acre site. One (1) acre is proposed to be developed for a retail store and parking lot. The parking lot is proposed to have 50 parking spaces, and generate less than 1,000 vehicle trips/day. The discharge is to be directed to a wetland resource area not determined to be a critical area, the land use is not a Land Use with a Higher Potential Pollutant Load ("LUHPPL"), and the soil does not have a rapid infiltration rate. The *Required Water Quality Volume* is to be directed to a wet basin, and not a stormwater infiltration BMP. Determine the *Required Water Quality Volume*.

Solution: The *Required Water Quality Volume* is determined for the impervious surfaces. Use Equation (3).

V_{WQ} = (D_{WQ}/12 inches/foot) * (A_{IMP} * 43,560 square feet/acre)
V_{WQ} = (½-inch/12 inches/foot) * (1 acre * 43,560 square feet/acre)
V_{WQ} = 1815 cubic feet

Example for 1-inch D_{WQ}: Assume a two (2) acre site. One (1) acre is to be developed for a retail store and parking lot. The parking lot is proposed to have 50 parking spaces, and generate less than 1,000 vehicle trips/day. The discharge is proposed to be directed to a wetland resource area that is a cold-water fishery. A cold-water fishery is defined as a critical area by the Wetland Protection Act Regulations. The *Required Water Quality Volume* is to be directed to a filtering Bioretention Area that is not designed to infiltrate. Determine the *Required Water Quality Volume*.

Solution: The *Required Water Quality Volume* is determined for the impervious surface

V_{WQ} = (D_{WQ}/12 inches/foot) * (A_{IMP} * 43,560 square feet/acre)
V_{WQ} = (1-inch/12 inches/foot) * (1 acre * 43,560 square feet/acre)
V_{WQ} = 3630 cubic feet

TSS REMOVAL PERCENTAGE COMPUTATIONS

MassDEP has two forms available to prepare the TSS removal computations; one is an automated EXCEL spreadsheet and the other is a hard copy version (that must be completed by hand). Both forms are the same, except that the Excel Spreadsheet performs the computations automatically. The automated Excel Spreadsheet is much easier to use than the hand method. A completed version of either form must be submitted as part of the Stormwater Report to demonstrate that the proposed treatment options will remove 80% of the TSS load on a design basis. A separate form must be completed for each stormwater outlet. For stormwater discharges that require 44% TSS pretreatment (e.g., within areas with rapid infiltration rates, Zone IIs, Interim Wellhead Protection Areas, or near or to other Critical Areas), the form must also be submitted to demonstrate that 44% TSS removal has been achieved prior to discharge to an infiltration BMP.

Information on the automated method is available on the MassDEP web site. When proposing proprietary structural treatment practices or when using the Low Impact Site Design Credit, proponents must use the manual form, since neither the proprietary treatment practices nor the Low Impact Site Design Credit are listed in the dropdown menu in the automated Excel spreadsheet. An example that demonstrates how to use the manual form is set forth below.

Figure 2.3.4 Example of TSS Removal Form

INSTRUCTIONS:
1. Complete Blue Blocks
2. In BMP Column, Click on Blue Cell to Activate Drop Down Menu
3. Select BMP from the Drop Down Menu

Location:

TSS Removal Calculation Worksheet

B BMP[1]	C TSS Removal Rate[2]	D Starting TSS Load*	E Amount Removed (C*D)	F Remaining Load (D-E)
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00

Total TSS Removal = 0%

Project:
Prepared By:
Date:

*Equals remaining load from previous BMP (E) which enters the BMP

1. BMP From Table on Page 1-7 of MassDEP Stormwater Mgt. Policy Handbook, Volume 1
2. TSS Removal Rate from Table on page 1-7 of the MassDEP Stormwater Mgt. Policy, Volume 1

Example for 44% TSS Pretreatment: Sheet runoff from a high-intensity parking lot with greater than 1,000 vehicle trips per day is directed to a series of off-line Deep Sump Catch Basins. The runoff from the deep sump catch basins is directed to an Oil/Grit Separator for further pretreatment, and then to an infiltration basin. There is a single stormwater outlet from the infiltration basin directed to a stream. MassDEP assigns a TSS annual removal rate for a properly designed Deep Sump Catch Basin of 25% and a properly designed Oil/Grit Separator of 25%. Use the Manual Form to determine whether the 44% pretreatment requirement is met.[27]

Solution: The TSS removal table (Figure 2.3.4) must be completed and presented with the Stormwater Report accompanying the Wetlands NOI. Manually, write in the name "Deep Sump Catch Basin" into Cell B1. In Cell C2, manually write in the assigned 25% TSS removal rate for Deep Sump Catch Basins. Only 25% TSS credit is provided, even though multiple Deep Sump Catch Basins capture runoff and direct it to the Oil/Grit Separator. Write 1.00 in Cell D1 (100% of the TSS load is presumed to be directed to the Deep Sump Catch Basin inlets). Multiply the 25% TSS removal rate for the Deep Sump Catch Basin by

[27] If runoff is directed to a BMP like an extended dry detention basin that is required to include a sediment forebay, no additional credit is given to the sediment forebay when determining whether 80% TSS removal is achieved. However, the 25% removal credit given to the sediment forebay can be used to satisfy the 44% pretreatment requirement prior to discharge to the infiltration structure for runoff from LUHPPLs, within an area with a rapid infiltration rate, within a Zone II or Interim Wellhead Protection Area, or near or to other critical areas.

the starting TSS load of 1. Fill the result of 0.25 or 25% in Cell E1. Next determine the remaining TSS load, after stormwater leaves the device. The remaining load is the Starting TSS Load minus the TSS removed by the device. In this case, the remaining load is 1 – 0.25 = 0.75 or 100% - 25% = 75%. Write 75% in Cell F1.

Next, manually write in the name of the second structural BMP, the Oil/Grit Separator, into Cell B2. In Cell C2, manually write in 0.25 or 25%, the assigned TSS removal rate for the Oil/Grit Separator properly designed in accordance with the Volume 2, Chapter 2 specifications. In Cell D2, manually write in 0.75 or 75%, which is the remaining load listed in Cell F1 that is being directed to the Oil/Grit Separator. Multiple Cells C2 by D2, which would be 0.25 x 0.75. The result is 0.1875 or 0.19, rounded. Write this result in Cell E2. The remaining load is then determined by subtracting Cell E2 from D2, or 0.75 – 0.19 = 0.56. The result of 0.56 or 56% is manually written into Cell F2. Since the stormwater is not routed through any other devices for pretreatment, the final result is determined by adding 25% and 19% to obtain 44%. Manually write this result in Cell E6.

Please note that the TSS removal rates for each device as set forth in the TSS chart included in Volume 1, Chapter 1 must not added. If the TSS removal rates set forth in the chart for each device were added, it would appear that the Deep Sump Catch Basins and Oil/Grit Separator would remove 50% of the presumed annual TSS load (25% +25% = 50%). This is not the case. Adding the removal rates for the Deep Sump Catch Basins and Oil/Grit Separator does not take into account the fact that the influent TSS load is reduced when stormwater is routed from the first structural BMP to the second structural BMP. In this example, the influent load to the Oil/Grit Separator is only 75%, not 100%, because the Deep Sump Catch Basin is presumed to have removed 25% of the initial TSS load for runoff enters the Oil/Grit Separator.

De Minimis Stormwater Discharges for Purposes of Standard 4

The 80% TSS removal rate must be achieved at each outlet discharging to a receiving wetland. The only exception to this is when the discharge is considered to be *de minimis*.[28] The stormwater discharge from an individual outlet is considered *de minimis* when all the following conditions are satisfied:

- Physical site conditions preclude installation of a TSS treatment practice prior to discharge (e.g., lack of space between a wetland and a road, lack of head differential).
- The discharge is less than or equal to 1 CFS for the runoff associated with the 2-year 24-hour storm.
- 80% TSS removal is achieved on an average weighted basis from the site as a whole using the weighted average method described below. This will require more than 80% TSS removal at some stormwater outlets to compensate for the outlets that achieve less

[28] MassDEP and MassHighway recognize that it may be difficult to meet the 80% TSS removal rate at each outlet along a MassHighway redevelopment or add-a-lane project. For redevelopment projects, MassHighway and MassDEP have identified a "macro" approach that allows MassHighway to propose more than 80% TSS at some points along the portion of a roadway within a subwatershed to compensate for those locations within the same subwatershed where, because of right-of way constraints, it is not possible to achieve 80% TSS removal. Information on this approach is contained in the 2004 MassHighway Handbook for Roads and Bridges. MassDEP and MassHighway intend to develop a similar approach for add-a-lane projects when the MassHighway Handbook is revised. MassDEP and MassHighway intend to work together to revise the MassHighway Handbook in light of the 2008 changes to the Stormwater Management Standards.

than 80% TSS removal and achieve an overall weighted average reduction in TSS of 80% or more across the entire site.

- The stormwater outlets where additional controls are used to achieve more than 80% TSS removal must discharge to the same reach of the same wetland or water body as the outlets that achieve less than 80% TSS removal. A discharge is not *de minimus* if stormwater from an outlet discharging untreated or partially treated stormwater is discharged to one wetland or water body and stormwater that achieves more than 80% TSS removal is discharged to another wetland or water body.
- Controls are placed at the outlet to prevent erosion or scour of the wetland/stream channel and bank.
- Standard 2 (Peak rate attenuation) and Standard 3 (recharge) must be achieved on a site-wide basis.
- Source control and pollution prevention measures that mitigate the impact of the untreated or partially treated discharges are identified in the Pollution Prevention Plan required by Standard 4 and fully implemented (e.g., such as street sweeping).
- The size of the drainage area contributing runoff to the untreated outlet has been reduced to the maximum extent practicable.

If all these conditions are met, the discharge is considered *de minimus*. In that event, the Weighted Average Method described below must be used to determine if the 80% TSS removal rate is achieved on a site-wide basis for purposes of design.

$$Weighted\ Average\,\% = \frac{\left(Area_1\right)\left(TSS_1\%\right) + (Area_2)(TSS_2\%) + (Area_n)(TSS_n\%)\big)}{(Area_1 + Area_2 + Area_n)} \quad \textbf{\textit{Equation (4)}}$$

Area = size, expressed in acres, square feet, or other units
TSS% = Assigned TSS removal rate, expressed as % (e.g. 25%)

Weights must be based on the size of each drainage area.

Example – De minimus discharge: Assume a site with 10 acres of impervious surfaces with two outlet points discharging to the same reach of a wetland resource area. Runoff from 9.995 impervious acres is to be directed to one outlet, after receiving 90% TSS removal. Drainage from a low point in the entry road from the remaining 0.005 acres (218 square feet) is to be directed to another outlet to the same wetland resource area, with no TSS treatment. Measures such as source reduction of winter sanding and quarterly street sweeping with vacuum sweepers are incorporated into the Pollution Prevention Plan required by Standard 4 to reduce TSS loading from the outlet point. In-pipe storage is proposed to reduce the peak rate of the discharge. Erosion controls such as riprap are proposed at the outlet to reduce the velocity of the discharge so it does not scour the wetland (Standard 1). The discharge is calculated to be less than 1 CFS. The size of the drainage area where treatment is not feasible has been reduced to the maximum extent practicable. No TSS treatment is possible, because there is insufficient head between the road sag point and the surface elevation of the wetland resource area. The overall weighted average is determined to be 89% using Equation 4. The impact to the wetland resource area from stormwater is considered *de minimis*, because the calculated discharge is less than 1 CFS and all the other conditions set forth above are met.

Example – Discharge is not de minimus: Assume a site with 10 acres of impervious surfaces with two outlet points discharging to the same reach of a wetland resource area. Runoff from 9 impervious acres is to be directed to one outlet, after receiving 90% TSS removal. Runoff from the remaining one acre is to be directed to another outlet, with no TSS treatment. The discharge rate from the one acre is determined to be 10 CFS. The overall weighted removal average is determined to be 81% TSS using Equation 4.

Solution: The discharge is not *de minimis*, because the 1 CFS threshold is exceeded. Therefore, weighting cannot be used. The discharge would result in a violation of Standard 1, because an untreated discharge is being made to waters of the Commonwealth.

WHEN ONE PRACTICE IS SIZED TO MEET BOTH STANDARDS 3 AND 4

Often one practice is sized to provide both water quality treatment and recharge. Unless 80% of the TSS load is proposed to be fully removed prior to discharge to the infiltration BMP, the infiltration BMP is being used to fulfill the requirements of both Standards 3 (Recharge) and 4 (Water Quality Treatment).[29] In such instance, the infiltration BMP must be sized to treat or hold the Target Volume, the larger of the *Required Water Quality Volume* and the *Required Recharge Volume*. For example, if the *Required Water Quality Volume* to be recharged is 1 inch and the *Required Recharge Volume* is 0.6-inches, the recharge system needs to be sized to handle the *Required Water Quality Volume,* since it is larger than the *Required Recharge Volume.* Only that portion of the *Required Water Quality Volume* directed to the infiltration BMP must be considered.

Example: Assume a two (2) acre site. One (1) acre is proposed to be a retail store and parking lot. The parking lot is proposed to have 50 parking spaces and generate less than 1,000 vehicle trips/day. The proposed retail building has a non-metal roof. The location is not near a critical area, the land use is not a land use with a higher potential pollutant load, and the soil was determined by in-situ testing to not have a rapid infiltration rate. The soils are Hydrologic Soil Group "A" soils. The recharge system, an infiltration basin, is proposed to meet both Standards 3 (recharge) and 4 (Water Quality). Runoff in excess of the *Water Quality Volume* is proposed to be routed to a dry detention basin for peak rate attenuation. Determine the storage volume of the infiltration basin, using the Static Method.

Solution: The *Required Water Quality Volume* is based on 0.5 inch of runoff and the *Required Recharge Volume* is based on 0.6-inches (see Table 2.3.2). (0.6 inches is more than 0.5 inches.) In this case, the Target Volume is the *Required Recharge Volume*, since it is larger than the *Required Water Quality Volume*.

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[29] The only exception is for rooftop runoff from a non-metal roof, or runoff from a metal roof that is located outside an industrial site and outside an Interim Wellhead Protection Area or Zone II.

REFERENCES FOR STANDARD 4

Claytor, R.A., and Schueler, T.R., 1996, Design of Stormwater Filtering Systems. Center for Watershed Protection, Silver Spring, MD.

Dewberry Companies, 2002, Land Development Handbook, Second Edition, McGraw Hill, New York, New York.

Dorman, M.E., J.P. Hartigan, R.F. Steg, and T.F. Quasebarth, 1996, Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Volume I: Research Report. FHWA-RD-96-095. Federal Highway Administration, Office of Research, Development and Technology.

Dorman, M.E., T.S. George, J.P. Hartigan, and T.F. Quasebarth, 1996, Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Volume II: Design Guidelines. FHWA-RD-96-096. Federal Highway Administration, Office of Research, Development and Technology.

Horner, Richard, R., Skupien, Joseph, J., Livingston, Eric, H., and Shaver, H., Earl, 1994, Fundamentals of Urban Runoff Management, Technical and Institutional Issues, Terrene Institute in cooperation with the U.S. EPA.

Minton, G., 2002, Stormwater Treatment, Resource Planning Associates, Seattle, WA.

Schueler, T. 1995. Site Planning for Urban Stream Protection. Metropolitan Washington Council of Governments, Washington, DC.

Winkler, E, Ahlfeld, D., Askar, G., Minihane, M., 2001, Final Report: Development of a Rational Basis for Designing Recharging Stormwater Control Structures and Flow and Volume Design Criteria. Prepared for Massachusetts Department of Environmental Protection Project 99-06/319. University of Massachusetts. (PDF File, April, 2001)

STANDARD 5. LAND USES WITH HIGHER POTENTIAL POLLUTANT LOADS

Source controls and pollution prevention measures to minimize or eliminate the exposure of any LUHPPLs to rain, snow, snow melt, and runoff must be identified in the Long-Term Pollution Prevention Plan.[30]

BMPs determined to be suitable for treating runoff from LUHPPL must be used.

One-inch rule applies when calculating *Required Water Quality Volume.*

Pretreatment Requirement 44% TSS removal must be achieved before discharge to infiltration structure.

If there is a potential for runoff with high concentrations of oil and grease, an oil grit separator, sand filter, filtering bioretention area or equivalent must be used to provide pretreatment.

For computations, see Standard 4.

<u>REFERENCES FOR STANDARD 5</u>

Massachusetts Department of Environmental Protection, Surface Water Quality Discharge Standards, 314 CMR 3.00 and 4.00

U.S. EPA, 2000, Multi-Sector General Permit

STANDARD 6. CRITICAL AREAS

Required Computations or Demonstrations

Standard 6 applies to discharges within Zone II, Interim Wellhead Protection Areas or near or to other Critical Areas: Shellfish Growing Areas, Bathing Beaches, Outstanding Resource Waters, Special Resource Waters, and Cold-Water Fisheries.

Source control and pollution prevention prevention measures must be identified in a long-term pollution prevention plan.

Use BMPs determined to be suitable for the particular critical area.

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[30] Some land uses with higher potential pollutant loads may be covered under the Multi-Sector General Permit. See Volume 1, Chapter 2. In that event, a SWPPP is required. Applicants may use one document to fulfill the SWPPP requirements of the Multi-Sector General Permit and the pollution prevention plan requirements of Standard 4. If there is a discharge to an ORW, MassDEP WM09 must be submitted.

One-inch rule is used to calculate the *Required Water Quality Volume.*

44% TSS removal must be achieved prior to discharge to the infiltration BMP.

See Standard No. 4 for computations.

STANDARD 7. REDEVELOPMENT

Required Computations or Demonstrations

Submit a Source Control and Pollution Prevention Prevention Plan as required by Standard 4.

Submit a Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan as required by Standard 8.[31]

Submit an Operation and Maintenance Plan as required by Standard 9.

Submit Illicit Discharge Compliance Statement required by Standard 10.[32].

Demonstrate that there are no new discharges that cause or contribute to erosion of wetlands or waters of the Commonwealth. Standard 1.

Complete computations to determine whether proposed structural BMPs fully meet the requirements of Standards 2 through 6. At a minimum, demonstrate that proposed stormwater management system meets Standards 2, 3, and the structural BMP requirements of Standards 4, and, if applicable, 5 and 6 to the maximum extent practicable. Demonstrate that measures have also been proposed to improve existing conditions. The "Redevelopment Checklist" set forth in Volume 2 Chapter 3 may be used to make these demonstrations.

STANDARD 8. CONSTRUCTION PERIOD CONTROLS

Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan as required by Standard 8.[33]

Computations or Demonstrations

[31] See Standard 8

[32] See Standard 10

[33] For projects subject to jurisdiction under the Wetlands Protection Act, the construction period pollution prevention erosion and sedimentation control plan should be included as part of the Stormwater Report submitted with the Notice of Intent. For highly complex projects where the proponent demonstrates that submission with the Notice of Intent is not possible, the issuing authority has discretion to issue an Order of Conditions authorizing the project prior to submission of the construction period erosion and sedimentation control plan. All Orders of Conditions shall provide that the construction period erosion and sedimentation control plan shall be submitted prior to the commencement of any land disturbance activity. Information on the erosion and sedimentation control plan is set forth in Volume 2, Chapter 1.

Necessary computations:

a. Area to be disturbed[34]

b. Computations demonstrating that control proposed measures are properly sized.

CONTROL PRACTICES PROPERLY SIZED

Computations must be provided to demonstrate that all control measures are properly sized in accordance with any relevant manufacturer specifications, good engineering practices, requirements specified in the Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas, and EPA Construction General Permit, whichever is more stringent. Special sizing is required for construction period sediment traps.

Sediment Trap Sizing: Sediment traps must provide storage for a calculated volume of runoff from the 2-year, 24-hour storm to meet EPA Construction General Permit requirements. The Massachusetts Erosion and Sedimentation Control Guidelines require that the construction period control sediment trap must be sized to provide 3,600 cubic feet of storage per acre drained. When computing the number of acres draining into a common location, it is not necessary to include flows from off-site areas and flows from on-site areas that are either undisturbed or have undergone final stabilization where such flows are diverted around both the disturbed area and the sediment trap.

Potential Soil Loss: Where potential soil loss needs to be evaluated as part of sizing a control practice, the Revised Universal Soil Loss Equation2 (RUSLE2) may be used. RUSLE2 is an automated method, based on the Universal Soil Loss Equation (USLE).

RUSLE2 NRCS Method[35] (5)

REFERENCES FOR STANDARD 8

Fifield, J.S., 2002, Field Manual on Sediment and Erosion Control Best Management Practices for Contractors and Inspectors, Forester Press.

Fifield, J.S., 2004, Designing for Effective Sediment and Erosion Control on Construction Sites, Forester Press

Massachusetts Department of Environmental Protection, 2003, Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas, http://www.mass.gov/dep/water/esfull.pdf

[34] Land disturbances greater or equal to 1 acre required to obtain coverage under EPA NPDES Construction General Permit. If a stormwater discharge is proposed to an ORW, MassDEP Application WM09 must be submitted.

[35] RULSE2 may be downloaded from NRCS via the web at: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm

Pitt, R., Clark, S., and Lake, D., 2007, Construction Site Erosion and Sediment Controls: Planning, Design and Performance, Forester Press

U.S. EPA, 2003, Construction General Permit for Small and Large Construction Activities

STANDARD 9. OPERATION AND MAINTENANCE PLAN

Operation and Maintenance Plan as required by Standard 9 must be submitted.[36]

No computations are necessary.

STANDARD 10. ILLICIT DISCHARGES TO DRAINAGE SYSTEM

Measures to prevent illicit discharges must be included in Pollution Prevention Plan.

Illcit Discharge Compliance Statement must be submitted[37].

No computations are necessary.

LOW IMPACT DEVELOPMENT SITE DESIGN CREDITS

The Low Impact Development Site Design Credits encourage environmentally sensitive site design and Low Impact Development techniques for managing stormwater that minimize impervious surfaces and preserve natural hydrologic conditions. The credits allow project proponents to reduce or eliminate the structural stormwater BMPs otherwise required to meet Standards 3 and 4 by directing stormwater runoff to qualifying pervious surfaces that provide recharge and treatment. The credits are based on research published by Schueler 1994 and others indicating that the greater the impervious area, the more stream channel erosion, water quality impacts, and reductions in base flow. Schueler 1994 estimated that water quality is good in streams from watersheds with less than 10% impervious cover, degraded in watersheds with 10 to 25% impervious cover, and poor when impervious cover exceeds 25%. The credit system is also based on the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) Smart Growth Toolkit, Appendix A.

THE IMPACT OF THE CREDITS:
As more fully detailed below, the credits may be used to reduce the *Required Recharge Volume* and the *Required Water Quality Volume* provided that any pervious surfaces used to treat and infiltrate stormwater runoff meet the requirements set forth herein.

[36] Information on the Operation and Maintenance Plan is set forth in Volume 1, Chapter 1 and Volume 2, Chapter 1.

[37] For projects subject to jurisdiction under the Wetlands Protection Act, the Illicit Discharge Compliance Statement may be included in the Stormwater Report submitted with the Notice of Intent. The Illicit Discharge Compliance Statement must be submitted before stormwater is discharged to the post-construction stormwater BMPs.

A proponent of a project that is eligible for the site design credit is required to:

- Develop and implement a construction period pollution prevention and erosion and sedimentation control plan and a long-term pollution prevention plan and operation and maintenance plan in accordance with all applicable provisions of Standards 4, 5, 6, 8, and 9 and to remove illicit discharges in accordance with Standard 10.

- Attenuate the peak discharge rate in accordance with Standard 2.

- Comply with the requirements of Standard 1 regarding new stormwater outfalls.

The application of these credits does not relieve the design engineer or reviewer from the standard of engineering practice associated with safe conveyance of stormwater runoff and good drainage design.

NOT ELIGIBLE FOR CREDIT:

The Low Impact Site Design Credit may not be applied to reduce the *Required Recharge Volume* and the *Required Water Quality Volume:*

- at sites in a Zone II with impervious surfaces covering 15% of the site or 2500 square feet, whichever is greater;

- at sites where stormwater runoff is directed to non-permeable soils, such as bedrock and soils classified as Hydrologic Soil Group D; and

- at sites with urban fill, soils classified as contaminated pursuant to the Massachusetts Contingency Plan (MCP), and soils with seasonal high groundwater –groundwater elevation within 2 feet of the land surface.

Sites with LUHPPL are not eligible for Credit No. 1.

Sites with LUHPPL are eligible for Credits 2 and 3, provided that no runoff from the areas or activities that may generate runoff with higher potential pollutant loads is directed to the pervious surfaces used to satisfy the credit, and provided further that the proposal satisfies all the other requirements set forth herein.

Runoff from metal roofs is only eligible for Credit 2 when the metal roof is located outside a Zone II or Interim Wellhead Protection Area and the building is not used for industrial purposes.

Runoff from green roofs is not eligible for Credit 2.

AVAILABLE CREDITS:

CREDIT 1. Environmentally Sensitive Development
CREDIT 2. Rooftop Runoff Directed to Qualifying Pervious Area
CREDIT 3. Roadway, Driveway or Parking Lot Runoff Directed to Qualifying Pervious Area

"Qualifying Pervious Areas" are defined as natural or landscaped vegetated areas fully stabilized, with runoff characteristics at or lower than the NRCS Runoff Curve Numbers in the table set forth below. The Qualifying Pervious Area may be located in the outer 50-foot portion of a wetland buffer zone. However, it must not be located in the inner 50-foot portion of a wetland buffer zone (that portion of the buffer zone immediately adjacent to a wetland).

Maximum NRCS Runoff Curve Numbers for Qualifying Pervious Area

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

CREDIT EXPLANATION

Credit 1: Environmentally Sensitive Development

This credit is given for environmentally sensitive site design techniques that "cluster development" or reduce development scale, to leave a significant amount of the site undisturbed in its natural state. If a site is designed, constructed, operated and maintained in accordance with the requirements of this credit, a project proponent need not develop and implement additional structural stormwater BMPs to meet Standards 3 and 4.

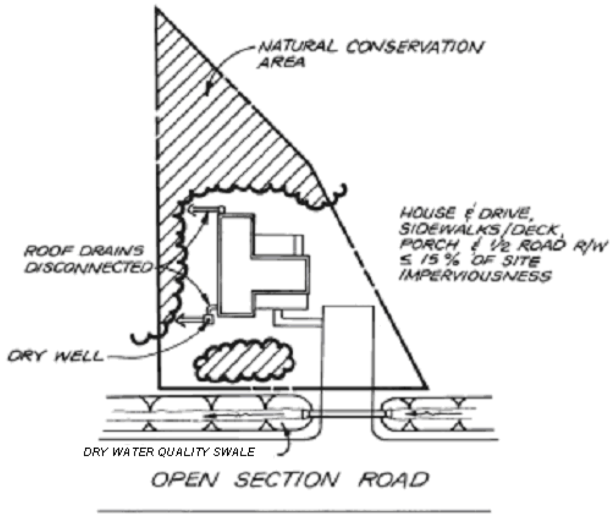

FIGURE 1: Credit No. 1 (Environmentally Sensitive Development) Example

Minimum Criteria for Credit

The *Required Recharge Volume* and the *Required Water Quality Volume* requirements are completely met without the use of structural practices in certain low density (less than 1 dwelling unit per acre) or cluster residential developments when the following conditions are met:

- The total impervious cover footprint must be less than 15 % of the base lot area. Because alterations are limited in these areas under the Wetlands Protection Act Regulations, 310 CMR 10.00, the following wetland resource areas may not be included in the base lot area used for purposes of determining compliance with this requirement: any vegetated wetlands (Bordering Vegetated Wetland (BVW), Isolated Vegetated Wetland (IVW), Salt Marsh); Land Under Water and Waterways; Land Under Ocean; Bank; Coastal Bank; or 5,000 square feet or 10% of the Riverfront Area, whichever is greater.
- No alteration may occur in any coastal wetland resource areas other than Land Subject to Coastal Storm Flowage.
- No alteration may occur in BVW or IVW.
- A minimum of 25% of the site must be protected as a natural conservation area. To qualify as a natural conservation area, an EEA Conservation Restriction must be placed on the protected area. Information on adopting conservation restrictions is available via the web at: http://www.mass.gov/envir/dcs/restrictions/default.htm. Because alterations are limited in these areas under the Wetlands Protection Act Regulations, 310 CMR 10.00, the Natural Conservation Area must not include the following wetland resource areas: any vegetated wetlands (BVW, IVW, Salt Marsh); Land Under Water and Waterways; Land Under Ocean; Bank; Coastal Bank; or more than 5000 square feet or 10% of the Riverfront Area, whichever is greater.
- Stream buffers must be incorporated into the design of any areas adjacent to perennial and intermittent streams on the site. A stream buffer is the inner 50 feet of the buffer zone adjacent to the bank. At a minimum, no work, including any alteration for stormwater management, may be proposed in the 50-foot-wide area in the buffer zone along any

wetland resource area. The proposed project shall not include any impervious surfaces in the 50-foot-wide area in the buffer zone along any wetland resource area.

- The amount of impervious surface shall not exceed 40% of the area of the buffer zone between 50 and 100 feet from any resource area or the amount of existing impervious surface, whichever is greater.
- No work may be proposed in a buffer zone that:
    - Borders an Outstanding Resource Water,
    - Contains estimated wildlife habitat which is identified on the most recent Estimated Habitat Map of State-listed Rare Wetlands Wildlife prepared by the Natural Heritage and Endangered Species Program,
    - Contains slopes greater than 15% prior to any work
- Rooftop runoff must be disconnected in accordance with the requirements applicable to Credit 2.
- Qualifying pervious areas are used to convey runoff from roads and driveways instead of curb and gutter systems.

Environmentally Sensitive Development Credit Example Application

Given the following base data:
Site Data: a single-family lot that is part of an 8-acre low-density subdivision in a critical area
Lot Area = 2.5 ac
Conservation Area = 0.65 ac
Conservation Area and Site is 10% wetland resource area
Impervious Area = 0.35 ac = 14%
Site Soils Types: 100% Hydrologic Soil Group "B" Soil
F = 0.35 inches, where F is the Recharge Factor required for "B" soils
Original required water quality volume = (1.0"/12 IN/FT) (0.35 acres) (43,560 SF/ACRE) = 1,270.5 ft^3
Original Required recharge volume = (2.5 acres) (0.14) (0.35"/12 IN/FT) (43,560 SF/ACRE) = 445 ft^3

Environmentally Sensitive Development Credit (see Figure 1)
Required Recharge Volume is considered met by site design**.**
Required Water Quality Volume is considered met by site design**.**

Percent Reductions Using Environmentally Sensitive Development Credit:
- *Required Water Quality Volume* = 100%
- *Required Recharge Volume* = 100%

Credit 2: Rooftop Runoff Directed to Qualifying Areas

This credit is available when rooftop runoff is directed to a qualifying pervious area where it can either infiltrate into the soil or flow over it with sufficient time and reduced velocity to allow for filtering. Qualifying pervious areas are flat locations, where the discharge is directed via sheet flow and not as a point source discharge. Dry water quality swales are not "qualifying pervious areas" for purposes of this credit. The credit may be obtained by grading the site to induce sheet flow over specially designed flat vegetated areas that can treat and infiltrate rooftop runoff.

If rooftop runoff is adequately directed to a qualifying pervious area, the rooftop area can be deducted from total impervious area, therefore reducing the *Required Water Quality Volume* and the size of the structural BMPs used to meet the TSS removal requirement of Standard 4. As more fully set forth below, redirected rooftop runoff can also be used to meet the recharge requirement as a non-structural practice.

Minimum Criteria for Credit

- ❑ The qualifying pervious area must be designed to prevent basement seepage. To prevent basement seepage, at a minimum, runoff must be directed away from the building foundation and be at least 10 feet away from the foundation.
- ❑ The rooftop area contributing runoff to any one downspout cannot exceed 1,000 ft^2.
- ❑ The rooftop cannot be a metal roof unless the building is located outside a Zone II or IWPA and the building must not be used for industrial purposes.
- ❑ The roof area contributing the runoff is not a "Green Roof."
- ❑ The length of the qualifying pervious area (in feet) shall be equal to or greater than the contributing rooftop area (in ft^2) divided by 13.3 (e.g., for 1,000 ft^2 roof/13.3 = 75 ft).
- ❑ The width of the qualifying pervious area (in feet) shall be equal to or greater than the roof length. For example, if a roof section is 20 feet wide by 50 feet long (1,000 ft^2 roof), the width of the qualifying pervious area shall be at least 50 feet.
- ❑ Although they may abut, there shall be no overlap between qualifying pervious areas. For example, the runoff from two 1,000 square foot sections of roof must be directed to separate qualifying pervious areas. They may not be directed to the same area.
- ❑ The lot must be greater than 6,000 sq. ft.
- ❑ The slope of the qualifying pervious area shall be less than or equal to 5.0%.
- ❑ Where provided, downspouts must be at least 10 feet away from the nearest impervious surface to prevent reconnection to the stormwater management system.
- ❑ Where a gutter/downspout system is not used, the rooftop runoff must be designed to sheet flow at low velocity away from the structure housing the roof.
- ❑ Qualifying pervious areas should be located on relatively permeable soils (HSG "A" and "B"). A soil evaluation by a *Competent Soils Professional* is required to confirm the soil type. The soil evaluation shall also confirm that the depth to groundwater is 2 feet or more and that the long-term *saturated hydraulic conductivity* of the soil is at least 0.17 inches/hour. The soil evaluation must identify the soil texture, Hydrologic Soil Group and depth to groundwater. See Soil Evaluation section of this Chapter. For *saturated hydraulic conductivity*, use Rawls Rates for the actual location where the qualifying pervious area is located.
- ❑ If a qualifying pervious area is located in less permeable soils (HSG "C"), the water table depth and permeability shall be evaluated by a Registered Professional Engineer to determine if a spreading device is needed to sheet flow stormwater over vegetated surfaces.
- ❑ The flow path through the qualifying pervious area shall comply with the setbacks established for structural infiltration BMPs (e.g., 50 feet away from any septic system

components – such as a soil absorption system or leach field, 50 feet from vegetated wetlands and land under water).

- ❑ For those rooftops draining toward land under water (e.g., stream) or vegetated wetlands, the end of the flow path length must be at least 50 feet from the edge of a vegetated wetland and bank.
- ❑ To take credit for rooftop disconnection associated with a Land Use with Higher Potential Pollutant Loads, the rooftop runoff must not commingle with runoff from any paved surfaces or activities or areas on the site that may generate higher pollutant loads.
- ❑ To prevent compaction of the soil in the qualifying pervious area, construction vehicles must not be allowed to drive over the area. If it becomes compacted, the soil must be amended, tilled and revegetated to restore its infiltrative capacity once construction is complete.
- ❑ Ponding of water directed to the qualifying pervious area is not permitted.
- ❑ The Operation and Maintenance Plan required by Stormwater Standard No. 9 must include measures to inspect the qualifying pervious area at least yearly for evidence of ponding. The Plan shall incorporate measures to address any ponding that is observed during the inspection. The Plan shall also include measures to replace any soil eroded from the qualifying pervious area and to replace any vegetation detrimentally impacted by the drainage.
- ❑ The qualifying pervious area may not include any wetland resource areas other than Riverfront, Land Subject to Coastal Storm Flowage, and Lands Subject to Flooding. Where a portion of the Buffer Zone is proposed to serve as part of the qualifying pervious area, the qualifying pervious area shall not extend into the inner 50 feet of the Buffer Zone.
- ❑ The qualifying pervious area must be owned or controlled (e.g., drainage easement) by the property owner.
- ❑ In locations where information is submitted during the public hearing or introduced by the Conservation Commission that there is a demonstrated history of groundwater flooding, the credit may not be utilized.

The rooftop areas contributing runoff to the qualifying pervious area can be deducted from the impervious surfaces used to calculate the *Required Water Quality Volume.*

The rooftop areas contributing runoff to the qualifying pervious area can also be used to reduce the *Required Recharge Volume* by calculating the *Required Recharge Volume* Rv using the "*Static"* Method and the *Recharge Area Requiring Treatment* Rea using the **Percent Area Approach.**

Derive equation from Equation 1.

$$Rv = F \text{ x Impervious Area}$$

$$Rv = (F)(\text{Site Area})(\text{I})/12 \qquad \textbf{\textit{Equation (14)}}$$

Rv is the storage volume of a structural infiltration practice determined using the "*Static*" Method.

Where: *Rv* = Recharge volume (acre-feet)

F = Recharge factor (dimensionless)
A = Site area (in acres)
I = Site imperviousness percentage (expressed as a decimal)

Table No.

Hydrologic Soil Group	Recharge Factor (*F*)
A	0.60 inches
B	0.35 inches
C	0.25 inches
D	0.10 inches

Rea = Recharge area requiring treatment (acres)

Rea = (*F*)(A)(I) ***Equation (15)***

F = Recharge factor based on Hydrologic Soil Group (HSG) (same values as above, but dimensionless)
A = Site area in acres
I = Site imperviousness percentage (expressed as a decimal)

The required recharge area (*Rea*) is equivalent to the recharge volume and can be achieved by a non-structural practice (e.g., filtration of sheet flow from redirected impervious surfaces).

1. Calculate both the *Rv* and *Rea* for the site;
2. The site impervious area draining to an approved nonstructural practice is subtracted from the *Rea* calculation from Credit Step 1, above;
3. The remaining *Rea* is divided by the original *Rea* to calculate a pro-rated[38] percentage that must be directed to structural infiltration BMPs;
4. The pro-rated percentage is multiplied by the original *Rv* to calculate a new *Rv* that must be met by an approved structural practice(s).

Credit 2 Rooftop Runoff Example

Given the following base data:
Site Data: 108 Single-Family Residential Lots (~ ½-acre lots)
Site Area = 45.1 ac
Original Impervious Area = 12.0 ac;
Site Soils Types: 78% "C", 22% "D"
Composite Recharge Factor, F = .78 (0.25) + .22 (0.1) = 0.217
Original *Required Recharge Volume Rv* = [(0.217)(45.1 ac)(12ac/45.1 ac)] /12 = 0.22 acre feet;
Recharge Area Requiring Treatment Rea = (0.217)(45.1)(12/45.1) = 2.60 ac
Original *Required Water Quality Volume* = 1.0"/impervious acre = 1.0"(12.0 ac)/12 = 1.0 acre foot

[38] If the disconnected area is large enough, the Credit could meet the full Recharge and Water Quality Volumes required by Standards 3 and 4.

(site is located near a critical area)

<u>Rooftop Credit (see Figure 3)</u>
42 houses disconnected
Average house area = 2,500 ft^2
Net impervious area reduction = (42)(2,500 ft2) / (43,560 ft^2/ac) = 2.41 acres
New impervious area = 12.0 – 2.41 = 9.59 acres;

Required recharge area (*Rea*) is 2.60 acres and 2.41 acres were disconnected, therefore 0.19 ac of impervious cover need to be met by an approved structural practice.
New *Required Recharge Volume Rv* = (0.19/2.60)(0.22 ac-ft) = 0.016 ac-ft

New *Required Water Quality Volume* = 1.0” (9.59)/12 = 0.80 acre-feet; or a 0.20 acre-foot reduction

Percent Reductions Using Rooftop Disconnection Credit:
• *Required Recharge Volume Rv* = (0.22-0.016)/0.22 = 0.927 = 92.7% Reduction
• *Required Water Quality Volume* = (1.0 – 0.8) /1.0 = 0.20 = 20.0% Reduction

Credit No 3: Roadway, Driveway or Parking Lot Runoff Directed to Qualifying Area

Credit is given for practices that direct runoff from impervious roads, driveways, and parking lots to pervious areas where plants provide filtration (through sheet flow) and the ground provides exfiltration. This credit can be obtained by grading the site to promote overland vegetative filtering. This credit is available for paved driveways, roads, and parking lots associated with all land uses, except for high-intensity parking lots that generate 1,000 or more vehicle trips per day or runoff not segregated from LUHPPL.

Disconnected impervious areas can be subtracted from the site impervious area when computing the *Required Water Quality Volume*. In addition, disconnected impervious surfaces can be used to reduce the *Required Recharge Volume* as determined by calculating the *Required Recharge Volume: Rv* using the "*Static"* Method and the *Recharge Area Requiring Treatment: Rea* using the **Percent Area Approach**. See example for Credit 2 - disconnection of rooftop runoff.

Minimum Criteria for Credit

The credit is subject to the following restrictions:

- The maximum contributing impervious flow path length shall be 75 feet.
- The length of the qualifying pervious area must be equal to or greater than the length of the contributing impervious area.
- The width of the qualifying pervious area shall be no less than the width of the contributing impervious surface. For example, if a driveway is 15 feet wide, the qualifying pervious area width shall be no less than 15 feet.
- The entire qualifying pervious area shall be on a slope less than or equal to 5.0%.
- The impervious area draining to any one discharge location cannot exceed 1,000 ft^2;

- Qualifying pervious areas should be located on relatively permeable soils (HSGs A and B). A soil evaluation is required to confirm the soil type. The soil evaluation shall also confirm that the depth to groundwater is 2 feet or more, and that the long term *saturated hydraulic conductivity* of the soil is at least 0.17 inches/hour. See Soil Evaluation section of this Chapter. For *saturated hydraulic conductivity*, use Rawls Rates for the actual location where the qualifying pervious area is located.
- In less permeable soils (HSGs C), the water table depth and permeability shall be evaluated by a Registered Professional Engineer to determine if a spreading device is needed to sheet flow stormwater over vegetated surfaces.
- For those non-rooftop areas draining toward land under water (e.g., stream) or vegetated wetlands, the end of the flow path length must be at least 50 feet from the edge of a vegetated wetland or bank,
- To prevent compaction, construction vehicles must not be allowed to drive over the qualifying pervious area. If compacted, the soil must be amended, tilled, and revegetated once construction is complete to restore its infiltrative capacity.
- Ponding of water directed to the qualifying area is not permitted.
- The Operation and Maintenance Plan required by Standard 9 must include measures to inspect the qualifying pervious area at least yearly for evidence of ponding, sediment deposition, and vegetation dieback. The Plan shall incorporate measures to remove any deposited sediment (e.g., sand from winter sanding operations), address any ponding, and replant any vegetation that has died (such as vegetation impacted by road salt applied during the winter). The Plan shall also include measures to replace any eroded soil from the qualifying pervious area. The Operation and Maintenance Plan shall not allow sealcoats containing coal-tar emulsions. The Operation and Maintenance Plan must address how future scarifying and repaving operations will be conducted to ensure that stormwater contaminated during repaving operations will not detrimentally impact regulatory wetland areas and buffer zones.
- Runoff from driveways, roadways and parking lots may be directed over soft shoulders, through curb cuts, or level spreaders to qualifying pervious areas. Measures must be employed at the discharge point to the qualifying pervious area to prevent erosion and promote sheet flow.
- The flow path through the qualifying pervious area shall comply with the setbacks established for structural infiltration Best Management Practices (e.g., 50 feet away from any septic system components including soil absorption systems, 50 feet from vegetated wetlands, bank, and land under water.)
- The qualifying pervious area may not include any wetland resource areas other than Riverfront and Land Subject to Coastal Storm Flowage, and Lands Subject to Flooding. Where a portion of the Buffer Zone is proposed to serve as part of the qualifying pervious area, the qualifying pervious area shall not extend into the inner 50 feet of the Buffer Zone.
- The qualifying pervious area must be owned or controlled (e.g., drainage easement) by the property owner.
- In locations where information is submitted during the public hearing or introduced by the Conservation Commission that there is a demonstrated history of groundwater flooding, the credit may not be used.

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Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands Program

Checklist for Stormwater Report

A. Introduction

Important: When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.

A Stormwater Report must be submitted with the Notice of Intent permit application to document compliance with the Stormwater Management Standards. The following checklist is NOT a substitute for the Stormwater Report (which should provide more substantive and detailed information) but is offered here as a tool to help the applicant organize their Stormwater Management documentation for their Report and for the reviewer to assess this information in a consistent format. As noted in the Checklist, the Stormwater Report must contain the engineering computations and supporting information set forth in Volume 3 of the Massachusetts Stormwater Handbook. The Stormwater Report must be prepared and certified by a Registered Professional Engineer (RPE) licensed in the Commonwealth.

The Stormwater Report must include:

- The Stormwater Checklist completed and stamped by a Registered Professional Engineer (see page 2) that certifies that the Stormwater Report contains all required submittals.[1] This Checklist is to be used as the cover for the completed Stormwater Report.
- Applicant/Project Name
- Project Address
- Name of Firm and Registered Professional Engineer that prepared the Report
- Long-Term Pollution Prevention Plan required by Standards 4-6
- Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan required by Standard 8[2]
- Operation and Maintenance Plan required by Standard 9

In addition to all plans and supporting information, the Stormwater Report must include a brief narrative describing stormwater management practices, including environmentally sensitive site design and LID techniques, along with a diagram depicting runoff through the proposed BMP treatment train. Plans are required to show existing and proposed conditions, identify all wetland resource areas, NRCS soil types, critical areas, Land Uses with Higher Potential Pollutant Loads (LUHPPL), and any areas on the site where infiltration rate is greater than 2.4 inches per hour. The Plans shall identify the drainage areas for both existing and proposed conditions at a scale that enables verification of supporting calculations.

As noted in the Checklist, the Stormwater Management Report shall document compliance with each of the Stormwater Management Standards as provided in the Massachusetts Stormwater Handbook. The soils evaluation and calculations shall be done using the methodologies set forth in Volume 3 of the Massachusetts Stormwater Handbook.

To ensure that the Stormwater Report is complete, applicants are required to fill in the Stormwater Report Checklist by checking the box to indicate that the specified information has been included in the Stormwater Report. If any of the information specified in the checklist has not been submitted, the applicant must provide an explanation. The completed Stormwater Report Checklist and Certification must be submitted with the Stormwater Report.

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[1] The Stormwater Report may also include the Illicit Discharge Compliance Statement required by Standard 10. If not included in the Stormwater Report, the Illicit Discharge Compliance Statement must be submitted prior to the discharge of stormwater runoff to the post-construction best management practices.

[2] For some complex projects, it may not be possible to include the Construction Period Erosion and Sedimentation Control Plan in the Stormwater Report. In that event, the issuing authority has the discretion to issue an Order of Conditions that approves the project and includes a condition requiring the proponent to submit the Construction Period Erosion and Sedimentation Control Plan before commencing any land disturbance activity on the site.

B. Stormwater Checklist and Certification

The following checklist is intended to serve as a guide for applicants as to the elements that ordinarily need to be addressed in a complete Stormwater Report. The checklist is also intended to provide conservation commissions and other reviewing authorities with a summary of the components necessary for a comprehensive Stormwater Report that addresses the ten Stormwater Standards.

Note: Because stormwater requirements vary from project to project, it is possible that a complete Stormwater Report may not include information on some of the subjects specified in the Checklist. If it is determined that a specific item does not apply to the project under review, please note that the item is not applicable (N.A.) and provide the reasons for that determination.

A complete checklist must include the Certification set forth below signed by the Registered Professional Engineer who prepared the Stormwater Report.

Registered Professional Engineer's Certification

I have reviewed the Stormwater Report, including the soil evaluation, computations, Long-term Pollution Prevention Plan, the Construction Period Erosion and Sedimentation Control Plan (if included), the Long-term Post-Construction Operation and Maintenance Plan, the Illicit Discharge Compliance Statement (if included) and the plans showing the stormwater management system, and have determined that they have been prepared in accordance with the requirements of the Stormwater Management Standards as further elaborated by the Massachusetts Stormwater Handbook. I have also determined that the information presented in the Stormwater Checklist is accurate and that the information presented in the Stormwater Report accurately reflects conditions at the site as of the date of this permit application.

Registered Professional Engineer Block and Signature

Signature and Date

Checklist

Project Type: Is the application for new development, redevelopment, or a mix of new and redevelopment?

☐ New development

☐ Redevelopment

☐ Mix of New Development and Redevelopment

Checklist (continued)

LID Measures: Stormwater Standards require LID measures to be considered. Document what environmentally sensitive design and LID Techniques were considered during the planning and design of the project:

- ☐ No disturbance to any Wetland Resource Areas
- ☐ Site Design Practices (e.g. clustered development, reduced frontage setbacks)
- ☐ Reduced Impervious Area (Redevelopment Only)
- ☐ Minimizing disturbance to existing trees and shrubs
- ☐ LID Site Design Credit Requested:
  - ☐ Credit 1
  - ☐ Credit 2
  - ☐ Credit 3
- ☐ Use of “country drainage” versus curb and gutter conveyance and pipe
- ☐ Bioretention Cells (includes Rain Gardens)
- ☐ Constructed Stormwater Wetlands (includes Gravel Wetlands designs)
- ☐ Treebox Filter
- ☐ Water Quality Swale
- ☐ Grass Channel
- ☐ Green Roof
- ☐ Other (describe): ______________________

Standard 1: No New Untreated Discharges

- ☐ No new untreated discharges
- ☐ Outlets have been designed so there is no erosion or scour to wetlands and waters of the Commonwealth
- ☐ Supporting calculations specified in Volume 3 of the Massachusetts Stormwater Handbook included.

Checklist (continued)

Standard 2: Peak Rate Attenuation

☐ Standard 2 waiver requested because the project is located in land subject to coastal storm flowage and stormwater discharge is to a wetland subject to coastal flooding.

☐ Evaluation provided to determine whether off-site flooding increases during the 100-year 24-hour storm.

☐ Calculations provided to show that post-development peak discharge rates do not exceed pre-development rates for the 2-year and 10-year 24-hour storms. If evaluation shows that off-site flooding increases during the 100-year 24-hour storm, calculations are also provided to show that post-development peak discharge rates do not exceed pre-development rates for the 100-year 24-hour storm.

Standard 3: Recharge

☐ Soil Analysis provided.

☐ Required Recharge Volume calculation provided.

☐ Required Recharge volume reduced through use of the LID site Design Credits.

☐ Sizing the infiltration, BMPs is based on the following method: Check the method used.

☐ Static ☐ Simple Dynamic ☐ Dynamic Field[1]

☐ Runoff from all impervious areas at the site discharging to the infiltration BMP.

☐ Runoff from all impervious areas at the site is *not* discharging to the infiltration BMP and calculations are provided showing that the drainage area contributing runoff to the infiltration BMPs is sufficient to generate the required recharge volume.

☐ Recharge BMPs have been sized to infiltrate the Required Recharge Volume.

☐ Recharge BMPs have been sized to infiltrate the Required Recharge Volume *only* to the maximum extent practicable for the following reason:

- ☐ Site is comprised solely of C and D soils and/or bedrock at the land surface
- ☐ M.G.L. c. 21E sites pursuant to 310 CMR 40.0000
- ☐ Solid Waste Landfill pursuant to 310 CMR 19.000
- ☐ Project is otherwise subject to Stormwater Management Standards only to the maximum extent practicable.

☐ Calculations showing that the infiltration BMPs will drain in 72 hours are provided.

☐ Property includes a M.G.L. c. 21E site or a solid waste landfill and a mounding analysis is included.

[1] 80% TSS removal is required prior to discharge to infiltration BMP if Dynamic Field method is used.

Checklist (continued)

Standard 3: Recharge (continued)

☐ The infiltration BMP is used to attenuate peak flows during storms greater than or equal to the 10-year 24-hour storm and separation to seasonal high groundwater is less than 4 feet and a mounding analysis is provided.

☐ Documentation is provided showing that infiltration BMPs do not adversely impact nearby wetland resource areas.

Standard 4: Water Quality

The Long-Term Pollution Prevention Plan typically includes the following:

- Good housekeeping practices;
- Provisions for storing materials and waste products inside or under cover;
- Vehicle washing controls;
- Requirements for routine inspections and maintenance of stormwater BMPs;
- Spill prevention and response plans;
- Provisions for maintenance of lawns, gardens, and other landscaped areas;
- Requirements for storage and use of fertilizers, herbicides, and pesticides;
- Pet waste management provisions;
- Provisions for operation and management of septic systems;
- Provisions for solid waste management;
- Snow disposal and plowing plans relative to Wetland Resource Areas;
- Winter Road Salt and/or Sand Use and Storage restrictions;
- Street sweeping schedules;
- Provisions for prevention of illicit discharges to the stormwater management system;
- Documentation that Stormwater BMPs are designed to provide for shutdown and containment in the event of a spill or discharges to or near critical areas or from LUHPPL;
- Training for staff or personnel involved with implementing Long-Term Pollution Prevention Plan;
- List of Emergency contacts for implementing Long-Term Pollution Prevention Plan.

☐ A Long-Term Pollution Prevention Plan is attached to Stormwater Report and is included as an attachment to the Wetlands Notice of Intent.

☐ Treatment BMPs subject to the 44% TSS removal pretreatment requirement and the one inch rule for calculating the water quality volume are included, and discharge:

- ☐ is within the Zone II or Interim Wellhead Protection Area
- ☐ is near or to other critical areas
- ☐ is within soils with a rapid infiltration rate (greater than 2.4 inches per hour)
- ☐ involves runoff from land uses with higher potential pollutant loads.

☐ The Required Water Quality Volume is reduced through use of the LID site Design Credits.

☐ Calculations documenting that the treatment train meets the 80% TSS removal requirement and, if applicable, the 44% TSS removal pretreatment requirement, are provided.

Checklist (continued)

Standard 4: Water Quality (continued)

☐ The BMP is sized (and calculations provided) based on:

- ☐ The ½” or 1” Water Quality Volume or
- ☐ The equivalent flow rate associated with the Water Quality Volume and documentation is provided showing that the BMP treats the required water quality volume.

☐ The applicant proposes to use proprietary BMPs, and documentation supporting use of proprietary BMP and proposed TSS removal rate is provided. This documentation may be in the form of the propriety BMP checklist found in Volume 2, Chapter 4 of the Massachusetts Stormwater Handbook and submitting copies of the TARP Report, STEP Report, and/or other third party studies verifying performance of the proprietary BMPs.

☐ A TMDL exists that indicates a need to reduce pollutants other than TSS and documentation showing that the BMPs selected are consistent with the TMDL is provided.

Standard 5: Land Uses With Higher Potential Pollutant Loads (LUHPPLs)

☐ The NPDES Multi-Sector General Permit covers the land use and the Stormwater Pollution Prevention Plan (SWPPP) has been included with the Stormwater Report.

☐ The NPDES Multi-Sector General Permit covers the land use and the SWPPP will be submitted ***prior to*** the discharge of stormwater to the post-construction stormwater BMPs.

☐ The NPDES Multi-Sector General Permit does ***not*** cover the land use.

☐ LUHPPLs are located at the site and industry specific source control and pollution prevention measures have been proposed to reduce or eliminate the exposure of LUHPPLs to rain, snow, snow melt and runoff, and been included in the long term Pollution Prevention Plan.

☐ All exposure has been eliminated.

☐ All exposure has ***not*** been eliminated and all BMPs selected are on MassDEP LUHPPL list.

☐ The LUHPPL has the potential to generate runoff with moderate to higher concentrations of oil and grease (e.g. all parking lots with >1000 vehicle trips per day) and the treatment train includes an oil grit separator, a filtering bioretention area, a sand filter or equivalent.

Standard 6: Critical Areas

☐ The discharge is near or to a critical area and the treatment train includes only BMPs that MassDEP has approved for stormwater discharges to or near that particular class of critical area.

☐ Critical areas and BMPs are identified in the Stormwater Report.

Checklist (continued)

Standard 7: Redevelopments and Other Projects Subject to the Standards only to the maximum extent practicable

☐ The project is subject to the Stormwater Management Standards only to the maximum Extent Practicable as a:

- ☐ Limited Project
- ☐ Small Residential Projects: 5-9 single family houses or 5-9 units in a multi-family development provided there is no discharge that may potentially affect a critical area.
- ☐ Small Residential Projects: 2-4 single family houses or 2-4 units in a multi-family development with a discharge to a critical area
- ☐ Marina and/or boatyard provided the hull painting, service and maintenance areas are protected from exposure to rain, snow, snow melt and runoff
- ☐ Bike Path and/or Foot Path
- ☐ Redevelopment Project
- ☐ Redevelopment portion of mix of new and redevelopment.

☐ Certain standards are not fully met (Standard No. 1, 8, 9, and 10 must always be fully met) and an explanation of why these standards are not met is contained in the Stormwater Report.

☐ The project involves redevelopment and a description of all measures that have been taken to improve existing conditions is provided in the Stormwater Report. The redevelopment checklist found in Volume 2 Chapter 3 of the Massachusetts Stormwater Handbook may be used to document that the proposed stormwater management system (a) complies with Standards 2, 3 and the pretreatment and structural BMP requirements of Standards 4-6 to the maximum extent practicable and (b) improves existing conditions.

Standard 8: Construction Period Pollution Prevention and Erosion and Sedimentation Control

A Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan must include the following information:

- Narrative;
- Construction Period Operation and Maintenance Plan;
- Names of Persons or Entity Responsible for Plan Compliance;
- Construction Period Pollution Prevention Measures;
- Erosion and Sedimentation Control Plan Drawings;
- Detail drawings and specifications for erosion control BMPs, including sizing calculations;
- Vegetation Planning;
- Site Development Plan;
- Construction Sequencing Plan;
- Sequencing of Erosion and Sedimentation Controls;
- Operation and Maintenance of Erosion and Sedimentation Controls;
- Inspection Schedule;
- Maintenance Schedule;
- Inspection and Maintenance Log Form.

☐ A Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan containing the information set forth above has been included in the Stormwater Report.

Checklist (continued)

Standard 8: Construction Period Pollution Prevention and Erosion and Sedimentation Control (continued)

☐ The project is highly complex and information is included in the Stormwater Report that explains why it is not possible to submit the Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan with the application. A Construction Period Pollution Prevention and Erosion and Sedimentation Control has ***not*** been included in the Stormwater Report but will be submitted ***before*** land disturbance begins.

☐ The project is ***not*** covered by a NPDES Construction General Permit.

☐ The project is covered by a NPDES Construction General Permit and a copy of the SWPPP is in the Stormwater Report.

☐ The project is covered by a NPDES Construction General Permit but no SWPPP been submitted. The SWPPP will be submitted BEFORE land disturbance begins.

Standard 9: Operation and Maintenance Plan

☐ The Post Construction Operation and Maintenance Plan is included in the Stormwater Report and includes the following information:

- ☐ Name of the stormwater management system owners;
- ☐ Party responsible for operation and maintenance;
- ☐ Schedule for implementation of routine and non-routine maintenance tasks;
- ☐ Plan showing the location of all stormwater BMPs maintenance access areas;
- ☐ Description and delineation of public safety features;
- ☐ Estimated operation and maintenance budget; and
- ☐ Operation and Maintenance Log Form.

☐ The responsible party is ***not*** the owner of the parcel where the BMP is located and the Stormwater Report includes the following submissions:

- ☐ A copy of the legal instrument (deed, homeowner's association, utility trust or other legal entity) that establishes the terms of and legal responsibility for the operation and maintenance of the project site stormwater BMPs;
- ☐ A plan and easement deed that allows site access for the legal entity to operate and maintain BMP functions.

Standard 10: Prohibition of Illicit Discharges

☐ The Long-Term Pollution Prevention Plan includes measures to prevent illicit discharges;

☐ An Illicit Discharge Compliance Statement is attached;

☐ NO Illicit Discharge Compliance Statement is attached but will be submitted ***prior to*** the discharge of any stormwater to post-construction BMPs.

TSS Removal Calculation Sheet Instructions

Either a completed automated form or non-automated form must be submitted as part of the Stormwater Report accompanying the Wetlands NOI

Automated Version Instructions

The automated version may be used EXCEPT when a Proprietary BMP is proposed. This is because Proprietary BMPs have variable removal rates.
The only exceptions are for Proprietary BMPs reviewed through the TARP Tier II Field Protocol for which MassDEP has granted written reciprocity.
BMPs must be designed in accordance with the Design Specifications contained in Mass. Stormwater Handbook Volume II to receive the TSS Removal Rating.
Separate Excel spreadsheets must be completed for each stormwater outlet or BMP train.
E.g. if there are two separate BMP trains discharging to two separate stormwater outlets, two separate sheets must be submitted.
Separate sheets must be submitted for Pretreatment (e.g. for 44% TSS removal prior to recharge) and Treatment (e.g. 80% TSS removal for new development).
To use automated sheet:
Click on Worksheet Tab labeled Automated Sheet
Click on Cell B11 (Shaded Blue)
Carrot Appears in lower right side of Cell B11
Click on Carrot
Drop Down Menu of BMPs will open. The BMPs are those listed in Volume I. No proprietary BMPs are listed in Drop Down Menu.
BMPs are listed alphabetically
Select One BMP per block. Start with most upgradient practices.
After BMP is selected in Cell B11, Cell C11 will automatically be populated with the DEP assigned TSS Removal Rate.
If there are multiple BMPs, go to Cell B12, select BMP, and so on (i.e. select BMPs in Cell B13, B14, and B15).
Final result is returned in Cell E16
All cells are locked except for Column B (to select BMPs) and Location, Project, Prepared By, and Date blocks.
Complete Location, Project, Prepared by, and Date Blocks.

Non-automated Sheet

The non-automated version must be completed if any Proprietary BMPs or traditional non-listed BMPs are proposed.
The non-automated version is locked to prevent it from being manipulated.
The non-automated version must be printed and completed by hand or typewriter.
Write name of BMP in Column B.
Write annual TSS removal rate in Column C (written documentation must be submitted to issuing authority substantiating TSS removal claim)
Multiply Column C by Starting Load in Column D and enter Result in Column E (e.g. Deep Sump CB 0.25 x 1 = 0.25, Enter 0.25 in Column E).
Subtract Column E from D, Enter Result in Column F (e.g. 1.00 - 0.25 = 0.75, Enter 0.75 in Column F).
Enter new BMP in Column B, next row down. Enter TSS Removal Rate in that same row.
In Column D, enter Starting Load from prior Row (e.g. 0.75).
Multiply Column C TSS Removal Rate by new starting load, and enter result into Column E, and so on.
Add up all the values listed in Column E.
Enter final result in Cell E16, block that is labeled Total TSS Removal.
Complete Location, Project, Prepared by, and Date Blocks.

Documentation

VERSION 1, March 4, 2008

Automated Sheet

Drop Down Menu in Column B created using "Data Validation"

Column C populated using data array from hidden table using "Vertical Lookup"

Column D values from Column F

Column E values producrs of Column C x Column D values

Column F values Column D - Column E

INSTRUCTIONS:
1. In BMP Column, click on Blue Cell to Activate Drop Down Menu
2. Select BMP from Drop Down Menu
3. After BMP is selected, TSS Removal and other Columns are automatically completed.

Version 1, Automated: Mar. 4, 2008

TSS Removal Calculation Worksheet

Location:

B BMP[1]	C TSS Removal Rate[1]	D Starting TSS Load*	E Amount Removed (C*D)	F Remaining Load (D-E)
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00
	0.00	1.00	0.00	1.00

Total TSS Removal = **0%**

Separate Form Needs to be Completed for Each Outlet or BMP Train

Project:
Prepared By:
Date:

*Equals remaining load from previous BMP (E) which enters the BMP

Non-automated TSS Calculation Sheet must be used if Proprietary BMP Proposed

1. From MassDEP Stormwater Handbook Vol. 1

INSTRUCTIONS:

1. Sheet is nonautomated. Print sheet and complete using hand calculations. Column A and B: See MassDEP Structural BMP Table
2. The calculations must be completed using the Column Headings specified in Chart and Not the Excel Column Headings
3. To complete Chart Column D, multiple Column B value within Row x Column C value within Row
4. To complete Chart Column E value, subtract Column D value within Row from Column C within Row
5. Total TSS Removal = Sum All Values in Column D

TSS Removal Calculation Worksheet

Location:

A BMP[1]	B TSS Removal Rate[1]	C Starting TSS Load*	D Amount Removed (B*C)	E Remaining Load (C-D)
		1.00		

Total TSS Removal =

Separate Form Needs to be Completed for Each Outlet or BMP Train

Project:

Prepared By:

Date:

*Equals remaining load from previous BMP (E) which enters the BMP

Non-automated TSS Calculation Sheet must be used if Proprietary BMP Proposed

1. From MassDEP Stormwater Handbook Vol. 1

From MassDEP Stormwater Handbook Vol. 1

TSS Removal Efficiencies for Best Management Practices	
Best Management Practice (BMP)	**TSS Removal Efficiency**
Non-Structural Pretreatment BMPs	
Street Sweeping	0-10%, See Volume 2, Chapter 1.
Structural Pretreatment BMPs	
Deep Sump Catch Basins	25% only if used for pretreatment and only if off-line
Oil Grit Separator	25% only if used for pretreatment and only if off-line
Proprietary Separators	Varies – see Volume 2, Chapter 4.
Sediment Forebays	25% if used for pretreatment
Vegetated filter strips	10% if at least 25 feet wide, 45% if at least 50 feet wide
Treatment BMPs	
Bioretention Areas including rain gardens	90% provided it is combined with adequate pretreatment
Constructed Stormwater Wetlands	80% provided it is combined with a sediment forebay
Extended Dry Detention Basins	50% provided it is combined with a sediment forebay
Gravel Wetlands	80% provided it is combined with a sediment forebay
Proprietary Media Filters	Varies – see Volume 2, Chapter 4
Sand/Organic Filters	80% provided it is combined with sediment forebay
Treebox filter	80% provided it is combined with adequate pretreatment
Wet Basins	80% provided it is combined with sediment forebay
Conveyance	
Drainage Channels	For conveyance only. No TSS Removal credit.
Grass Channels (formerly biofilter swales)	50% if combined with sediment forebay or equivalent
Water Quality Swale – wet & dry	70% provided it is combined with sediment forebay or equivalent
Infiltration BMPs	
Dry Wells	80% for runoff from non-metal roofs; may also be used for runoff from metal roofs but only if metal roof is not located within a Zone II, or IWPA or at an industrial site
Infiltration Basins & Infiltration Trenches	80% provided it is combined with adequate pretreatment (sediment forebay or vegetated filter strip, grass channel, water quality swale) prior to infiltration
Leaching Catch Basins	80% provided a deep sump catch basin is used for pretreatment
Subsurface Structure	80% provided they are combined with one or more pretreatment BMPs prior to infiltration.
Other BMPs	
Dry Detention Basins	For peak rate attenuation only. No TSS Removal credit.
Green Roofs	See Volume 2. Chapter 2. May reduce required water quality volume. No TSS Removal Credit.
Porous Pavement	80% if designed to prevent runon and with adequate storage capacity. Limited to uses identified in Volume 2, Chapter 2.
Rain Barrels and Cisterns	May reduce required water quality volume. No TSS Removal Credit.

APPENDIX D:

STORMWATER BEST MANAGEMENT PRACTICES (BMP) PERFORMANCE ANALYSIS

Stormwater Best Management Practices (BMP) Performance Analysis

***Revised* Document*:* March 2010**
(Original Document: December 2008)

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NOTICE

This report documents the development of long-term performance curves for stormwater best management practices (BMPs) in the New England region. Performance curves were developed for BMPs including infiltration trench, infiltration basin, gravel wetland, bioretention, porous pavement, grass swale, wet pond, and dry pond. In the original version of this report (December 2008), the surface areas for infiltration basin was estimated using the "Simple Dynamic" method (MassDEP, 2008), which assumed that the treatment volume was discharged into the infiltration basin in two hours and exfiltrated during the two hours. However, the "Simple Dynamic" approach was not consistent with the way that the surface areas for other BMPs were sized. Also this approach limits the applicability of this curve beyond Massachusetts. In order to maintain the consistency across all BMPs, the calculation of infiltration basin surface area is updated to follow the "Static" method (MassDEP, 2008), which is independent of the drawdown time and the infiltration rate.

This revision (March 2010) results in updated infiltration basin performance curves, which are included in Appendix B. The previous infiltration basin performance curves based on the "Simple Dynamic" method are moved to Appendix C for the readers interested in this method.

EXECUTIVE SUMMARY

The purpose of this project is to generate long-term cumulative performance information for several types of stormwater best management practices (BMPs). The information can be used to provide estimates of long-term cumulative efficiencies for several types of BMPs, according to their sizing. The curves reflect pollutant removal performance of BMPs designed and maintained in accordance with Massachusetts stormwater standards. Developing a BMP rating curve involved several major steps: (1) selecting an appropriate long-term precipitation record (data and location) that is representative of a major urbanized area within the New England region, (2) generating hydrograph and pollutant time series using a land-based hydrologic and water quality model, (3) simulating BMP hydraulic and treatment processes in BMP models, and (4) creating BMP performance curves on the basis of BMP model simulation results.

After a detailed review and analysis of precipitation records of 12 weather stations in New England, weather data from the Boston, Massachusetts, station was selected to generate BMP performance estimates for this project. The U.S. Environmental Protection Agency's (EPA's) Storm Water Management Model (SWMM) and a BMP analysis tool called BMP Decision Support System (BMPDSS) were employed for generating and simulating hydrology and water quality constituents. To represent the New England conditions, the models were calibrated and tested using BMP performance data collected by the University of New Hampshire Stormwater Center (UNHSC).

Calibrated BMPDSS models were applied for the following eight types of stormwater BMPs: surface infiltration practices (e.g., infiltration basins), subsurface infiltration systems (e.g., infiltration trenches), gravel wetland systems, bioretention systems, water quality swales, porous pavement systems, wet ponds, and extended dry detention ponds. The models were used to generate long-term cumulative performance estimates expressed as performance curves. For each BMP, performance curves were developed for five land uses and three water quality constituents. The land uses consist of (1) Commercial, (2) Industrial, (3) High-Density Residential, (4) Medium-Density Residential, (5) Low-Density Residential; the water quality constituents consist of (1) total phosphorous (TP), (2) total suspend solids (TSS), (3) Zinc (Zn). In total, 282 BMP performance curves were developed (see Appendix B).

1. INTRODUCTION

The Water Permits Division (WPD), within the Office of Wastewater Management (OWM) of the U.S. Environmental Protection Agency (EPA), is responsible for implementation and oversight of the National Pollutant Discharge Elimination System (NPDES) permit program. This program regulates point source discharges of pollutants to surface waters of the United States.

WPD provides oversight and assistance to EPA Regions in implementing the NPDES program. EPA Regions are responsible for oversight of state NPDES permitting authorities and directly implement the NPDES permitting program in areas not delegated to states and tribes. EPA headquarters and Regions also provide direct and indirect assistance to states to help them successfully implement the NPDES program. New Hampshire and the Commonwealth of Massachusetts have not assumed the authority to administer the NPDES program for discharges of pollutants to surface waters in their respective states. Therefore, EPA remains the Permitting Authority in Massachusetts and New Hampshire.

The purpose of this project is to generate long-term performance information for several types of stormwater best management practices (BMPs). The information would be used to illustrate the long-term cumulative efficiencies of each selected BMP in terms of pollutant removal, according to its design and capacity. Developing a BMP rating curve involves the following major components (Figure 1-1): selecting an appropriate precipitation record (data and location) to represent an area within the New England region, generating hydrograph and pollutant time series using a water quality model, simulating appropriate BMP treatments in BMP models, and creating BMP performance curves on the basis of BMP model simulation results. A BMP analysis tool called BMP Decision Support System (BMPDSS) was used for this project. This tool has been developed by Tetra Tech, Inc. (Tetra Tech 2005 a & b), with considerable investment from EPA Region 3 and Prince George's County, Maryland. Also, the tool has been adapted for use in Vermont using funding from the Vermont Agency of Natural Resources. The tool can perform many types of analyses including estimating cumulative pollutant removal for several types of BMPs, including some of the newer-generation BMPs (e.g., bioretention/filtration). A detailed description on BMPDSS is presented in Appendix A. This report presents the details of this project including the results of a precipitation analysis (chapter 2), a land analysis (chapter 3), the BMP analysis (chapter 4), and developing the performance curves (chapter 5).

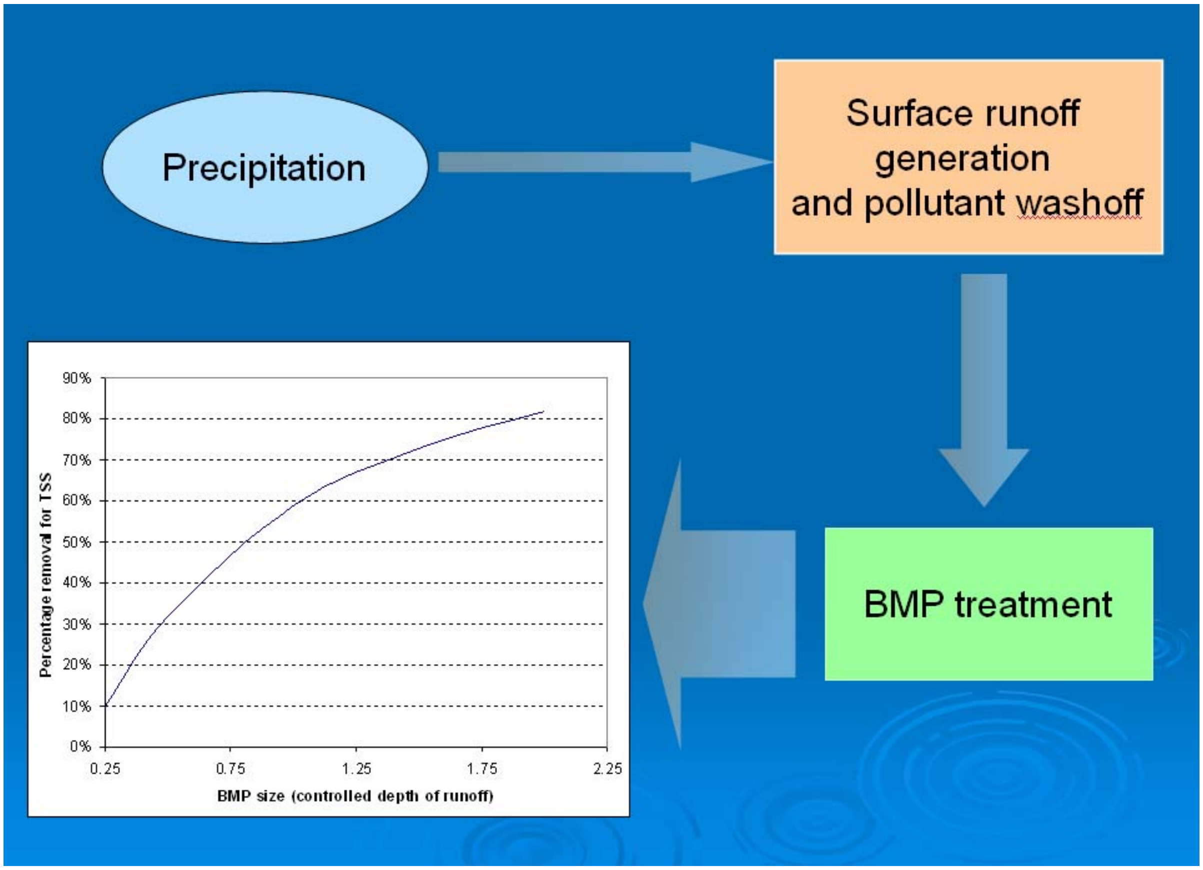


Figure 1-1. BMP performance curve development scheme.

2. PRECIPITATION ANALYSIS

Weather is the driving force for watershed runoff and, therefore, is likely to be an important determinant for BMP performance. Different geographic locations can have significantly different precipitation patterns. For this project, a precipitation data analysis was performed using data from 12 weather stations throughout the major urban/suburban areas of the six New England states (see Figure 2-1). The purpose of this analysis was to evaluate precipitation variability in New England and to guide selection of a representative weather data set for developing BMP performance curves.

2.1. Data Collection and Review

Twelve stations in and around major urban areas of the New England region were selected for analysis (see Figure 2-1). These stations were selected because they have long-term hourly rainfall records that are mostly complete and they are in and around the major urban areas in each of the six New England states. The National Climate Data Center (NCDC) hourly weather records for these weather stations were retrieved and are summarized in Table 2-1. As indicated, the associated climate region, elevation, data record details, and average annual rainfall for each station are provided.

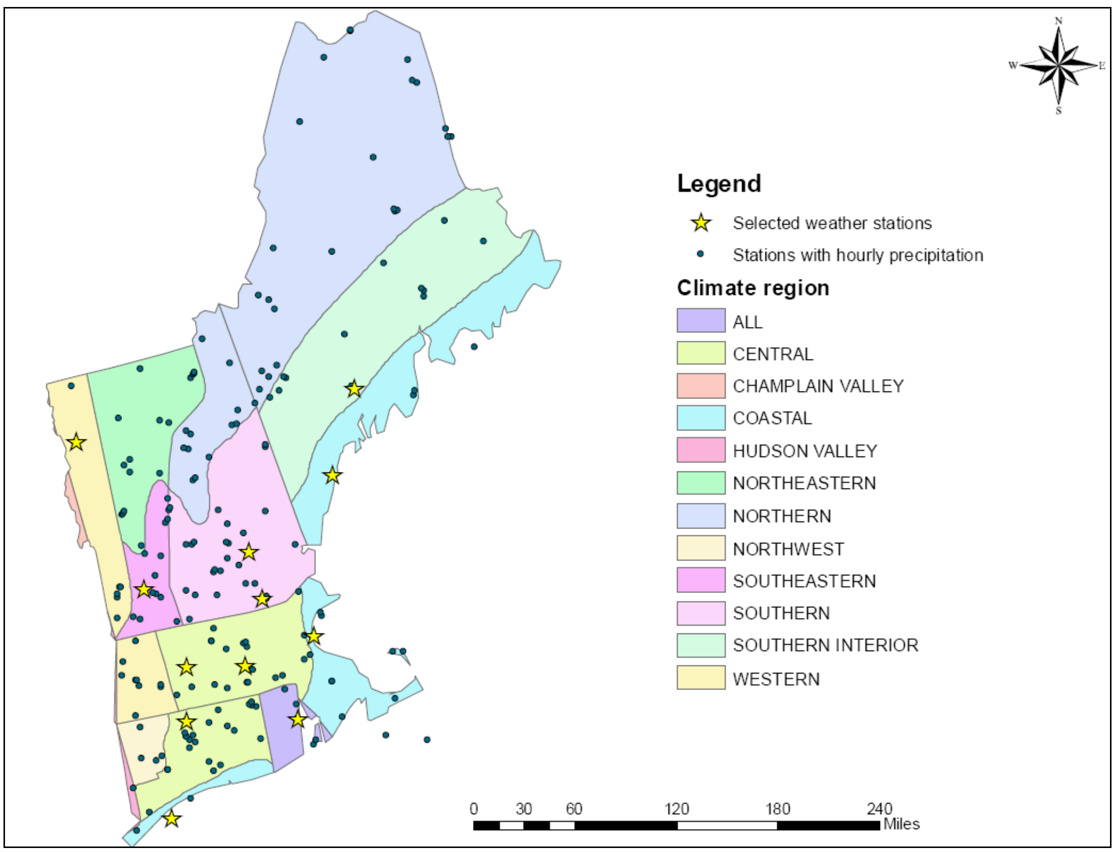


Figure 2-1. Locations of weather stations in the New England region.

Table 2-1. Summary of weather records in selected 12 stations throughout New England

Station ID	Station name	Climate region	Elevation (ft)	Record	Coverage	Avg. annual rainfall (in)
CT0806	Bridgeport Sikorsky Airport	Coastal	5	1948–present	100%	41.25
CT3456	Hartford Airport	Central	160	1954–present	100%	44.15
MA0120	Amherst	Central	150	1948–present	86%	43.31
MA0770	Boston Logan Int'l Airport	Coastal	20	1948–present	100%	42.66
MA9923	Worcester Airport	Central	986	1948–present	96%	46.03
ME0273	Augusta	Southern Interior	35	1952–present	84%	42.05
ME6905	Portland Airport	Coastal	45	1948–present	99%	42.27
NH1683	Concord	Southern	346	1948–present	100%	36.76
NH5712	Nashua	Southern	130	1950–present	91%	44.77
RI6698	Providence Airport	All	51	1948–present	100%	44.57
VT0277	Ball Mountain Lake	Southern	1,130	1962–present	92%	45.75
VT1081	Burlington Int'l Airport	Western	330	1948–present	99%	33.89

Among the 12 selected stations, average annual precipitations range from a low of 33.89 inches at Burlington, Vermont, to a high of 46.03 inches at Worcester, Massachusetts. The overall average annual precipitation for these stations is 42.29 inches, and, as indicated in Table 2-1, most of the stations have an average annual precipitation within 2.5 inches of this overall average. Boxplots of the annual total rainfall at each weather station were generated (Figure 2-2) to illustrate the variability in annual rainfall among the 12 stations. The boxplots clearly show that Worcester, Massachusetts (MA9923) has the highest average annual total rainfall, while the average annual rainfall at Burlington, Vermont (VT1081) is notably lower than the other 11 stations. Also apparent is similarity in annual precipitation among the other stations.

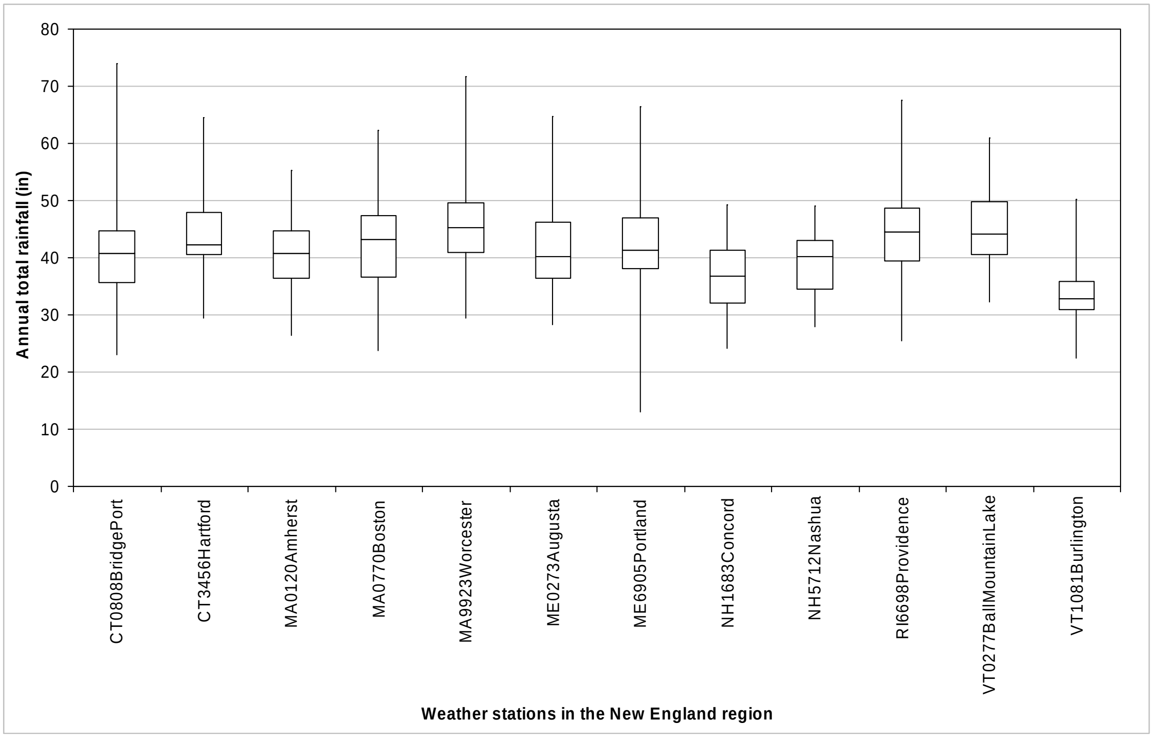


Figure 2-2. Boxplots of annual total rainfall for selected weather stations in New England.

2.2. Event Frequency Analysis

While annual average precipitation is an important factor to distinguish differences among stations, the distribution of precipitation events by size or depth is important too. Long-term BMP performance will be influenced by the number of small, medium, and large precipitation events (i.e., distribution) that the BMP treats. From a water quality perspective, BMPs will typically perform more effectively for smaller storms primarily because the BMPs operate below their designed hydraulic capacity. Therefore, a BMP placed in a location with mostly small events will likely have a different long-term cumulative performance than if it were placed in a location with mostly large events, even if both locations have similar annual average precipitations.

A frequency analysis of the precipitation events by depth was performed for each of the 12 stations to further understand the variability of precipitation patterns in the New England region. The goal of the precipitation event frequency analysis is to identify how the precipitation events are distributed across different categories of total depth. Three rainfall depth categories were used in the frequency analysis: (1) lower than 0.1 inch, (2) 0.1 inch to 1 inch, and (3) higher than 1 inch. The total number of events and the corresponding percentage of the total number of events were determined for each size category for each of the 12 stations. The resulting precipitation event distributions are summarized in Table 2-2.

Table 2-2. Summary of precipitation event frequency distribution sorted by precipitation depth

Station ID	Station name	Precipitation amount (inches)		
		< 0.1	0.1–1.0	> 1
CT0806	Bridgeport Sikorsky Airport	46%	46%	8%
CT3456	Hartford Airport	48%	44%	8%
MA0120	Amherst	45%	47%	8%
MA0770	Boston Logan Int'l Airport	49%	44%	7%
MA9923	Worcester Airport	48%	44%	8%
ME0273	Augusta	45%	47%	8%
ME6905	Portland Airport	49%	47%	8%
NH1683	Concord	49%	47%	5%
NH5712	Nashua	47%	45%	8%
RI6698	Providence Airport	48%	44%	8%
VT0277	Ball Mountain Lake	43%	49%	8%
VT1081	Burlington Int'l Airport	56%	41%	3%
Average of all stations		48%	45%	7%

As indicated, there is similarity in the distributions of rainfall events among the twelve stations barring the Burlington, Vermont station. On average, 48 percent of the events are < 0.1 inch, 45 percent of the events are 0.1 to 1.0 inches, and only 7 percent are > 1.0 inch. The rainfall events with depths between 0.1 and 1.0 inch are the most significant in terms of pollutant loading from urban areas because of the high frequency of these sized events and because they generate enough runoff to wash off most of the pollutants that have accumulated on impervious surfaces. Rainfall events of 0.1 or less are frequent but are not significant in terms of pollutant loading because they generate very little, if any, runoff volume, even from impervious areas. Precipitation events greater than 1 inch are relatively infrequent, and although they generate large runoff volumes, most of the pollutant washoff occurs during the early portion of the storms so that water quality BMPs sized for smaller storms (< 1 inch) can still be highly effective at capturing the pollutant load.

Weather data from the Boston, Massachusetts, station was selected to generate BMP performance estimates for this project. The Boston station (MA0770), in the *Costal* climate region and in a highly urbanized portion of eastern Massachusetts, has an average annual precipitation of 42.66 inches, which closely matches the overall average annual precipitation of 42.29 inches, as well as the annual precipitation of most of the other stations. The precipitation frequency distribution of the Boston station closely matches the distribution of the other stations except for the Burlington, Vermont, station. The Boston station is appropriate for assessing runoff conditions in the Boston metropolitan area of Massachusetts, which is one of the most urbanized areas in New England. Also, the NPDES permitting program for discharges in Massachusetts needs BMP performance estimates for designated urban areas to assess stormwater management plans developed under the NPDES stormwater permitting program.

While the Boston data set appears to be similar (in terms of annual precipitation and event distributions) to most of the data sets from the other stations, it would be useful for a future effort to test the sensitivity of predicted BMP performances to rainfall variability in New England by using data from a weather station that is the most different from the Boston data. On the basis of the analysis conducted for this project, the Burlington, Vermont (VT1081) data set would be a good candidate for evaluating how sensitive BMP performance is to different weather conditions in New England. The boxplots (Figure 2-3) of annual total rainfall from these weather stations (VT1081 and MA0770) illustrate the differences in annual precipitation between them. Also, the frequency distribution analysis reveals that the event distribution for Burlington, Vermont, is the most different from the event distribution of Boston, Massachusetts.

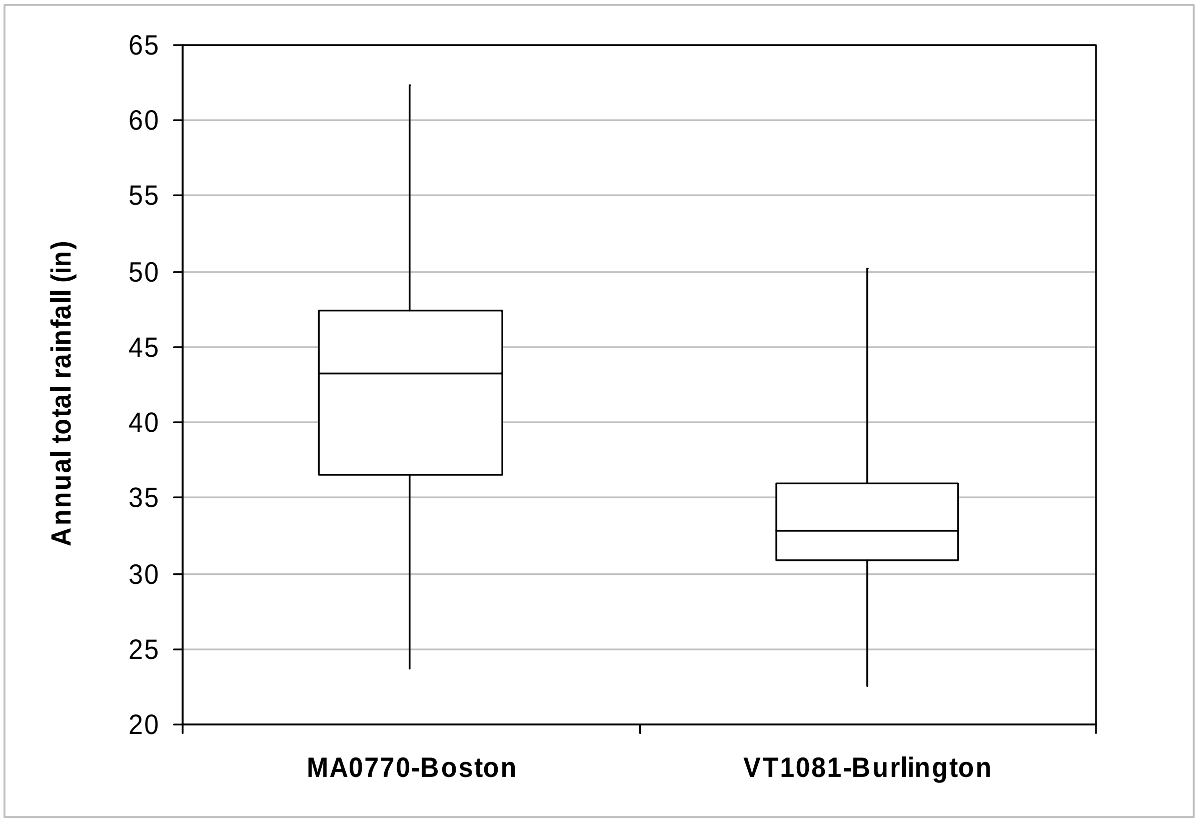


Figure 2-3. Recommended weather stations based on annual precipitation for evaluating BMP performances.

3. LAND ANALYSIS

The goal of the land analysis was to generate the flow and pollutant time series (hydrographs and pollutographs) for each land use type. These time series were later used in the BMP modeling to estimate BMP performances. The land analysis involved selecting representative pollutant loading targets as well as selecting an appropriate the model to use for generating flows and pollutant time series.

3.1. Land Representation for Pollutant Loading

The ultimate goal for this project is to predict BMP performances on the basis of the capacity of BMPs to treat runoff depths (and corresponding volumes) generated by specified amounts of rainfall. Thus, the inflow and pollutant time series play an important role in determining the shape of final BMP performance curves. The approach used in this project to generate the pollutant loadings is similar to the approaches incorporated into widely used urban stormwater models such as the Storm Water Management Model (SWMM) (Huber and Dickinson 1988) and the P8-UCM (Walker 1990) and involves simulating the buildup and washoff of pollutants from impervious surfaces only. Using the impervious surfaces to generate pollutant loading greatly simplifies estimating loadings because it avoids having to represent a high number of combinations of pervious soil and land cover conditions. Also, impervious areas generate most of the runoff in urban/suburban catchments and pollutant load because accumulated pollutants are readily washed off of impervious surfaces. In contrast, runoff volumes and pollutant loads from pervious surfaces tends to be much lower and are highly variable because of attenuation by soils and vegetation.

Moreover, the performance curves generated by this project are intended to apply to urban settings, which typically consist of highly impervious surfaces. The curves are expected to be most frequently used at a site-scale level where BMPs will be designed to treat runoff from developed impervious portions of sites (e.g., commercial center, streets, and parking lots).

A further evaluation of the precipitation characteristics for Boston, Massachusetts, also supports the use of only impervious surfaces for generating pollutant time series. A detailed breakdown of rainfall depth frequency analysis for Boston is shown in Figure 3-1, which illustrates that most of the rain events that have occurred in Boston have been relatively small events (e.g., 84 percent of the events $\leq$ 0.6 inches). To better appreciate the significance of the precipitation characteristics as it relates to impervious and pervious surfaces, a table of initial abstraction (I_a) for various pervious surfaces and hydrologic soils groups (HSG) is provided (see Table 3-1). Soils are assigned to an HSG on the basis of their permeability. HSG A is the most permeable, and HSG D is the least permeable. I_a values indicate the depth of rainfall that will not generate runoff. As indicated, pervious areas are not expected to generate runoff for most rainfall events in the Boston metropolitan region. For example, an open space area with fair condition and HSG C soils has an I_a of 0.53 inch. Therefore, such an area is not expected to generate runoff for rain events equal or less than 0.53 inches, which corresponds to 81 percent of all the rainfall events represented by the 56-year record. Also, rain events with 0.53 inch and less account for approximately 68 percent of the total rainfall volume for the same record. Figure 3-2 illustrates a cumulative frequency distribution for total precipitation volume based on precipitation depth.

For stabilized urban and suburban areas, much of the annual pollutant load is believed to be generated from impervious areas because most of the runoff volume is generated by rainfall falling on impervious areas and because pollutants that have been accumulated on impervious surfaces are readily washed off during even small rain events.

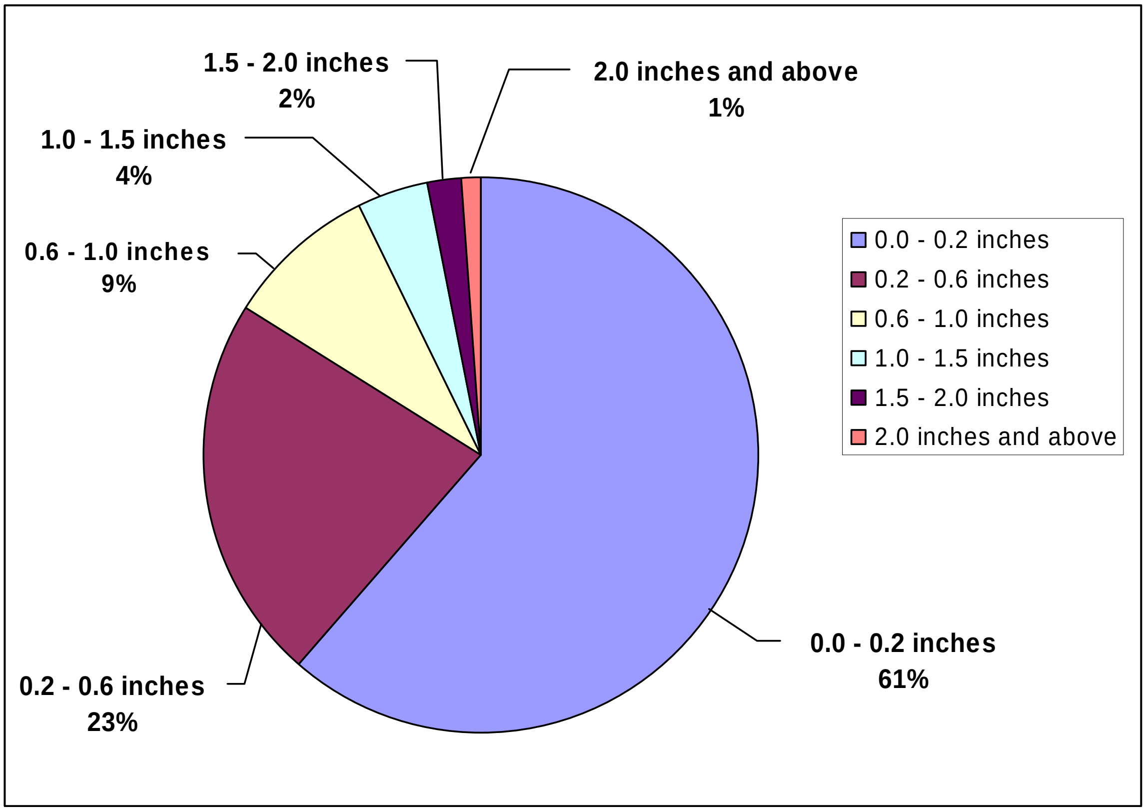


Figure 3-1. Percentage of total number of precipitation events by size of precipitation events for Boston, Massachusetts (1948–2004).

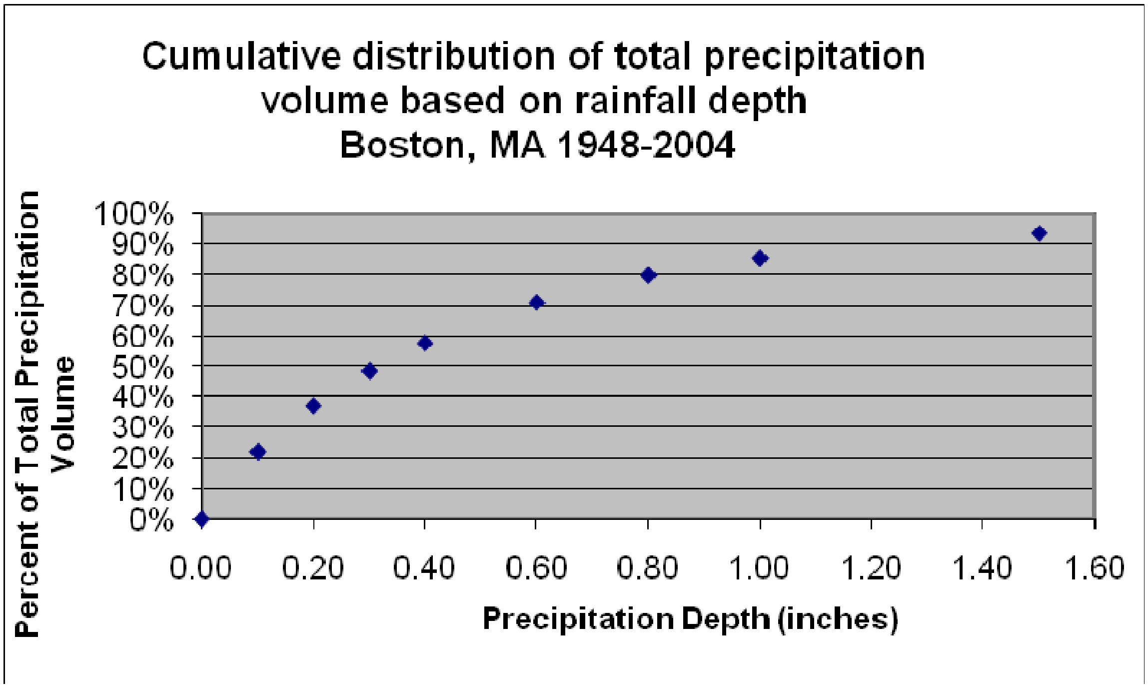


Figure 3-2. Cumulative distribution of total precipitation volume by rainfall depth for Boston, Massachusetts (1948–2004).

Table 3-1. Ia values for various land use and HSGs

Land use/cover conditions		Initial abstraction (inch) HSG A	HSG B	HSG C	HSG D
Open space	Poor (grass < 50%)	0.94	0.53	0.33	0.25
	Fair (grass 50–75%)	2.08	0.90	0.53	0.38
	Good (grass > 75%)	3.13	1.28	0.70	0.50
Residential	1/8 acre or less	0.60	0.35	0.22	0.17
	1/4 acre	1.28	0.67	0.41	0.30
	1/3 acre	1.51	0.78	0.47	0.33
	1/2 acre	1.70	0.86	0.50	0.35
	1 acre	1.92	0.94	0.53	0.38
	2 acres	2.35	1.08	0.60	0.44

Source: USDA-NRCS 1986

3.2. Selection of Water Quality Model

EPA's Stormwater Management Model (SWMM) was selected for generating runoff volume and pollutant time series. The SWMM is a dynamic rainfall-runoff simulation model developed primarily for urban areas and can be used for both single-event and long-term (continuous) simulations using various time steps (Huber and Dickinson 1988). SWMM has the ability to analyze the buildup, washoff, and transport of a number of pollutants within a watershed for a long-term precipitation record (Rossman 2007). Four pollutants, total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), and zinc (Zn) were selected for this analysis because they are commonly associated with urban runoff and are responsible for numerous water quality problems in New England.

Annual average pollutant loading export rates of these pollutants were obtained from the *Fundamentals of Urban Runoff Management: Technical and Institutional Issues* (Shaver et al. 2007). The pollutant export loading rates for different land uses are shown in Table 3-2. These pollutant loading export rates were selected for this project because they have been reported in several sources of stormwater management literature. Also, use of these TP export rates were applied to the Charles River watershed (310 square miles) and found to closely match (within 1 percent) the measured annual phosphorus load for a 5-year period (1998 to 2002) (MassDEP and US EPA 2007).

Table 3-2. Summary of typical pollutant loading export rates from different land uses

Land cover/Source category	Pollutant loading export rates (lbs/ac-yr)			
	TSS	TP	TN	Zn
Commercial	1,000	1.5	9.8	2.1
Industrial	670	1.3	4.7	0.4
High-Density Residential	420	1.0	6.2	0.7
Medium-Density Residential	250	0.3	3.9	0.1
Low-Density Residential	65	0.04	0.4	0.04

Source: Shaver et al. 2007

3.3. Setup and Calibration of SWMM Water Quality Model

The weather data from the Boston, Massachusetts, station was used to generate runoff volume and pollutant time series in the New England region using the SWMM.

3.3.1. Water Quality Processes in SWMM

In the SWMM, the water quality simulation is divided into two processes: buildup and washoff. The amount of buildup is estimated as a function of the preceding dry-weather days and can be computed using one of three functions: Power, Exponential, and Saturation. The washoff process simulates the pollutant washoff from a given land use and can be computed using one of three functions: Exponential, Rating Curve, and Event Mean Concentration.

The SWMM buildup and washoff routines used to represent these processes provide a more reliable pollutant loading time series as compared to other methods (e.g., event mean concentration). This is because the buildup and washoff routines account for the pollutant mass balance over time. The routines also represent the time between events when pollutants accumulate and the predominance of small rainfall events and the effect of rainfall intensity on washing off pollutant load that has accumulated on impervious surfaces.

In this project, a power function was assumed for the pollutant buildup and an exponential function was assumed for the pollutant washoff. As for the buildup, the pollutant buildup (*B*) accumulates proportionally to time (*t*) raised to some power, until a maximum is reached,

$$B = Min\ (C_1, C_2 t^{C_3}) \qquad (1)$$

where C_1 = maximum buildup possible (mass per unit of area or curb length), C_2=buildup rate constant (1/days), and C_3=time exponent.

In the exponential washoff function, the washoff load (*W*) in units of mass per hour is proportional to the product of runoff raised to some power and to the amount of buildup remaining,

$$W = C_1 q^{C_2} B \qquad (2)$$

where C_1 = washoff coefficient, C_2 = washoff exponent, q = runoff rate per unit area (inches/hour [in/hr]), and B = pollutant buildup in mass (lbs) per unit area or curb length.

3.3.2. Setup and Calibration of SWMM

A SWMM was created for each of the five land uses. Each SWMM consists of a one-acre sub-catchment that represents one of the five land use categories. An 11-year period (01/01/1992 through 12/31/2002) of weather data (temperature, evaporation, and wind speed) from the Boston station (MA0770) was used as input to the model to generate hourly runoff volume and pollutant load time series.

Field-verified exponential pollutant buildup and washoff relationships from the Greater Toronto Area (Behera et al. 2006) are referred to when calibrating the SWMM water quality model. The pollutant buildup and washoff parameters were further adjusted from the Behera et al. (2006) values until the predicted annual average pollutant loading export rates are closely matched with those specified in Table 3-2. The final calibrated pollutant buildup and washoff parameters for each land use, as well as the results of the calibration, are listed below in Table 3-3 through Table 3-7.

Table 3-3. Calibration results for the Commercial land use

Pollutant	Buildup ($B=Min(C_1, C_2t^{C_3})$)			Washoff ($W=C_1q^{C_2}B$)		Calibration results (kg/ac-yr)		
	C_1	C_2	C_3	C_1	C_2	Target	Calibrated	Error (%)
TP	7.00	0.036	0.49	0.78	1.41	0.68	0.683	0.6%
TSS	68.11	0.85	1.54	6.97	1.57	453.59	453.23	0%
TN	23.11	0.04	0.915	4.69	0.61	4.45	4.454	0.1%
Zn	15.59	0.027	0.17	10.01	0.74	0.95	0.946	0.4%

Table 3-4. Calibration results for the Industrial land use

Pollutant	Buildup ($B=Min(C_1, C_2t^{C_3})$)			Washoff ($W=C_1q^{C_2}B$)		Calibration results (kg/ac-yr)		
	C_1	C_2	C_3	C_1	C_2	Target	Calibrated	Error (%)
TP	6.11	0.034	0.46	0.75	1.37	0.59	0.594	0.7%
TSS	41.12	0.81	1.44	6.71	1.53	303.91	303.49	0.1%
TN	12.44	0.022	0.84	4.01	0.62	2.13	2.11	0.9%
Zn	2.38	0.0085	0.084	6.02	1.31	0.18	0.18	0%

Table 3-5. Calibration results for the High-Density Residential land use

Pollutant	Buildup ($B=Min(C_1, C_2t^{C_3})$)			Washoff ($W=C_1q^{C_2}B$)		Calibration results (kg/ac-yr)		
	C_1	C_2	C_3	C_1	C_2	Target	Calibrated	Error (%)
TP	4.75	0.031	0.42	0.71	1.37	0.45	0.449	0.2%
TSS	28.12	0.76	1.26	5.91	1.46	190.51	190.57	0%
TN	18.94	0.027	0.88	4.31	0.57	2.81	2.811	0.04%
Zn	4.78	0.013	0.088	7.22	1.11	0.32	0.322	0.6%

Table 3-6. Calibration results for the Medium-Density Residential land use

Pollutant	Buildup ($B=Min(C_1, C_2t^{C_3})$)			Washoff ($W=C_1q^{C_2}B$)		Calibration results (kg/ac-yr)		
	C_1	C_2	C_3	C_1	C_2	Target	Calibrated	Error (%)
TP	1.77	0.027	0.31	0.43	1.27	0.229	0.225	1.7%
TSS	19.48	0.62	1.12	5.11	1.21	113.40	113.50	0.1%
TN	10.94	0.019	0.82	4.01	0.52	1.77	1.768	0.1%
Zn	1.24	0.006	0.051	2.11	1.89	0.045	0.045	0%

Table 3-7. Calibration results for the Low-Density Residential land use

Pollutant	Buildup ($B=Min(C_1, C_2t^{C_3})$)			Washoff ($W=C_1q^{C_2}B$)		Calibration results (kg/ac-yr)		
	C_1	C_2	C_3	C_1	C_2	Target	Calibrated	Error (%)
TP	0.27	0.0064	0.09	0.19	1.14	0.018	0.019	5.5%
TSS	4.18	0.31	0.87	2.11	1.02	29.48	29.48	0%
TN	8.44	0.0035	0.44	3.01	0.21	0.18	0.181	0.6%
Zn	0.98	0.0039	0.021	1.47	2.35	0.018	0.019	5.5%

Following calibration of the SWMM for the land uses, model simulations were performed to generate runoff volume and pollutant time series for each land use. These time series were used as input to the BMP modeling system to predict long-term BMP performance (see Sections 4 and 5).

4. BMP ANALYSIS

The BMP analysis involves two major tasks designed to support the development of long-term performance curves for the following BMPs:

- Subsurface infiltration systems (infiltration trench)
- Surface infiltration systems (infiltration basin)
- Gravel wetland
- Bioretention systems
- Porous pavement
- Swales
- Dry detention ponds
- Wet ponds

The first task was to recalibrate and test BMPDSS for New England conditions using BMP performance data collected at the University of New Hampshire Stormwater Center (UNHSC). The second task evaluated BMP design criteria from the New England states and selected the design criteria for each BMP for use in the BMPDSS to develop long-term performance curves.

4.1. BMPDSS Calibration and Testing

Prince George's County BMPDSS, was selected as the BMP model to simulate long-term pollutant removal performance of the selected BMPs. Performance curves were generated by varying the capacity or size (amount of runoff captured) of the BMPs. The BMPDSS model was recalibrated (BMPDSS was previously calibrated for Prince George's County, Maryland) using BMP performance data collected by UNHSC to represent current data and New England conditions. Recalibration was performed for all the BMPs except for the dry detention pond because performance data for dry detention ponds were not available from UNHSC. This section details the BMPDSS calibration and testing task.

4.1.1. Overview of the Calibration Process

The calibration process involved adjusting BMP design parameters (porosity, infiltration rate, vegetation cover percentage, and so on) to best simulate the BMP's hydraulic and pollutant removal performance. The goal of the calibration process was to match model hydrologic and water quality predictions with observed data for the calibration events. BMPDSS was calibrated for the following BMPs: (1) infiltration system, (2) gravel wetland, (3) bioretention system, (4) porous pavement, (5) grass swale, and (6) wet pond.

Calibrating a BMP using the BMPDSS model was a three-step process. First, the hydrologic and water quality time series were generated using SWMM. This involved calibrating SWMM to match the observed discrete inflow volume and water quality data. The calibrated SWMM was used to generate continuous hourly time series, which BMPDSS requires as input. Second, a hydraulic calibration of BMPDSS for each BMP was performed using the SWMM-generated inflow time series. During this process, the BMP's hydrologic parameters (porosity, infiltration rate, vegetation cover percentage, and such) were adjusted as needed to achieve acceptable agreement between model predications and measured flow data. Finally, the water quality calibration of each BMP was completed by adjusting the water quality-related parameters (e.g., first order decay coefficients and filtering efficiencies). As with the hydraulic calibration, the objective of the water quality calibration was to achieve acceptable agreement between BMPDSS predictions and measured BMP outflow pollutant concentrations.

Depending on the BMP, the water quality simulation can consider two mechanisms: general loss or decay of pollutant (by settling, plant uptake, volatilization, and such) and pollutant filtration through a substrate. For each type of BMP, the appropriate pollutant removal mechanisms were selected. For example, wet detention pond and swale BMPs include only the general loss component because the filtration mechanism is not applicable, whereas, bioretention, gravel wetland, infiltration system, and porous pavement BMPs include both general loss and filtration mechanisms.

The general loss or decay is represented using a first order decay model:

$$C_t = C_0 \, e^{(-kt)} \qquad (3)$$

where C_t is the pollutant concentration at time t, C_0 is the initial pollutant concentration, and k is the first order decay rate (T^{-1}).

Pollutant filtration through substrate is simulated using percent removal:

$$C_{ud\_out} = P_{rem} \, C_{in} \, e^{(-kt)} \qquad (4)$$

where C_{ud_out} is the underdrain outflow pollutant concentration, C_{in} is pollutant concentration in inflow to the substrate, and P_{rem} is media filtration percent removal rate (0–1). Figure 4-1 illustrates the water quality simulation processes that occur in a BMP unit in BMPDSS. Parameters k and P_{rem} were adjusted during the water quality calibration process.

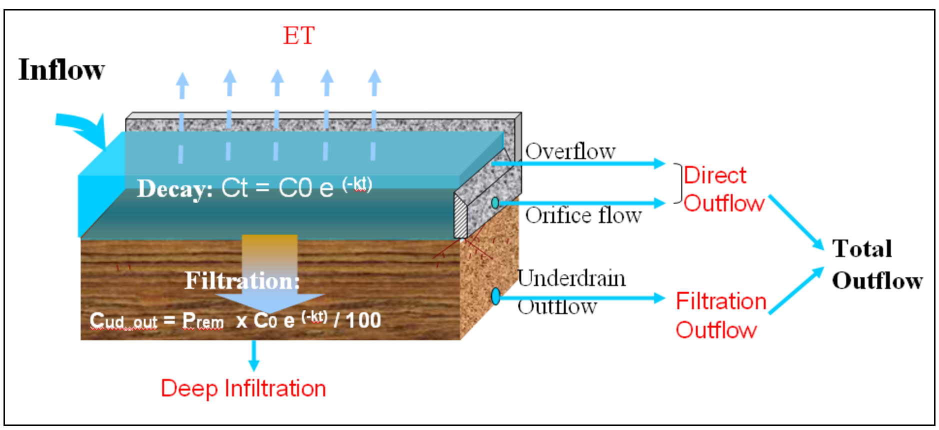


Figure 4-1. Water quality simulation processes.

For calibration, hydraulic and water quality parameters were adjusted for each BMP using three rainfall events with the goal of achieving the best match between model predictions and measured data for each event. The average of the adjusted hydraulic and water quality parameters for three events became the calibrated parameters for each BMP.

Final testing of the BMPDSS model performance for each calibrated BMP was conducted by performing continuous simulations of the BMPDSS for the period of 2004–2006 and comparing the model predicted 2004–2006 BMP pollutant load reductions to the long-term BMP performances reported by UNHSC in its 2007 Annual Report (UNHSC 2007). The UNHSC calculated the long-term performance using many monitoring events conducted over this period. This approach for testing the model's performance using long-term performance model results and data is particularly appropriate because the calibrated BMPDSS models were used for long-term simulations in the performance curve generations. During the testing process, the calibrated BMPDSS model was applied for each BMP for the period of 2004–2006 using hourly flow and quality results from SWMM as input. Then the model-predicted total inflow pollutant load and outflow load for the period were determined to calculate the pollutant reduction percentages (see section 4.1.4).

4.1.2. BMPDSS Calibration Events

The calibration events for BMPDSS are summarized in Table 4-1. As shown, six events were selected for use in the BMP calibration process ensuring that performance data are available for at least three events for each BMP. SWMM was calibrated with observed inflow and inflow pollutant concentrations for each selected storm. Calibrated time series of flow and pollutant concentrations were then used as input into BMPDSS for the BMP calibration.

Table 4-1. Selection of calibration events for BMPs

	1	2	3	4	5	6
BMP list	10/30/2004	8/13/2005	11/30/2005	1/12/2006	5/9/2006	6/21/2006
Bioretention area	√				√	√
Grass swale			√	√	√	
Gravel wetland		√		√		√
Infiltration system		√		√	√	
Porous pavement		√	√	√		
Wet pond		√			√	√

4.1.3. BMPDSS calibration results

Hydrologic calibrations of the BMP was first performed, followed by the water quality calibrations for the selected pollutants TSS, TP, TN, and Zn. However, it was determined during the calibration that there was insufficient TN data to complete the calibration of the BMP models for TN. Therefore, TN was dropped from the project, and the water quality calibrations focused on TSS, TP, and Zn.

1. Infiltration system

Calibration for event 08/13/2005

The hydrologic calibration of the infiltration system for event 08/13/2005 is illustrated in Figure 4-2. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-2.

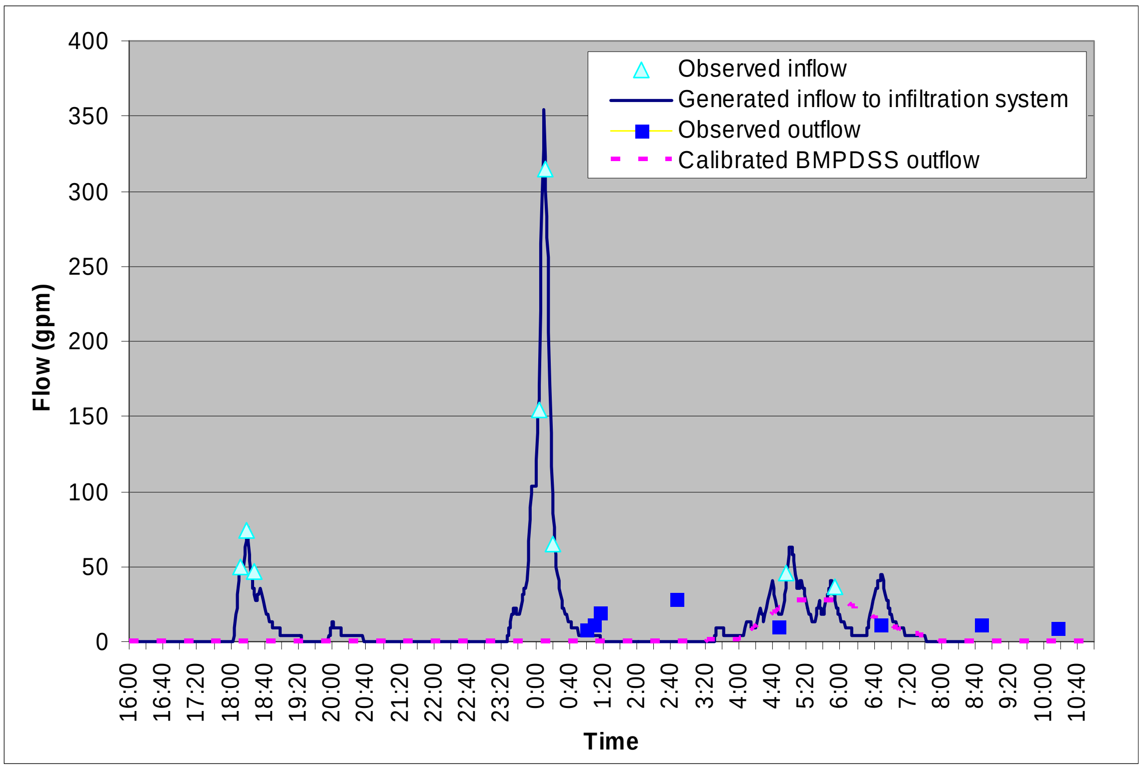


Figure 4-2. The hydrologic calibration of BMPDSS for infiltration system for event 08/13/2005.

Calibration for event 01/12/2006

The hydrologic calibration of the infiltration system for event 01/12/2006 is illustrated in Figure 4-3. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-2.

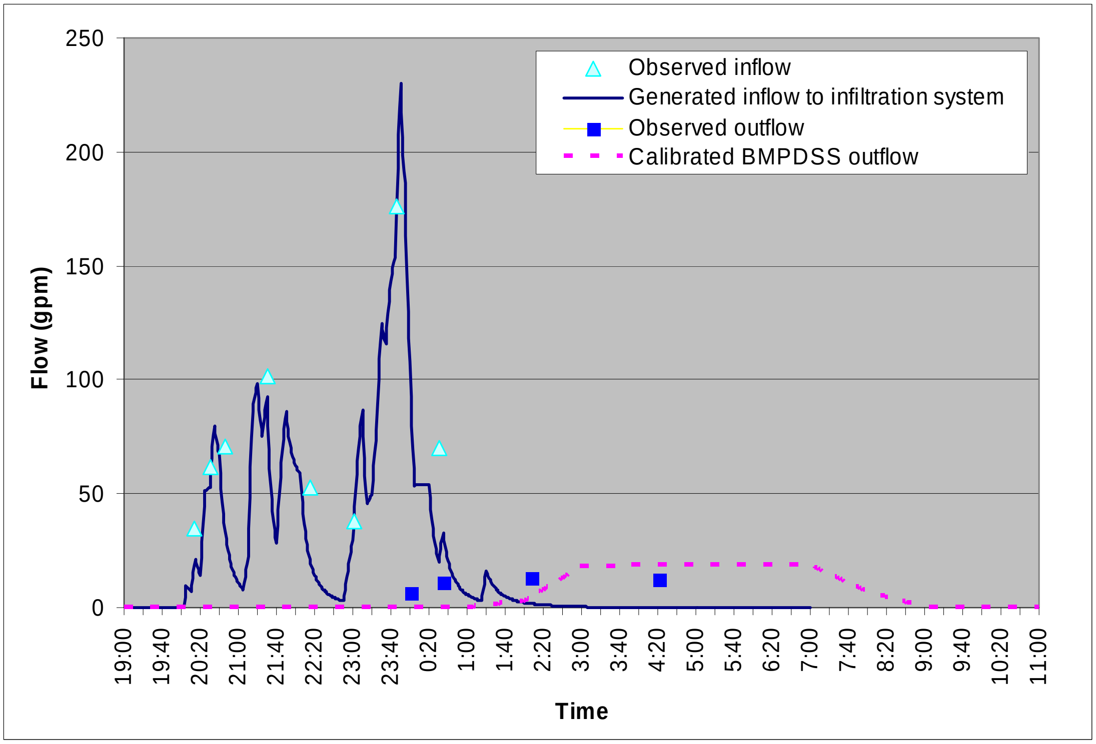


Figure 4-3. The hydrologic calibration of BMPDSS for infiltration system for event 01/12/2006.

Calibration for event 05/09/2006

The hydrologic calibration of the infiltration system for event 05/09/2006 is illustrated in Figure 4-4. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-2.

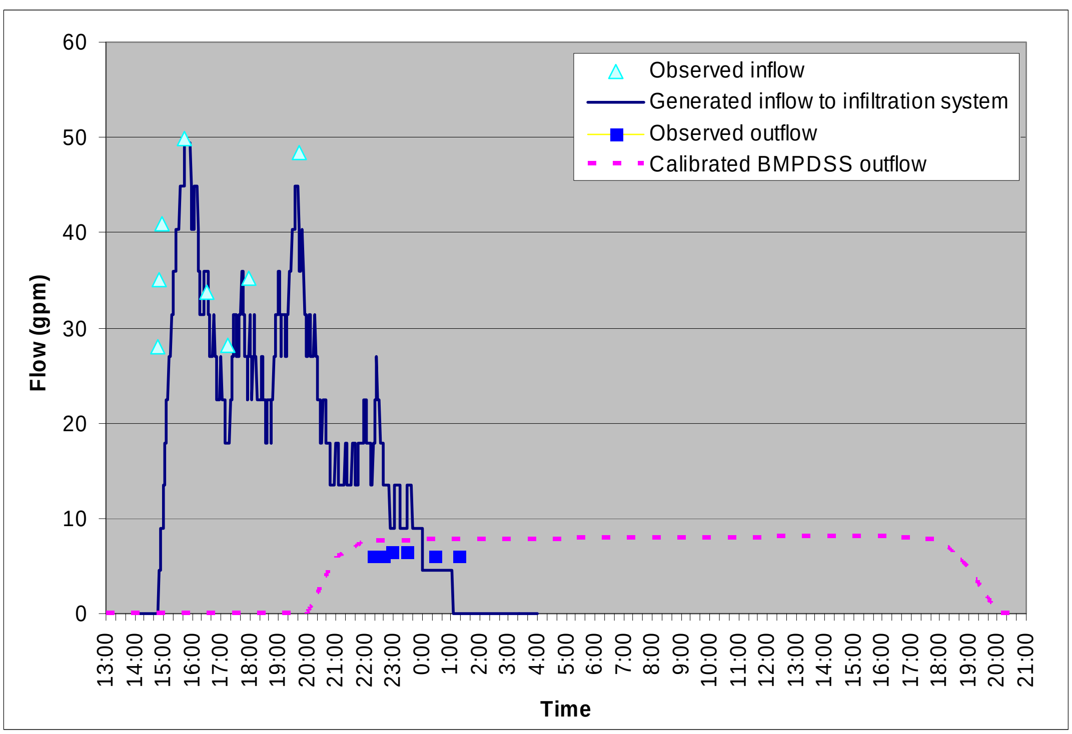


Figure 4-4. The hydrologic calibration of BMPDSS for infiltration system for event 05/09/2006.

The individual calibrated pollutant decay rate and percent removal parameters for the three calibration events were averaged (Table 4-2) to determine the overall calibrated water quality parameters for the infiltration system.

Table 4-2. Summary of calibration results for infiltration system

Calibration events			Pollutants		
			TSS	TP	Zn
08/13/2005	Observed EMC (mg/L)	Inflow	72.13	0.16	0.11
		Outflow	0.17	0.03	0
	BMPDSS performance	Calibrated outflow	0.17	0.03	0.006
		Decay	0.76	0.31	0.47
		Perct. removal	0.93	0.70	0.85
01/12/2006	Observed EMC (mg/L)	Inflow	52.06	0.10	0.03
		Outflow	0	0.01	0
	BMPDSS performance	Calibrated outflow	0.03	0.01	0.001
		Decay	0.73	0.29	0.44
		Perct. removal	0.90	0.65	0.81
05/09/2006	Observed EMC (mg/L)	Inflow	94.03	0.12	0.04
		Outflow	0	0.02	0
	BMPDSS performance	Calibrated outflow	0.01	0.02	0
		Decay	0.73	0.21	0.44
		Perct. removal	0.91	0.50	0.79
Calibrated parameters		Decay	0.74	0.27	0.45
		Perct. removal	0.91	0.62	0.82

2. Gravel wetland

<u>Calibration for event 08/13/2005</u>
The hydrologic calibration of the gravel wetland for event 08/13/2005 is illustrated in Figure 4-5. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-3.

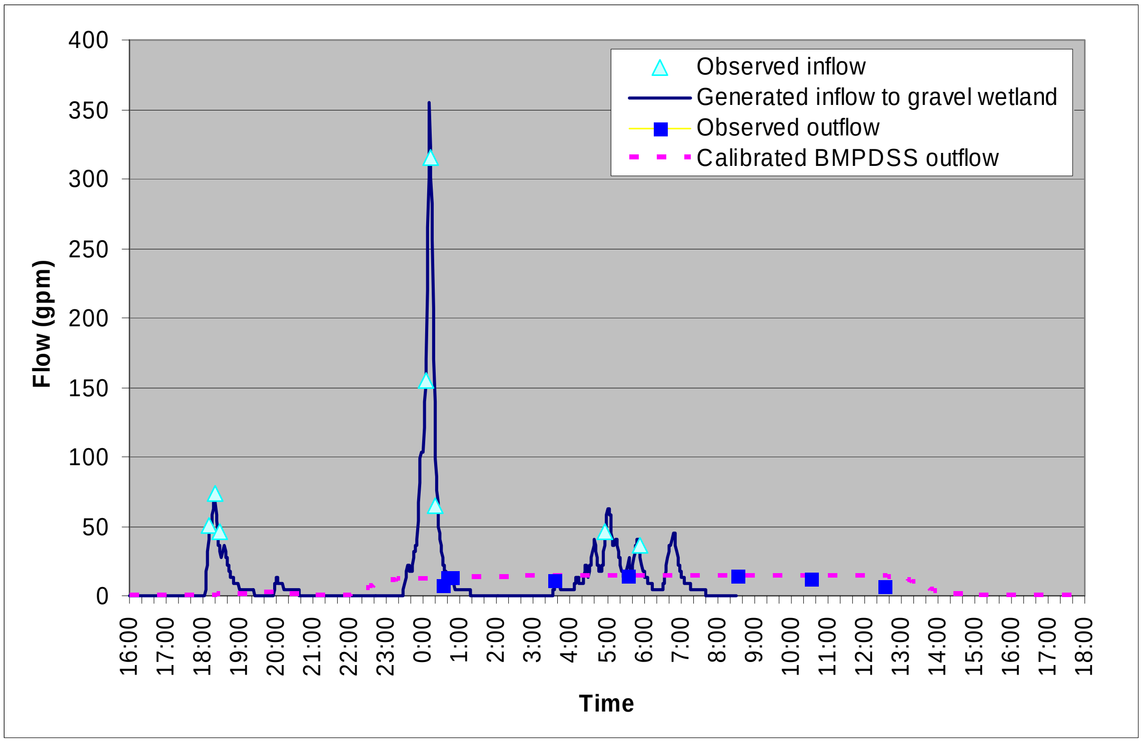


Figure 4-5. The hydrologic calibration of BMPDSS for gravel wetland for event 08/13/2005.

<u>Calibration for event 01/12/2006</u>
The hydrologic calibration of the gravel wetland for event 01/12/2006 is illustrated in Figure 4-6. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-3.

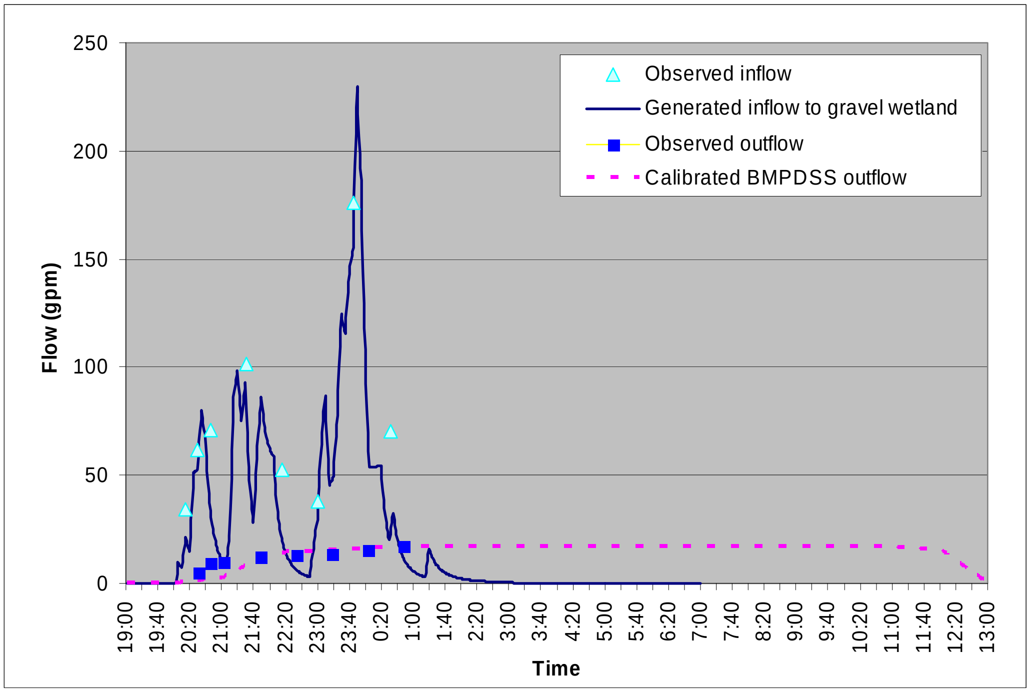


Figure 4-6. The hydrologic calibration of BMPDSS for gravel wetland for event 01/12/2006.

Calibration for event 06/21/2006

The hydrologic calibration of the gravel wetland for event 06/21/2006 is illustrated in Figure 4-7. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-3.

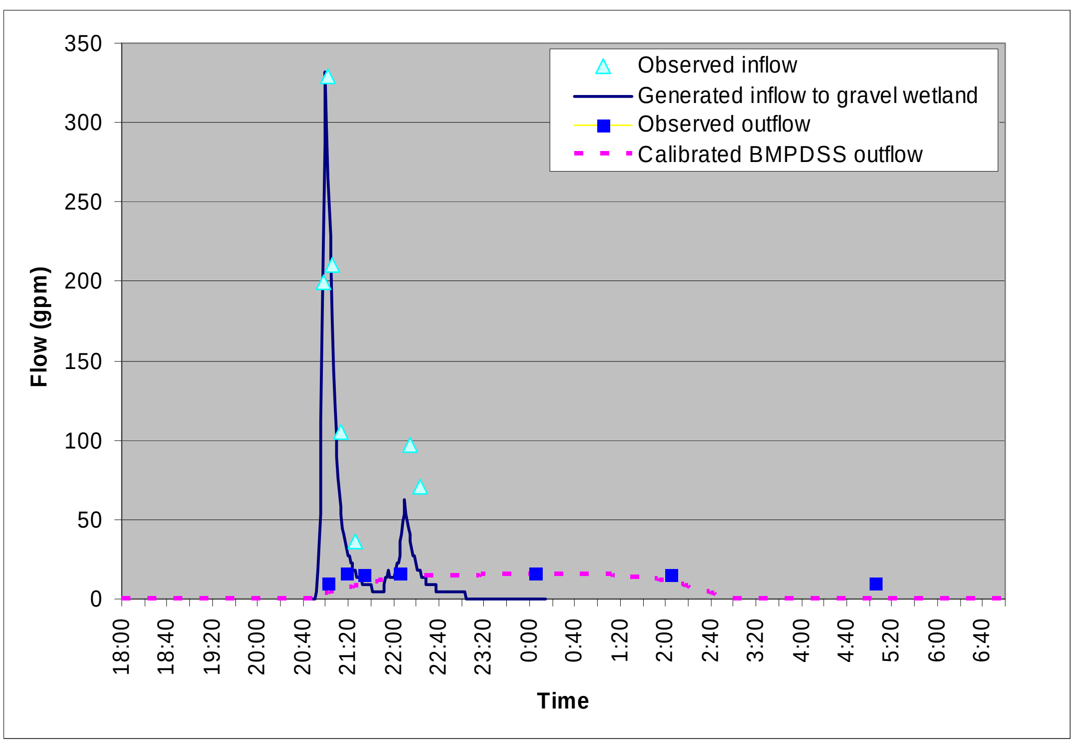


Figure 4-7. The hydrologic calibration of BMPDSS for gravel wetland for event 06/21/2006.

The individual calibrated pollutant decay rate and percent removal parameters from the three calibration events were averaged (Table 4-3) to determine the overall calibrated water quality parameters for the gravel wetland.

Table 4-3. Summary of calibration results for gravel wetland

Calibration events			Pollutants		
			TSS	TP	Zn
08/13/2005	Observed EMC (mg/L)	Inflow	72.13	0.16	0.11
		Outflow	0	0.08	0
	BMPDSS performance	Calibrated outflow	0.116	0.08	0.008
		Decay	0.34	0.15	0.25
		Perct. removal	0.87	0.24	0.54
01/12/2006	Observed EMC (mg/L)	Inflow	52.06	0.10	0.03
		Outflow	0	0.02	0.01
	BMPDSS performance	Calibrated outflow	0.29	0.02	0.01
		Decay	0.39	0.06	0.18
		Perct. removal	0.86	0.14	0.55
06/21/2006	Observed EMC (mg/L)	Inflow	75.87	0.29	0.05
		Outflow	0.44	0.12	0
	BMPDSS performance	Calibrated outflow	0.45	0.12	0.006
		Decay	0.35	0.12	0.14
		Perct. removal	0.83	0.22	0.47
Calibrated parameters		Decay	0.36	0.11	0.19
		Perct. removal	0.85	0.20	0.52

3. Bioretention area

<u>Calibration for event 10/30/2004</u>

The hydrologic calibration of the bioretention area for event 10/30/2004 is illustrated in Figure 4-8. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-4.

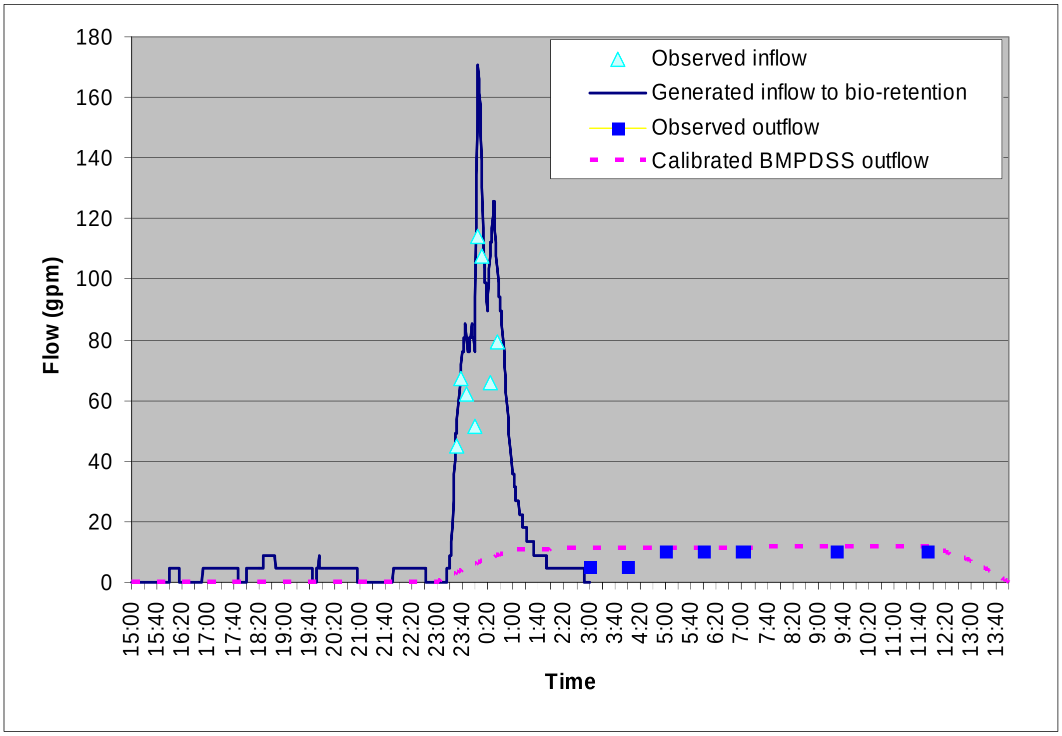


Figure 4-8. The hydrologic calibration of BMPDSS for bioretention area for event 10/30/2004.

<u>Calibration for event 05/09/2006</u>

The hydrologic calibration of the bioretention area for event 05/09/2006 is illustrated in Figure 4-9. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-4.

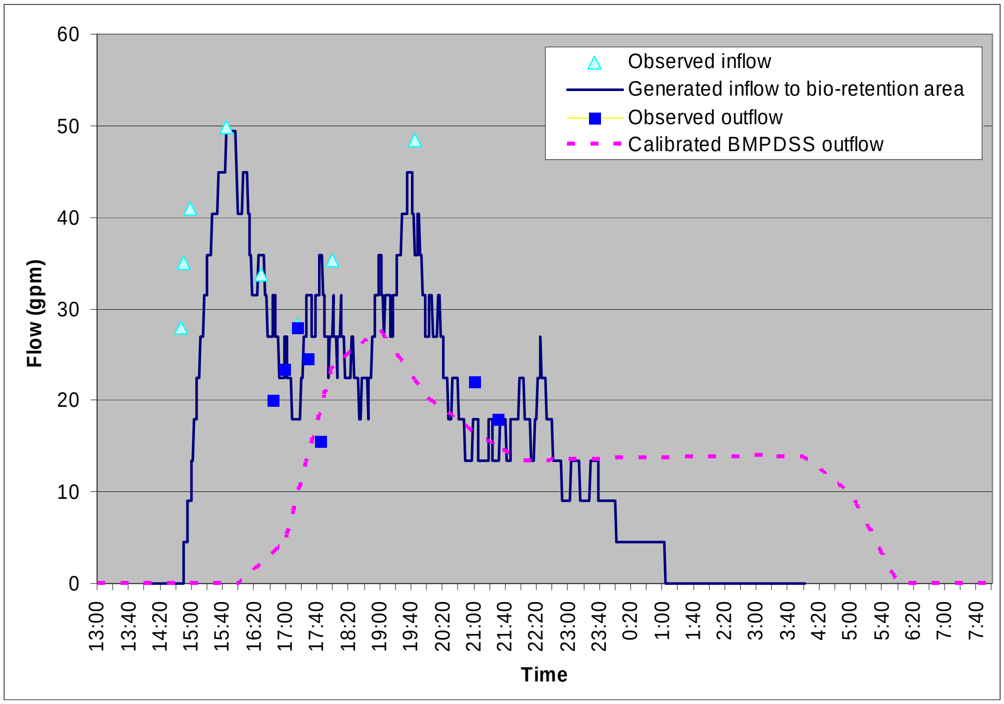


Figure 4-9. The hydrologic calibration of BMPDSS for bioretention area for event 05/09/2006.

Calibration for event 06/21/2006

The hydrologic calibration of the bioretention area for event 06/21/2006 is illustrated in Figure 4-10. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-4.

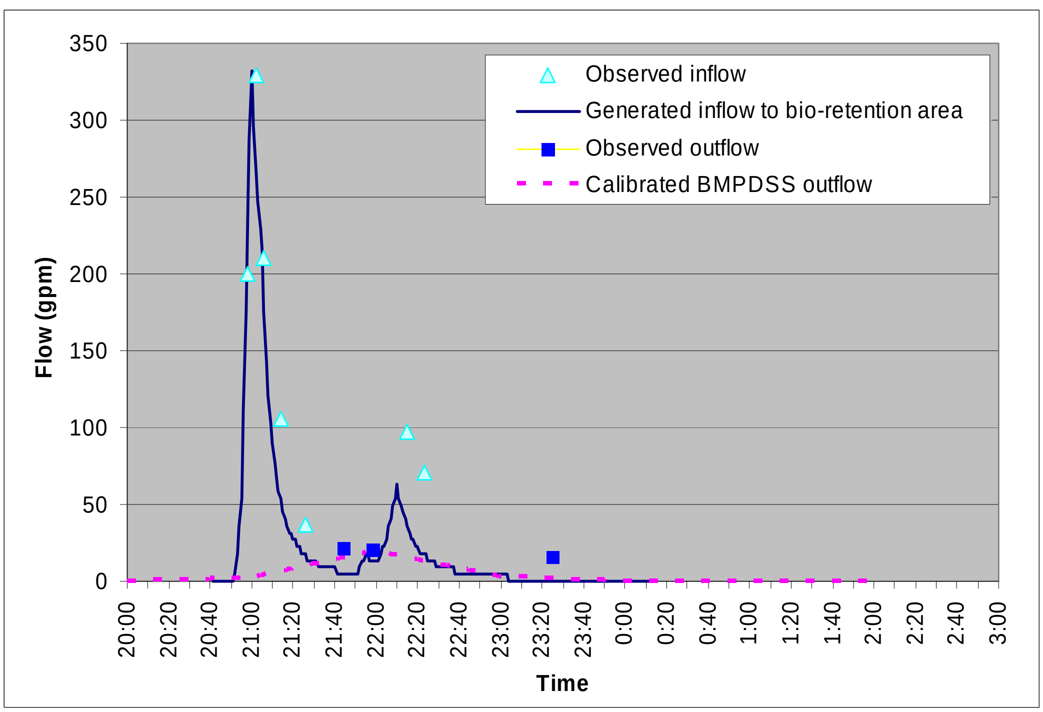


Figure 4-10. The hydrologic calibration of BMPDSS for bioretention area for event 06/21/2006.

The individual calibrated pollutant decay rate and percent removal parameters from the three events were averaged (Table 4-4) to determine the overall calibrated water quality parameters for the bioretention area.

Table 4-4. Summary of calibration results for bioretention area

Calibration events			Pollutants		
			TSS	TP	Zn
10/30/2004	Observed EMC (mg/L)	Inflow	32.56	0.02	0.08
		Outflow	0.56	0	0
	BMPDSS performance	Calibrated outflow	0.56	0.02	0.002
		Decay	0.62	0.13	0.49
		Perct. removal	0.74	0.48	0.84
05/09/2006	Observed EMC (mg/L)	Inflow	94.03	0.12	0.04
		Outflow	0	0.12	0
	BMPDSS performance	Calibrated outflow	1.3	0.12	0.003
		Decay	0.92	0.17	0.49
		Perct. removal	0.98	0.50	0.84
06/21/2006	Observed EMC (mg/L)	Inflow	75.87	0.29	0.05
		Outflow	0	0.16	0
	BMPDSS performance	Calibrated outflow	0.20	0.16	0.001
		Decay	0.82	0.10	0.49
		Perct. removal	0.95	0.31	0.84
Calibrated parameters		Decay	0.79	0.13	0.49
		Perct. removal	0.89	0.43	0.84

4. Porous pavement

Calibration for event 08/13/2005
The hydrologic calibration of the porous pavement for event 08/13/2005 is illustrated in Figure 4-11. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-5.

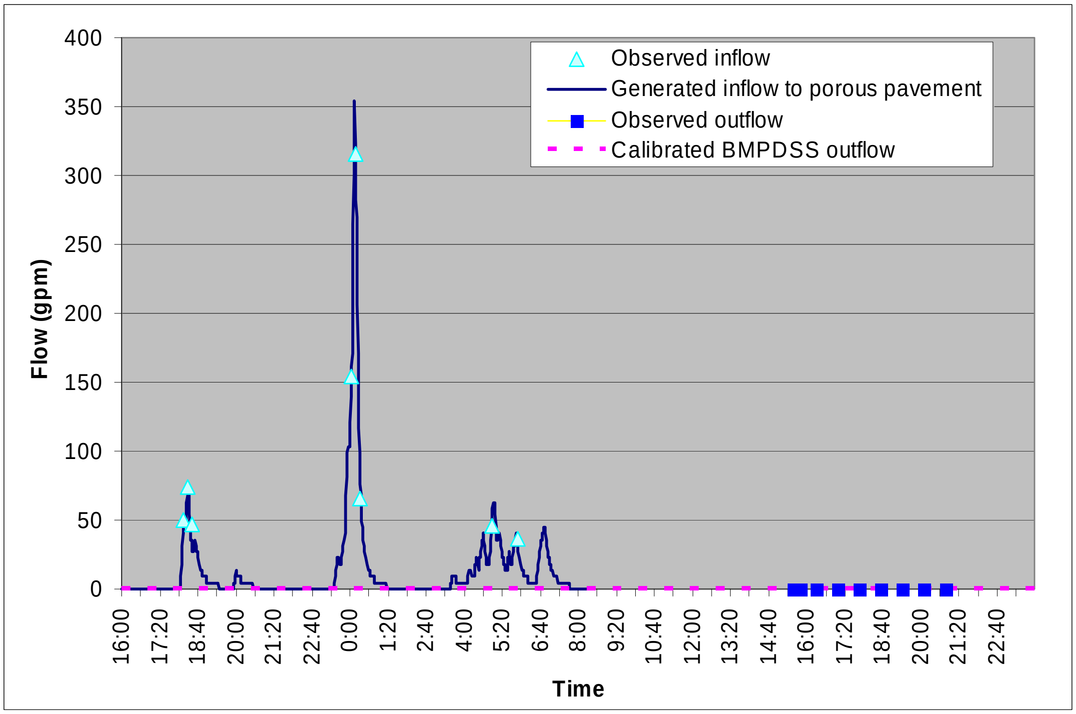


Figure 4-11. The hydrologic calibration of BMPDSS for porous pavement for event 08/13/2005.

Calibration for event 11/30/2005
The hydrologic calibration of the porous pavement for event 11/30/2005 is illustrated in Figure 4-12. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-5.

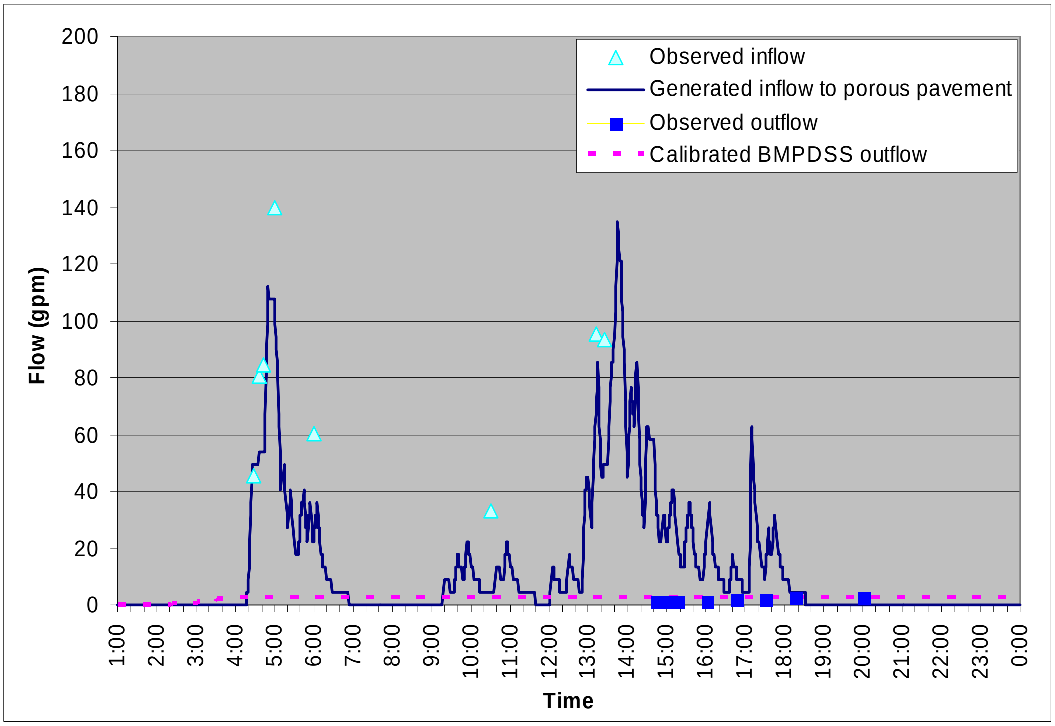


Figure 4-12. The hydrologic calibration of BMPDSS for porous pavement for event 11/30/2005.

Calibration for event 01/12/2006

The hydrologic calibration of the porous pavement for event 01/12/2006 is illustrated in Figure 4-13. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-5.

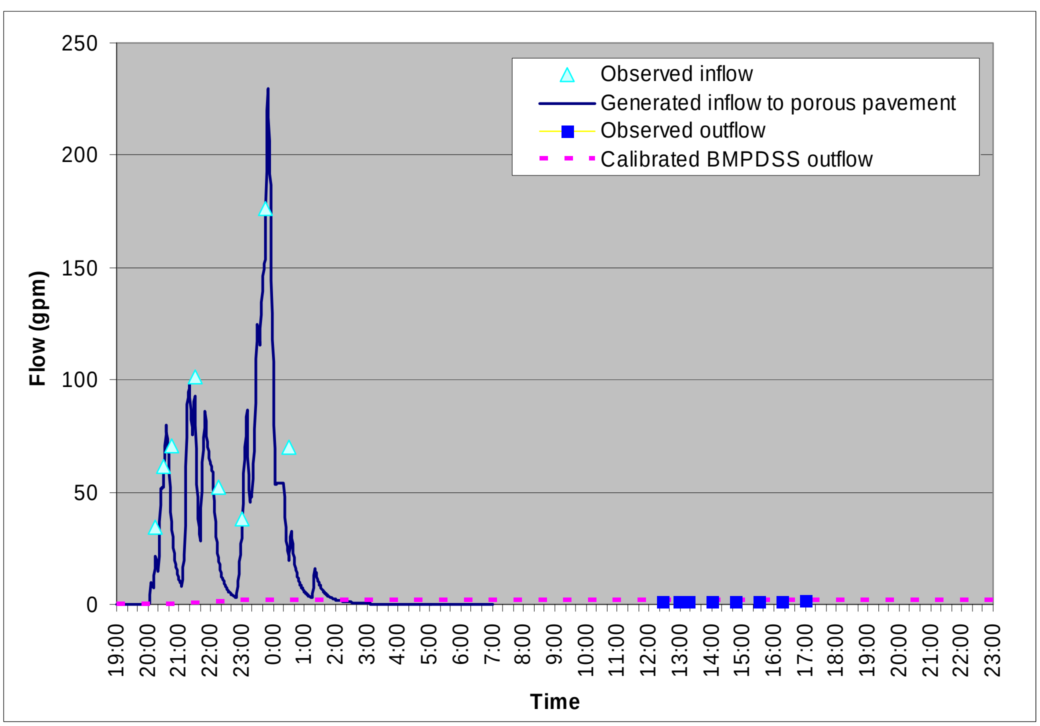


Figure 4-13. The hydrologic calibration of BMPDSS for porous pavement for event 01/12/2006.

The individual calibrated pollutant decay rate and percent removal parameters from the three calibration events were averaged (Table 4-5) to determine the overall calibrated water quality parameters for the porous pavement.

Table 4-5. Summary of calibration results for porous pavement

Calibration events			Pollutants		
			TSS	TP	Zn
08/13/2005	Observed EMC (mg/L)	Inflow	72.13	0.16	0.11
		Outflow	0	0.04	0
	BMPDSS performance	Calibrated outflow	0.59	0.04	0.006
		Decay	0.17	0.0053	0.11
		Perct. removal	0.53	0.11	0.24
11/30/2005	Observed EMC (mg/L)	Inflow	17.31	0.09	0.03
		Outflow	0	0.06	0
	BMPDSS performance	Calibrated outflow	0.94	0.06	0.01
		Decay	0.23	0.006	0.17
		Perct. removal	0.84	0.11	0.31
01/12/2006	Observed EMC (mg/L)	Inflow	52.06	0.10	0.03
		Outflow	0	0.04	0.05
	BMPDSS performance	Calibrated outflow	0.92	0.04	0.05
		Decay	0.27	0.004	0.14
		Perct. removal	0.88	0.09	0.29
Calibrated parameters		Decay	0.22	0.0051	0.14
		Perct. removal	0.75	0.1	0.28

5. Grass swale

Calibration for event 11/30/2005

The hydrologic calibration of the grass swale for event 11/30/2005 is illustrated in Figure 4-14. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-6.

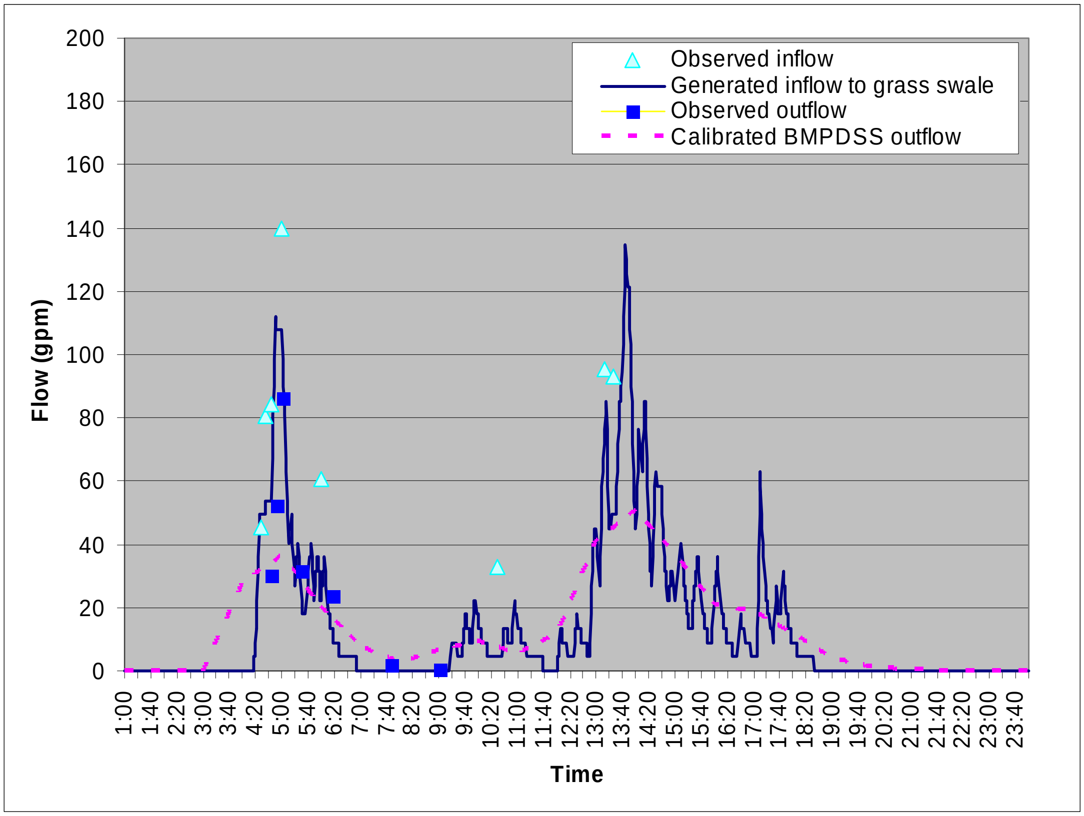


Figure 4-14. The hydrologic calibration of BMPDSS for grass swale for event 11/30/2005.

Calibration for event 01/12/2006

The hydrologic calibration of the grass swale for event 01/12/2006 is illustrated in Figure 4-15. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-6.

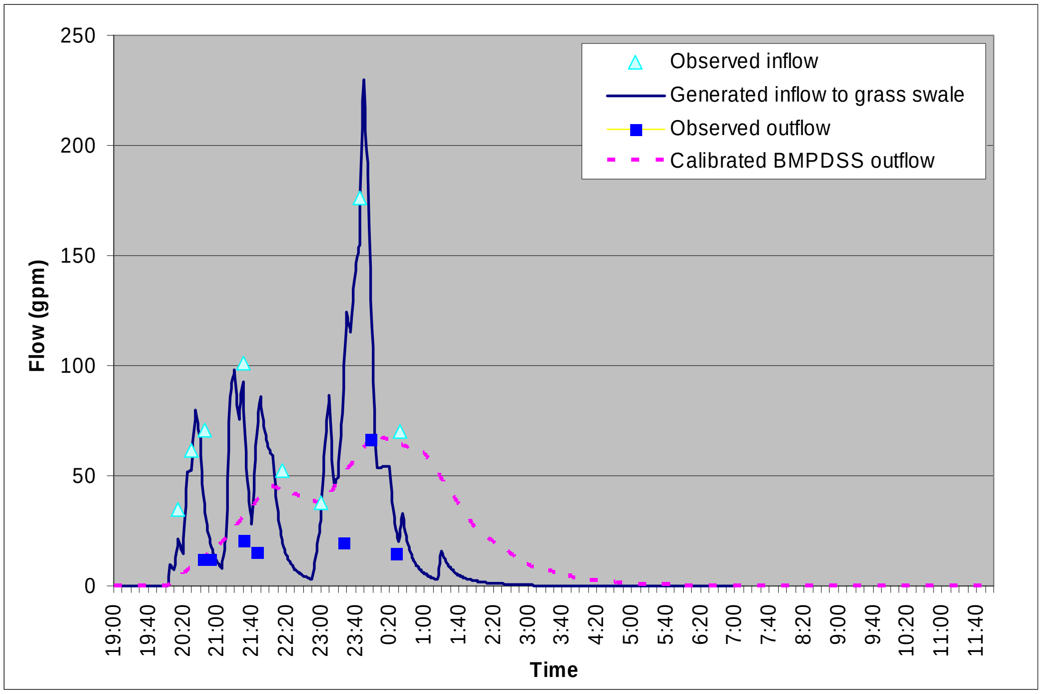


Figure 4-15. The hydrologic calibration of BMPDSS for grass swale for event 01/12/2006.

Calibration for event 05/09/2006

The hydrologic calibration of the grass swale for event 05/09/2006 is illustrated in Figure 4-16. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-6.

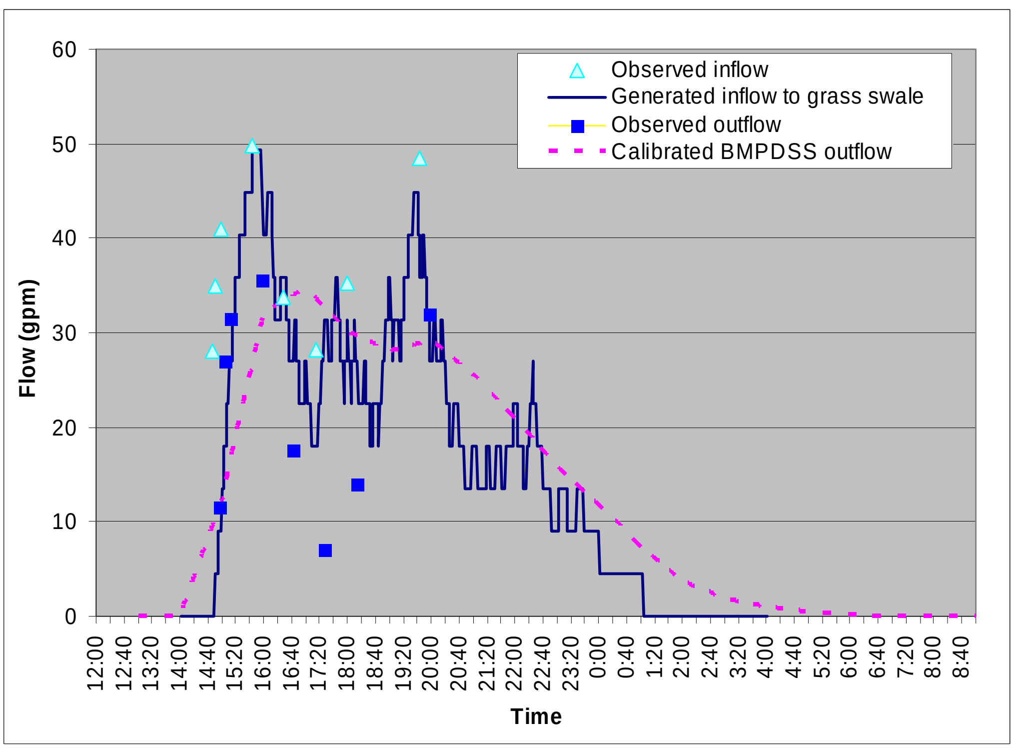


Figure 4-16. The hydrologic calibration of BMPDSS for grass swale for event 05/09/2006.

The individual calibrated pollutant decay rate and percent removal parameters from the three calibration events were averaged (Table 4-6) to determine the overall calibrated water quality parameters for the grass swale.

Table 4-6. Summary of calibration results for grass swale

Calibration events			Pollutants		
			TSS	TP	Zn
11/30/2005	Observed EMC (mg/L)	Inflow	17.31	0.09	0.03
		Outflow	20.88	0.17	0.02
	BMPDSS performance	Calibrated outflow	20.71	0.16	0.02
		Decay	0.93	0.04	2.15
		Perct. removal	N/A	N/A	N/A
01/12/2006	Observed EMC (mg/L)	Inflow	52.06	0.10	0.03
		Outflow	45.05	0.10	0.03
	BMPDSS performance	Calibrated outflow	41.44	0.16	0.03
		Decay	0.20	0.17	0.85
		Perct. removal	N/A	N/A	N/A
05/09/2006	Observed EMC (mg/L)	Inflow	94.03	0.12	0.04
		Outflow	0.5	0.08	0
	BMPDSS performance	Calibrated outflow	0.5	0.07	0.008
		Decay	0.85	0.10	2.35
		Perct. removal	N/A	N/A	N/A
Calibrated parameters		Decay	0.66	0.10	1.78
		Perct. removal	N/A	N/A	N/A

6. Wet pond

Calibration for event 08/13/2005
The hydrologic calibration of the wet pond for event 08/13/2005 is illustrated in Figure 4-17. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-7.

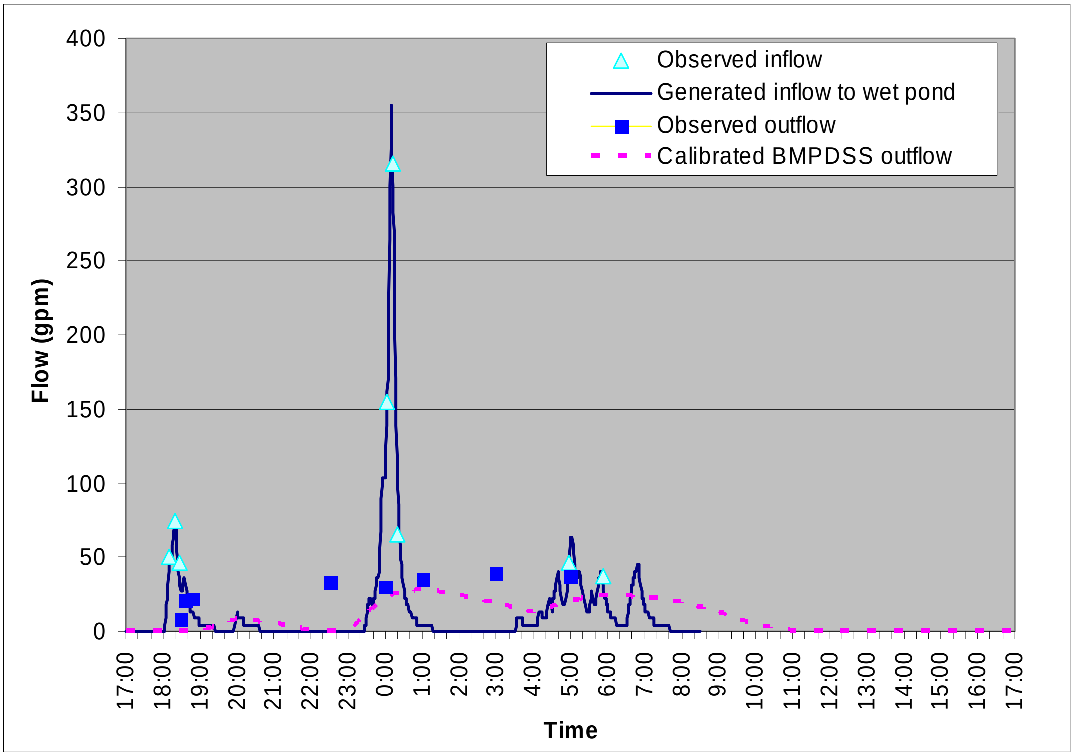


Figure 4-17. The hydrologic calibration of BMPDSS for wet pond for event 08/13/2005.

Calibration for event 05/09/2006
The hydrologic calibration of the wet pond for event 05/09/2006 is illustrated in Figure 4-18. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-7.

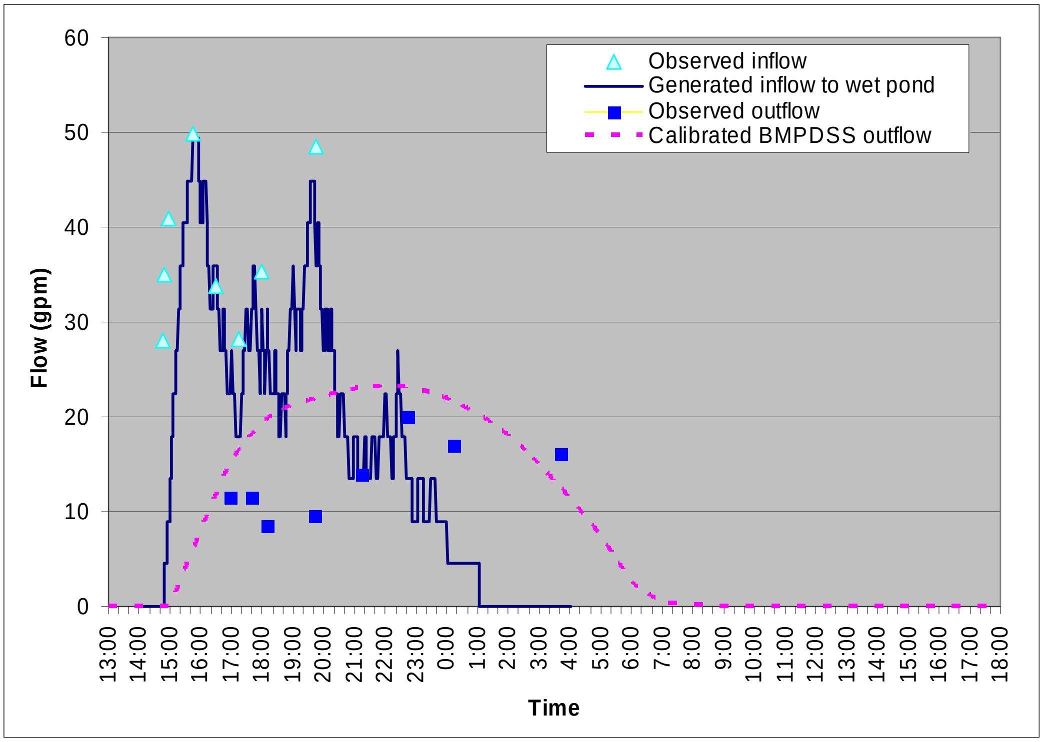


Figure 4-18. The hydrologic calibration of BMPDSS for wet pond for event 05/09/2006.

<u>Calibration for event 06/21/2006</u>

The hydrologic calibration of the wet pond for event 06/21/2006 is illustrated in Figure 4-19. The water quality calibration results for TSS, TP, and Zn are summarized in Table 4-7.

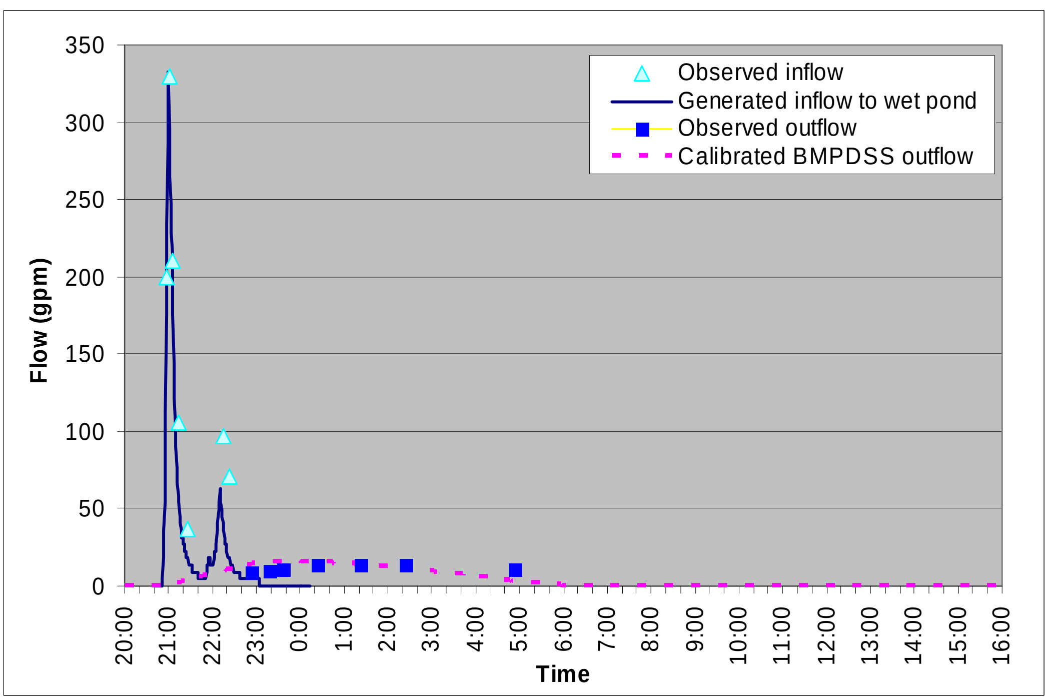


Figure 4-19. The hydrologic calibration of BMPDSS for wet pond for event 06/21/2006.

The individual calibrated pollutant decay rate and percent removal parameters from the three calibration events were averaged (Table 4-7) to determine the overall calibrated water quality parameters for the wet pond.

Table 4-7. Summary of calibration results for wet pond

Calibration events			Pollutants		
			TSS	TP	Zn
08/13/2005	Observed EMC (mg/L)	Inflow	72.13	0.16	0.11
		Outflow	47.62	0.14	0.02
	BMPDSS performance	Calibrated outflow	47.36	0.14	0.02
		Decay	0.20	0.01	1.40
		Perct. removal	N/A	N/A	N/A
05/09/2006	Observed EMC (mg/L)	Inflow	94.03	0.12	0.04
		Outflow	0.8	0.04	0.005
	BMPDSS performance	Calibrated outflow	0.8	0.04	0.005
		Decay	0.40	0.03	1.50
		Perct. removal	N/A	N/A	N/A
06/21/2006	Observed EMC (mg/L)	Inflow	75.87	0.29	0.05
		Outflow	34.03	0.21	0
	BMPDSS performance	Calibrated outflow	34.23	0.21	0.003
		Decay	0.18	0.05	1.69
		Perct. removal	N/A	N/A	N/A
Calibrated parameters		Decay	0.26	0.03	1.53
		Perct. removal	N/A	N/A	N/A

4.1.4. BMPDSS Test Results

The calibrated BMPDSS models performances were tested by comparing the model simulated long-term pollutant removal for the 2004–2006 period to the UNHSC reported long-term BMP performances reported for the same period. The calibrated BMPDSS models were run for the 2004–2006 period, and the pollutant removal rates of each BMP were calculated and compared to the UNHSC-reported values (UNHSC 2007). It is important to note that the UNHSC-reported values represent the median pollutant removal of selected storms (approximately 17–20 storms) for each BMP. BMPDSS-simulated pollutant removal reports the cumulative pollutant removal of all storms (34 storms) that occurred during the selected period including those analyzed by UNHSC.

1. Infiltration system

The test results of the infiltration system BMPDSS model are shown in Table 4-8. As shown, the BMPDSS model simulation results for TSS, TP, and Zn removal are similar to the UNHSC-reported values.

Table 4-8. Test results of infiltration system removal efficiencies for 2004–2006

Total pollutant load	TSS (lbs)	TP (lbs)	Zn (lbs)
Inflow	279.29	2.81	0.45
Outflow	4.21	0.48	0.01
Pollutant removal	98%	83%	98%
UNHSC-report percentage	99%	81%	99%

2. Gravel wetland

The test results of the gravel wetland BMPDSS model are shown in Table 4-9. As shown, the BMPDSS model simulation results for TSS, TP, and Zn removal are similar to the UNHSC-reported values.

Table 4-9. Test results of gravel wetland removal efficiencies for 2004–2006

Total pollutant load	TSS (lbs)	TP (lbs)	Zn (lbs)
Inflow	279.29	2.81	0.45
Outflow	4.61	1.05	0.04
Pollutant removal	98%	63%	91%
UNHSC-report percentage	99%	55%	99%

3. Bioretention area

The test results of the bioretention area BMPDSS model are shown in Table 4-10. As shown, the BMPDSS model simulation results for TSS and Zn are similar (< 5 percent difference) to the UNHSC-reported values. However, the BMPDSS model simulated a much higher long-term pollutant removal rate for TP than the UNHSC-reported value. The bioretention system at UNHSC has gone through several design and construction related issues during the selected period. The observed data could have been influenced by these uncertainties. A review of bioretention performance data reported by others indicates that the UNHSC-reported TP removal of 5 percent is relatively low for a well-functioning bioretention type of BMP.

Consequently, the bioretention module in the existing BMPDSS, which was calibrated to bioretention performance data from the University of Maryland (Tetra Tech 2007) has resulted in a long-term TP removal of 64 percent. The BMPDSS model prediction for TP removal appears to be reasonable when compared to the pollutant removal percentages reported by EPA for bioretention systems (USEPA 1999), which is 70–83 percent.

Table 4-10. Test results of bioretention area removal efficiencies for 2004–2006

Total pollutant load	TSS (lbs)	TP (lbs)	Zn (lbs)
Inflow	279.29	2.81	0.45
Outflow	15.82	1.13	0.02
Pollutant removal	94%	60%	96%
UNHSC-reported percentage	99%	5%	99%

4. Porous pavement

The test results of the porous pavement BMPDSS model are shown in Table 4-11. As shown, the BMPDSS model simulation results for TSS, TP, and Zn removal are similar to the UNHSC-reported values.

Table 4-11. Test results of porous pavement removal efficiencies for 2004–2006

Total pollutant load	TSS (lbs)	TP (lbs)	Zn (lbs)
Inflow	279.29	2.81	0.45
Outflow	5.46	1.58	0.04
Pollutant removal	98%	43%	92%
UNHSC-reported percentage	99%	38%	96%

5. Grass swale

The test results of the grass swale BMPDSS model are shown in Table 4-12. As shown, the BMPDSS model simulation results for TSS, TP, and Zn removal are similar to the UNHSC-reported values.

Table 4-12. Test results of grass swale removal efficiencies for 2004–2006

Total pollutant load	TSS (lbs)	TP (lbs)	Zn (lbs)
Inflow	279.29	2.81	0.45
Outflow	87.87	2.01	0.08
Pollutant removal	69%	29%	83%
UNHSC-reported percentage	60%	NT	88%

6. Wet pond

The test results of the wet pond BMPDSS model are shown in Table 4-13. As shown, the BMPDSS model simulation results for TSS, TP, and Zn removal are similar to the UNHSC-reported values.

Table 4-13. Test results of wet pond removal efficiencies for 2004–2006

Total pollutant load	TSS (lbs)	TP (lbs)	Zn (lbs)
Inflow	279.29	2.81	0.45
Outflow	85.46	2.25	0.02
Pollutant removal	69%	20%	96%
UNHSC-reported percentage	72%	16%	93%

4.1.5. BMPDSS Calibration Summary

The BMPDSS model was calibrated and tested for six BMPs using observed data from UNHSC. Three events were selected for calibrating each BMP, and the BMP model performances were tested against the 2004–2006 pollutant reduction percentages documented in the UNHSC 2007 Annual Report.

Calibrations of the BMPDSS model indicate that the model is capable of simulating the hydraulic performances of BMPs, and the models test results show that the long-term prediction of BMP performances are in close agreement with the values reported by UNHSC.

The successful calibration and testing of the BMPDSS models with UNHSC data supports the use of the models to generate credible long-term BMP performance curves for the New England Region (Section 5).

4.2. BMPDSS Representation

In developing BMP performance curves, one important step is to represent the selected eight BMPs in the BMPDSS model with appropriate specifications. In this project, BMP specifications were represented by following the *Structural BMP Specifications for the Massachusetts Stormwater Handbook* (MassDEP 2008a). This section provides an overview of the eight BMPs that were represented in BMPDSS. A brief description of design specifications is provided for each BMP, followed by the modeling schematic of that BMP in BMPDSS.

4.2.1. Infiltration System

Infiltration trenches and infiltration basins are two common systems in use. Infiltration trenches are shallow excavations filled with stone. They can be designed to capture sheet flow or piped inflow. The stone and piping or storage units (if applicable) provide underground storage for stormwater runoff so that it can be gradually infiltrated through the bottom or sides of the trench into the subsoil. Infiltration basins are stormwater runoff impoundments that are constructed over permeable soils. Pretreatment is critical for effective performance of infiltration basins. Runoff from the design storm is stored until it infiltrates through the soil of the basin floor. The *Massachusetts Stormwater Handbook* requires 44 percent TSS removal through pretreatment in critical areas for infiltration basins. For developing BMP performance curves, infiltration trenches and infiltration basins were sized according to the Massachusetts standards.

Figure 4-20 illustrates an infiltration trench (representative of subsurface infiltration practices)

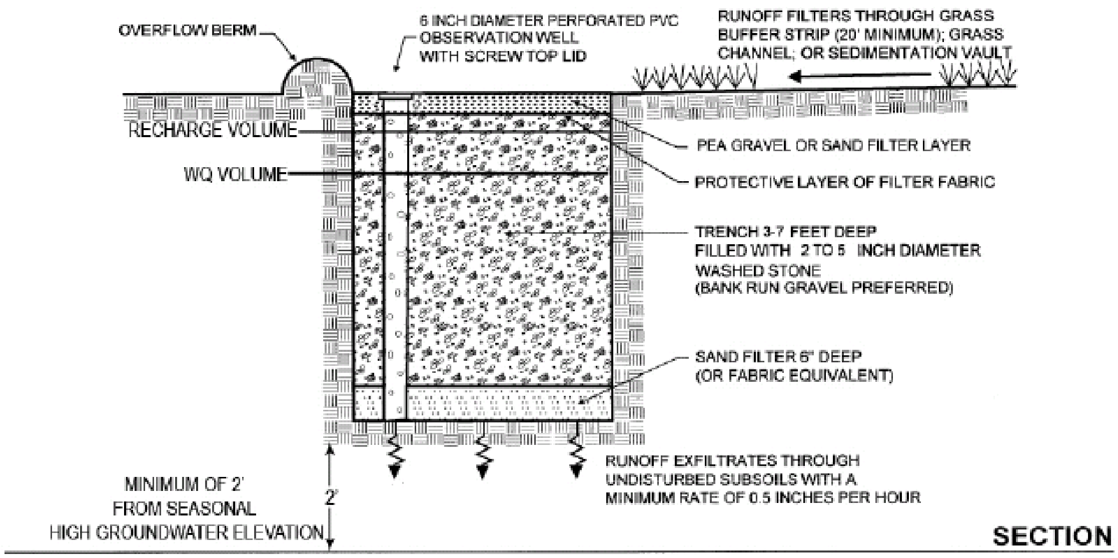


Figure 4-20. A typical infiltration trench design.

The representation of an infiltration trench in BMPDSS is shown in Figure 4-21. As shown, surface runoff is routed to the infiltration unit. Overflow from the infiltration unit is routed through an orifice.

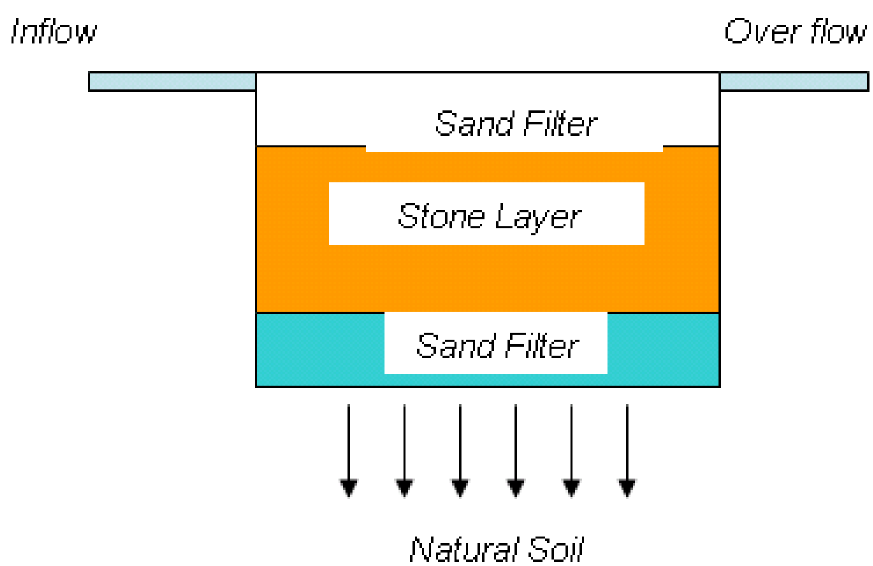


Figure 4-21. BMPDSS representation schematic for the infiltration trench.

A list of major parameters for the Figure 4-21 representation is summarized in Table 4-14.

Table 4-14. Design parameters for representing the infiltration trench in BMPDSS

Components of representation		Design parameters	Value
Infiltration Unit	Sand filter	Porosity	0.40
		Depth	6 in
	Stone layer	Depth	6 feet
		Porosity	0.45

The treatment capacity depends on the infiltration rate of soil at the bottom of the system. Therefore, BMP performance curves were developed for six different infiltration rates, 0.17, 0.27, 0.52, 1.02, 2.41, and 8.27 in/hr. Using the runoff volumes to be treated, the surface areas of the infiltration trench were estimated. To develop the curves, first the infiltration systems were sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each of the BMP sizes simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding BMP size.

Figure 4-22 illustrates an infiltration basin (representative of a surface infiltration system).

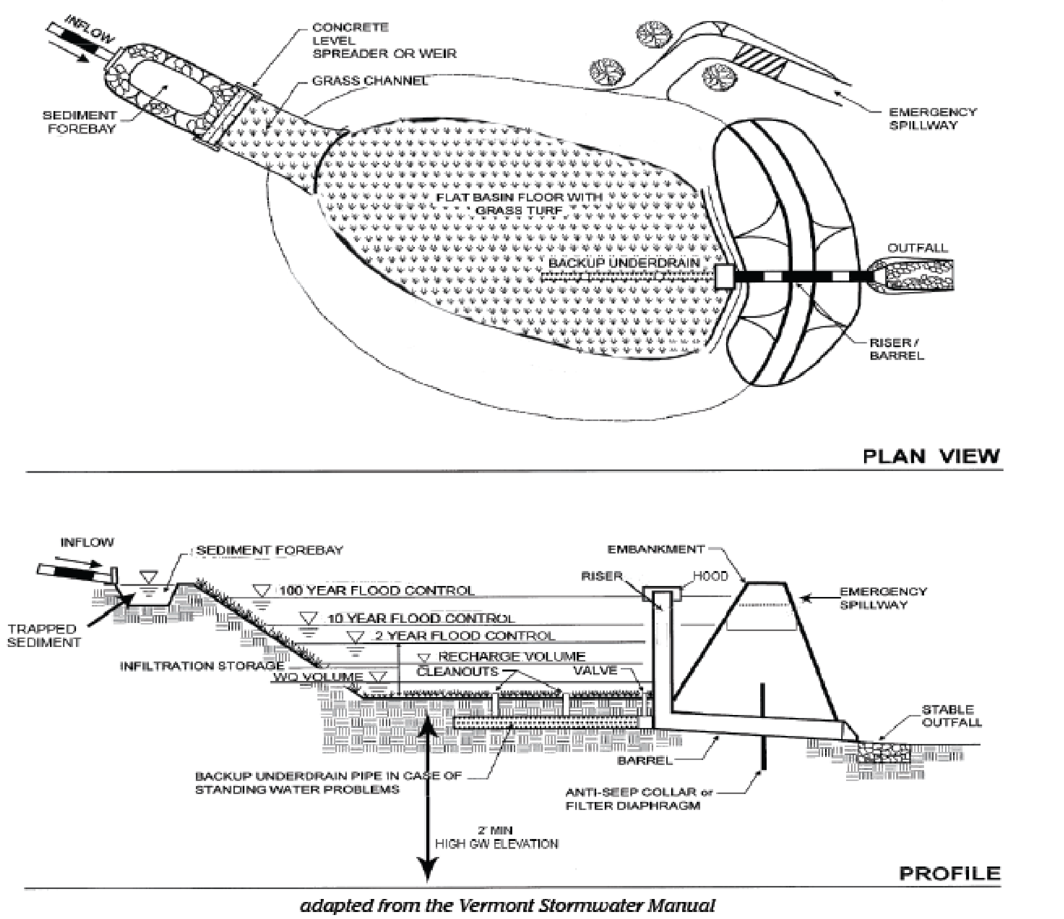


Figure 4-22. Typical design of an infiltration basin.

A representation of the infiltration basin in BMPDSS is shown in Figure 4-23. As shown, surface runoff is routed to the infiltration unit. Overflow from the infiltration unit is routed through a weir.

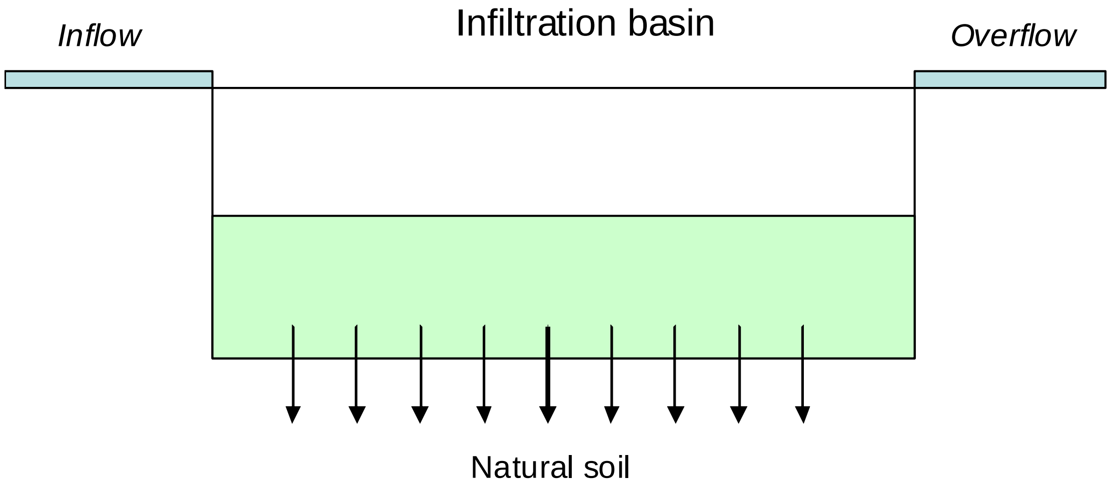


Figure 4-23. BMPDSS representation of infiltration basin

When representing the infiltration basin in BMPDSS, the depth of the infiltration basin was set at 2 feet. The surface area of the infiltration basin was initially sized according to the *Static* method and using the equation on page 17, chapter 1, volume 3 of *Documenting Compliance with the Massachusetts Stormwater Management Standards* (MassDEP 2008b).

Similar to the infiltration trench, the treatment capacity of the infiltration basin depends on the infiltration rate of soil at the bottom of the basin. Therefore, the BMP performance curves were developed for six different infiltration rates, 0.17, 0.27, 0.52, 1.02, 2.41, and 8.27 in/hr. Depending on the runoff volume to be treated, the surface areas of the infiltration basin was estimated. To develop the curves, first the infiltration systems were sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each of the BMP sizes simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding BMP size.

4.2.2. Gravel Wetland

The gravel wetland consists of a series of horizontal flow through treatment cells preceded by a sediment forebay. Figure 4-24 illustrates the two treatment basins of the gravel wetland design in accordance with MA standards (same as at UNHSC). Incoming runoff is first routed to the sediment forebay, from which a riser pipe releases runoff into the first treatment basin. The riser pipe in the first treatment basin then routes flow to an underground gravel reservoir, where pollutant removal occurs by several processes including filtration, sedimentation, absorption, and oxidation. The root system on top of the gravel layer provides biological treatment through pollutant uptake and biological activities. Water leaves the first treatment basin through either an underdrain pipe that connects the first treatment basin to the second basin or an overflow orifice designed to contain the channel protection volume on the surface of the system. The second treatment basin functions similarly as the first basin. The only difference is that the crest height for the underdrain outlet pipe is elevated to 8 inches below the wetland soil surface so that the gravel reservoir remains full.

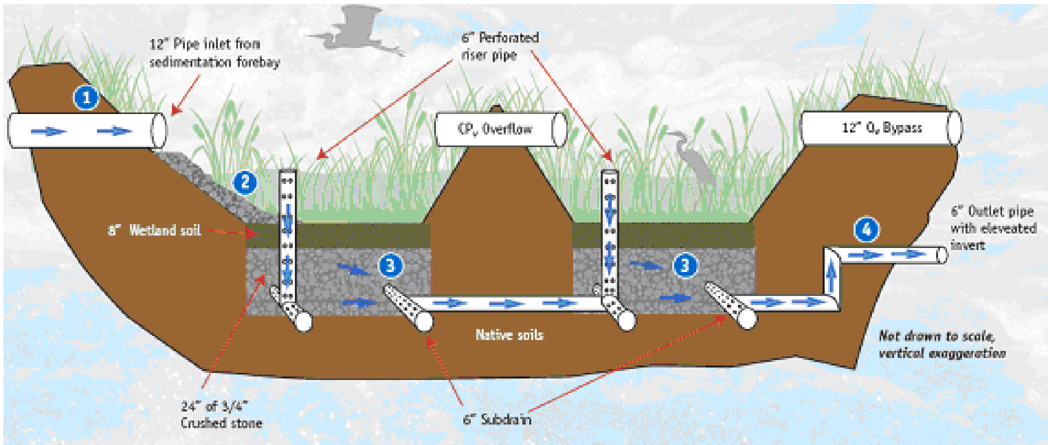


Figure 4-24. The UNHSC design of gravel wetland (as per MA standard).

The gravel wetland schematic for BMPDSS is illustrated in Figure 4-25. The schematic consists of a dry pond and two modified bioretention areas. The details representing a bioretention system are presented in the next section. Outflow from the dry pond (sediment forebay) is routed to the first treatment basin (Modified BA#1) through outlet structures (Orifice #1 and Weir #1). Inflow to the first treatment basin is routed to the gravel layer through the wetland soils by setting an artificially high infiltration rate. An underdrain orifice (Orifice #3) connects the first treatment basin to the second basin, and an overflow orifice (Orifice #2) provides an additional bypassing path. The second treatment basin is structurally similar to the first basin, except that the outflow pipe is elevated and set just below the wetland soil layer. A list of the design parameters, shown in the Figure 4-25 schematic, is summarized in Table 4-15.

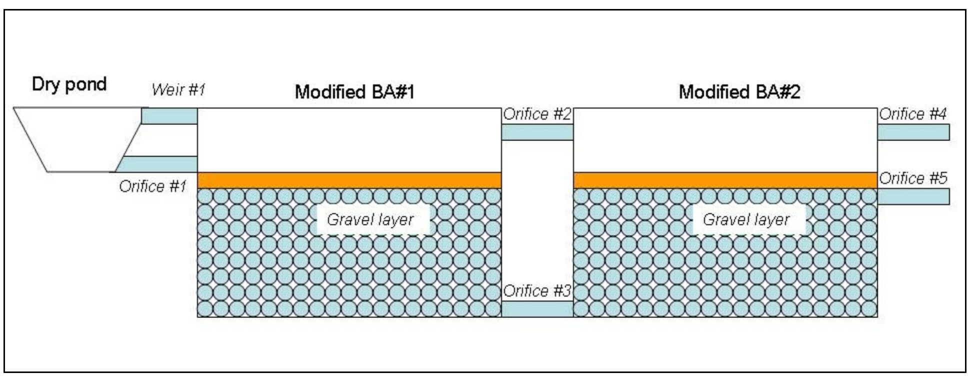


Figure 4-25. BMPDSS representation schematic for the UNHSC grave wetland design.

Table 4-15. Design parameters for representing gravel wetland in BMPDSS

Components of representation		Design parameters	Value
Sediment Forebay (10% of Treatment Volume)		Depth	1.3 feet
		Surface area	Variable
Wetland Cell #1 (45% of Treatment Volume)	Ponding area	Surface area	Variable
		Depth	2.2 feet
	Gravel layer	Depth	24 in
Wetland Cell #2 (45% of Treatment Volume)	Ponding area	Surface area	Variable
		Maximum depth	2.2 feet
	Gravel layer	Depth	24 in

Depending on the runoff volume treated, the surface areas of sediment forebay and treatment cells were estimated. To develop the curves, first the gravel wetland system was sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each of the gravel wetland system sizes simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding BMP size.

4.2.3. Bioretention Area

The design specification of bioretention area is illustrated in Figure 4-26 as presented in the *Structural BMP Specifications for the Massachusetts Stormwater Handbook* (MassDEP 2008a). As shown, a ponding area, mulch layer, planting soil mix, and gravel mix in an underdrain area are required for a typical bioretention system. Depending on conditions of the underlying soil, bioretention can be designed as a filtration facility with a sealed or impermeable bottom or as an infiltration facility by allowing natural infiltration to the subsoil.

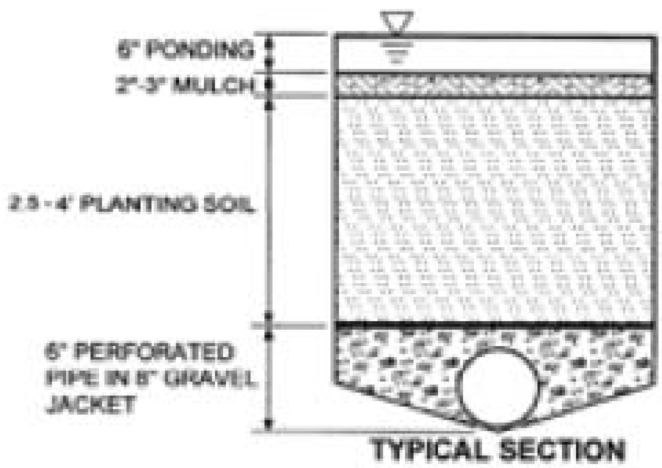


Figure 4-26. Typical cross-section of a bioretention area.

The existing bioretention template in BMPDSS consists of two modules: one surface storage module and one subsurface treatment module (Figure 4-27). The storage module represents the ponding area on the bioretention basin, and two types of hydraulic control structures (orifice and weir) are available for releasing runoff downstream. The treatment module underneath the storage module receives infiltrated water from above. The treatment module consists of two layers: the planting soil layer on top and the underlying gravel layer. An underdrain system in the gravel layer transports treated water from the system.

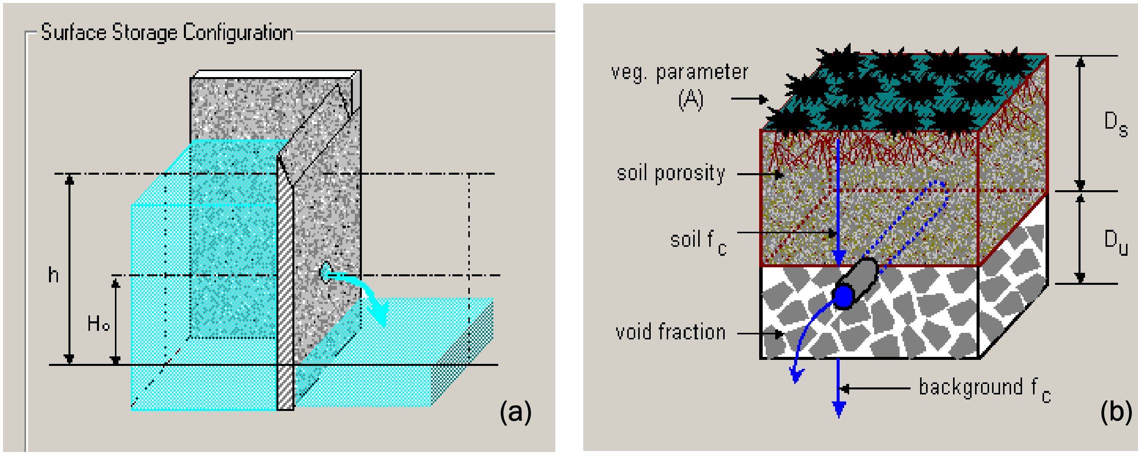


Figure 4-27. The surface storage module (a) and subsurface treatment module (b) in the BMPDSS representation of a bioretention area.

As shown in Figure 4-27b, the BMPDSS program has two layers of materials (soil and gravel) in the bioretention unit.

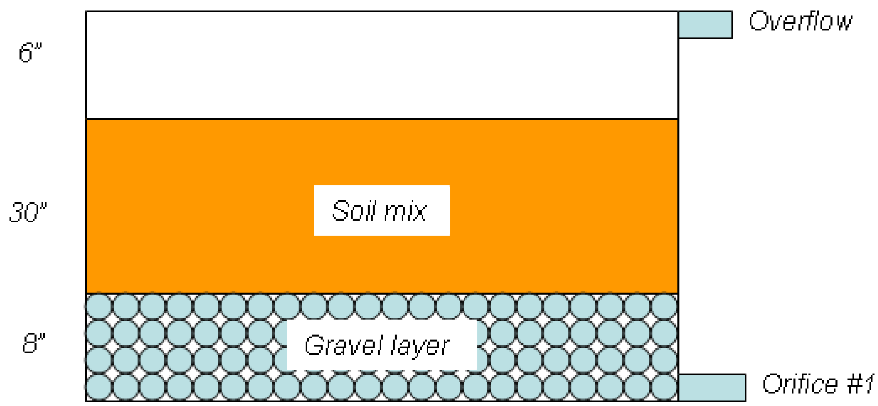


Figure 4-28. BMPDSS representation schematic for a bioretention area.

As indicated in the BMPDSS schematic (Figure 4-28), the bioretention system model closely matches the key design features of a bioretention area. Design and other parameters for the above schematic are summarized in Table 4-16 below.

Table 4-16. Design and other parameters for representing bioretention area in BMPDSS

Components of representation	Parameters	Value
Ponding	Maximum depth	6 in
	Surface area	Varies with runoff depth treated
	Vegetative parameter[a]	85-95%
Soil mix	Depth	30 in
	Porosity	40%
	Hydraulic conductivity[b]	4 inches/hour
Gravel layer	Depth	8 in
	Porosity	40%
	Hydraulic conductivity[b]	14 inches/hour
Orifice #1	Diameter	6 in

[a] Refers to the percentage of surface covered with vegetation
[b] Refers to the hydraulic conductivity

Depending on the runoff volume to be treated, the surface areas of bioretention systems were estimated. To develop the curves, first the bioretention system was sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each of the bioretention areas simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding BMP size.

4.2.4. Porous Pavement

Figure 4-29 illustrates a typical design of porous pavement as presented in Massachusetts' stormwater handbook, which consists of five filtering layers. The four layers, from the top to bottom, are porous asphalt, stone choker course, sand/gravel layer, filter blanket, and the stone infiltration reservoir. The existing BMPDSS module for representing porous pavement is similar to the bioretention area subsurface treatment basin (Figure 4-27b) shown previously. The BMPDSS representation also assumes a two-layer design of the porous pavement, which includes a porous asphalt layer and a stone reservoir layer. However, when the module is used for porous pavement, changes are needed to the vegetation coverage (change to 0) and soils layer (adjust to reflect the depth, porosity, and hydraulic conductivity of the porous asphalt).

The BMPDSS porous pavement module must be adjusted to accommodate a typical design. Because the existing module allows for only two filtering layers, the typical design of four layers needs to be composited into two on the basis of the hydraulic conductivity and depth. In doing so, the three layers above the stone infiltration reservoir are composited into one. The resulting schematic in BMPDSS is shown in Figure 4-30.

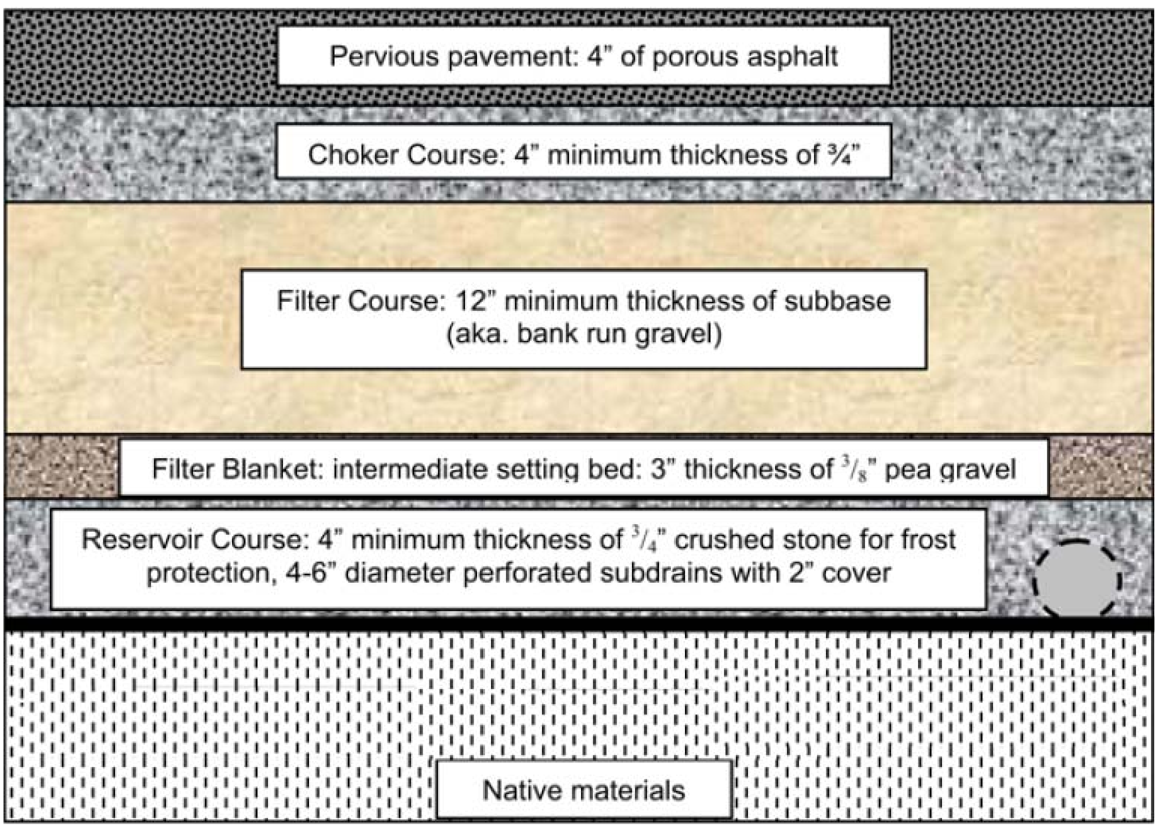


Figure 4-29. Typical cross-section of porous pavement.

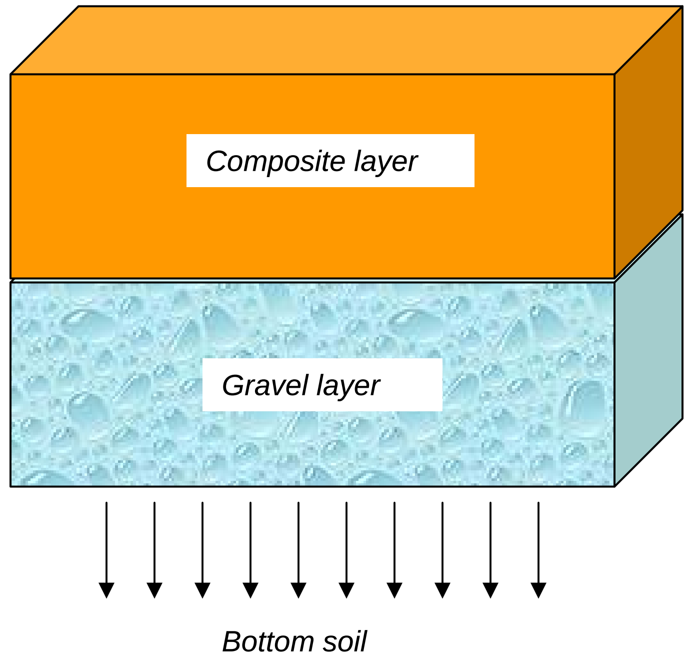


Figure 4-30. The BMPDSS representation schematic for porous pavement design.

To accurately reflect the combined effects of the top three layers in typical design, principles depicting flow through multiple layers (Hillel 1998) were followed to generate the effective hydraulic conductivity for the composite layer in Figure 4-30. A list of the input parameters to complete the representation is summarized in Table 4-17.

Table 4-17. Design parameters for representing porous pavement in BMPDSS

Components of representation		Design parameters	Value
Composite layer	Porous asphalt	Depth	4 in
		Porosity	18–20%
		Hydraulic conductivity	750 in/hr
	Chocker course	Depth	4 in
		Porosity	40%
		Hydraulic conductivity	14 in/hr
	Filter course	Depth	12–32 in
		Porosity	25%
		Hydraulic conductivity	1.4 in/hr
Gravel layer		Depth	8 in
		Porosity	40%
		Hydraulic conductivity	14 in/hr

Porous pavement treats all the rainfall falls on it. It is impossible to size this BMP to treat a selected depth of runoff. In order to meet the transportation and other requirements, porous pavement needs to meet specific design standards. Four different sizes of porous pavement (by varying the thickness of the filter course), 12 (MA minimum requirement), 18, 24, 32 inches (UNHSC design standard) were used to develop the performance curves for this BMP.

4.2.5. Water Quality Swales

Water quality swales are vegetated open channels designed to treat the required water quality volume and to convey runoff from large storms. According to Massachusetts' stormwater handbook, there are two different types of water quality swales that may be used to satisfy the state's stormwater management standards; dry swales and wet swales. Although the design, construction, and processes for these swales differ, both types of swales perform similarly in pollutant removal (MassDEP 2008a).

A typical water quality wet swale is illustrated in Figure 4-31. Wet swales store the water quality volume in a series of cells within the channel, which can be formed by berms or check dams and can contain wetland vegetation. The pollutant removal mechanisms in wet swales are similar to those of stormwater wetlands, which rely on sedimentation, adsorption, and microbial breakdown (MassDEP 2008a).

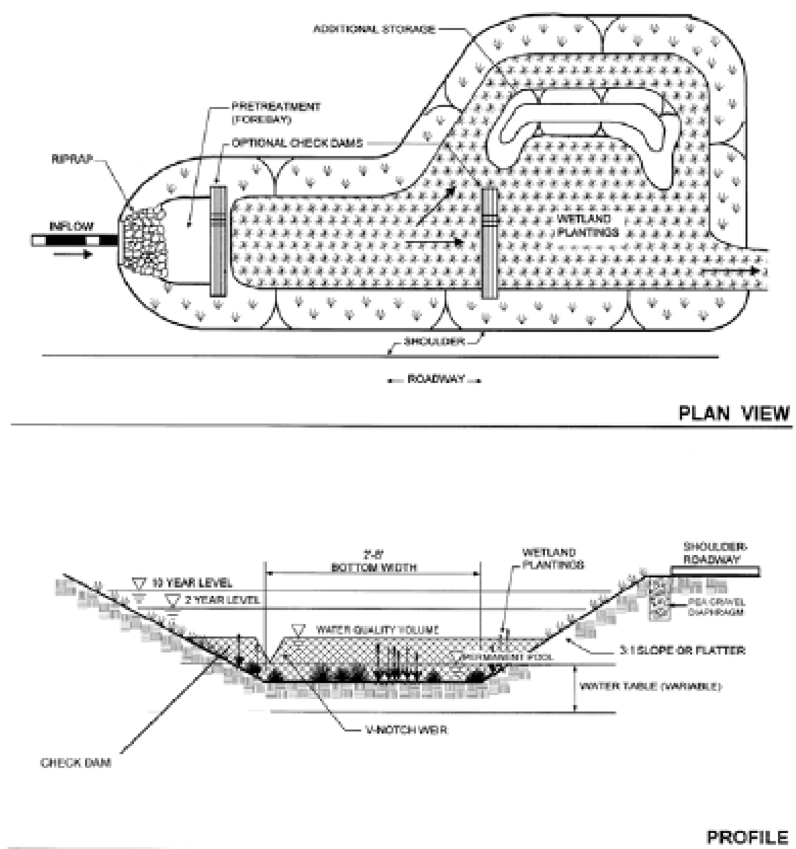


Figure 4-31. Typical design of a water quality wet swale.

The BMPDSS grass swale template consists of three components. The first component is the transport module (Figure 4-32), which routes stormwater flow through the grass swale channel. The second module (storage module) retains the water quality volume. It is similar to the surface storage module for a bioretention system as shown in Figure 4-27a. The third module is the subsurface infiltration module, which is similar to the subsurface treatment module for the bioretention area shown in Figure 4-27b. When used for the grass swale infiltration, the two-layer module shown in Figure 4-27b must be consolidated to one layer (eliminating the gravel layer).

A list of the design parameters required to represent water quality swale is summarized in Table 4-18.

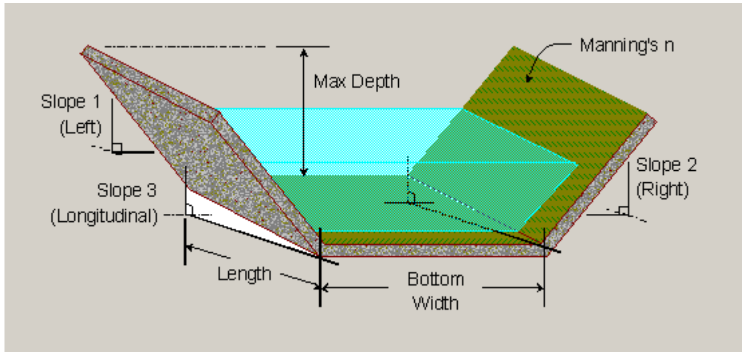


Figure 4-32. The BMPDSS transport module for grass swales.

Table 4-18. Design parameters for representing a wet swale in BMPDSS

Components of representation	Design parameters	Value
Swale channel	Bottom width	2–8 feet
	Maximum depth	4 feet
	Side slope	4:1
	Longitudinal slope	1%
	Length	Variable
	Manning's roughness	0.25
	Vegetative parameter	80%

Depending on the runoff volume treated, the length and the width of the swale were estimated. To develop the curves, first the swales were sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each swale simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding swale size.

4.2.6. Wet Retention Pond (Wet Basins)

Wet basins use a permanent pool of water as the primary mechanism to treat stormwater. The pool allows sediments to settle (including fine sediments) and removes soluble pollutants. A typical design of a wet retention pond is shown in Figure 4-33 (MassDEP 2008a). As shown, the design is composed of a sediment forebay and a wet pond that has permanent pool for water quality treatment.

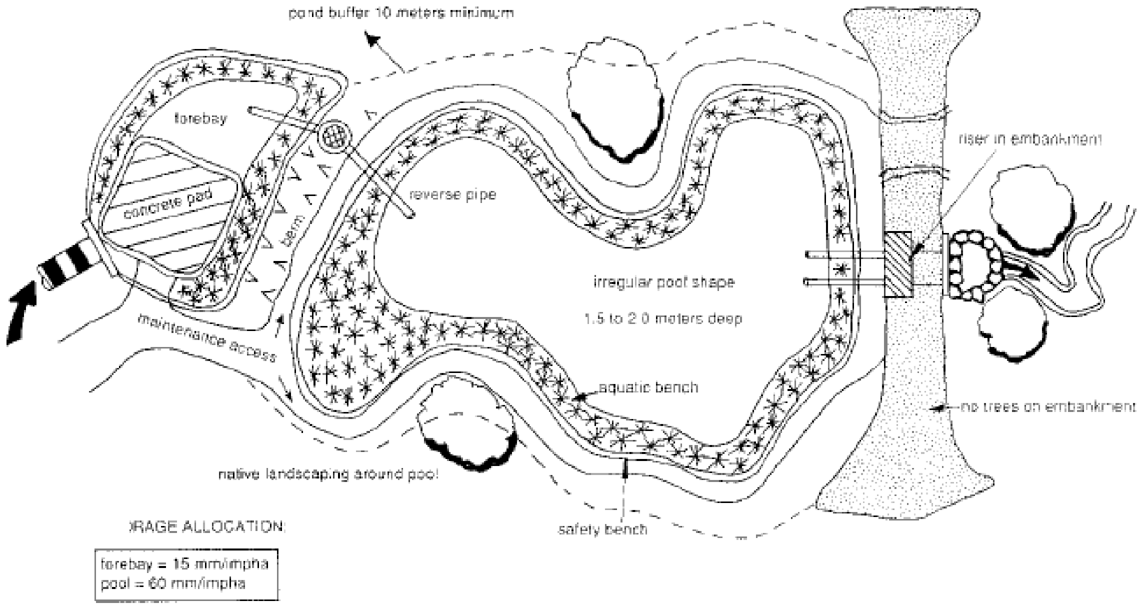


Figure 4-33. A typical extended dry design of a wet retention pond.

The two components of a wet pond design have corresponding modules in BMPDSS. The sediment forebay, to capture 0.24 inch/impervious acre, can be represented with a dry pond. BMPDSS has a multi-stage pond module (Figure 4-34), which can be used to represent the wet pond. As shown in Figure 4-34, the multi-stage pond allows for inputting an irregular cross-section, which is presented using stage-storage relationship; multiple outlet structures are allowed.

Figure 4-34. The BMPDSS multi-stage pond module.

The proposed schematic of a wet retention pond in BMPDSS is shown in Figure 4-35. As shown, the schematic consists of a dry pond and a permanent pool. Weir #1 discharges flow from the sediment forebay to the permanent pool, which has the overflow structure (Orifice #1).

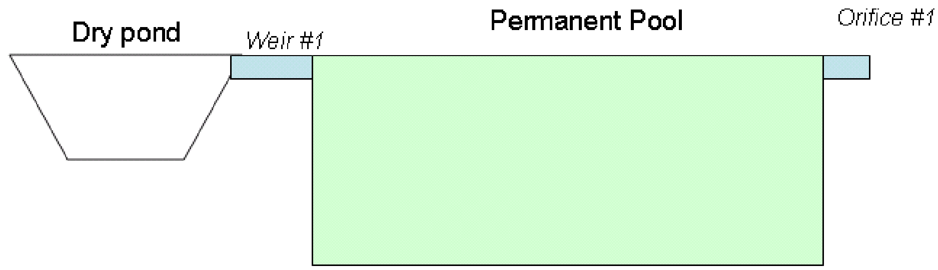


Figure 4-35. BMPDSS representation schematic for wet retention pond design.

Depending on the runoff volume treated, the surface area of permanent pool is estimated. It is assumed the permanent pool has a depth of 6 feet and a side slope of 4:1 as Horizontal:Veritcal. Sediment forebay volume will be 0.25 times the permanent pool volume. According to the Massachusetts standards, this volume is excluded from the treatment volume. A list of the design parameters for the schematic is summarized in Table 4-19.

Table 4-19. Design parameters for representing a wet retention pond in BMPDSS

Components of representation	Design parameters	Value
Sediment forebay (Volume = 0.25 × Permanent Pool & Slope 4:1)	Bottom area	Variable
	Maximum depth	2 feet
	Surface area	Variable
Permanent Pool (Volume = Runoff Depth Treated × Area Treated & Slope 4:1)	Bottom area	Variable
	Maximum depth	6 feet
	Surface area	Variable

To develop the curves, the wet ponds were first sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each wet pond size simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding BMP size.

4.2.7. Extended Dry Detention (Dry Basins)

Extended dry detention basins are modified conventional dry detention basins designed to hold stormwater for at least 24 hours, allowing solids to settle and reducing local and downstream flooding. Extended dry detention basins can be designed with either a fixed or adjustable outflow device. Other components such as a micropool or shallow marsh can be added to enhance pollutant removal. A typical extended dry detention design is presented in Figure 4-36.

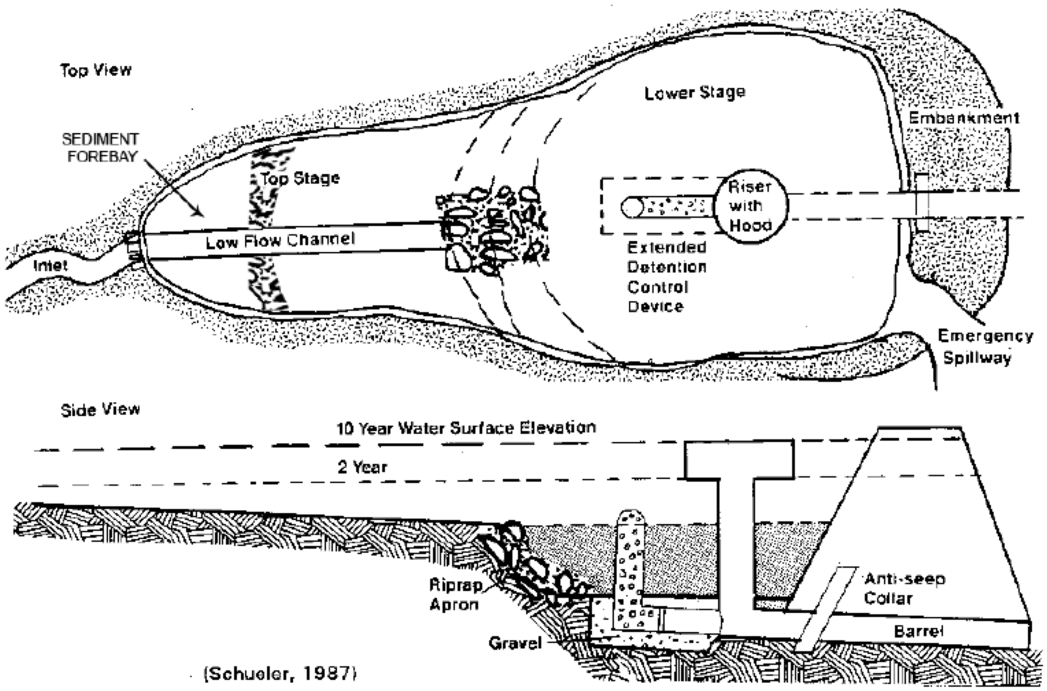


Figure 4-36. A typical design of an extended dry detention pond.

The proposed schematic of an extended dry detention pond in BMPDSS is shown in Figure 4-37. As shown, the representation consists of a dry pond and a permanent pool. Weir #1 discharges flow from the sediment forebay to detention basin, which has the overflow structure (Orifice #1) and discharge orifice (Orifice #2). The discharge orifice is sized to store the design volume and discharge in 24 hours. The sediment forebay, to capture 0.24 inches/impervious acre, can be represented with a dry pond.

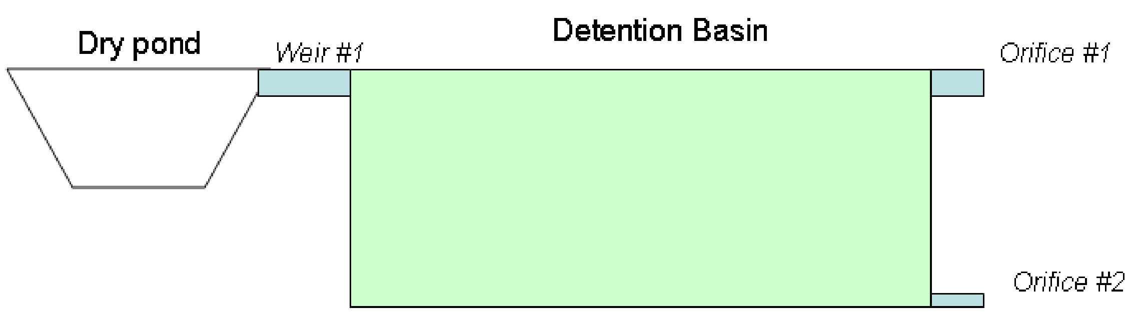


Figure 4-37. BMPDSS representation schematic for extended dry detention pond design.

Depending on the runoff volume treated, the surface area of detention basin is estimated. It is assumed that the detention basin has a depth of 6 feet and a side slope of 4:1 as Horizontal:Vertical. Sediment forebay volume will be 0.25 times of permanent pool volume. According to the Massachusetts standards, this volume is excluded from the treatment volume. A list of the design parameters for the schematic is summarized in Table 4-20.

Table 4-20. Design parameters for representing extended dry detention pond in BMPDSS

Components of representation	Design parameters	Value
Sediment forebay (Volume = 0.25 × Permanent Pool & Slope 4:1)	Bottom area	Variable
	Maximum depth	2 feet
	Surface area	Variable
Detention basin (Volume = Runoff Depth Treated × Area Treated & Slope 4:1)	Bottom area (length: width = 2:1)	Variable
	Maximum depth	6 feet
	Surface area	Variable

To develop the curves, the extended dry ponds were first sized with a physical storage capacity of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 inches of runoff volume from the contributing impervious surfaces. Next, long-term continuous simulations were performed using BMPDSS for a 10-year period to determine the cumulative pollutant load removed for TP, TSS, and Zn. Finally, for each pond size simulated, the cumulative pollutant removal performance (expressed as % removed) was plotted against the corresponding BMP size.

5. PERFORMANCE CURVE

The calibrated BMPDSS model was applied for the following eight types of stormwater BMP to generate estimates of long-term cumulative BMP performances:

1. Surface infiltration systems (e.g., basin)
2. Subsurface infiltration systems (e.g., trench)
3. Gravel wetland systems
4. Bioretention systems
5. Water quality swales
6. Porous pavement systems
7. Wet ponds
8. Extended dry detention ponds

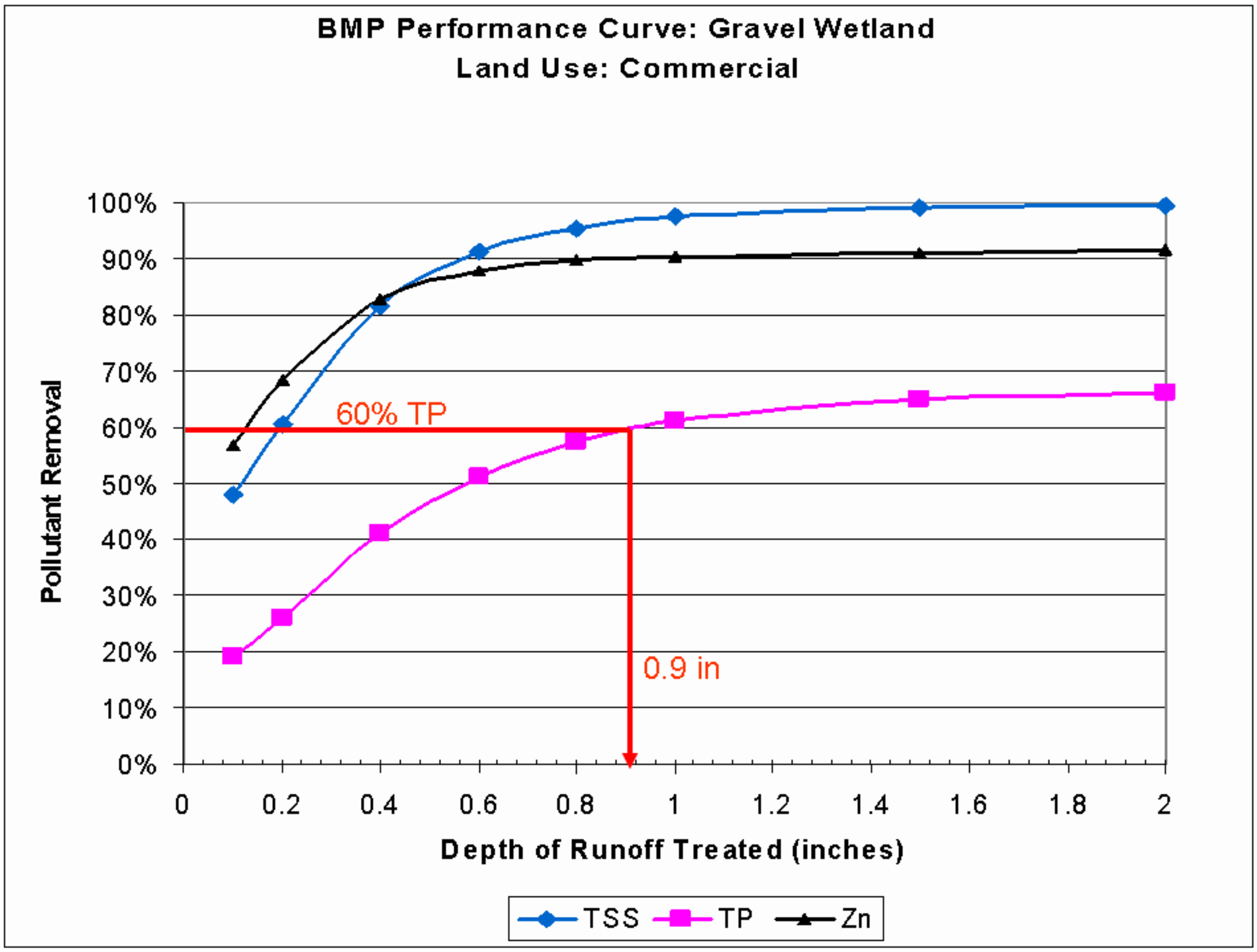
Long-term BMP performance estimates for each BMP were generated for pollutant loading rates associated with each of the five land uses selected for the project (Commercial, Low-Density Residential, Medium-Density Residential, High-Density Residential, and Industrial). Long-term cumulative BMP performance estimates are presented as performance curves for each of the three water quality constituents, TP, TSS, and Zn. Performance curves were not generated for TN because there were insufficient TN monitoring data available for the BMPs during model calibration. Additionally, performance curves of runoff volume captured (runoff volume reduction) were generated for both the surface and subsurface infiltration systems. The runoff capture performance curves can be used to estimate change in effective impervious cover for limited circumstances. These curves will be equivalent to percent reduction in effective impervious area only in terms of annual runoff volume reductions.

The performance curves are intended to be used to estimate long-term cumulative pollutant removal efficiencies (or runoff volume for infiltration systems) for BMPs that are based on similar design standards and according to the size (i.e., capacity) of the BMP system. Section 5.1 presents the concept of BMP performance curves, how they can be applied, and the assumptions and limitations of employing them.

5.1. BMP Performance Curve and Application

A series of BMP performance rating curves were developed for five land uses through the linkage of water quality and BMP models. Each BMP rating curve depicts the relationship between the size of a BMP and the percentage of pollutant removal over a long period of time (i.e., 10 years). The rating curves will help the practitioners to size BMPs for achieving known pollutant reduction goals or for determining appropriate pollutant removal credits for existing BMPs of known size. An example rating curve for gravel wetland performance in commercial land use is shown in Figure 5-1. The X axis is the size of the gravel wetland, represented by the depth (volume) of runoff to be treated by the gravel wetland. The Y axis is the long-term cumulative pollutant removal performance expressed as percent reduction. The rating curve shown in Figure 5-1 can be used for sizing BMPs depending on the objectives of pollutant removal. For example, if a target of 60 percent TP removal is sought for the gravel wetland system in Figure 5-1, a horizontal line can be drawn from the 60 percent value on the Y axis to the point where it intersects the TP performance curve. The vertical line drawn from the point on the TP curve intersects the X axis at approximately 0.9 inch. Thus, a gravel wetland needs to be sized for 0.9 inch of runoff to achieve an annual 60 percent reduction in TP.

For each BMP, there is a different rating curve for each pollutant. Thus, when sizing a BMP for meeting several pollutant-removal objectives, the practitioner must first find the required BMP sizes according to each of the pollutant-rating curves, and then select the largest BMP size.



Note: To get 60 percent TP reduction, it requires a gravel wetland sized to store and treat approximately 0.9 inch of runoff from impervious area.

Figure 5-1. The BMP performance curve of a gravel wetland in a commercial land use.

5.2. Example Application of BMP Performance Curve

One commercial site and one low-density residential site were selected to demonstrate how the BMP performance curves could be applied. Although the sites are real, the application is hypothetical. The demonstrated application below assumes that there are no existing BMPs.

5.2.1. Commercial Application

Site Details: Total Area = 40 acres, Total Impervious Area = 21 acres
Location: Town of Bellingham, MA
BMP Treatment Objective: 65 percent reduction of TP
Site Overview: The site has two impervious sections. The upper section includes a small building, roads, and parking lots at the upper portion of the property boundary. The lower section includes the large building complex, roads, and parking lots. The upper section has imperviousness of approximately 2 acres and the lower section has approximately 19 acres.
Assumptions: Soil infiltration rate = 0.52 in/hr, High groundwater depth = 10 ft

This sample site is shown in Figure 5-2.

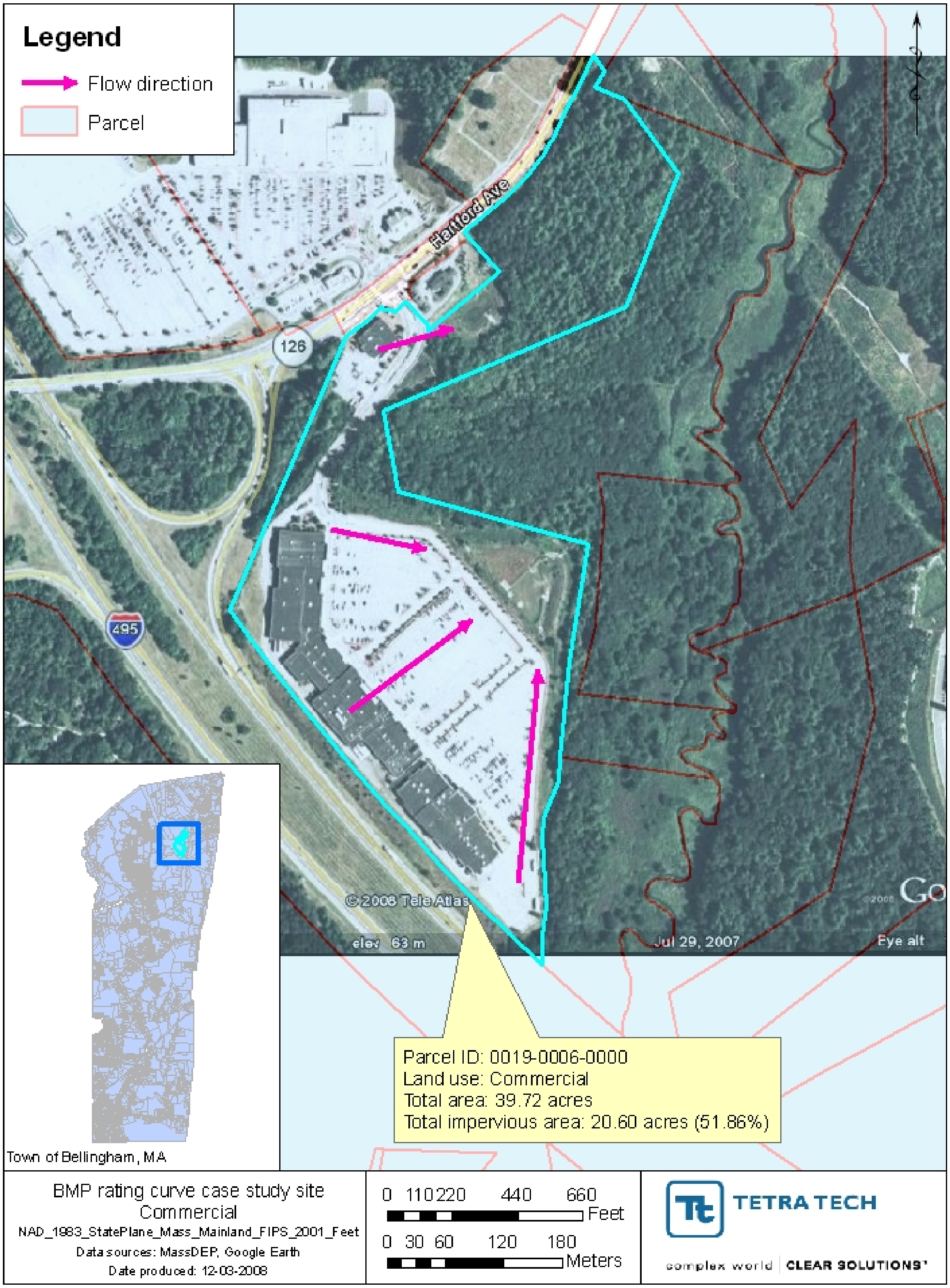


Figure 5-2. A sample commercial lot requires 65 percent TP reduction.

BMP Selection

Among the BMPs for which performance information was generated, the wet pond, dry detention pond, and water quality swale were unsuitable for this site because the maximum TP removals are less than 65 percent. However, the gravel wetland and infiltration trench were identified as suitable options.

<u>Gravel wetland</u>
Figure 5-3 illustrates the rating curve for a gravel wetland BMP in a commercial site.

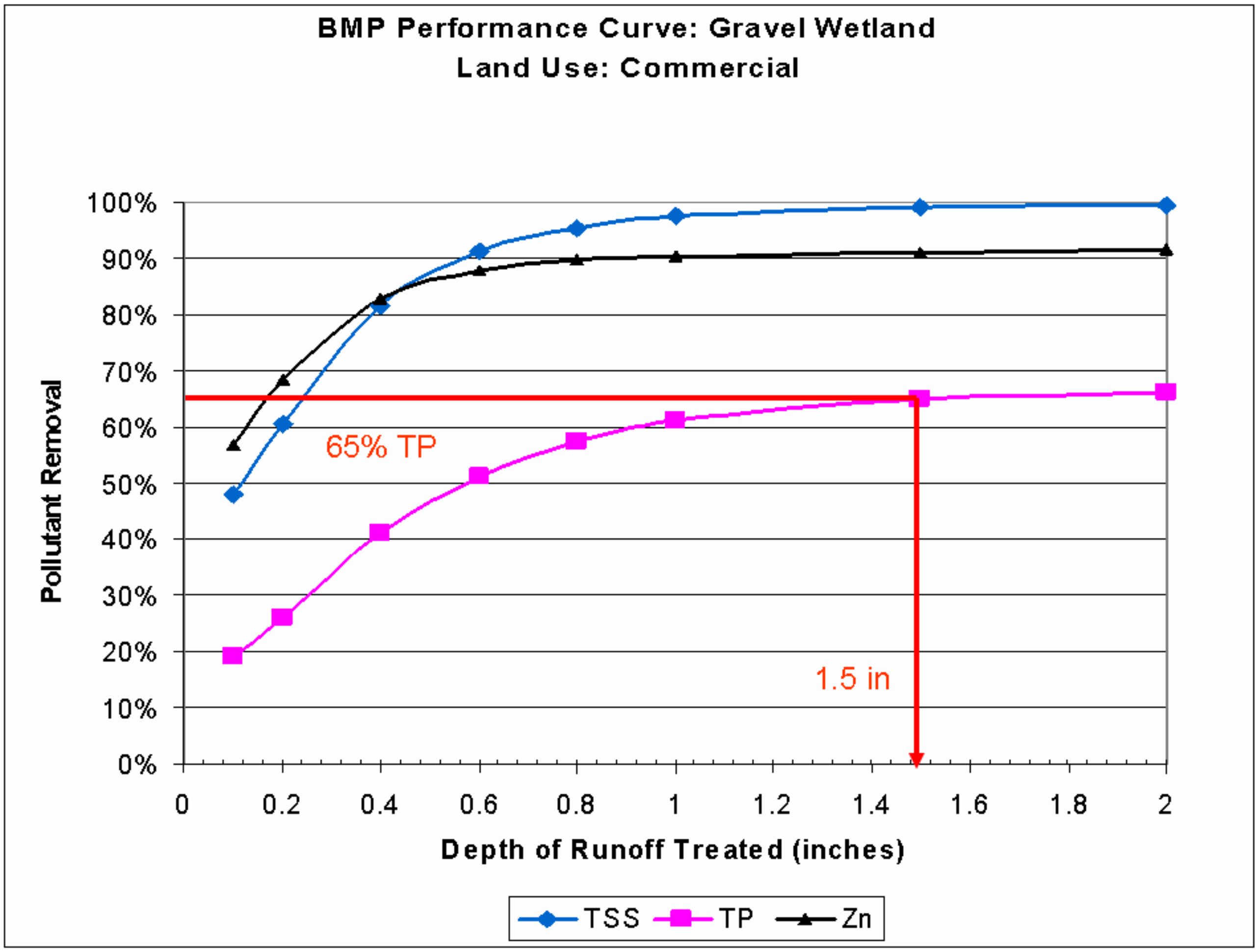


Figure 5-3. BMP performance curve of gravel wetland in commercial land use.

To obtain 65 percent TP reduction, 1.5 inches of runoff from impervious surface needs to be stored and treated in a gravel wetland.

Storage of the upper section gravel wetland = 1.5 in × 2 acres = 0.25 ac-ft
Storage of the lower section = 1.5 in × 19 acres = 2.375 ac-ft

Table 5-1 lists the design parameters for the gravel wetlands to reduce TP by 65 percent at the selected commercial site.

Table 5-1. Design parameters for potential gravel wetlands to reduce TP by 65 percent at the commercial site.

Components of representation		Design parameters	Upper gravel wetland	Lower gravel wetland
Sediment Forebay (10% of Treatment Volume)		Depth (in)	16	16
		Surface area (sq. ft)	817	7,760
Wetland Cell #1 (45% of Treatment Volume)	Ponding area	Surface area (sq. ft)	1,750	16,630
		Depth (in)	24	24
	Gravel layer (porosity = 0.4)	Depth (in)	24	24
Wetland Cell #2 (45% of Treatment Volume)	Ponding area	Surface area (sq. ft)	1,750	16,630
		Depth (in)	24	24
	Gravel layer (porosity = 0.4)	Depth (in)	24	24

Note: The selected BMP also provides approximately 99 percent reduction in TSS and 90 percent reduction in Zn from the impervious area.

<u>Option 2: Infiltration Trench</u>

Figure 5-4 illustrates the rating curve for an infiltration trench BMP in a commercial land use.

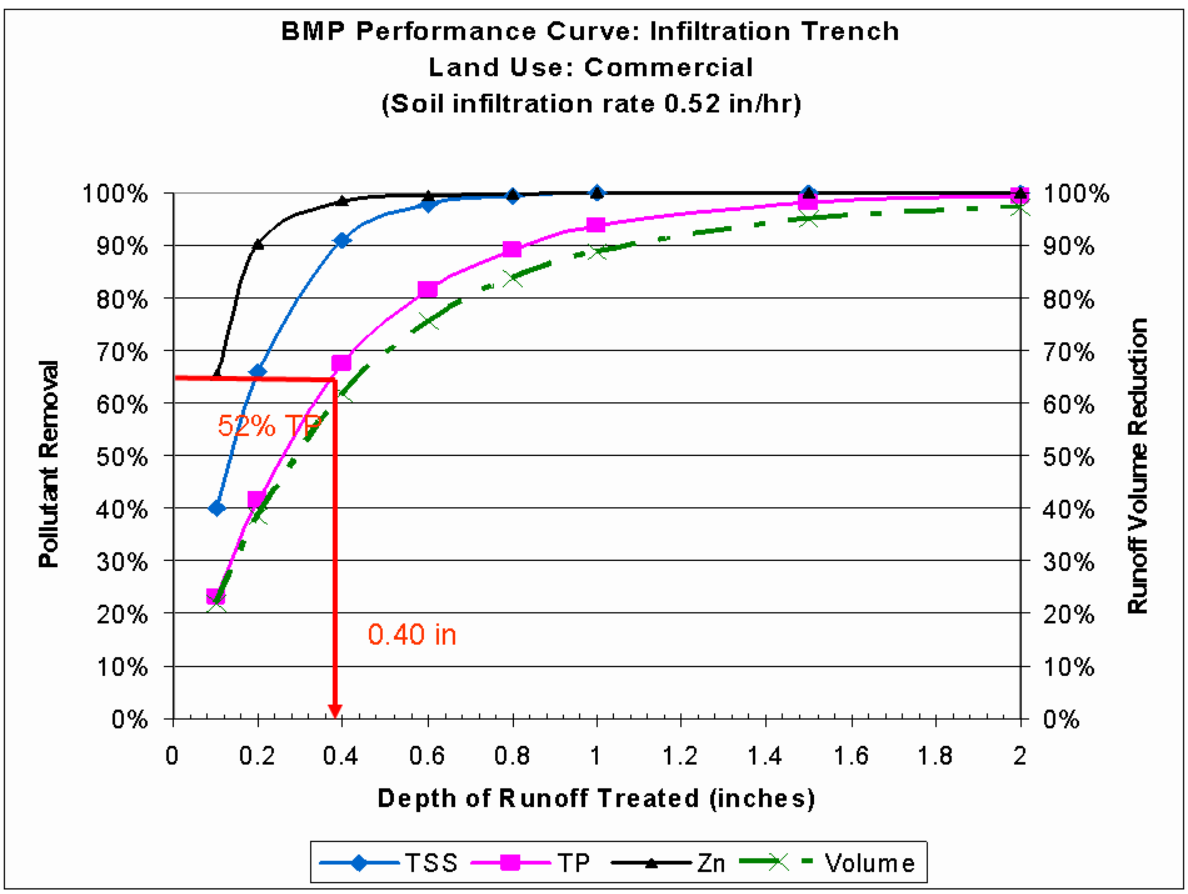


Figure 5-4. BMP performance curve of an infiltration trench in a commercial land use (soil infiltration rate is 0.52 in/hr).

For an infiltration trench, the Massachusetts stormwater specifications require pretreatment. This estimation assumes that the pretreatments are designed appropriately. To obtain 65 percent TP reduction, the trench system needs to have a storage capacity of 0.4 inch of runoff from impervious surfaces. These design parameters are listed in Table 5-2.

Storage of the upper section infiltration basin = 0.4 in × 2 acres = 0.07 ac-ft
Storage of the lower section = 0.4 in × 19 acres = 0.63 ac-ft

Table 5-2. Design parameters for the potential infiltration trenches to reduce TP by 65 percent at the commercial site.

Components of representation		Design parameters	Value
Infiltration trench	Sand filter	Porosity	0.40
		Depth	6 in
	Stone layer	Depth	6 feet
		Porosity	0.45
Surface area (sq. ft)	Upper Infiltration Trench		1,010
	Lower Infiltration Trench		9,470

Note: The selected infiltration trench also provides approximately 98 percent reduction in Zn, 90 percent reduction in TSS and 60 percent reduction in runoff volume from the impervious area.

5.2.2. Low-Density Residential Application

Site Details: Total Area = 1.3 acres, Total Impervious Area = 0.4 acres
Location: Town of Milford, MA
BMP Treatment Objective: 65 percent reduction of TP
Site Overview: The site has a building and driveway as impervious area.
Assumptions: Soil infiltration rate = 0.27 in/hr, High groundwater depth = 10 ft

This sample site is shown in Figure 5-5.

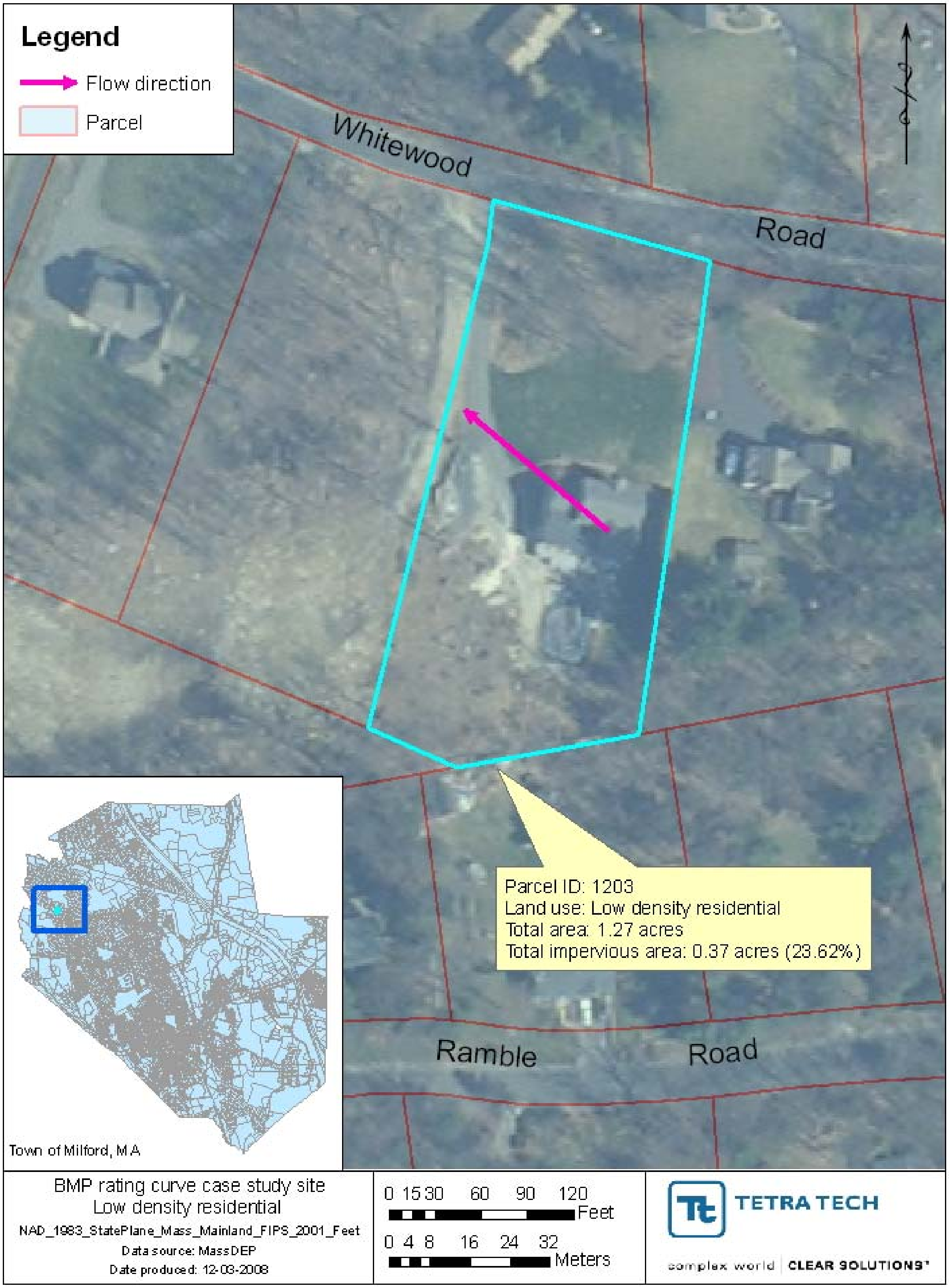


Figure 5-5. A sample Low-Density residential lot requires 65 percent TP reduction.

BMP Selection

Among the BMPs for which the performance information was generated, the wet pond, dry detention pond, and water quality swale were unsuitable for this site because they could not achieve the needed TP removal (maximum TP removals of these BMPs are less than 65 percent). In this case, a bioretention system (rain garden) is identified as a suitable BMP to treat the runoff from the impervious area.

Figure 5-3 illustrates the rating curve for a bioretention BMP in a low-density residential site.

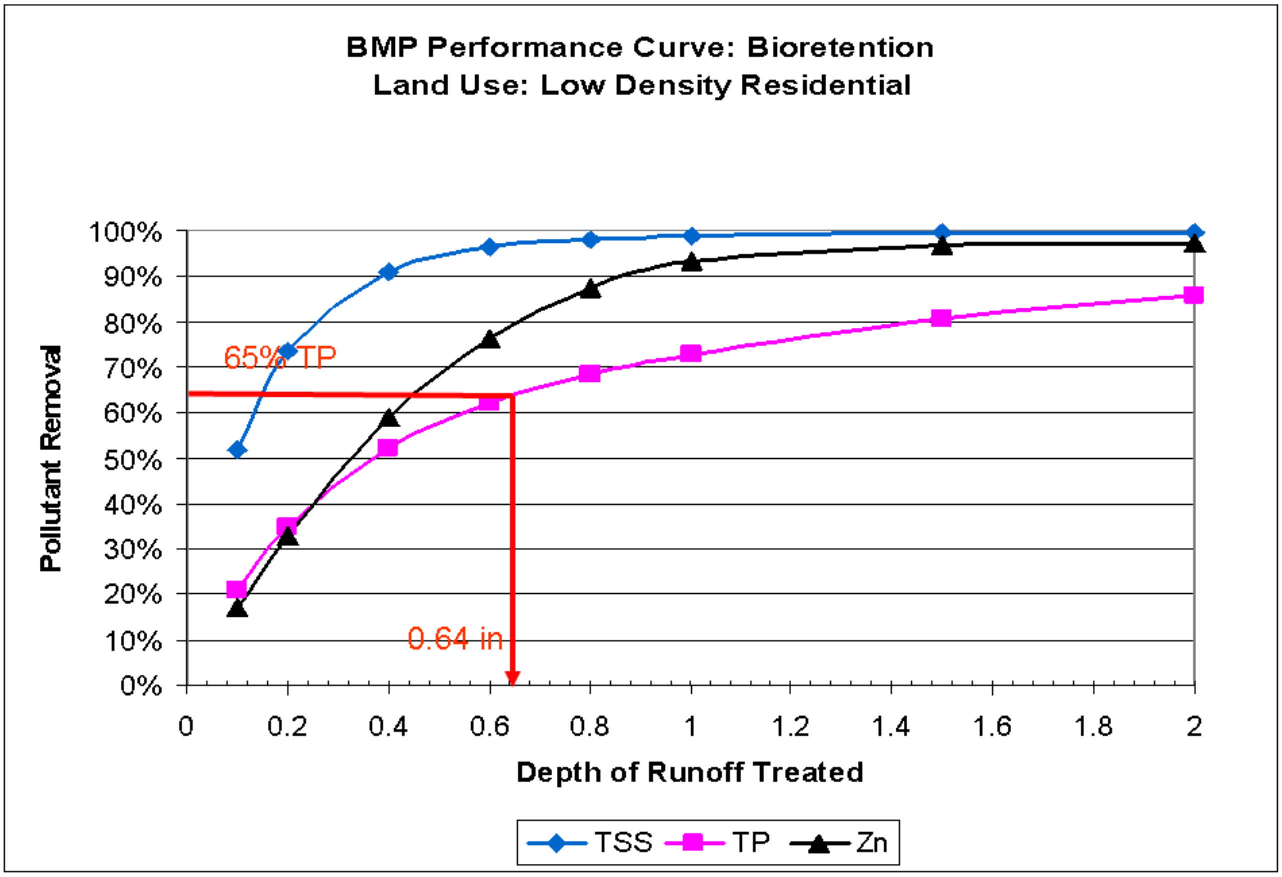


Figure 5-6. BMP performance curve of bioretention in low-density residential land use.

To obtain 65 percent TP reduction, the bioretention area must have a storage capacity of 0.64 inches of runoff from impervious surfaces.

Storage of bioretention = 0.64 in × 0.4 acres = 0.02 ac-ft

Assuming the design parameters and specifications as presented in Table 4-16, the surface area of bioretention = 525 sq. ft.

Note: The selected BMP also provides approximately 97 percent reduction in TSS and 80 percent reduction in Zn.

5.3. Assumptions and Limitations

BMP performance curves developed and reported here rely on the modeling of real BMP systems. Calibrated land-based and BMP models were used to simulate hydrologic and water quality processes for both the land and BMP components. All assumptions of the models that were used—SWMM (Huber and Dickinson 1988) for land simulation and BMPDSS (Tetra Tech 2005a) for BMP simulation—are applicable to this study. Another major assumption is that the BMPs are appropriately designed, built, and maintained as required by Massachusetts stormwater requirements presented in the *Structural BMP Specifications for the Massachusetts Stormwater Handbook* (MassDEP 2008a). The following is the summary of assumptions and limitations for developing and applying BMP performance curves that were created for this project.

- BMP configuration and placement:
    - The curves represent the pollutant removal performance of each BMP as an independent unit. It would be inappropriate to use these curves directly if BMPs were to be installed in series.
    - Another assumption and limitation is that the BMP performance curves were developed to treat stormwater runoff from impervious surfaces. Thus, it would be inappropriate to use these curves directly to size BMPs to treat runoff from pervious surfaces. However, if a system were designed to treat runoff from an area that includes both impervious and pervious areas, the size of the BMP should account for any runoff volume that could be contributed by the pervious area. This should not be an issue if the BMP size is less than the initial abstraction for the pervious area because the pervious area should not contribute runoff for storms less than this size. However, if, for example, the BMP were sized to treat 1 inch of runoff from impervious area and the drainage area includes pervious area with an initial abstraction of 0.7 inches, the actual size of the BMP capacity would need to be increased by 0.3 inch from the pervious area to obtain full reduction credit for treating the impervious area.
- BMP performance and applicability
    - Operation and maintenance of BMPs are performed according to the specifications and, therefore, BMPs maintain the same performance during their life time.
    - Soil characteristics of BMP sites remain the same over the BMPs' life time.
    - BMP performance curves were developed using the precipitation records from Boston, Massachusetts. It would be appropriate to use the curves for other regions with similar precipitation characteristics. The use of these curves beyond the precipitation characteristics of Boston, Massachusetts, would require further examination.

The benefits of the system of developed BMP performance curves are much more than its limitations. The system provides a quick assessment tool targeted to the New England region that can be used to evaluate selected BMP siting to meet a range of reduction targets for specific pollutants. The direct use of the system of curves saves resources required for detailed modeling and other evaluations for each site. The system of curves also can be used to quantify the credits associated with existing BMPs. The system can be used to evaluate the alternatives of BMPs for mitigating the effects of development and benefits of redevelopment.

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1. Mark Voorhees, U.S. Environmental Protection Agency
2. Stephen Silva, U.S. Environmental Protection Agency
3. David Webster, U.S. Environmental Protection Agency
4. David Gray, U.S. Environmental Protection Agency
5. Eric Perkins, U.S. Environmental Protection Agency
6. Holly Galavotti, U.S. Environmental Protection Agency
7. Jennie Bridge, U.S. Environmental Protection Agency
8. John Smaldone, U.S. Environmental Protection Agency
9. Thelma Murphy, U.S. Environmental Protection Agency
10. Maggie Theroux, U.S. Environmental Protection Agency
11. Todd Borci, U.S. Environmental Protection Agency
12. William Walshrogalski, U.S. Environmental Protection Agency
13. Dennis Dunn, Massachusetts Department of Environmental Protection
14. David C. Noonan, Massachusetts Department of Environmental Protection
15. Frederick Civian, Massachusetts Department of Environmental Protection
16. Paul Hogan. Massachusetts Department of Environmental Protection
17. Christopher Bellucci, Connecticut Department of Environmental Protection
18. Robert Roseen, University of New Hampshire
19. Tham Saravanapavan, Tetra Tech, Inc.

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APPENDIX A: BACKGROUND ON BMPDSS

A.1. Land Use Time Series

In BMPDSS, hydrographs and pollutographs from the drainage area are routed through BMPs placed in the project area. To simplify the land simulation process, land use-based hydrographs and pollutographs are developed using watershed model and stored in the database. For example, Hydrologic Simulation Program, FORTRAN (HSPF) was applied to generate the time series in the Prince George's County version of BMPDSS. The BMP performance analysis for New England employs SWMM (as detailed in section 3 of this report) for generating hydrographs and pollutographs for the selected land uses and stored in the geospatial database.

A.2. BMPDSS

Jurisdictions with established urban areas and newly developing areas must find cost-effective means for minimizing effects of development and for planning future growth. BMPDSS can be applied to analyze the overall performance of multiple BMPs and find an optimal solution for their implementation. BMPDSS can provide assessment of both distributed (including LID-type) and centralized BMPs in combinations implemented for a given watershed management or TMDL implementation plan and can support selection of the optimum plan that maximizes benefits and leads to significant cost savings. This quantitative approach can provide assurance to stormwater managers and regulators that goals or TMDL reduction requirements are achievable and practicable, thereby ensuring that investments in selected BMPs are justified.

The BMPDSS is a decision-making tool for placing BMPs at strategic locations in urban watersheds on the basis of integrated data collection and hydrologic, hydraulic, and water quality modeling. The key questions that can be addressed by the analysis system are as follows:

1. What is the benefit of management?
2. What is the difference between management options/scenarios including one or more practices?
3. What is the cost? That is, what is the difference in cost versus the measures of benefit described in questions 1 and 2?

The potential users of this system include local and county government planners; state, and federal regulatory reviewers; public concerned citizen/stakeholder groups; private industry; consultants; and academics.

The system uses GIS information and technology and time series data for watershed runoff flow and pollutant concentration (generated by the watershed model), integrates BMP process simulation models, and applies system optimization techniques for BMP planning and selection. ESRI ArcGIS is employed as the system platform to provide GIS-based visualization and support for developing networks that include sequences of land uses, BMPs, and stream reaches. The system also provides interfaces for BMP placement, BMP attribute data input, and decision optimization management. The system includes a standalone BMP simulation and evaluation module, which complements both research and regulatory stormwater control assessment efforts and allows flexibility in examining various BMP design alternatives. Process-based simulation of BMPs provides a technique that is sensitive to local climate and rainfall patterns. The routing simulation component routes the flow and water quality constituents through the conveyance network. The system also incorporates a meta-heuristic optimization technique to find the most cost-effective BMP placement and implementation plan given a control target or a fixed cost.

ArcGIS Interface

The ArcGIS interface is the main user interface. It includes the main application window with menus, buttons, and dialog boxes. The interface is implemented in Visual Basic programming language with ArcObjects, and it requires two ArcGIS components—ArcView 9.x (ArcMap) and Spatial Analyst. The ArcGIS interface allows the user to read and edit the spatial and temporal data sets and interact with the database component of the system. The interface also provides a platform for BMP placement and configuration, delineating drainage area, and establishing a routing network.

BMP Simulation Module

The BMP simulation module uses process-based algorithms to simulate BMP function and removal efficiency and accepts flow and water quality time series (acquired through observation or generated by runoff models) as input data. Process-based algorithms include weir and orifice control structures, storm swale characteristics, flow and pollutant transport, flow routing and networking, infiltration and saturation, evapotranspiration, and a general loss/decay representation for a pollutant. BMP effectiveness can be evaluated and estimated over a wide range of storm conditions, site designs, and flow routing configuration approaches. The processes incorporated include the following:

- Infiltration
- Orifice outflow
- Controlled orifice release (the user can define an hourly outflow rate, and there is an on/off switch)
- Weir-controlled overflow spillway
- Underdrain outflow
- Bottom slope influence
- Bottom roughness influence
- General loss or decay of pollutant (due to settling, plant uptake, volatilization, and so forth)
- Pollutant filtration through the soil medium (represented by underdrain outflow)
- Evapotranspiration

The major BMP types that can be represented in BMPDSS are storage-type devices (such as rain barrels, cisterns, and detention basins), bioretention basins, filters, and swales (Figure A-1).

Figure A-1. Available BMP options in BMPDSS.

Routing/Transport Module

Flow and pollutants are routed through the pipes or channels in a routing network with the user's choice of cross section by using the Storm Water Management Model (SWMM) (version 5) transport algorithms. The SWMM-Transport module tracks the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period.

Water quality routing within conduit links assumes that the conduit behaves like a continuously stirred tank reactor (CSTR). The concentration of a constituent exiting the conduit at the end of a time step is found by integrating the conservation of mass equation, using average values for quantities that might change over the time step, such as flow rate and conduit volume. Input flows and pollutants loadings from external and dry-weather inflows are supplied through time series data associated with a junction of the conduit inlet.

Optimization Component

The optimization component provides evolutionary optimization techniques to identify the most cost-efficient BMP selection and placement strategies according to user-defined decision criteria, including assessment points (e.g., outfall locations) and evaluation factors (e.g., flow and water quality). The function of the optimization engine is to determine the locations, types, and design configurations of the BMPs that best satisfy the user-defined water quality, water quantity, or cost objectives within user-defined constraints. The system provides an evaluation factor pick-list from which the user can choose. In the current version (version 1.0), the following factors are provided:

- Water Quantity Evaluation Factors
- Annual Average Flow Volume (AAFV)
- Peak Discharge Flow (PDF) within simulation period
- Flow Exceeding Frequency (FEF) for user-specified threshold rate
- Water Quality Evaluation Factors (sediment and other user-specified pollutants)
    - Annual Average Load (AAL)
    - Annual Average Concentration (AAC)
    - Maximum Moving Average Concentration (MAC) for a user-specified time period

Each evaluation factor can be presented in three modes: (1) percent of existing condition, (2) scaled between pre-developed and existing condition, and (3) value.

As an important factor in optimization formulation, the cost function estimates the total costs of the BMP systems. BMPDSS includes a generic cost function to provide relationships between BMP cost and excavation volume; a linear, land-cost term is also included.

The optimization component employs scatter search as the solution algorithm. Scatter search is a meta-heuristic search technique that has been explored and used in optimizing complex systems (Glover et al. 1999[1]). The scatter search approach does not emphasize randomization, particularly in the sense of being indifferent to choices among alternatives. Instead, the approach is designed to incorporate strategic responses, both deterministic and probabilistic, that take evaluation and history into account. Scatter search focuses on generating relevant outcomes without losing the ability to produce diverse solutions because of the way the generation process is implemented (Laguna and Marti 2002[2]). Because of this feature of scatter search, for optimization problems that have a CPU time-consuming evaluator, it is expected that scatter search can find the near-optimal solution more efficiently and serve as a better optimization engine.

Post-processor

To aid in the processing, analysis, and examination of output data produced by BMPDSS, a result analysis tool or post-processor has been incorporated into the system. The post-processor has two components. One is in the ArcGIS environment and is mainly for displaying the evaluation factor values for defined assessment points; the other is a Microsoft Excel spreadsheet with macros. The post-processor tool is designed to facilitate the evaluation of BMP/LID performance and to provide insights for the following assessment questions:

- What are the hydrologic and water quality impacts of a proposed or existing development site?
- What is a reasonable pre-developed condition for the site?
- How does the developed scenario compare with the pre-development condition?

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1 Glover, F., M. Laguna, and R. Marti. 1999. Scatter Search to Appear in Theory and Applications of Evolutionary Computation: Recent Trends. Ed., A. Ghosh and S. Tsutsui. Springer-Verlag.

2 Laguna, M., and R. Marti. 2002. The OptQuest Callable Library to Appear in Optimization Software Class Libraries. Ed. S. Voss and D.L. Woodruff. Kluwer Academic Publishers, Boston. Pp. 193–218.

- How does the developed-with-BMPs scenario compare to the pre-development condition?
- How does a single BMP or a BMP/LID network perform under storms of differing magnitude and duration?
- What is the effect on BMP performance when consecutive storm events occur?
- What are the long-term effects of the BMP/LID network on hydrology and water quality?

A.3. BMP Model Representation

Most processes of BMPs can be divided into two main classifications:

- Class A: Storage/Infiltration BMPs
    - Physical storage volume exists.
    - Storage routing techniques needs to be applied.
    - Outflow can be controlled by weir, orifice, pump, etc.
- Class B: Channelized BMPs
    - No physical storage volume exists.
    - Friction flow routing technique needs to be applied.
    - Outflow can be estimated by a frictional flow formula (e.g., Manning's equation).

Storage/Infiltration BMPs can include bioretention, wet- or dry- ponds, wetlands, retention basins, infiltration trenches, porous pavements, rain barrels and cisterns. The primary benefit for these BMPs is storage and infiltration. Secondary processes must be considered when evaluating volume or water quality benefits, including processes associated with filtration, settling of sediment, and pollutants decay (Figure A-2). Channelized BMPs include grass swales (Figure A-3).

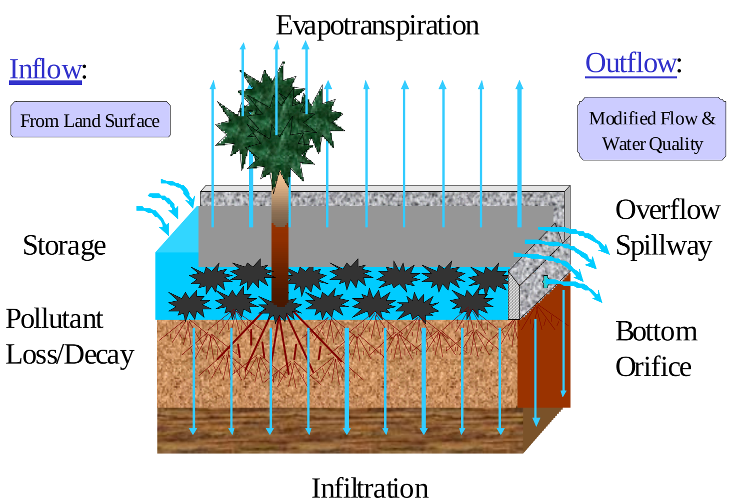

Figure A-2. Major processes included in Class A: Storage/Infiltration BMPs.

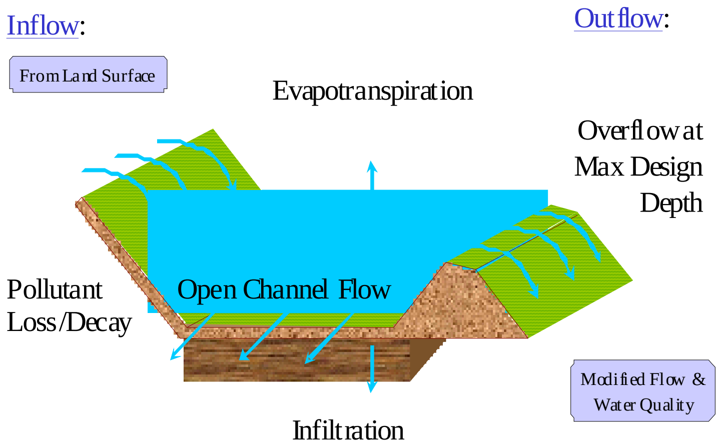

Figure A-3. Major processes included in Class B: Channelized BMPs.

Key processes that affect BMP effectiveness include infiltration and pollutant removal. The BMP simulation module in BMPDSS employs Holtan-Lopez empirical model (Equation 1) to represent infiltration and evapotransporation during a storm event.

$$f = GI\ AS_a^{1.4} + f_c \qquad (1)$$

In equation 1, f is the infiltration rate (in/hr); GI is the growth index of vegetation in percent maturity, varying from 0.1 to 1.0; A is the vegetative parameter that characterizes surface-connected porosity and the density of plant roots, which affect infiltration; S_a is the available storage in the surface layer (inches); and f_c is the final constant infiltration rate (in/hr), which is a function of the infiltration capacity of the substrate.

The water quality simulation considers two mechanisms: general loss or decay of pollutant (because of settling, plant-uptake, volatilization, and so on); and pollutant filtration through substrate. The general loss or decay is represented using a first order decay model:

$$C_t = C_0\, e^{(-kt)} \qquad (2)$$

where, C_t is the pollutant concentration at time t, C_0 is the initial pollutant concentration, and k is the first order decay rate (T^{-1}).

The pollutant filtration through substrate is simulated using percent removal:

$$C_{ud\_out} = P_{rem}\, C_{in}\, e^{(-kt)} / 100 \qquad (3)$$

where, C_{ud_out} is the underdrain outflow pollutant concentration, C_{in} is pollutant concentration in inflow to the substrate, P_{rem} is percent removal rate (%), and t is time (model simulation occurs at a 1-hour time-step).

Figure A-4 illustrates the water quality simulation processes that take place in a BMP.

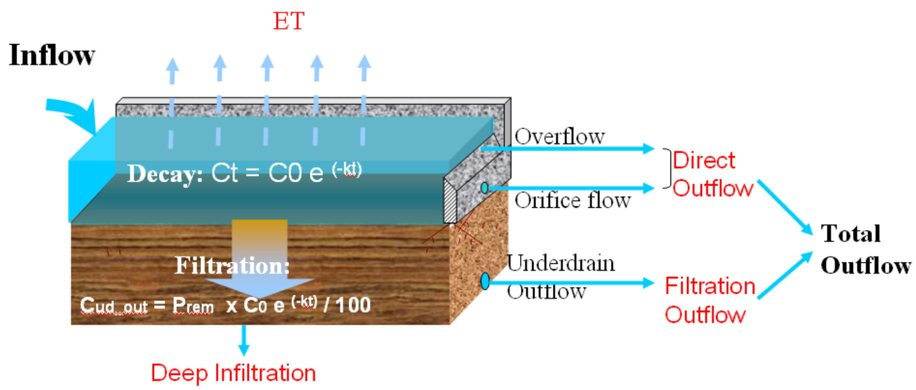

Figure A-4. Water quality simulation processes.

APPENDIX B: BMP PERFORMANCE CURVES

BMP Performance Curve: Infiltration Trench

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September 2008

BMP Performance Table

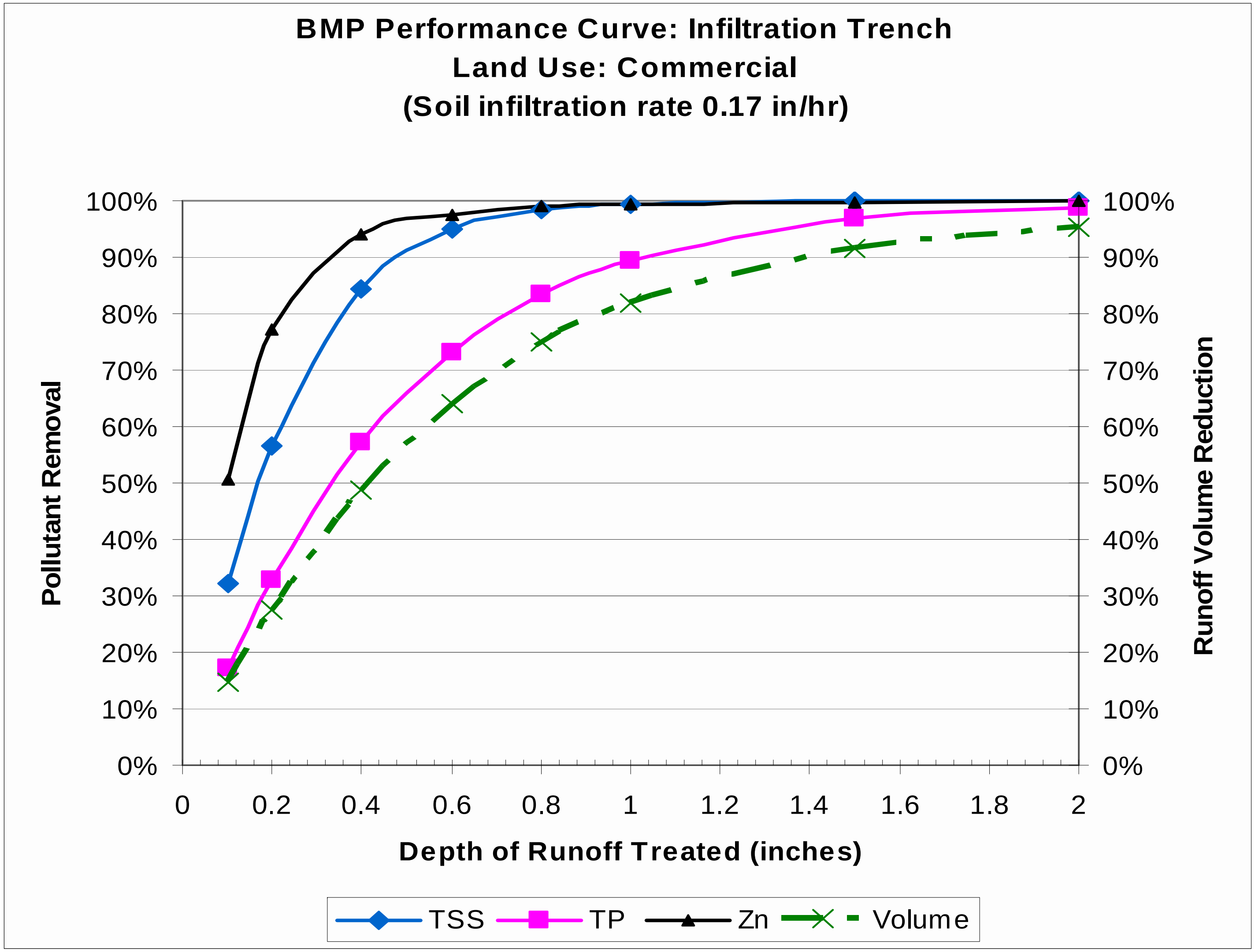
BMP Name: Infiltration Trench

Soil Infiltration Rate: 0.17 in/hr

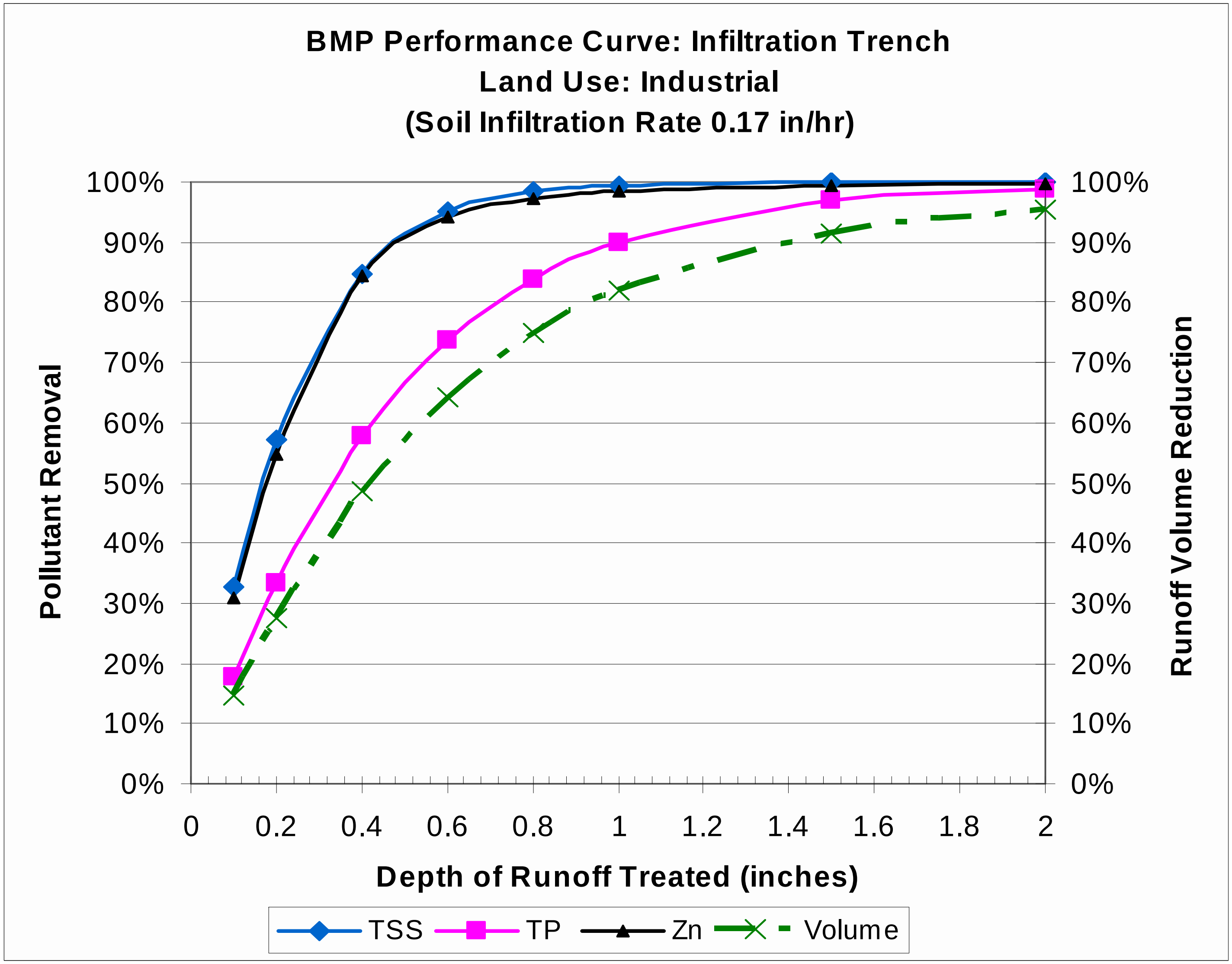
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	32%	56%	84%	95%	98%	99%	100%	100%
	TP	17%	33%	57%	73%	83%	89%	97%	99%
	Zn	51%	77%	94%	98%	99%	99%	100%	100%
Industrial	TSS	33%	57%	85%	95%	98%	99%	100%	100%
	TP	18%	33%	58%	74%	84%	90%	97%	99%
	Zn	31%	55%	84%	94%	97%	98%	100%	100%
High-Density Residential	TSS	34%	58%	85%	95%	98%	99%	100%	100%
	TP	18%	33%	57%	73%	83%	89%	97%	99%
	Zn	36%	62%	88%	96%	98%	99%	100%	100%
Medium-Density Residential	TSS	43%	68%	91%	98%	99%	100%	100%	100%
	TP	18%	33%	57%	72%	82%	88%	96%	98%
	Zn	13%	27%	52%	70%	82%	90%	98%	99%
Low-Density Residential	TSS	39%	62%	85%	94%	98%	99%	100%	100%
	TP	19%	34%	56%	71%	81%	87%	95%	97%
	Zn	10%	21%	44%	63%	76%	85%	96%	99%
Runoff Volume Reduction		15%	28%	49%	64%	75%	82%	92%	95%

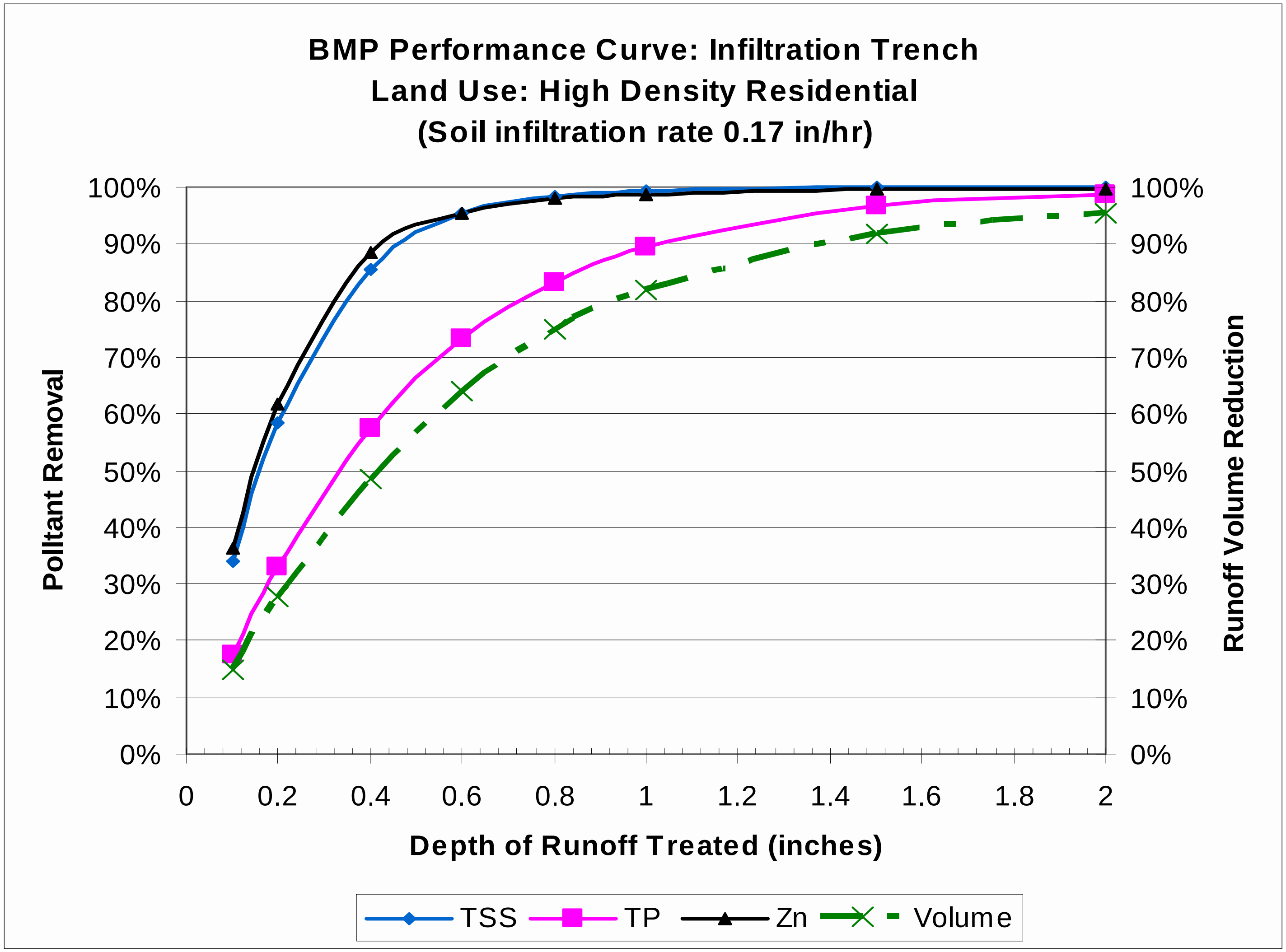
Annual Pollutant Loading Rates

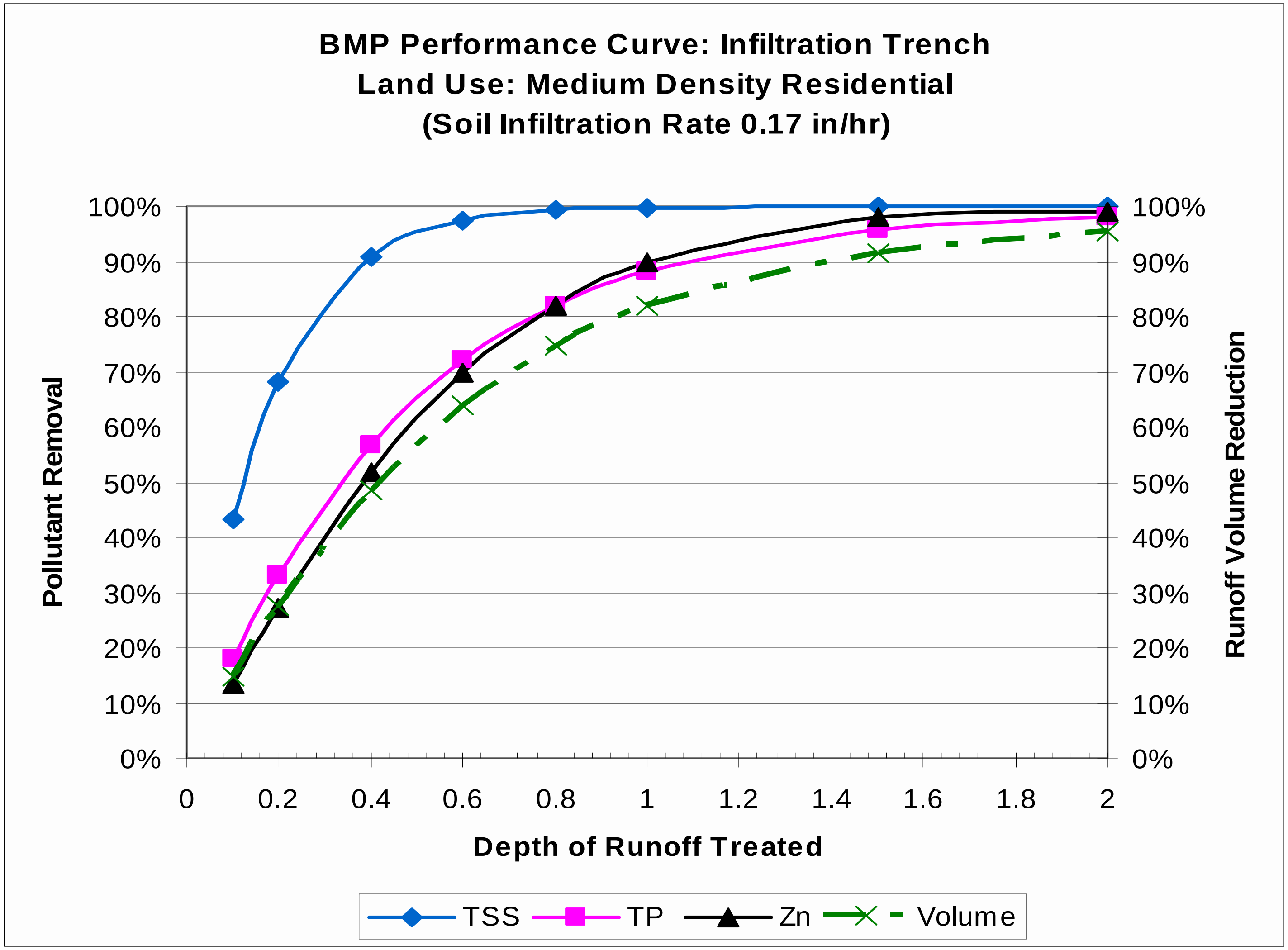
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

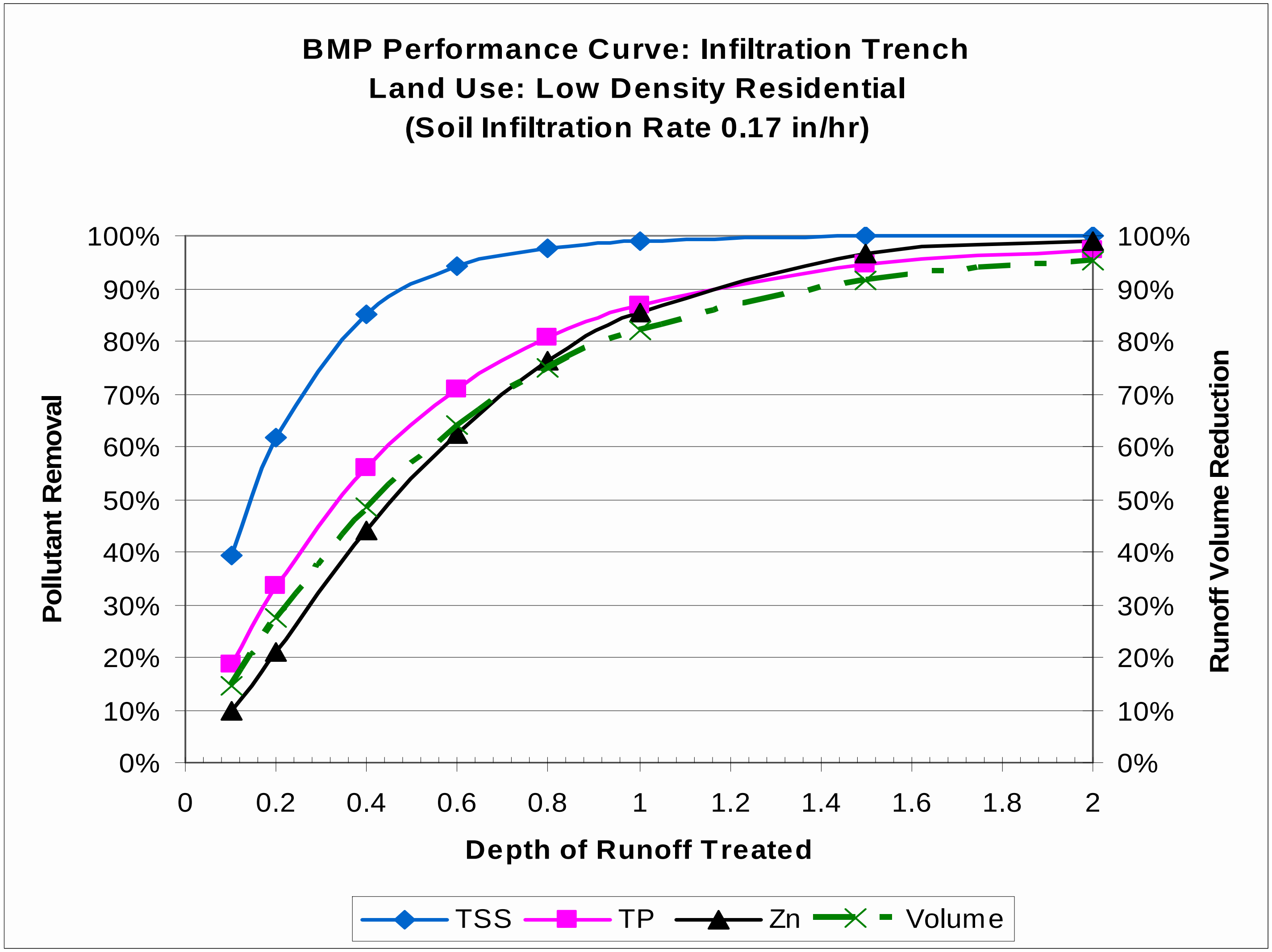


BMP Performance Curve: Infiltration Trench
Land Use: Commercial
(Soil infiltration rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Industrial
(Soil Infiltration Rate 0.17 in/hr)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
Runoff Volume Reduction
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: High Density Residential
(Soil infiltration rate 0.17 in/hr)
Polltant Removal
Runoff Volume Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Medium Density Residential
(Soil Infiltration Rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume



BMP Performance Curve: Infiltration Trench
Land Use: Low Density Residential
(Soil Infiltration Rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench

BMP Performance Table

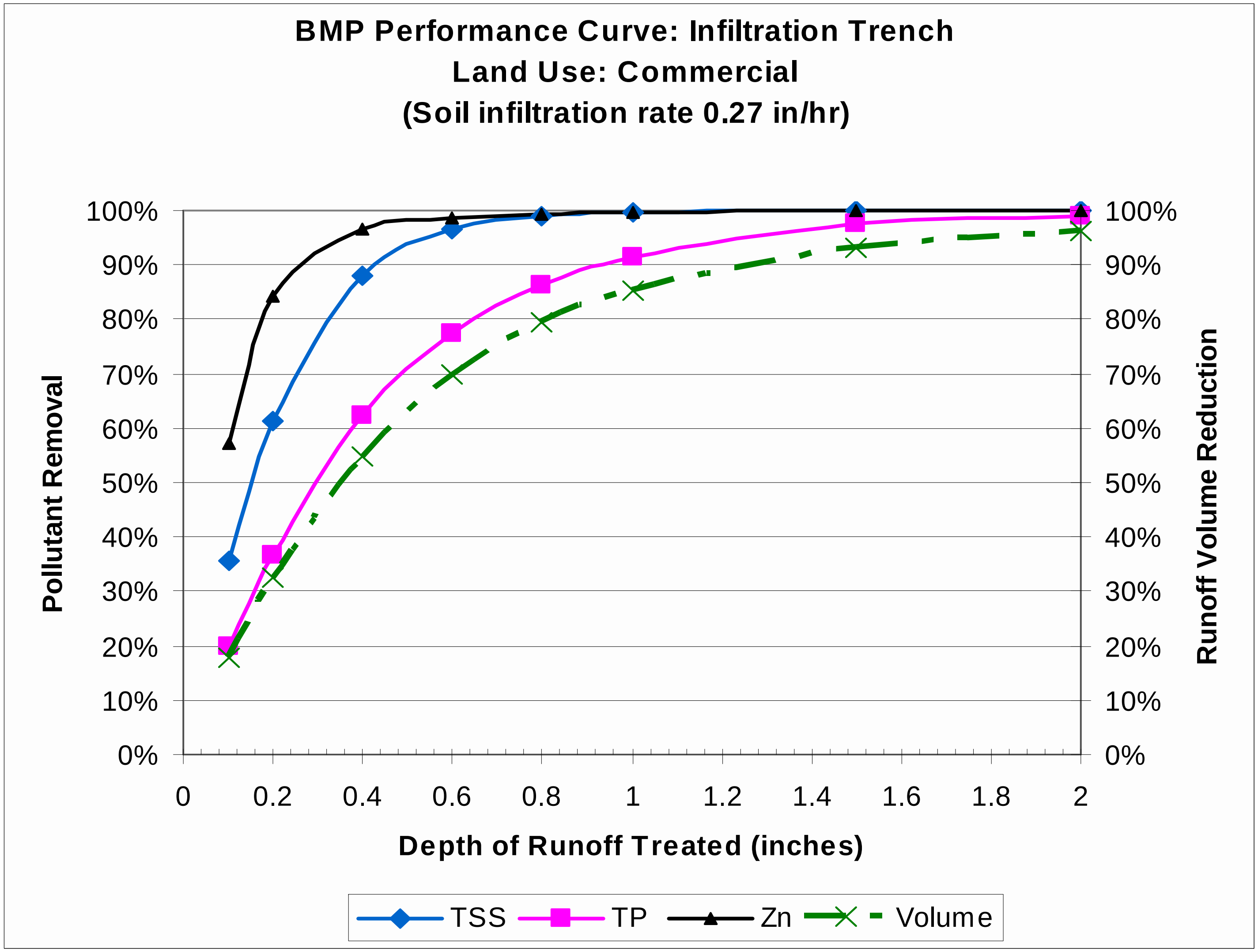
BMP Name: Infiltration Trench

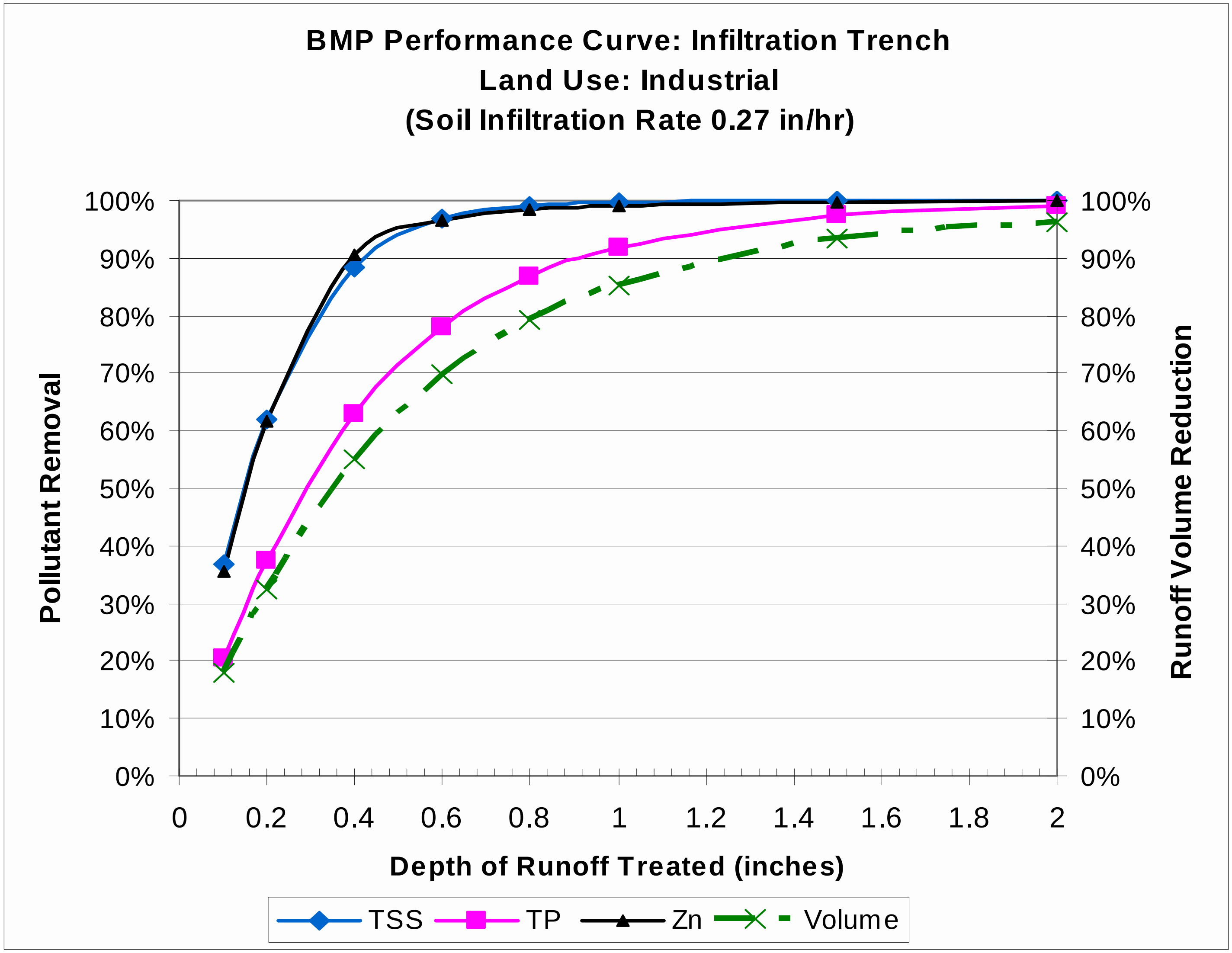
Soil Infiltration Rate: 0.27 in/hr

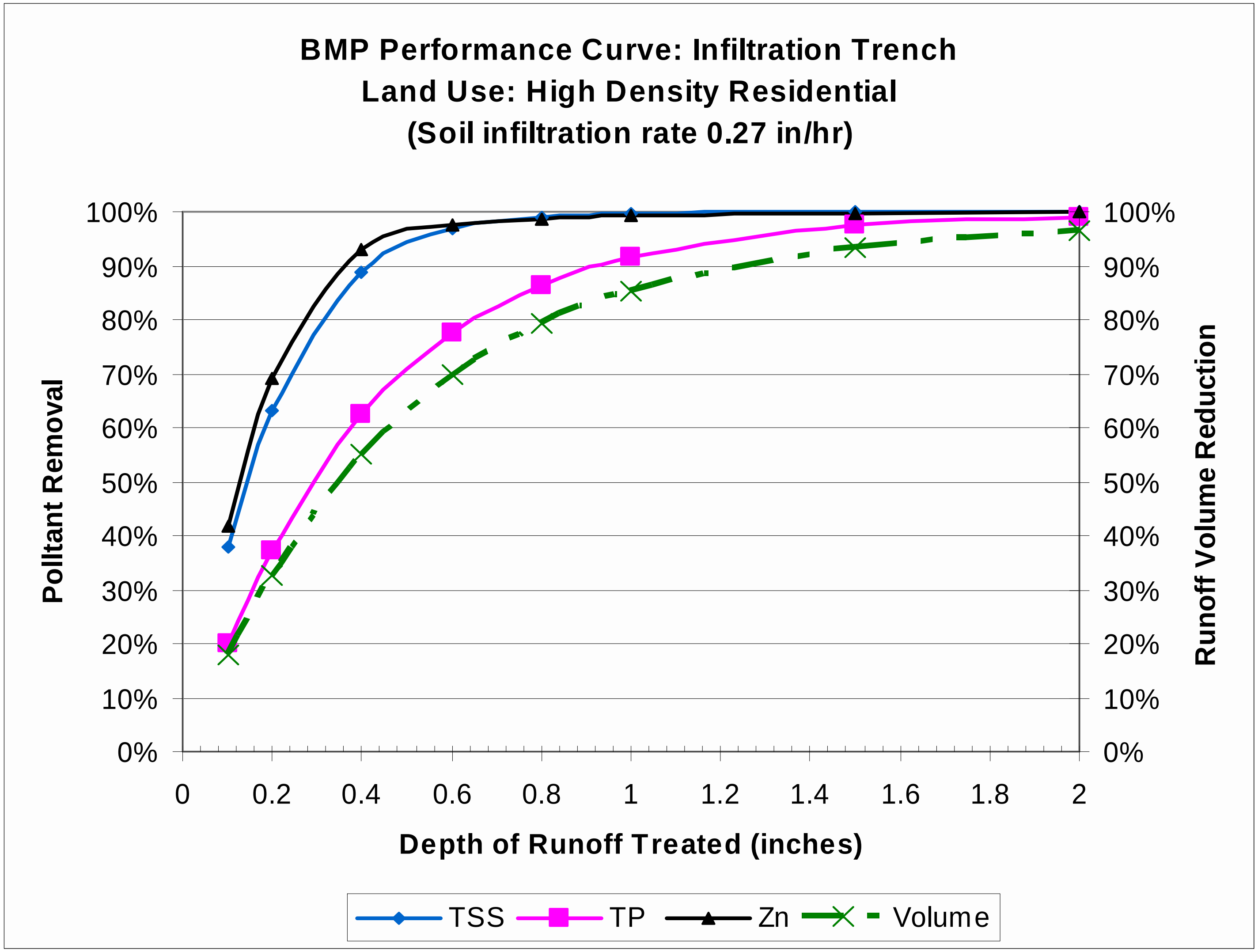
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	36%	61%	88%	97%	99%	100%	100%	100%
	TP	20%	37%	62%	78%	86%	91%	97%	99%
	Zn	57%	84%	97%	99%	99%	100%	100%	100%
Industrial	TSS	37%	62%	88%	97%	99%	100%	100%	100%
	TP	20%	38%	63%	78%	87%	92%	98%	99%
	Zn	35%	62%	91%	97%	98%	99%	100%	100%
High-Density Residential	TSS	38%	63%	89%	97%	99%	100%	100%	100%
	TP	20%	37%	62%	78%	86%	91%	97%	99%
	Zn	42%	69%	93%	97%	99%	99%	100%	100%
Medium-Density Residential	TSS	47%	73%	93%	98%	100%	100%	100%	100%
	TP	21%	37%	62%	76%	85%	90%	97%	99%
	Zn	15%	31%	57%	75%	86%	93%	99%	99%
Low-Density Residential	TSS	43%	66%	88%	96%	98%	99%	100%	100%
	TP	21%	38%	61%	75%	84%	89%	96%	98%
	Zn	11%	24%	49%	68%	81%	89%	98%	99%
Runoff Volume Reduction		18%	32%	55%	70%	79%	85%	93%	96%

Annual Pollutant Loading Rates

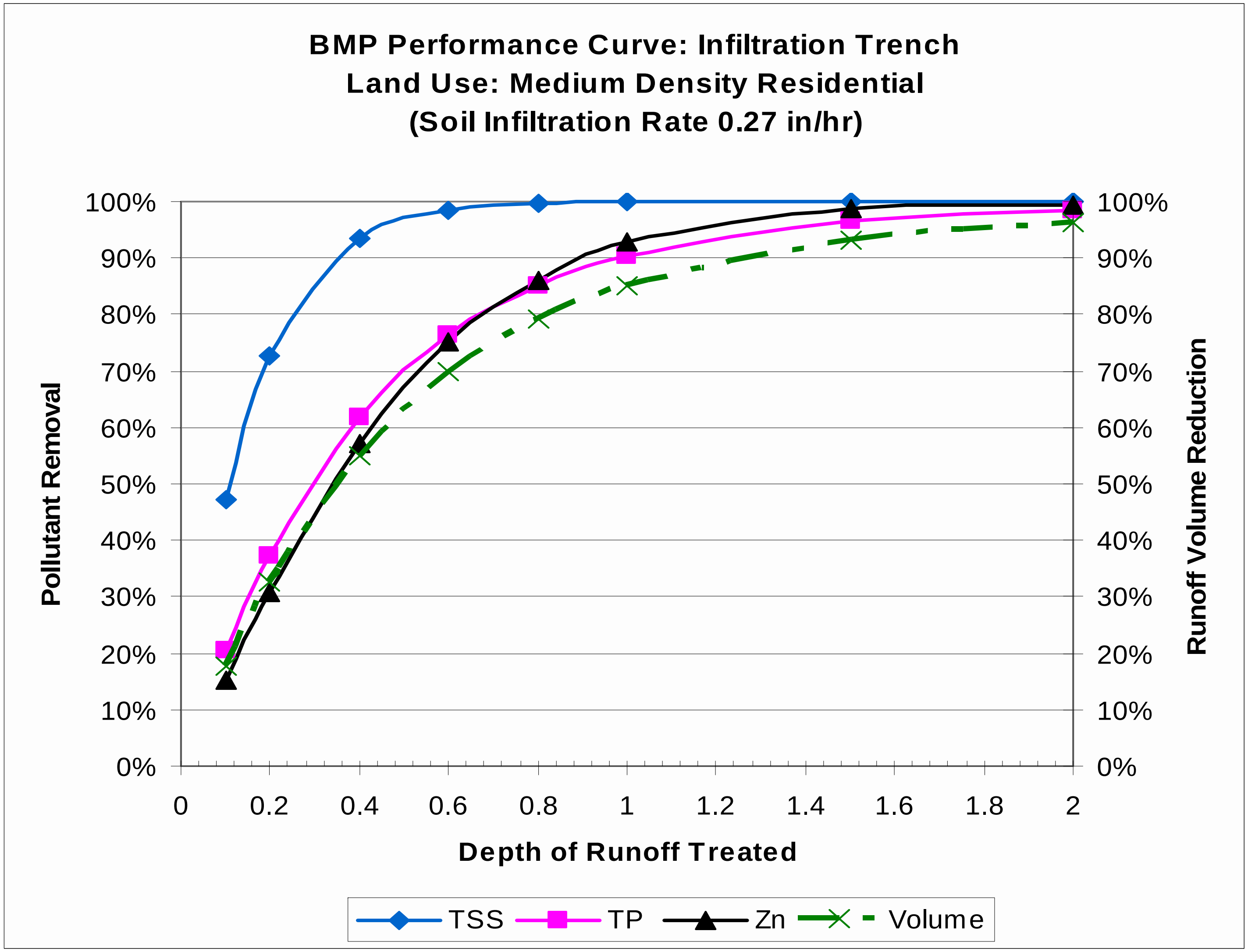
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

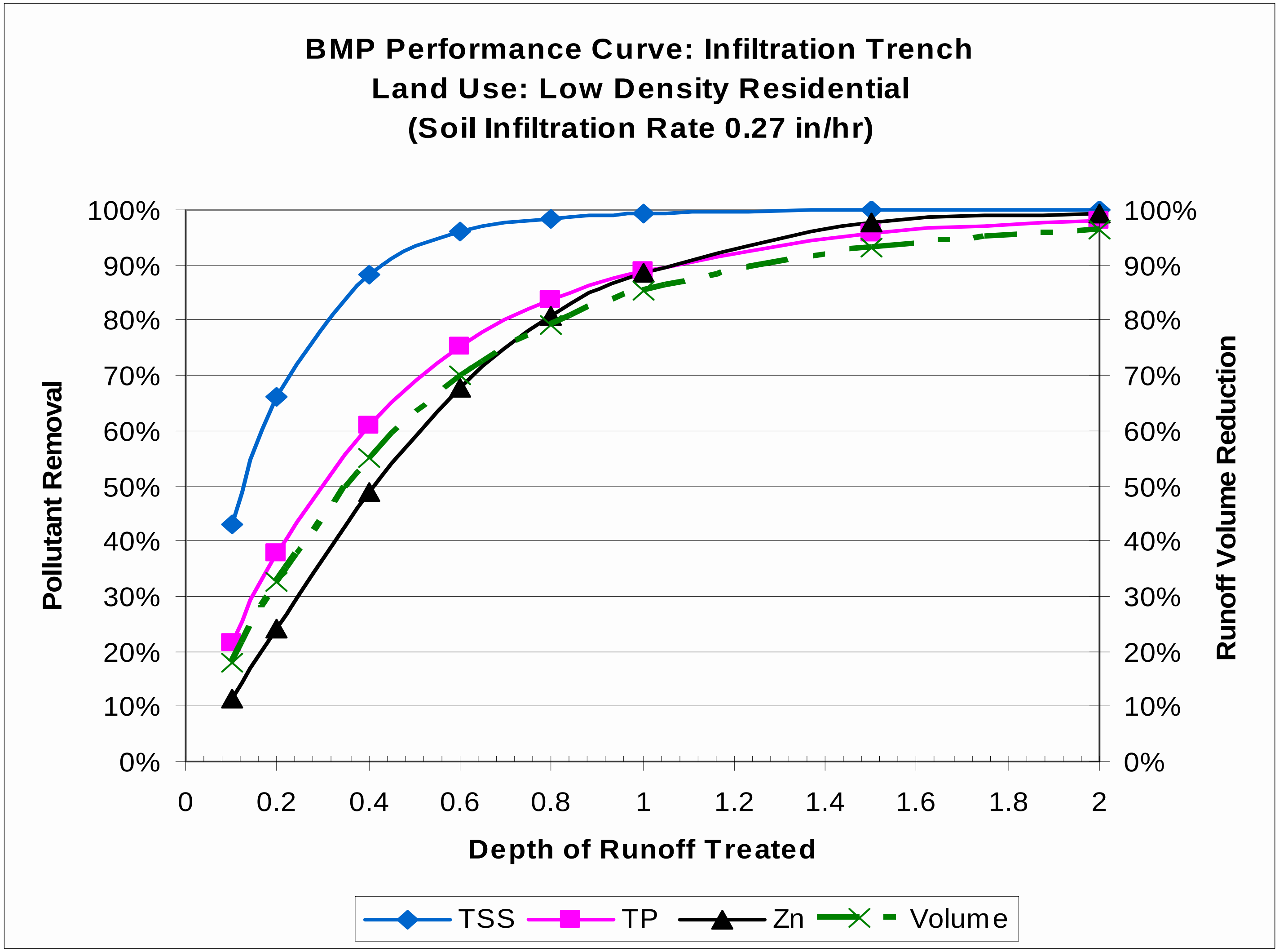

BMP Performance Curve: Infiltration Trench
Land Use: Commercial
(Soil infiltration rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Industrial
(Soil Infiltration Rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume



BMP Performance Curve: Infiltration Trench
Land Use: High Density Residential
(Soil infiltration rate 0.27 in/hr)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Polltant Removal
Runoff Volume Reduction
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Medium Density Residential
(Soil Infiltration Rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Low Density Residential
(Soil Infiltration Rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

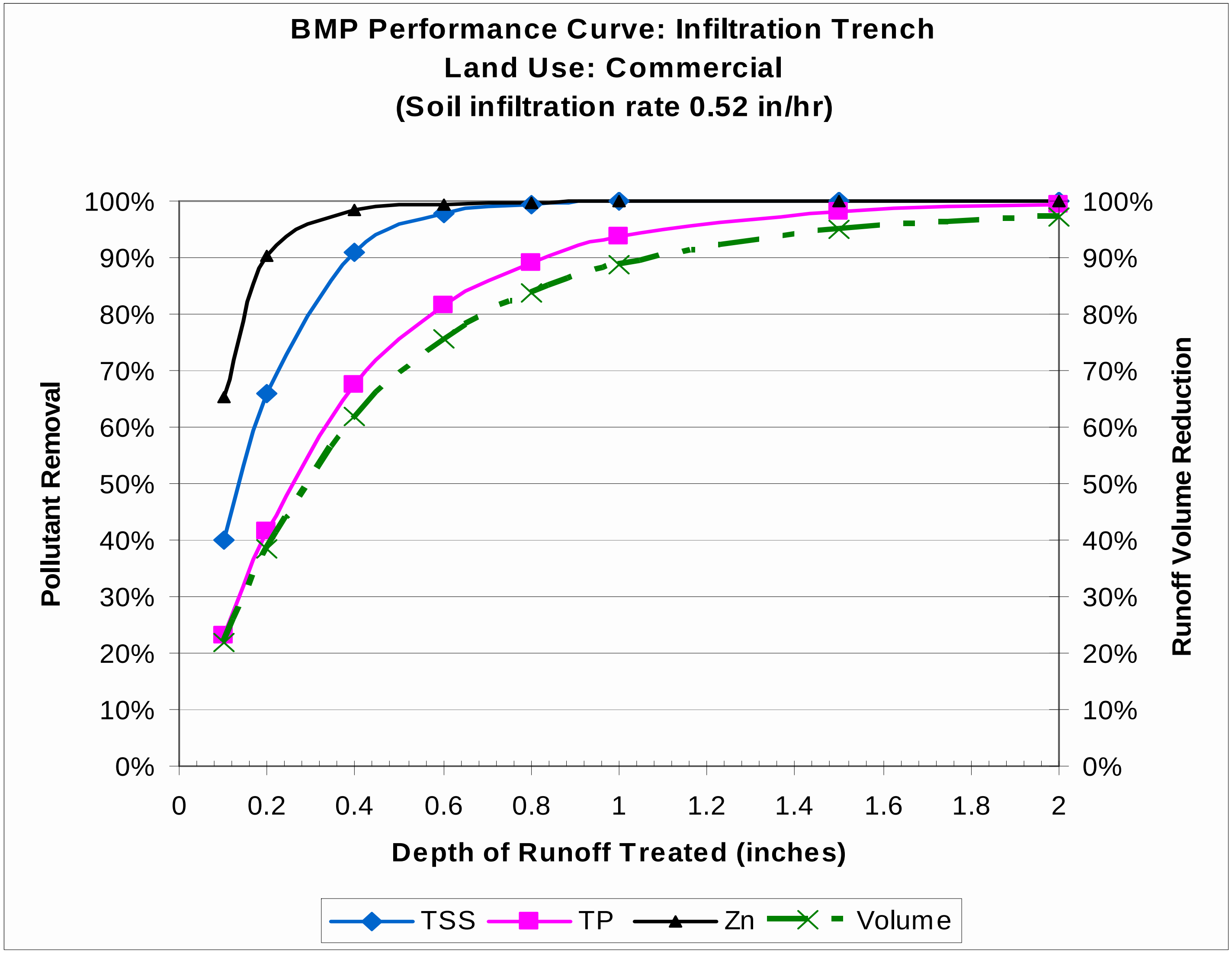
BMP Name: Infiltration Trench

Soil Infiltration Rate: 0.52 in/hr

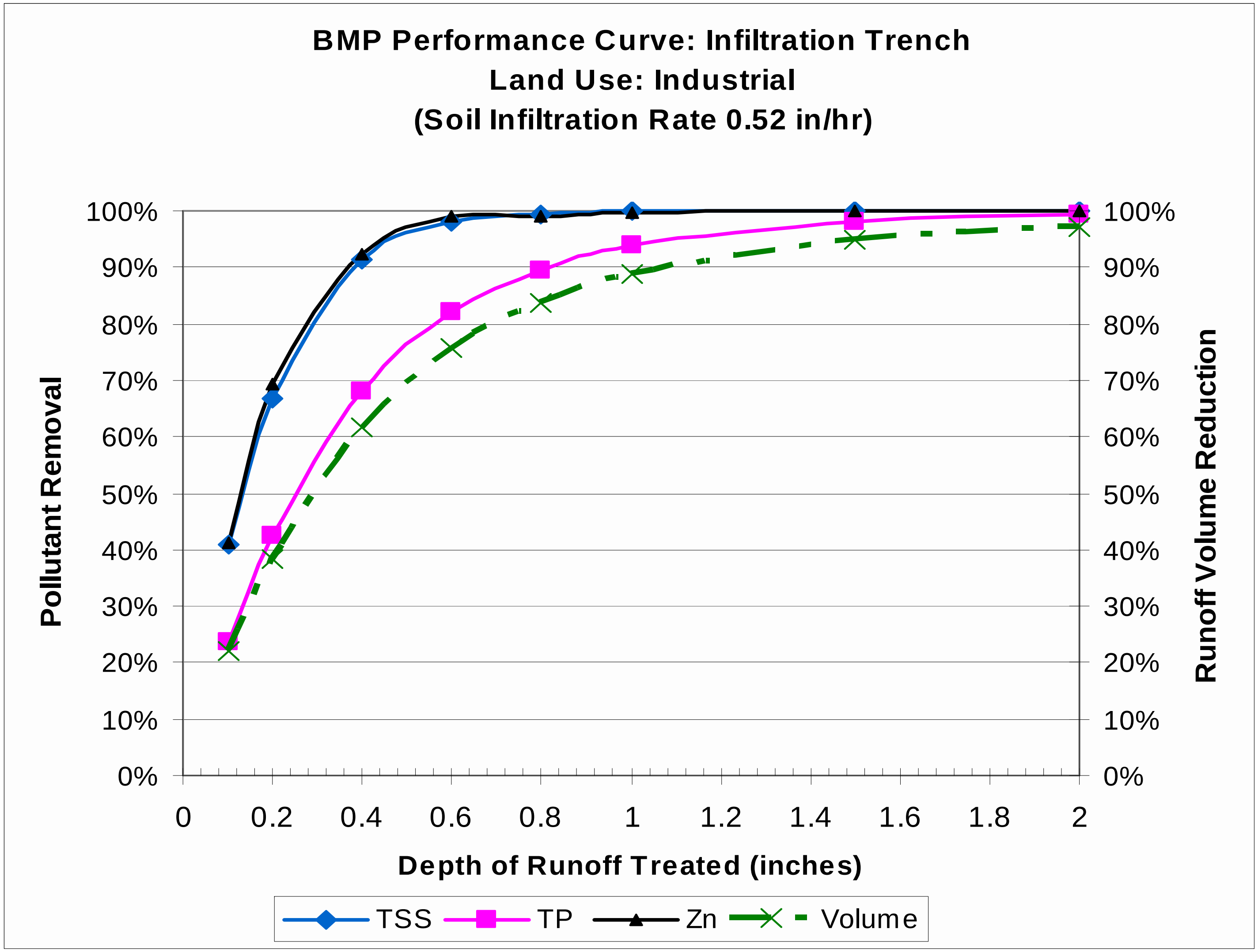
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	40%	66%	91%	98%	99%	100%	100%	100%
	TP	23%	42%	67%	82%	89%	94%	98%	99%
	Zn	65%	90%	98%	99%	100%	100%	100%	100%
Industrial	TSS	41%	67%	91%	98%	99%	100%	100%	100%
	TP	24%	42%	68%	82%	90%	94%	98%	99%
	Zn	41%	69%	92%	99%	99%	100%	100%	100%
High-Density Residential	TSS	42%	68%	91%	98%	99%	100%	100%	100%
	TP	24%	42%	68%	82%	89%	94%	98%	99%
	Zn	48%	77%	97%	99%	99%	100%	100%	100%
Medium-Density Residential	TSS	52%	77%	95%	99%	100%	100%	100%	100%
	TP	24%	42%	67%	81%	88%	93%	97%	99%
	Zn	18%	35%	63%	81%	91%	96%	100%	100%
Low-Density Residential	TSS	47%	70%	91%	97%	99%	100%	100%	100%
	TP	25%	43%	66%	80%	87%	92%	97%	98%
	Zn	13%	28%	55%	73%	85%	93%	99%	99%
Runoff Volume Reduction		22%	38%	62%	76%	84%	89%	95%	97%

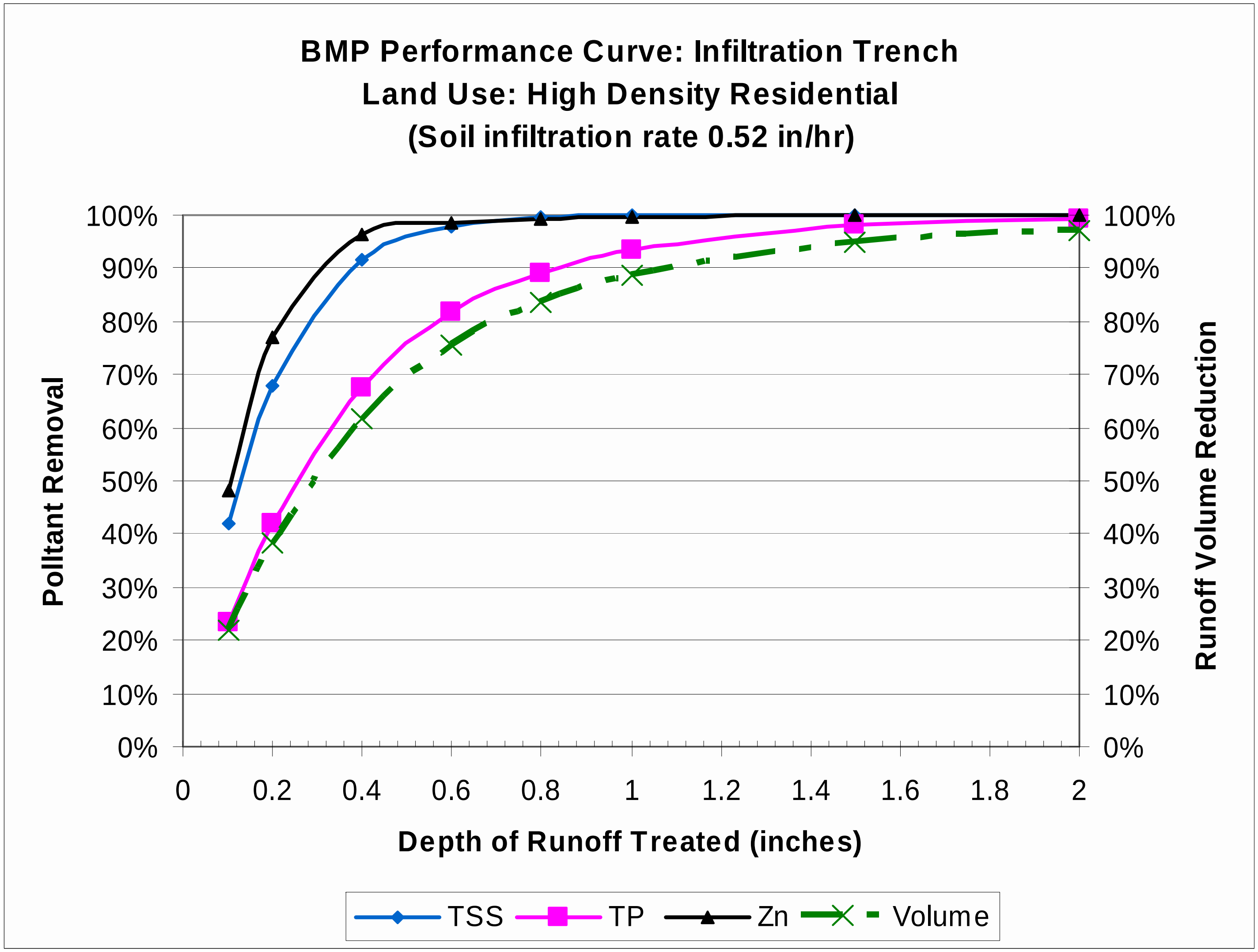
Annual Pollutant Loading Rates

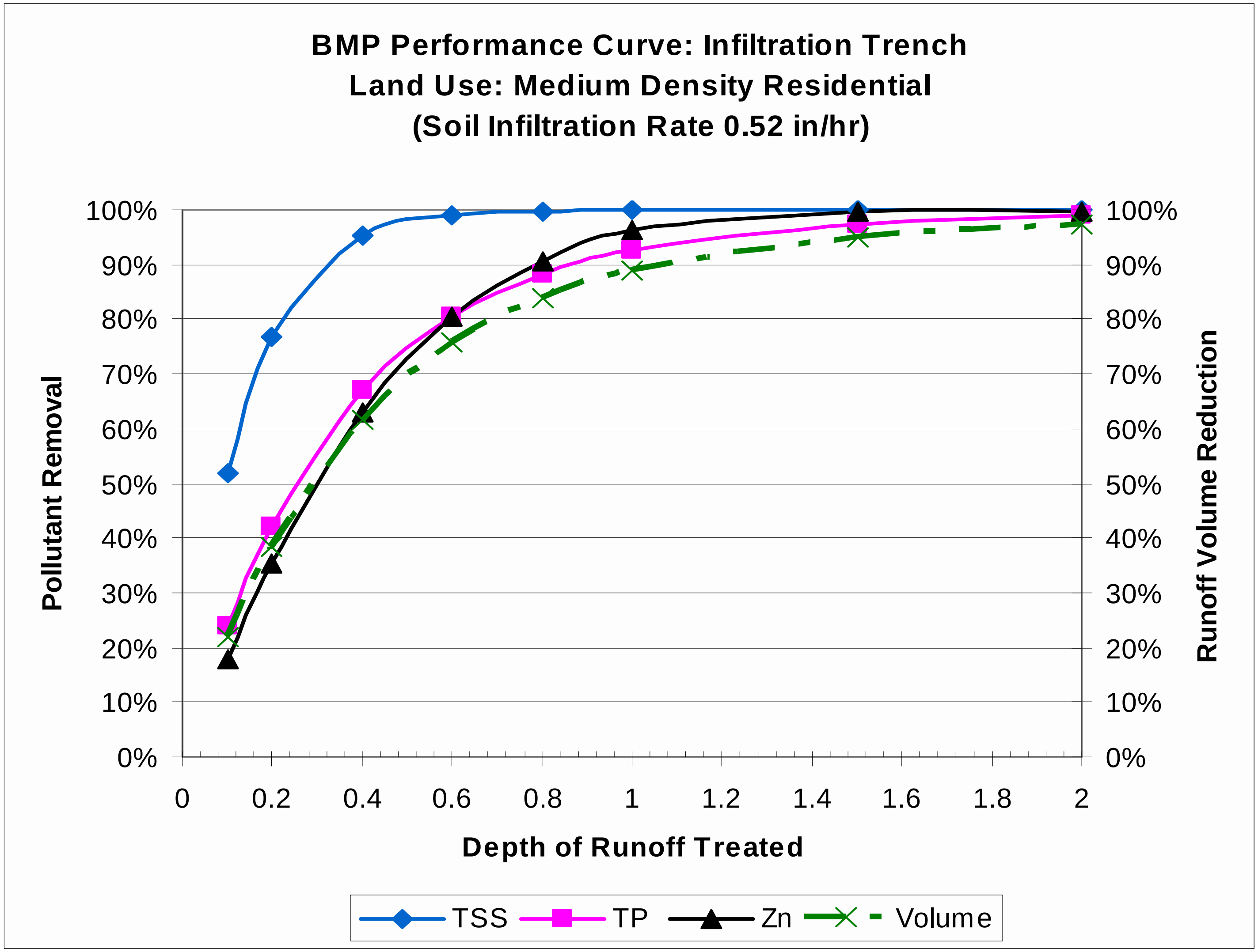
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

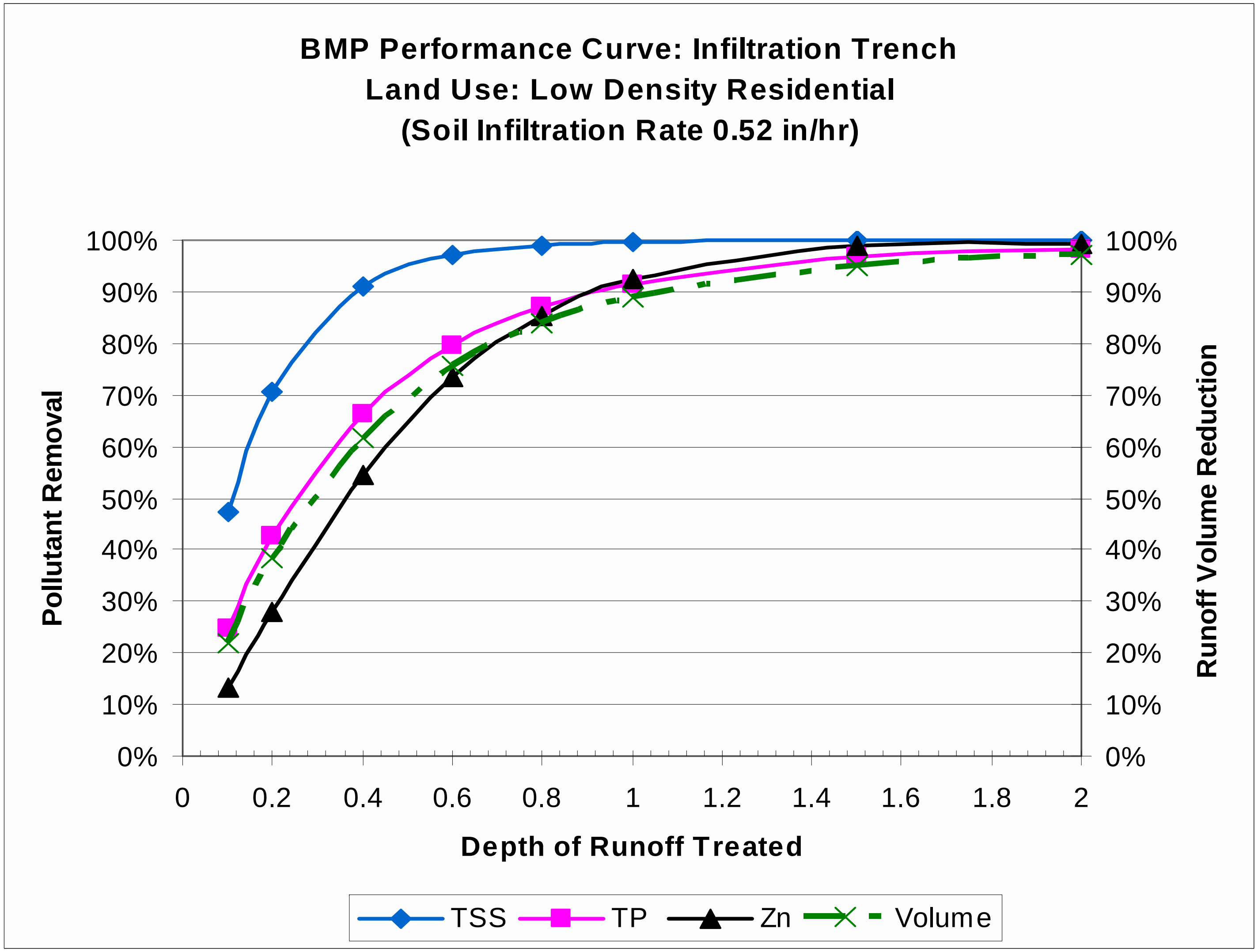

BMP Performance Curve: Infiltration Trench
Land Use: Commercial
(Soil infiltration rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench




BMP Performance Curve: Infiltration Trench
Land Use: High Density Residential
(Soil infiltration rate 0.52 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Medium Density Residential
(Soil Infiltration Rate 0.52 in/hr)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
Runoff Volume Reduction
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Low Density Residential
(Soil Infiltration Rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

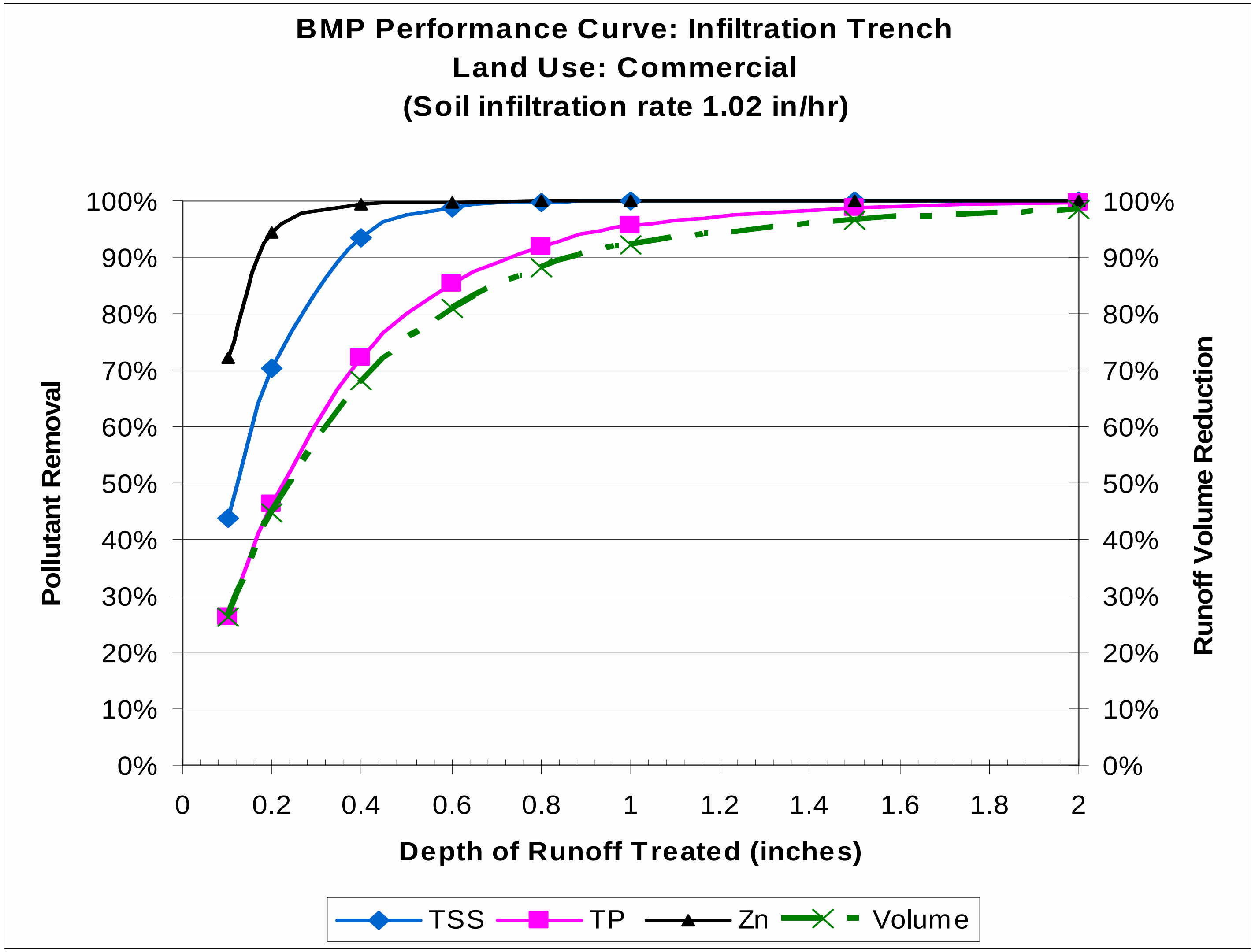
BMP Name: Infiltration Trench

Soil Infiltration Rate: 1.02 in/hr

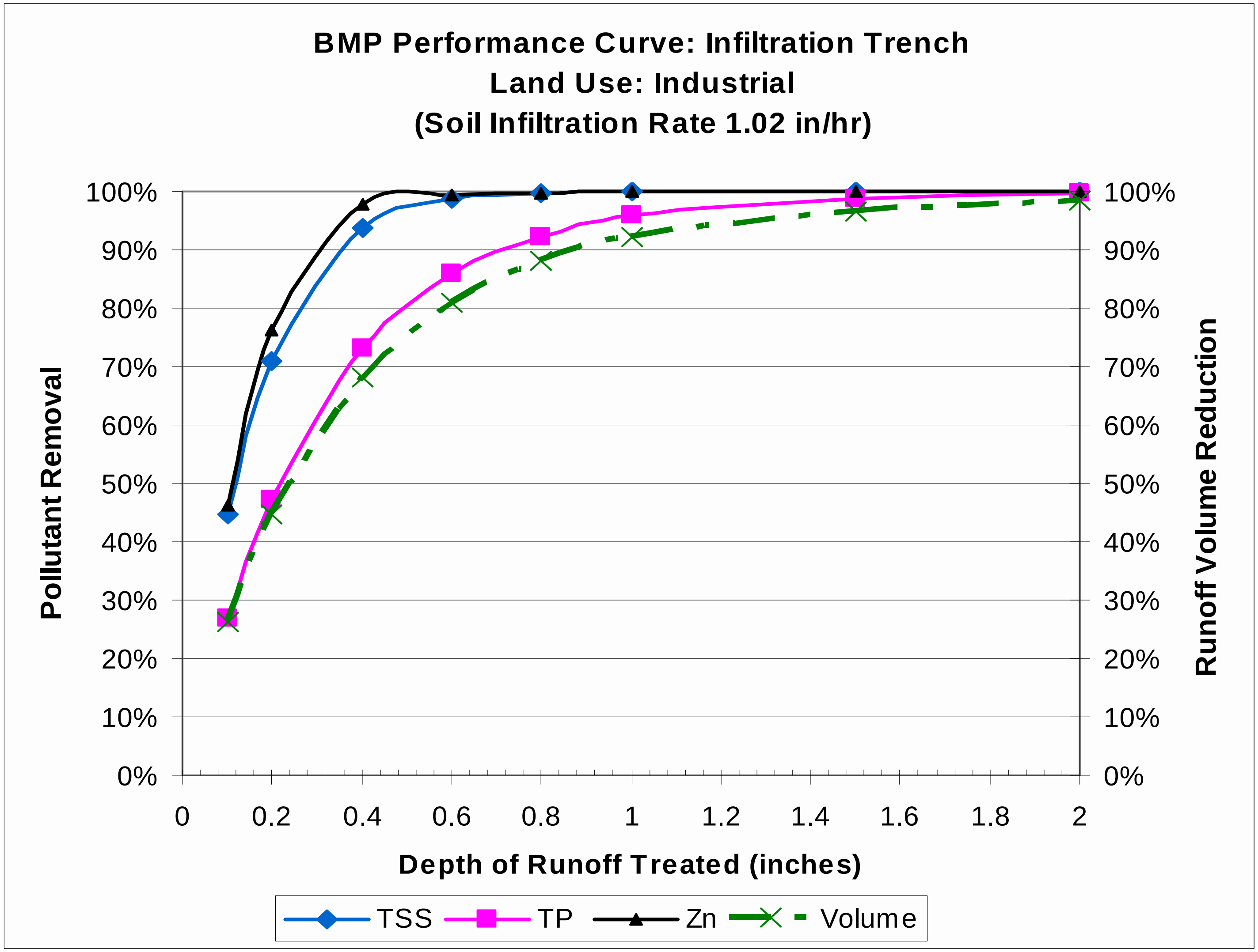
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	44%	70%	93%	99%	100%	100%	100%	100%
	TP	26%	46%	72%	85%	92%	96%	99%	100%
	Zn	72%	94%	99%	100%	100%	100%	100%	100%
Industrial	TSS	45%	71%	94%	99%	100%	100%	100%	100%
	TP	27%	47%	73%	86%	92%	96%	99%	100%
	Zn	46%	76%	98%	99%	100%	100%	100%	100%
High-Density Residential	TSS	46%	72%	94%	99%	100%	100%	100%	100%
	TP	27%	47%	73%	86%	92%	96%	99%	100%
	Zn	54%	84%	98%	99%	100%	100%	100%	100%
Medium-Density Residential	TSS	55%	80%	97%	99%	100%	100%	100%	100%
	TP	27%	47%	72%	85%	91%	95%	98%	99%
	Zn	21%	40%	69%	86%	95%	99%	100%	100%
Low-Density Residential	TSS	51%	74%	93%	98%	99%	100%	100%	100%
	TP	28%	47%	71%	84%	90%	94%	98%	99%
	Zn	15%	32%	60%	79%	90%	96%	99%	100%
Runoff Volume Reduction		26%	45%	68%	81%	88%	92%	97%	98%

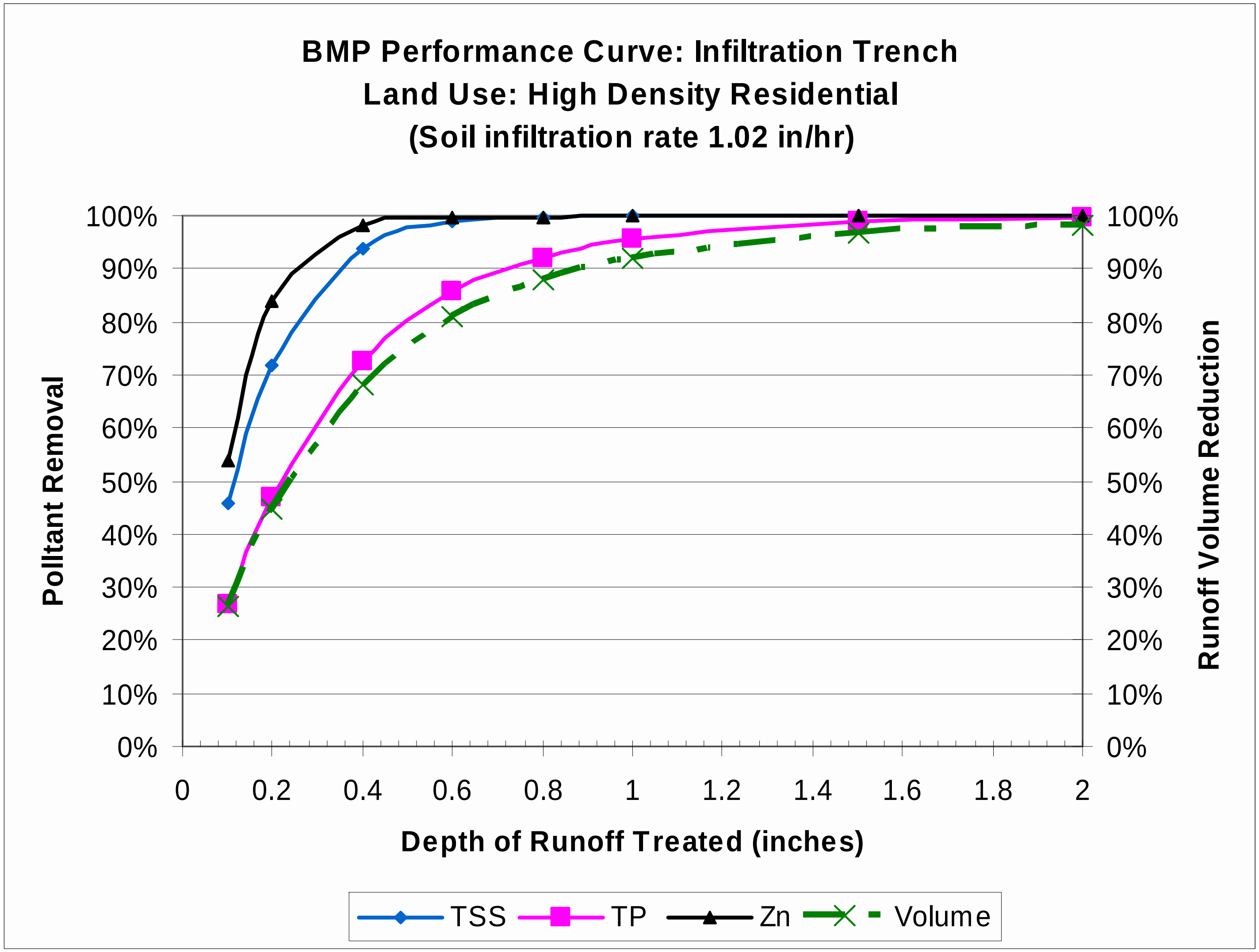
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

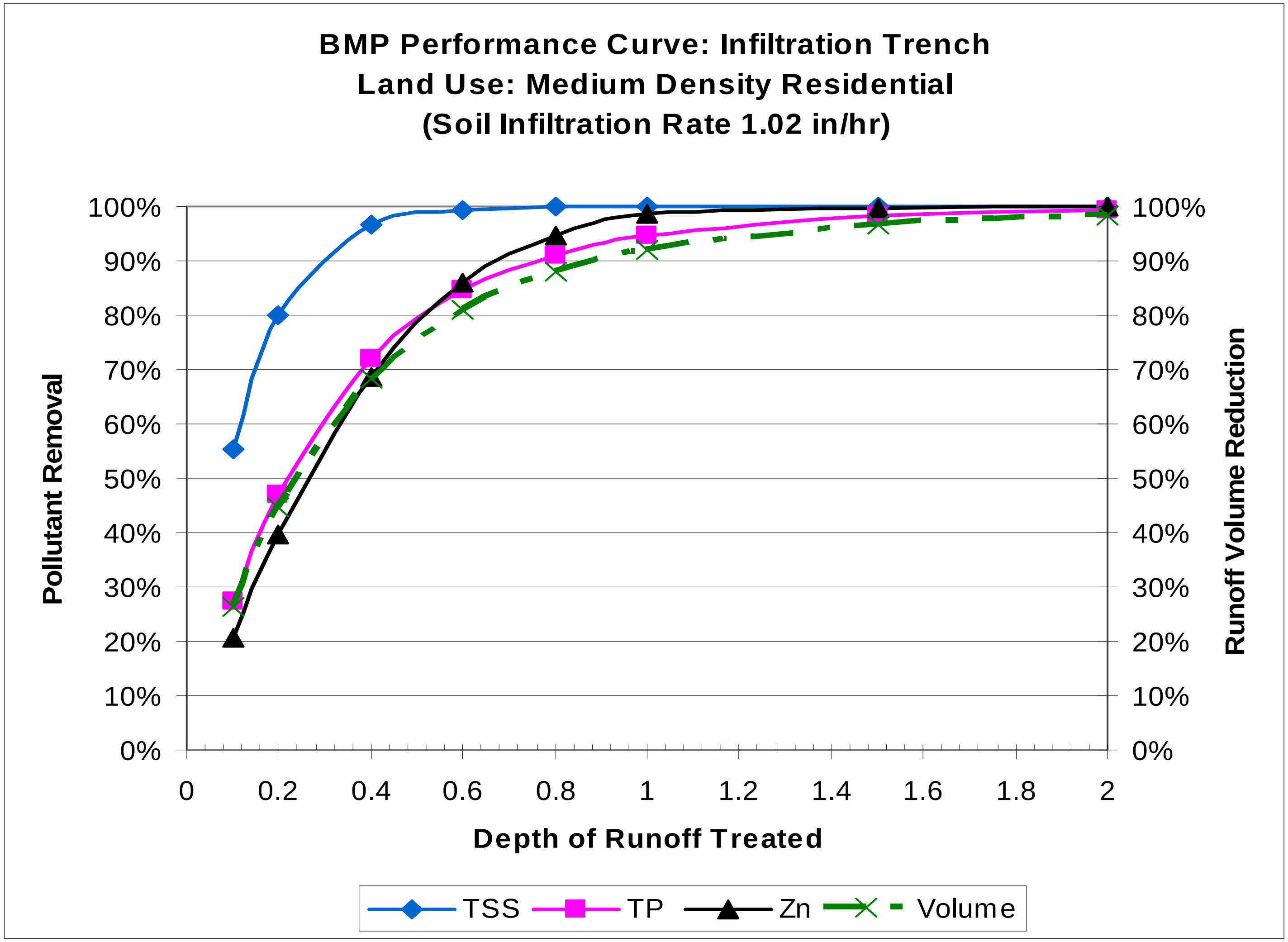

BMP Performance Curve: Infiltration Trench
Land Use: Commercial
(Soil infiltration rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

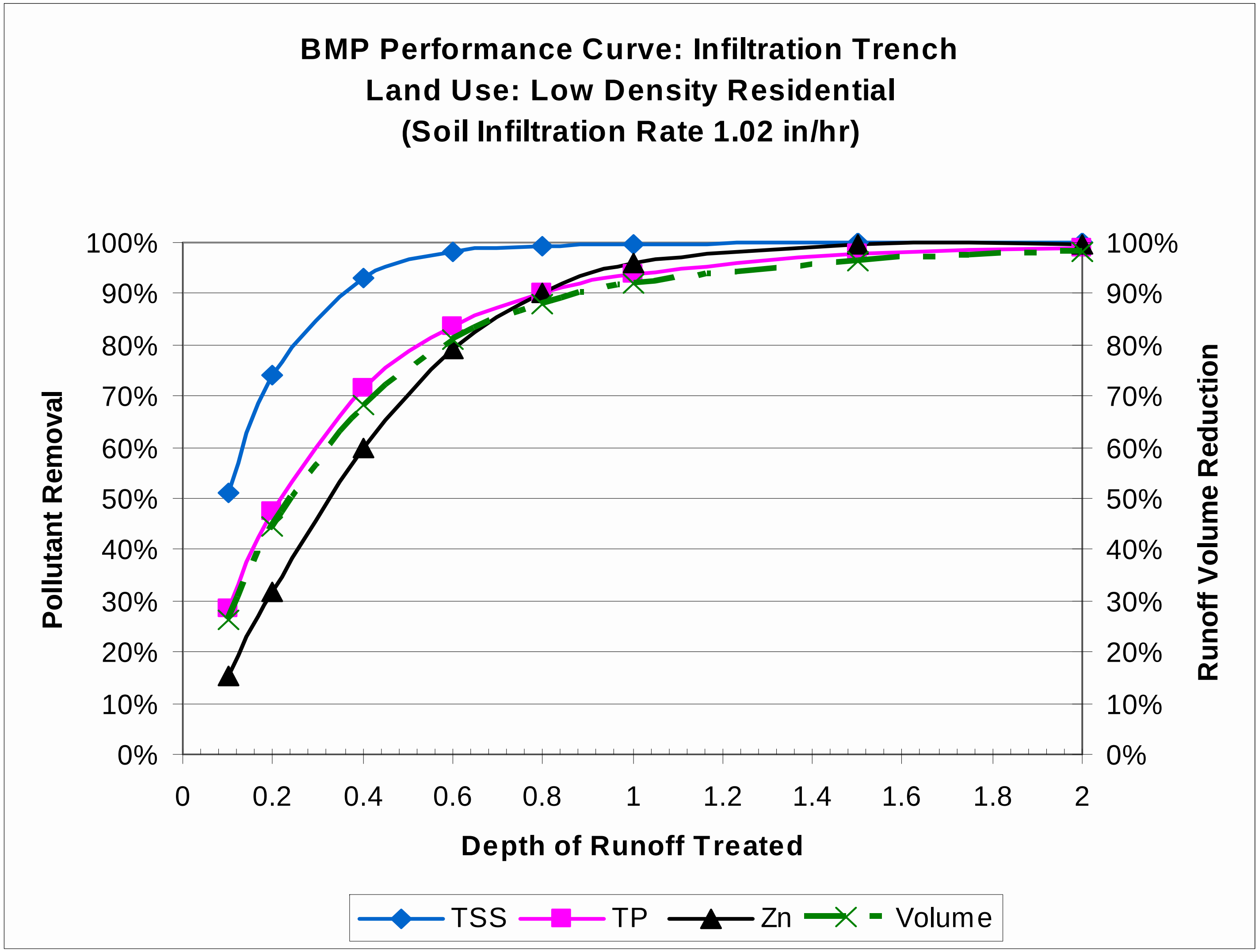
BMP Performance Curve: Infiltration Trench




BMP Performance Curve: Infiltration Trench
Land Use: High Density Residential
(Soil infiltration rate 1.02 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench




BMP Performance Curve: Infiltration Trench
Land Use: Low Density Residential
(Soil Infiltration Rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
Depth of Runoff Treated
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench

BMP Performance Table

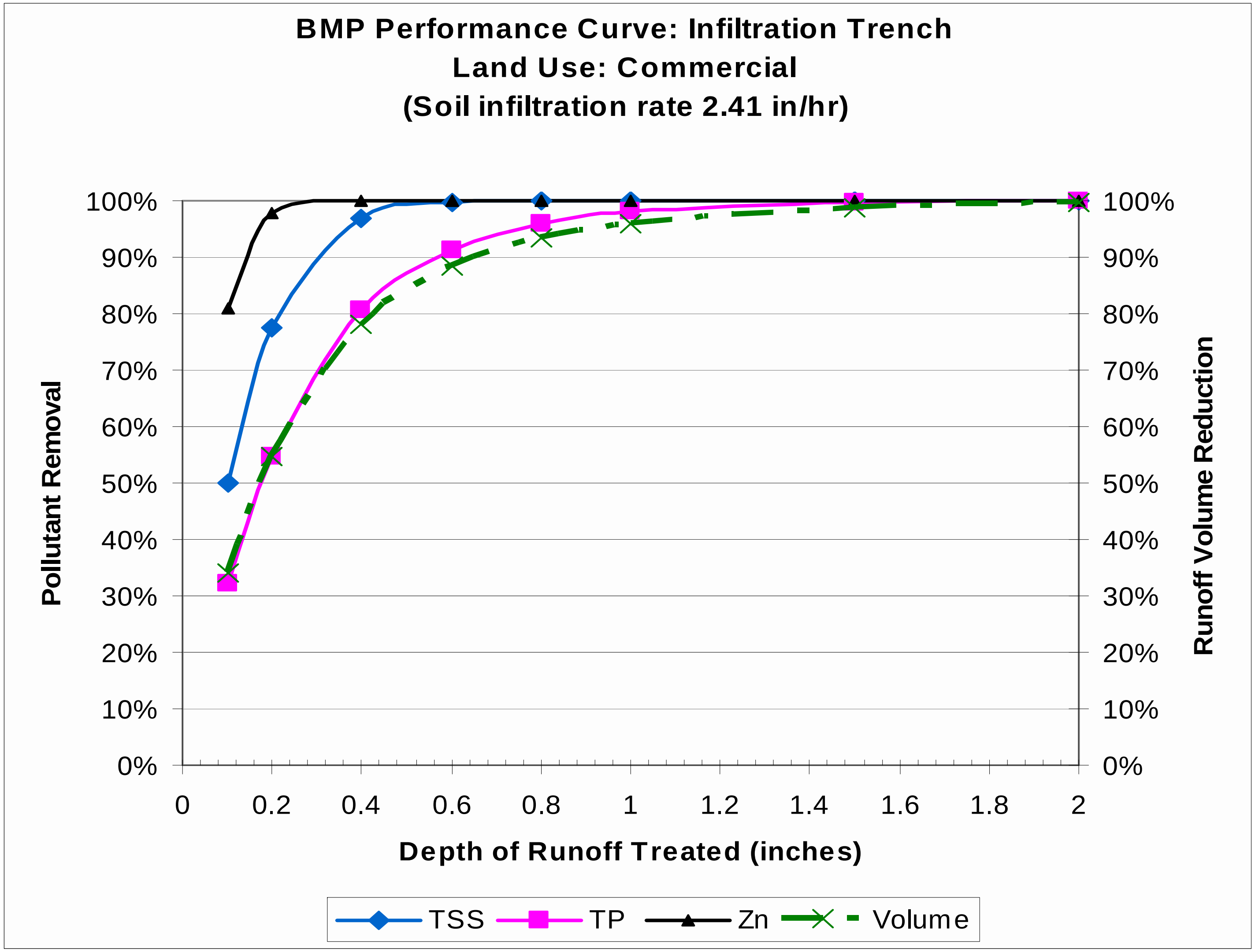
BMP Name: Infiltration Trench

Soil Infiltration Rate: 2.41 in/hr

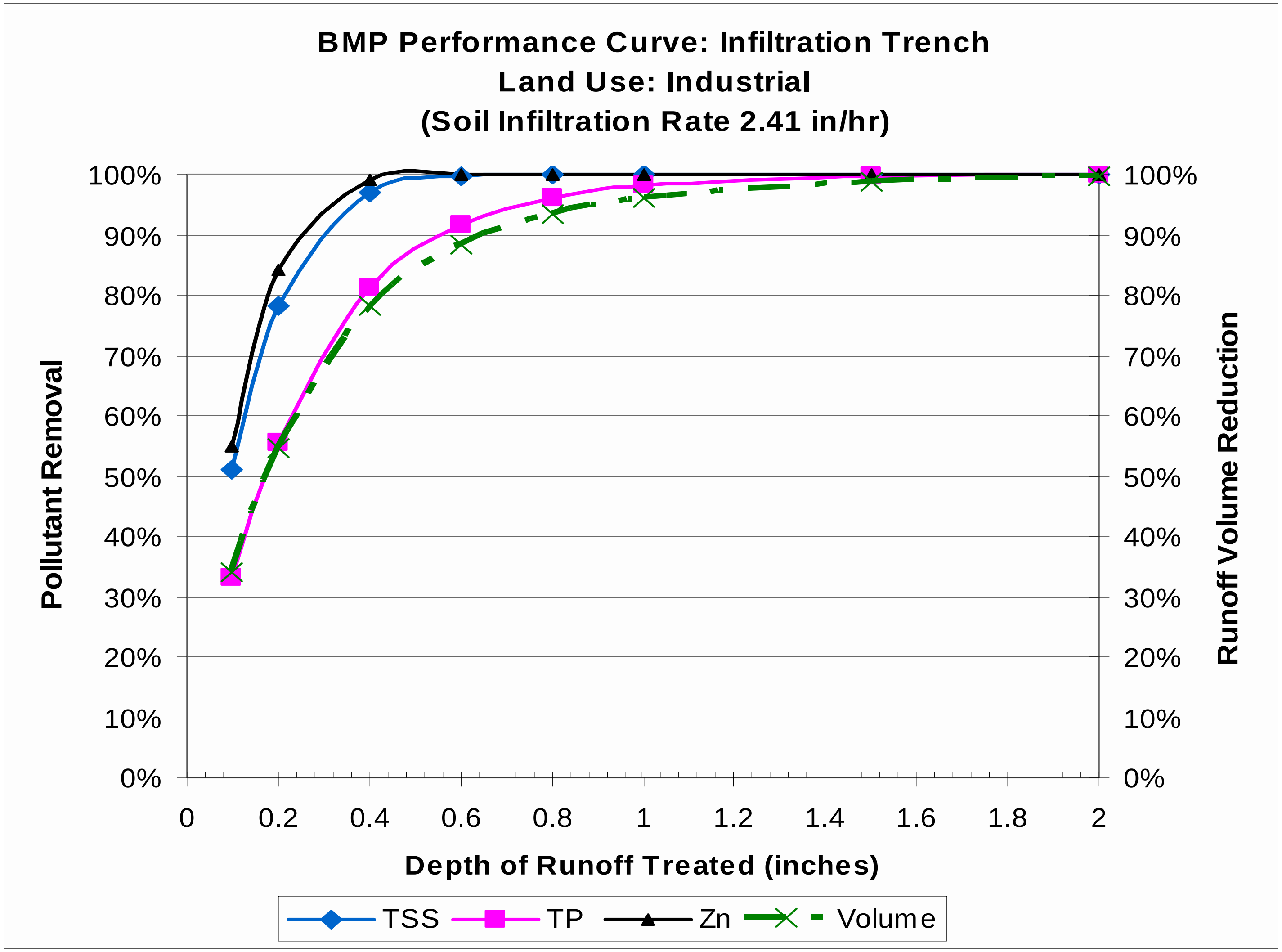
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1	1.5	2
Commercial	TSS	50%	77%	97%	100%	100%	100%	100%	100%
	TP	32%	55%	81%	91%	96%	98%	100%	100%
	Zn	81%	98%	100%	100%	100%	100%	100%	100%
Industrial	TSS	51%	78%	97%	100%	100%	100%	100%	100%
	TP	33%	56%	81%	92%	96%	98%	100%	100%
	Zn	55%	84%	99%	100%	100%	100%	100%	100%
High-Density Residential	TSS	52%	79%	97%	100%	100%	100%	100%	100%
	TP	33%	55%	81%	91%	96%	98%	100%	100%
	Zn	63%	92%	100%	100%	100%	100%	100%	100%
Medium-Density Residential	TSS	62%	86%	98%	100%	100%	100%	100%	100%
	TP	33%	55%	80%	90%	95%	97%	99%	100%
	Zn	25%	48%	79%	94%	99%	100%	100%	100%
Low-Density Residential	TSS	57%	80%	96%	99%	100%	100%	100%	100%
	TP	35%	56%	80%	90%	95%	97%	99%	100%
	Zn	19%	39%	71%	89%	97%	100%	100%	100%
Runoff Volume Reduction		34%	55%	78%	88%	93%	96%	99%	100%

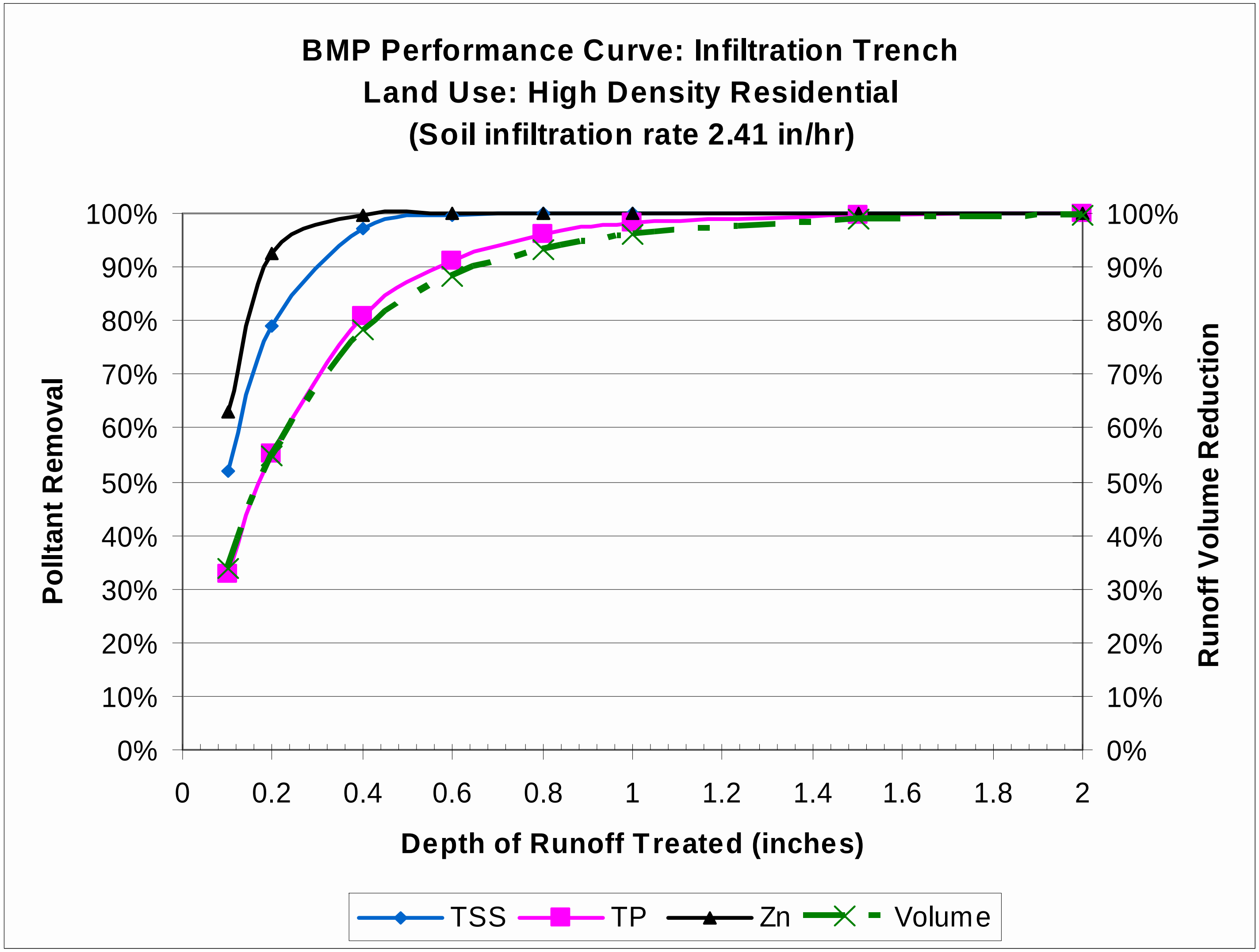
Annual Pollutant Loading Rates

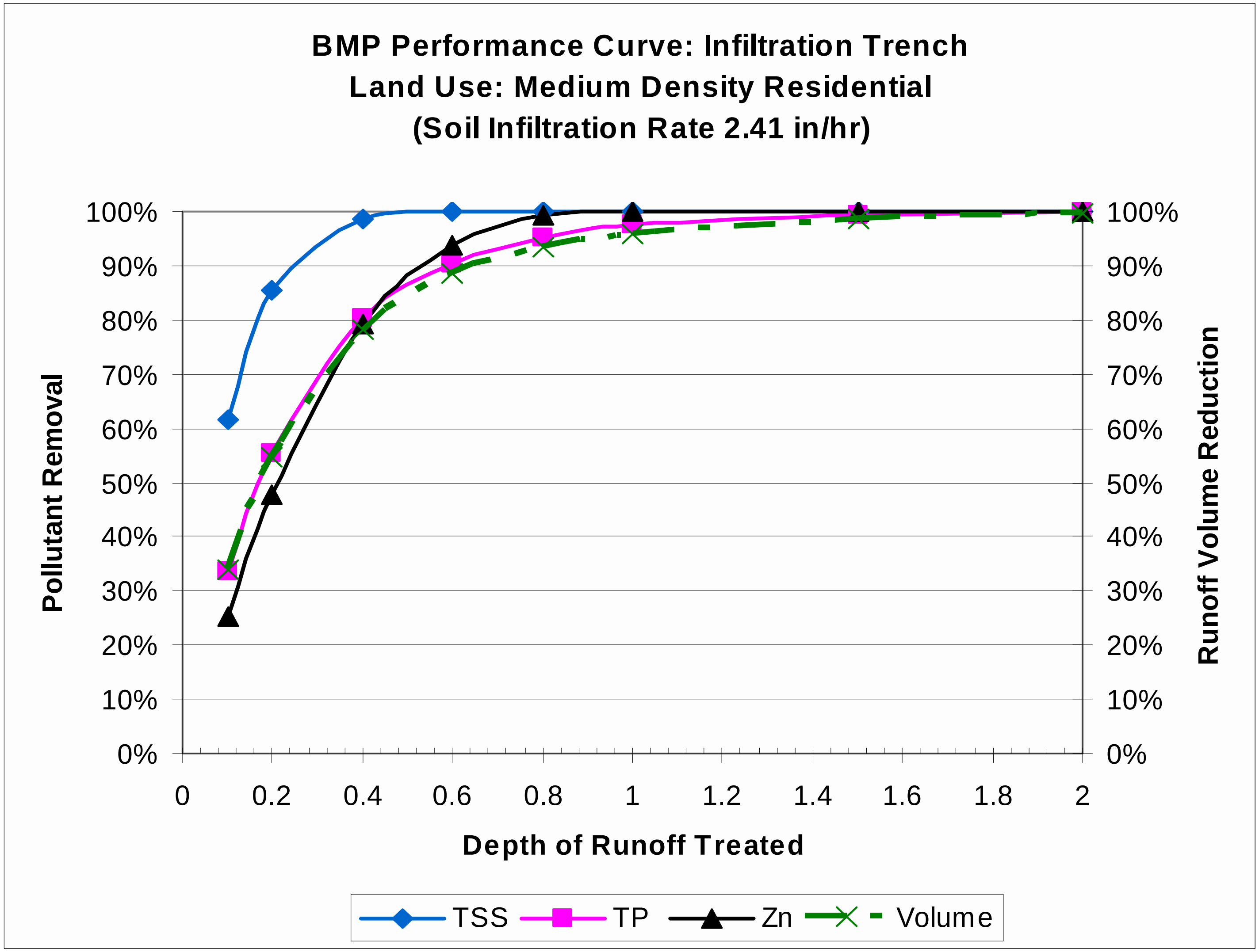
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

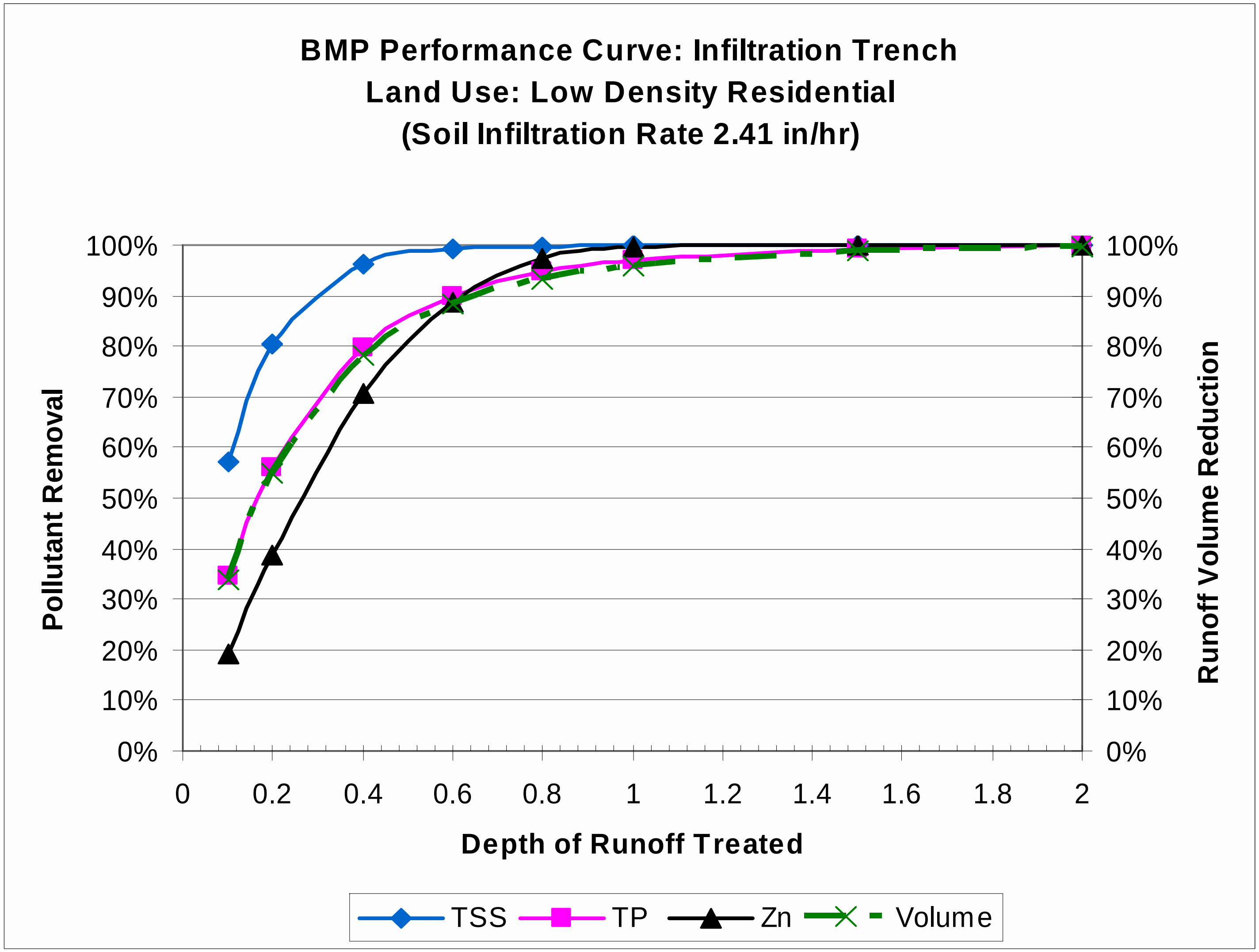

BMP Performance Curve: Infiltration Trench
Land Use: Commercial
(Soil infiltration rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench




BMP Performance Curve: Infiltration Trench
Land Use: High Density Residential
(Soil infiltration rate 2.41 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Medium Density Residential
(Soil Infiltration Rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Trench
Land Use: Low Density Residential
(Soil Infiltration Rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

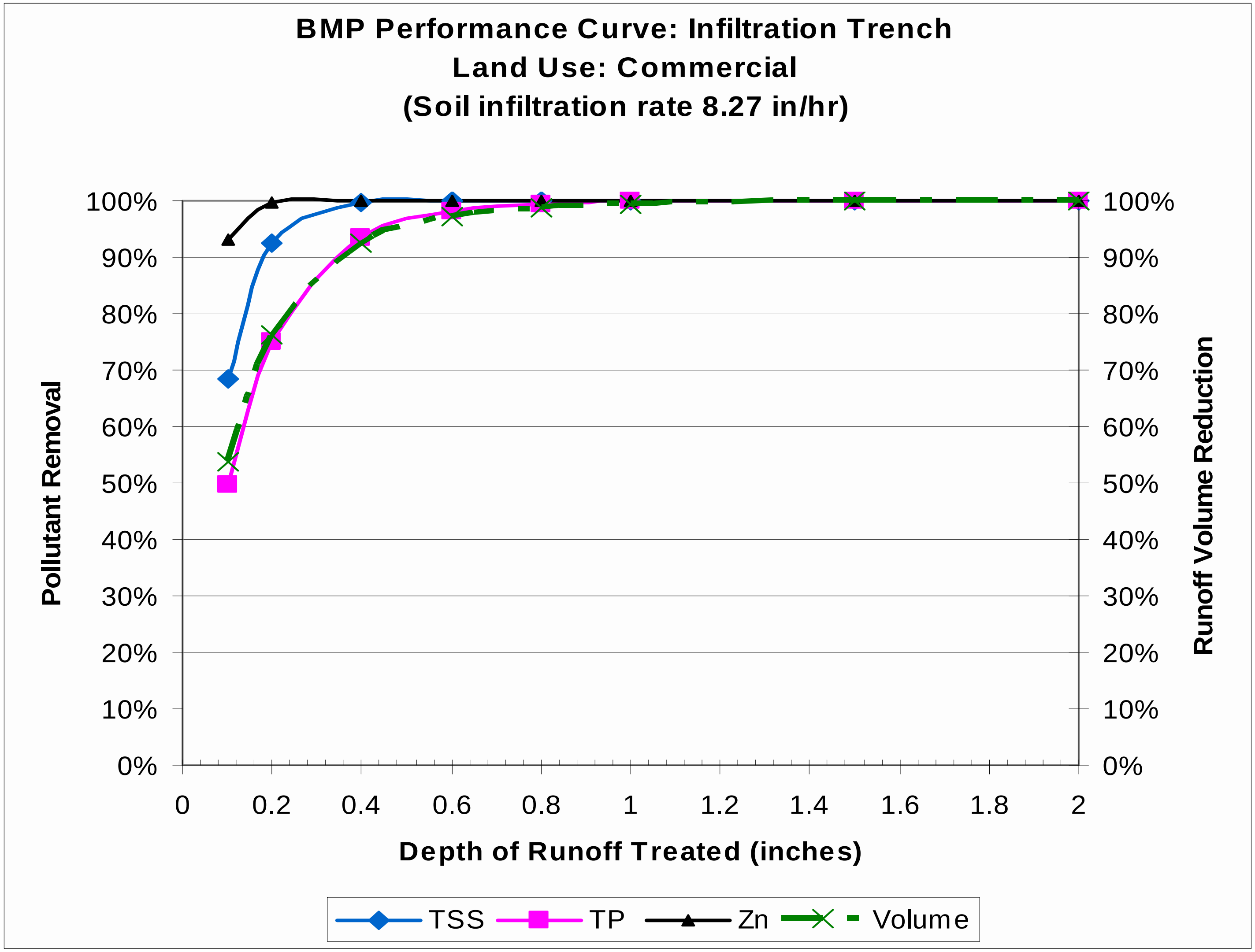
BMP Name: Infiltration Trench

Soil Infiltration Rate: 8.27 in/hr

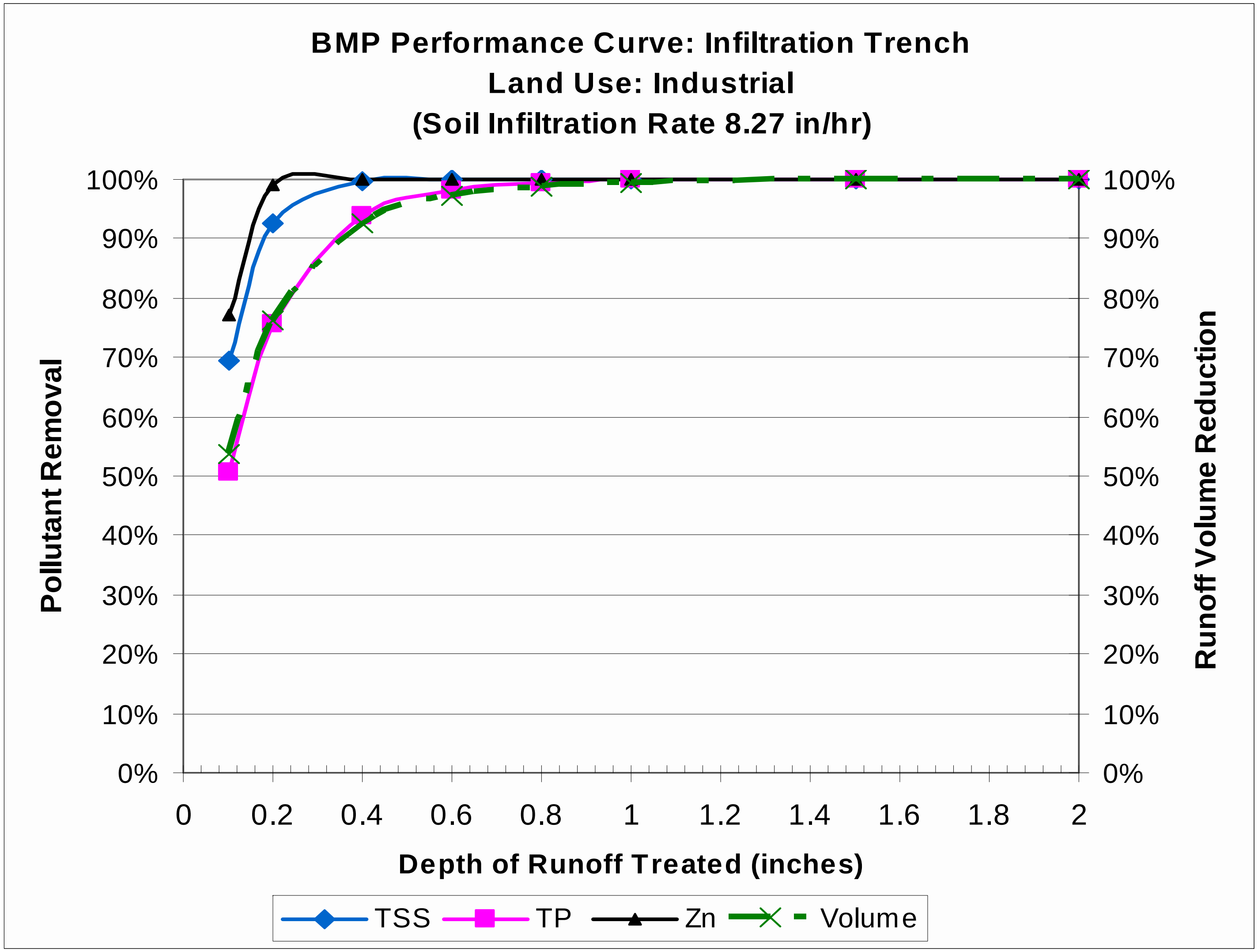
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1	1.5	2
Commercial	TSS	68%	92%	100%	100%	100%	100%	100%	100%
	TP	50%	75%	94%	98%	99%	100%	100%	100%
	Zn	93%	100%	100%	100%	100%	100%	100%	100%
Industrial	TSS	69%	93%	100%	100%	100%	100%	100%	100%
	TP	51%	76%	94%	98%	100%	100%	100%	100%
	Zn	77%	99%	100%	100%	100%	100%	100%	100%
High-Density Residential	TSS	70%	93%	100%	100%	100%	100%	100%	100%
	TP	50%	75%	94%	98%	99%	100%	100%	100%
	Zn	84%	99%	100%	100%	100%	100%	100%	100%
Medium-Density Residential	TSS	78%	95%	100%	100%	100%	100%	100%	100%
	TP	51%	75%	93%	98%	99%	100%	100%	100%
	Zn	41%	70%	97%	100%	100%	100%	100%	100%
Low-Density Residential	TSS	73%	92%	99%	100%	100%	100%	100%	100%
	TP	53%	76%	93%	98%	99%	100%	100%	100%
	Zn	32%	60%	93%	100%	100%	100%	100%	100%
Runoff Volume Reduction		54%	76%	93%	97%	99%	100%	100%	100%

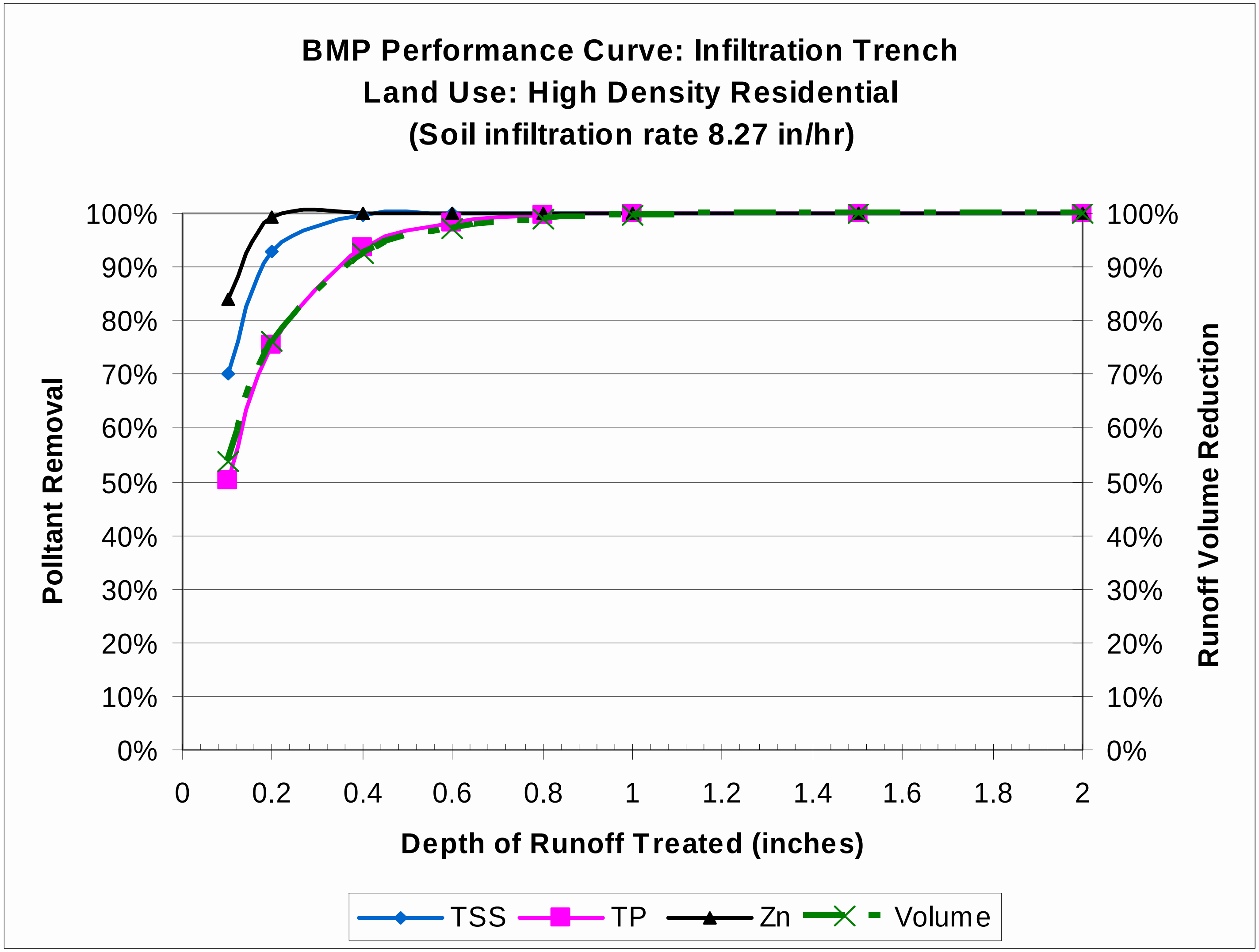
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

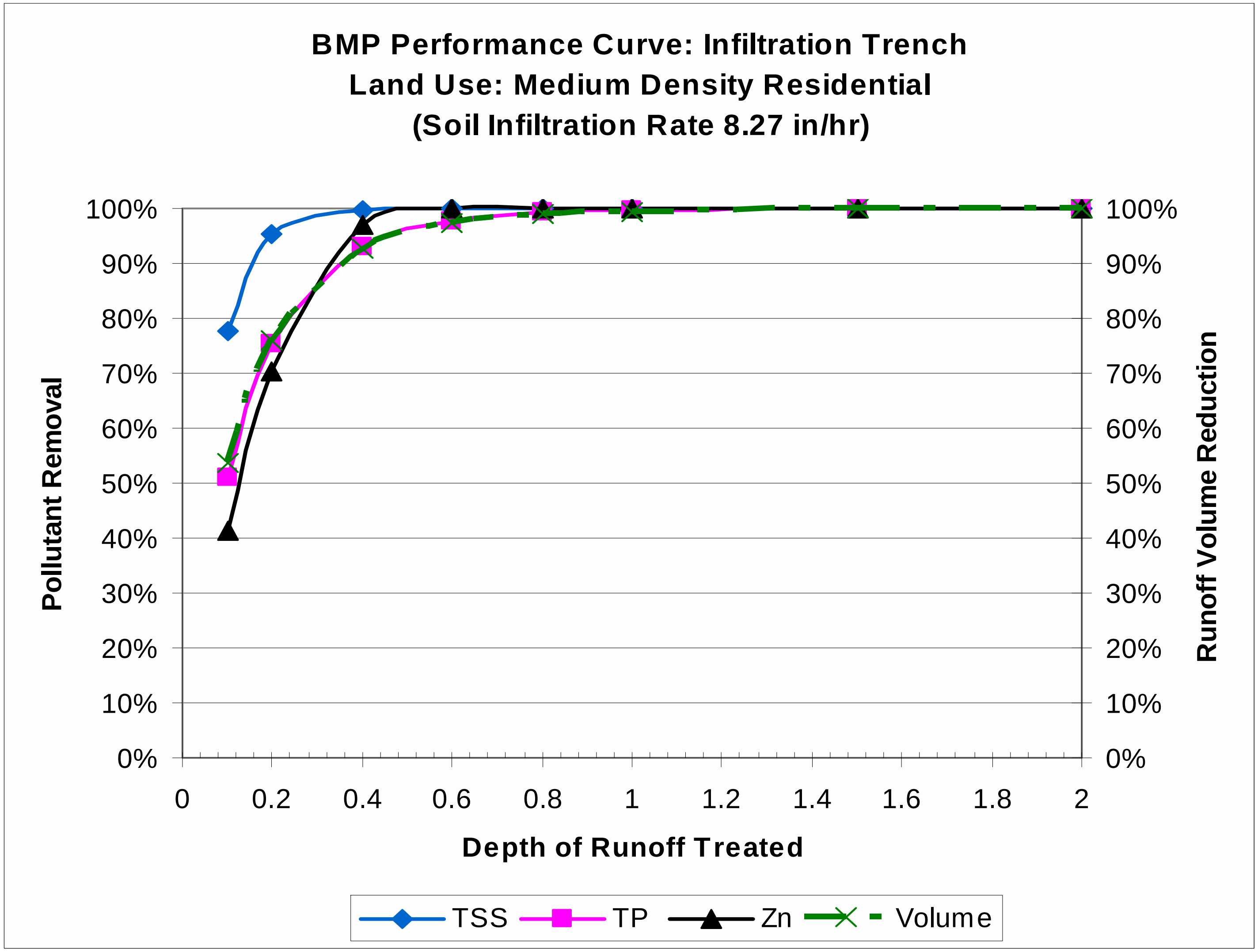

BMP Performance Curve: Infiltration Trench
Land Use: Commercial
(Soil infiltration rate 8.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench




BMP Performance Curve: Infiltration Trench
Land Use: High Density Residential
(Soil infiltration rate 8.27 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Trench



BMP Performance Curve: Infiltration Basin

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

March 2010

BMP Performance Table

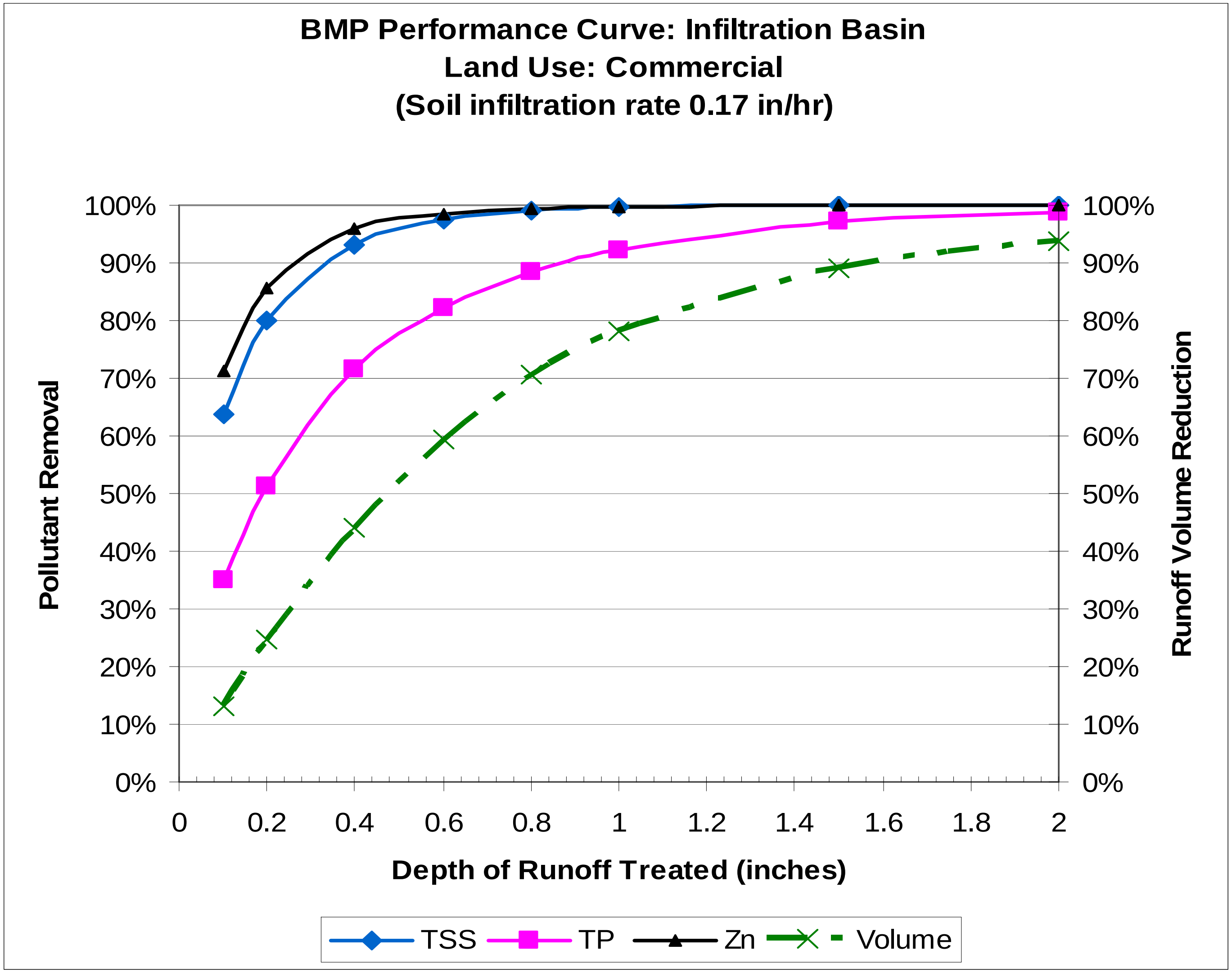
BMP Name: Infiltration Basin

Soil Infiltration Rate: 0.17 in/hr

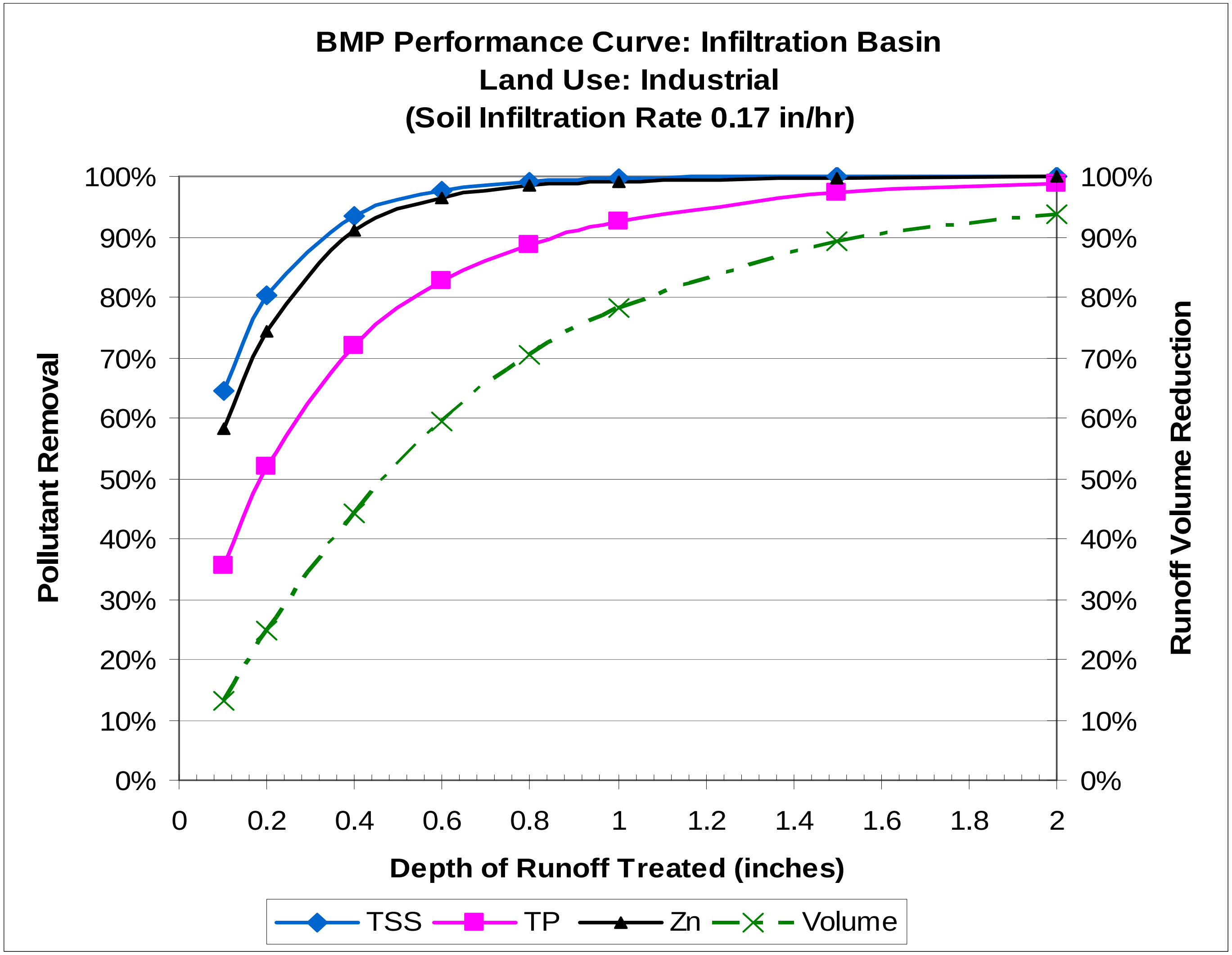
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	64%	80%	93%	98%	99%	100%	100%	100%
	TP	35%	51%	71%	82%	88%	92%	97%	99%
	Zn	71%	86%	96%	98%	99%	100%	100%	100%
Industrial	TSS	64%	80%	93%	98%	99%	100%	100%	100%
	TP	36%	52%	72%	83%	89%	92%	97%	99%
	Zn	58%	74%	91%	96%	98%	99%	100%	100%
High Density Residential	TSS	65%	81%	94%	98%	99%	100%	100%	100%
	TP	35%	52%	72%	82%	88%	92%	97%	99%
	Zn	63%	78%	93%	97%	99%	99%	100%	100%
Medium Density Residential	TSS	70%	85%	96%	99%	99%	100%	100%	100%
	TP	36%	52%	71%	82%	88%	92%	97%	98%
	Zn	39%	56%	75%	85%	91%	95%	99%	100%
Low Density Residential	TSS	68%	82%	94%	98%	99%	99%	100%	100%
	TP	37%	52%	71%	82%	88%	91%	96%	98%
	Zn	34%	51%	71%	81%	88%	92%	98%	99%
Runoff Volume Reduction		13%	25%	44%	59%	71%	78%	89%	94%

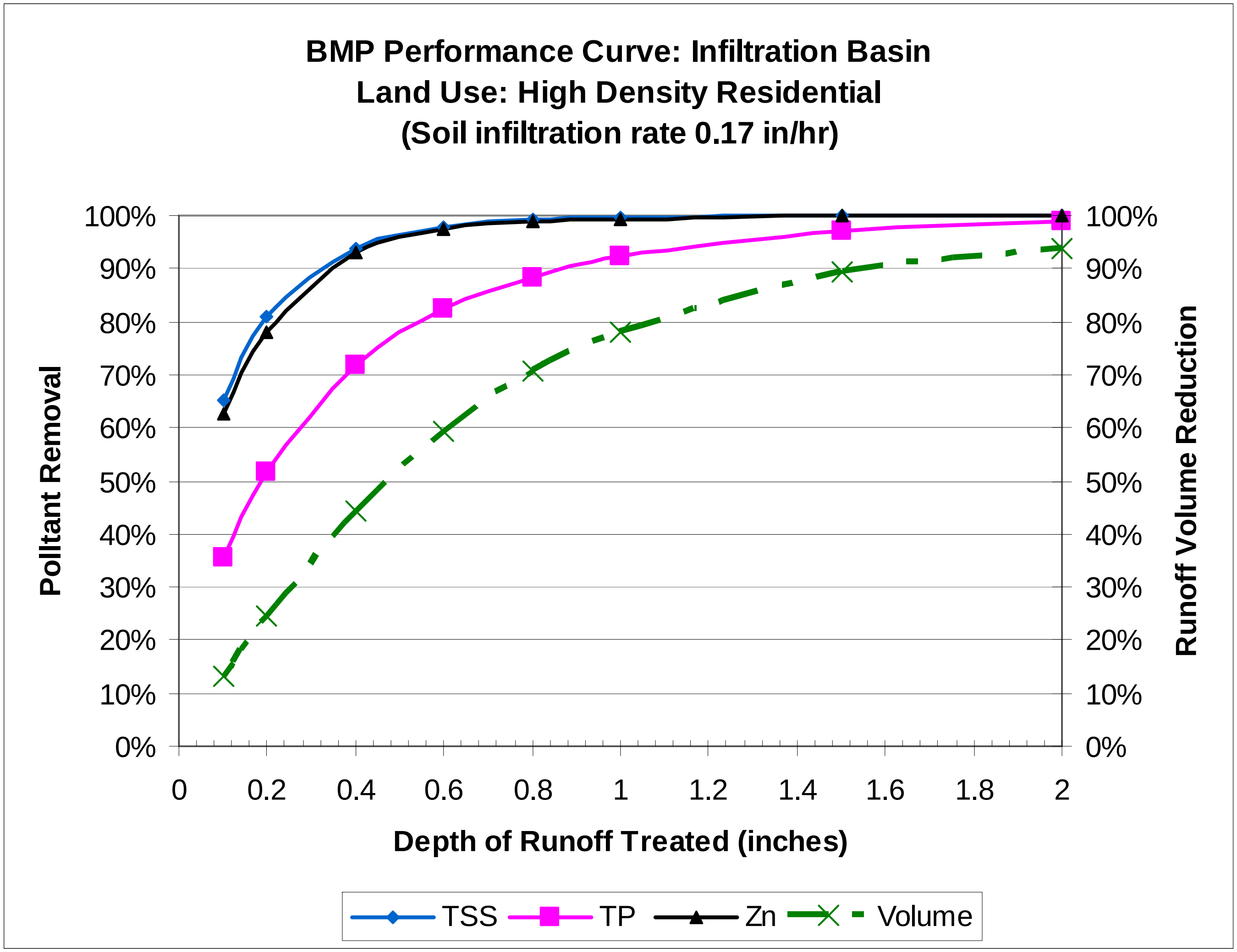
Annual Pollutant Loading Rates

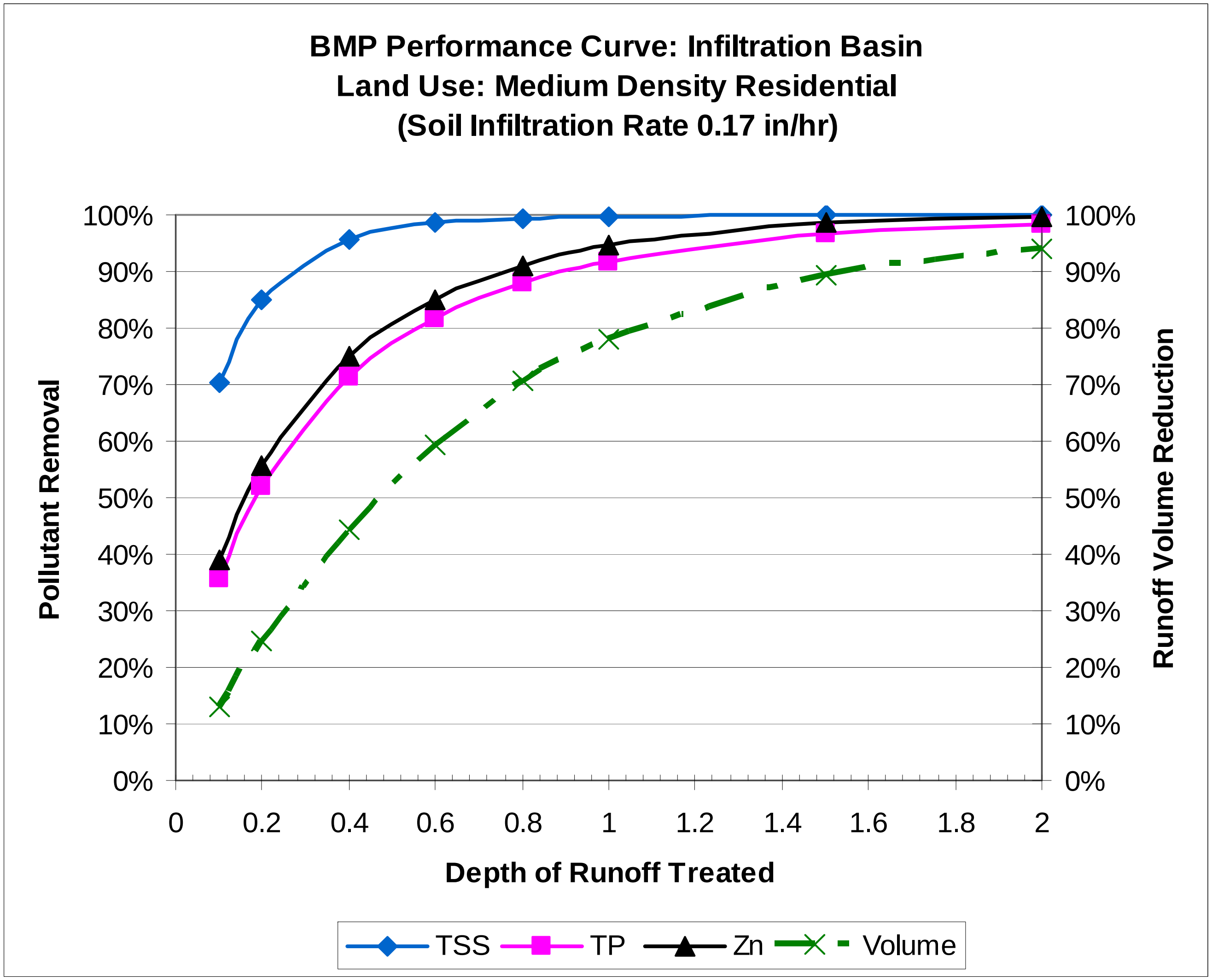
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High Density Residential	465.08	1.10	0.79
Medium Density Residential	274.63	0.55	0.11
Low Density Residential	72.11	0.042	0.043

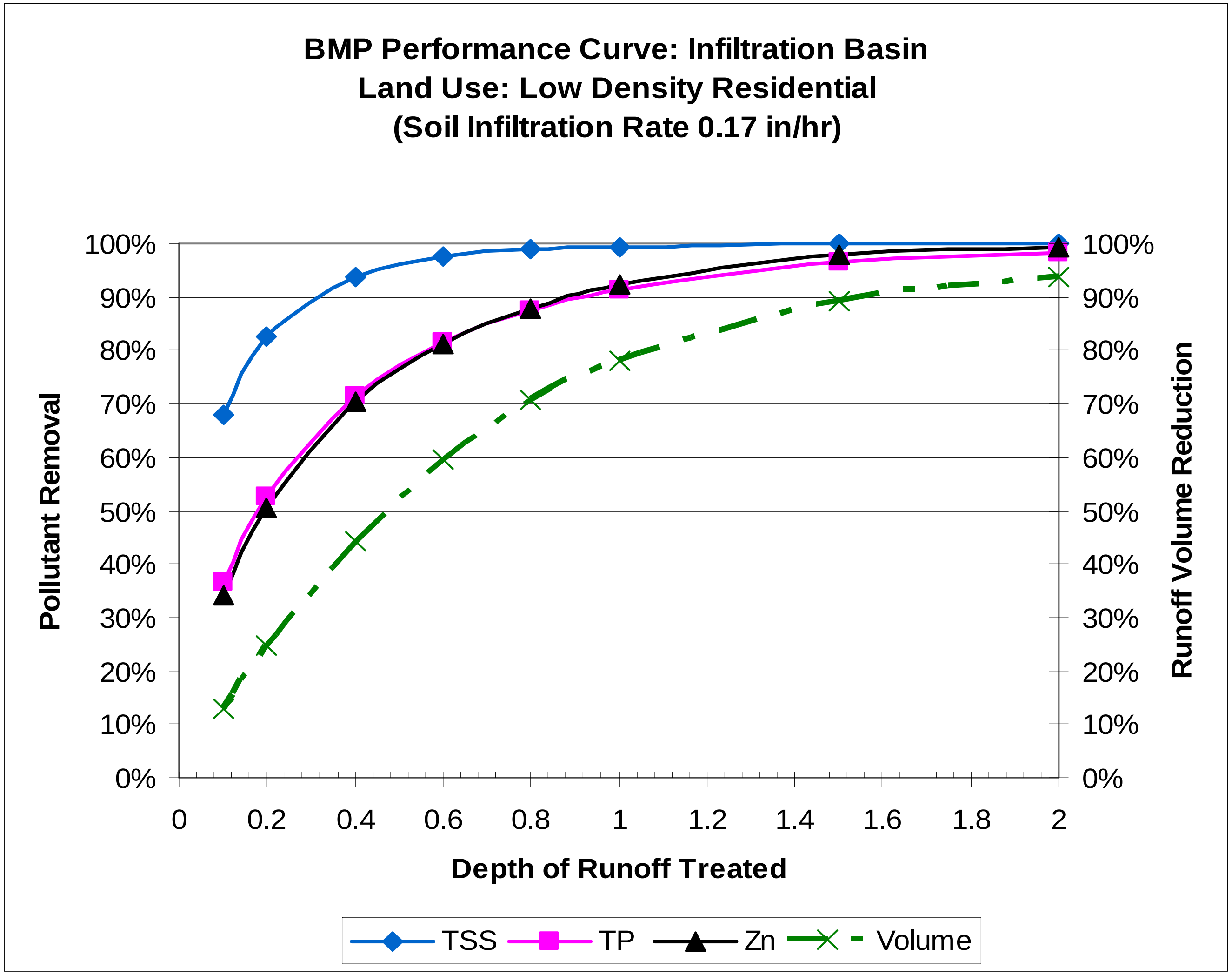

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 0.17 in/hr)
Polltant Removal
Runoff Volume Reduction
Depth of Runoff Treated (inches)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Medium Density Residential
(Soil Infiltration Rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume



BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

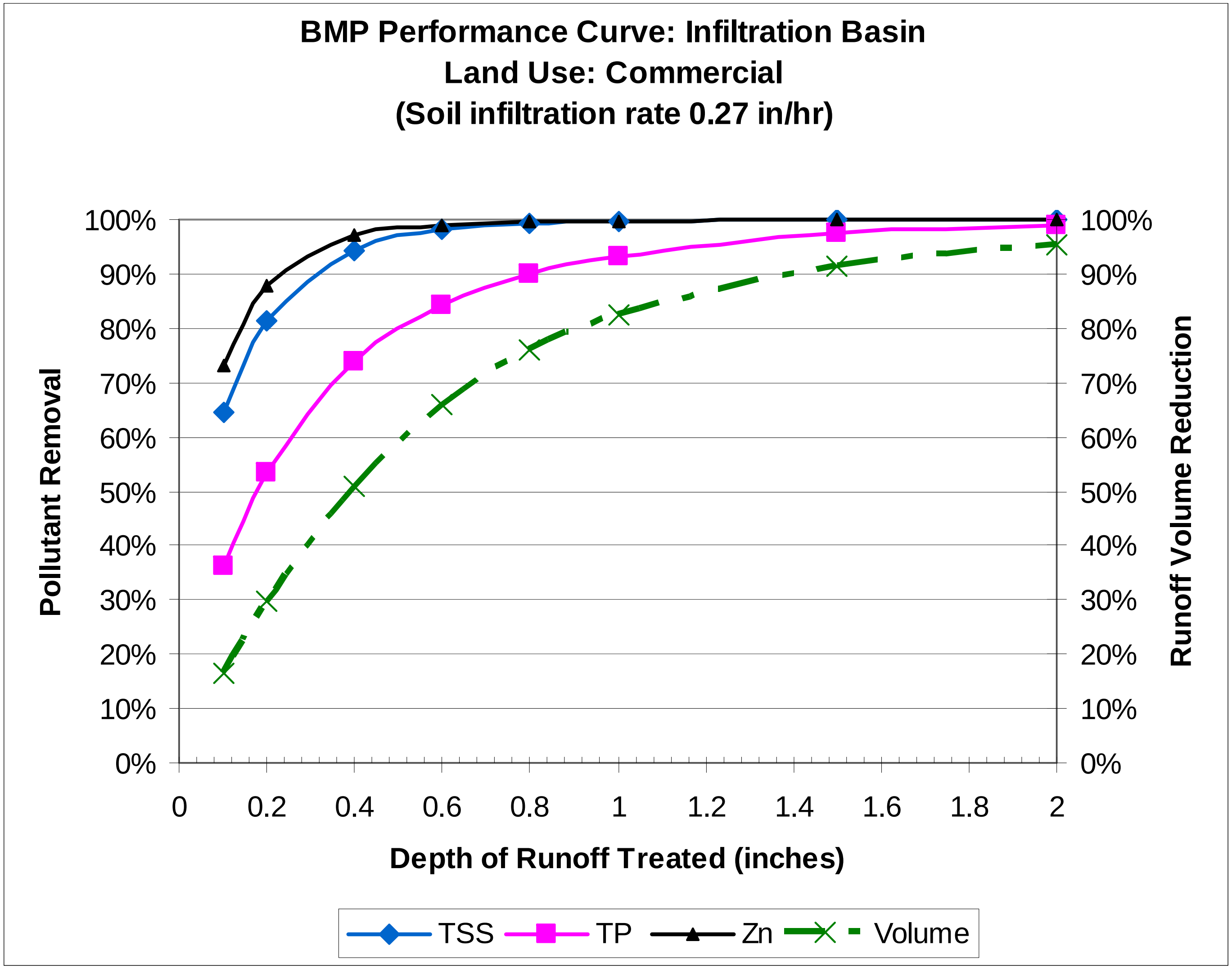
BMP Name: Infiltration Basin

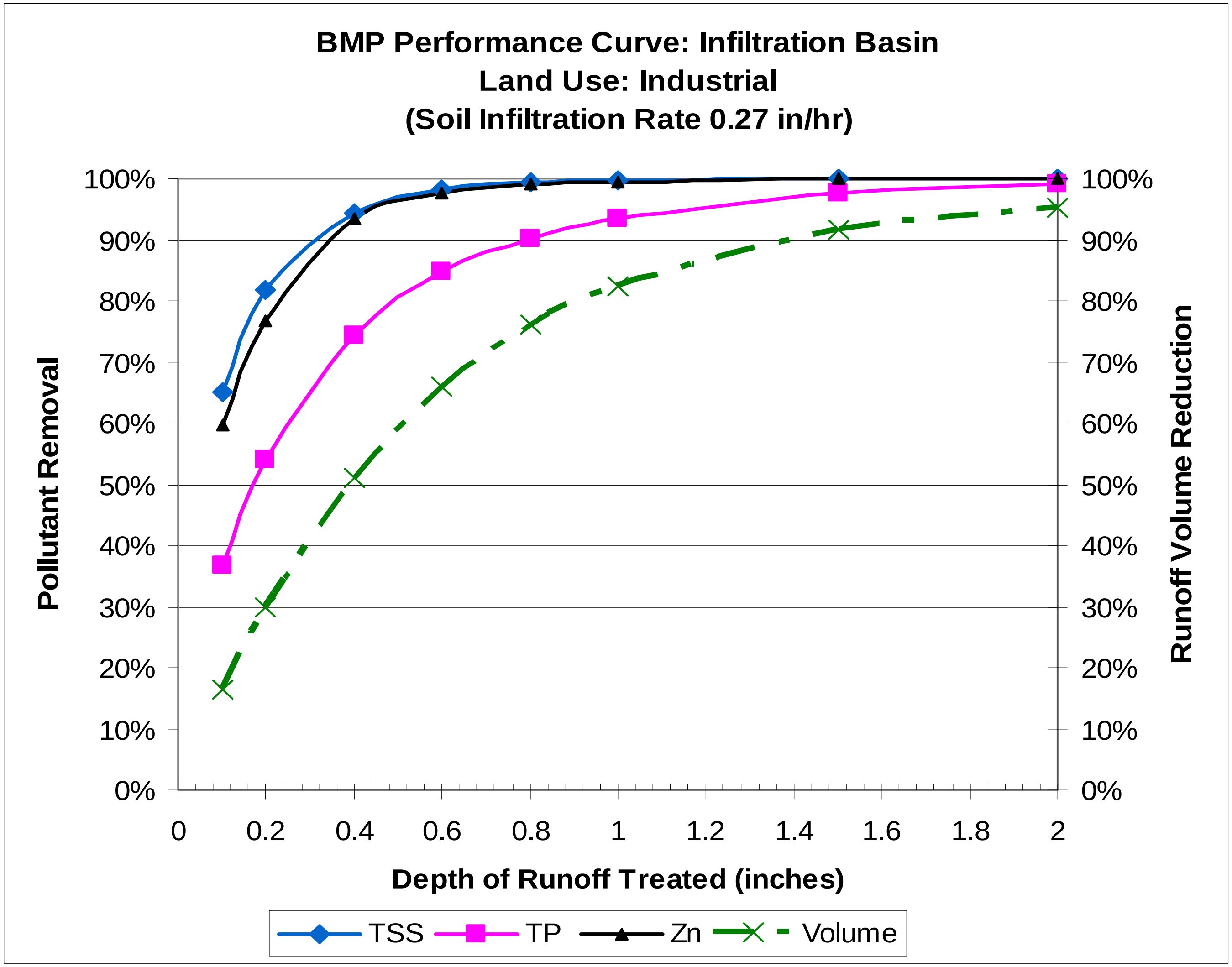
Soil Infiltration Rate: 0.27 in/hr

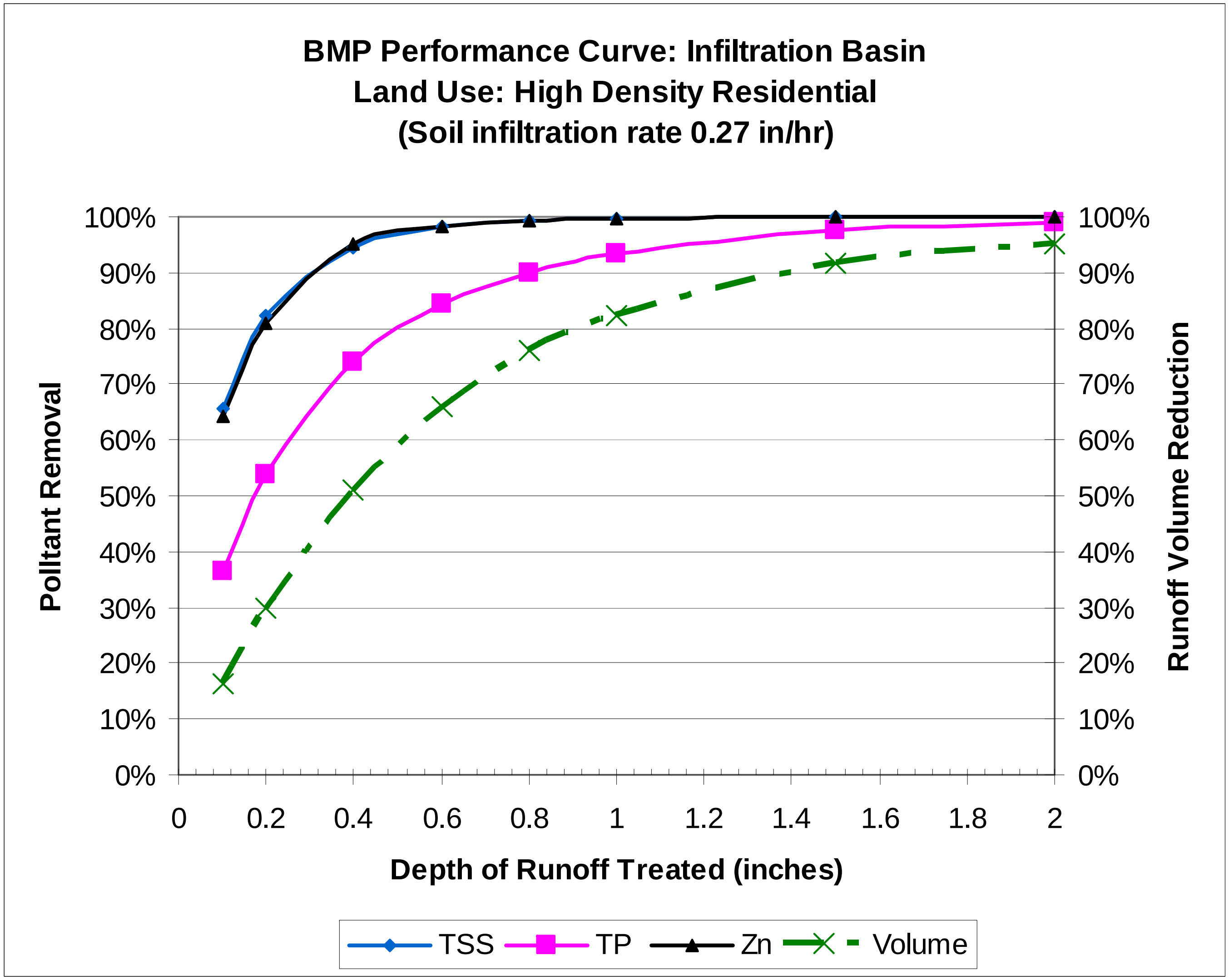
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	65%	81%	94%	98%	99%	100%	100%	100%
	TP	36%	54%	74%	84%	90%	93%	98%	99%
	Zn	73%	88%	97%	99%	100%	100%	100%	100%
Industrial	TSS	65%	82%	94%	98%	99%	100%	100%	100%
	TP	37%	54%	74%	85%	90%	94%	98%	99%
	Zn	60%	77%	93%	98%	99%	99%	100%	100%
High Density Residential	TSS	66%	82%	95%	98%	99%	100%	100%	100%
	TP	37%	54%	74%	84%	90%	93%	98%	99%
	Zn	64%	81%	95%	98%	99%	100%	100%	100%
Medium Density Residential	TSS	71%	86%	96%	99%	100%	100%	100%	100%
	TP	37%	54%	74%	84%	89%	93%	97%	99%
	Zn	40%	58%	77%	87%	93%	96%	99%	100%
Low Density Residential	TSS	69%	84%	95%	98%	99%	100%	100%	100%
	TP	38%	55%	74%	84%	89%	93%	97%	98%
	Zn	34%	53%	73%	83%	90%	94%	98%	100%
Runoff Volume Reduction		16%	30%	51%	66%	76%	82%	91%	95%

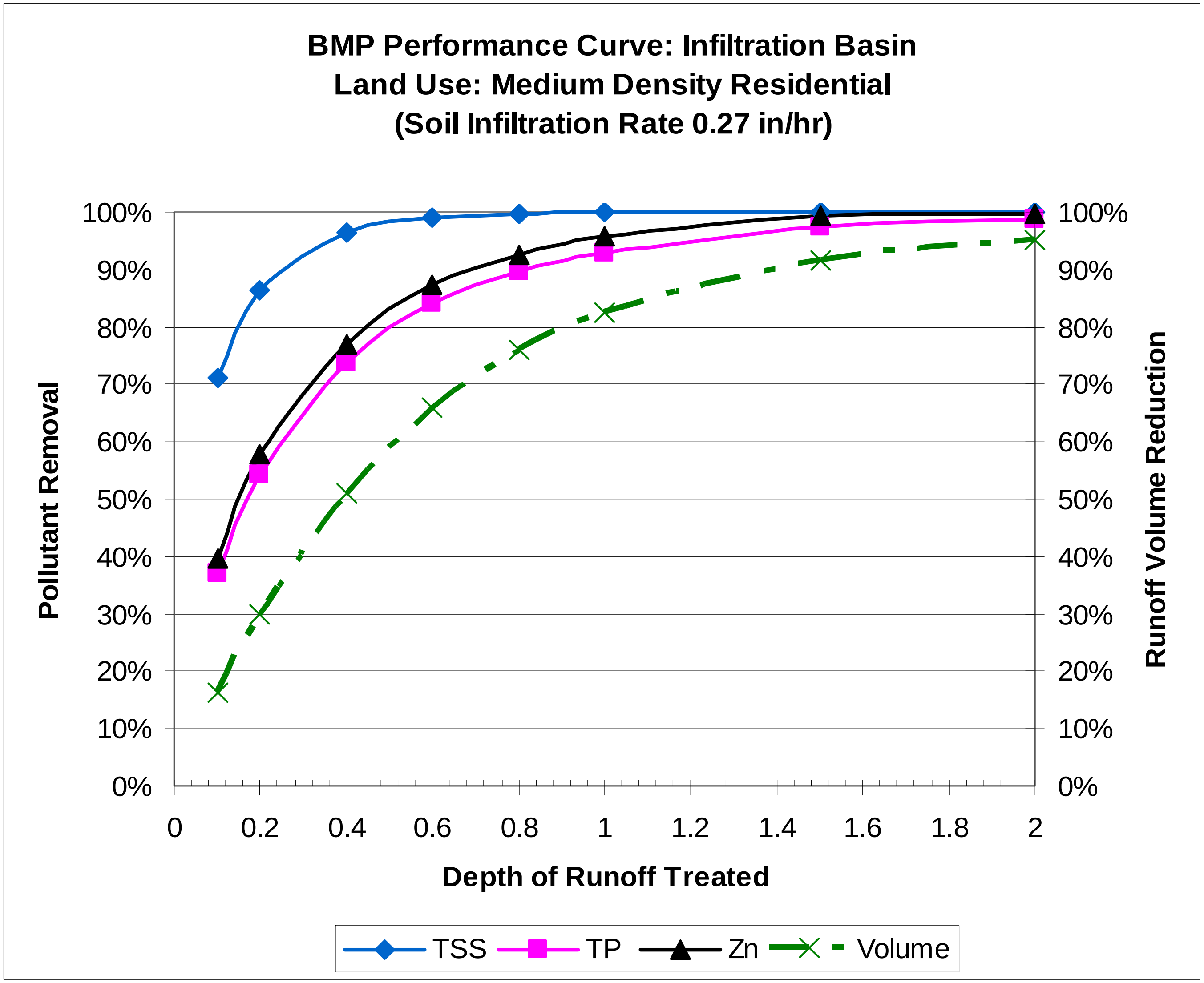
Annual Pollutant Loading Rates

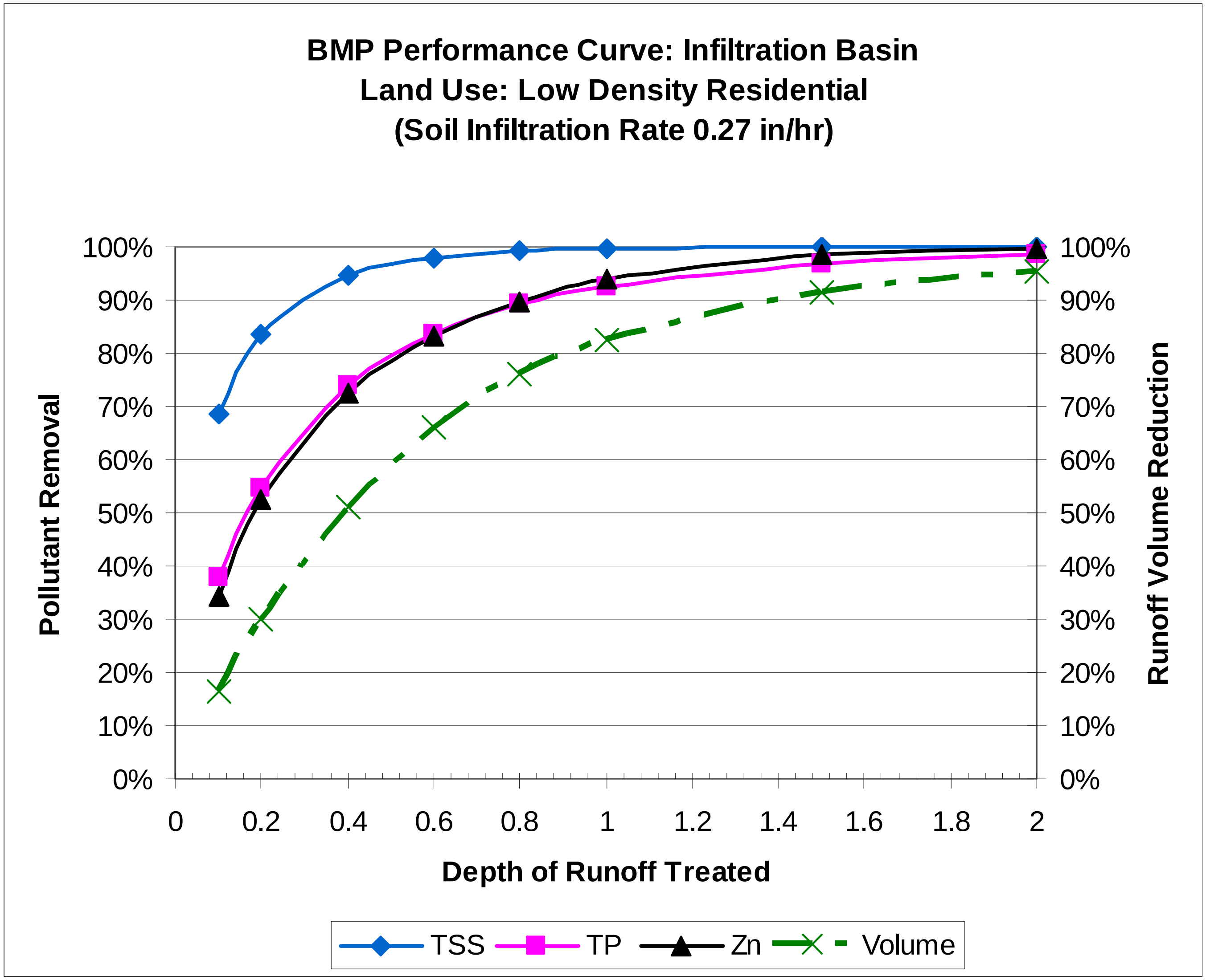
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High Density Residential	465.08	1.10	0.79
Medium Density Residential	274.63	0.55	0.11
Low Density Residential	72.11	0.042	0.043


BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Industrial
(Soil Infiltration Rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 0.27 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Medium Density Residential
(Soil Infiltration Rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
Depth of Runoff Treated
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
Depth of Runoff Treated
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin

BMP Performance Table

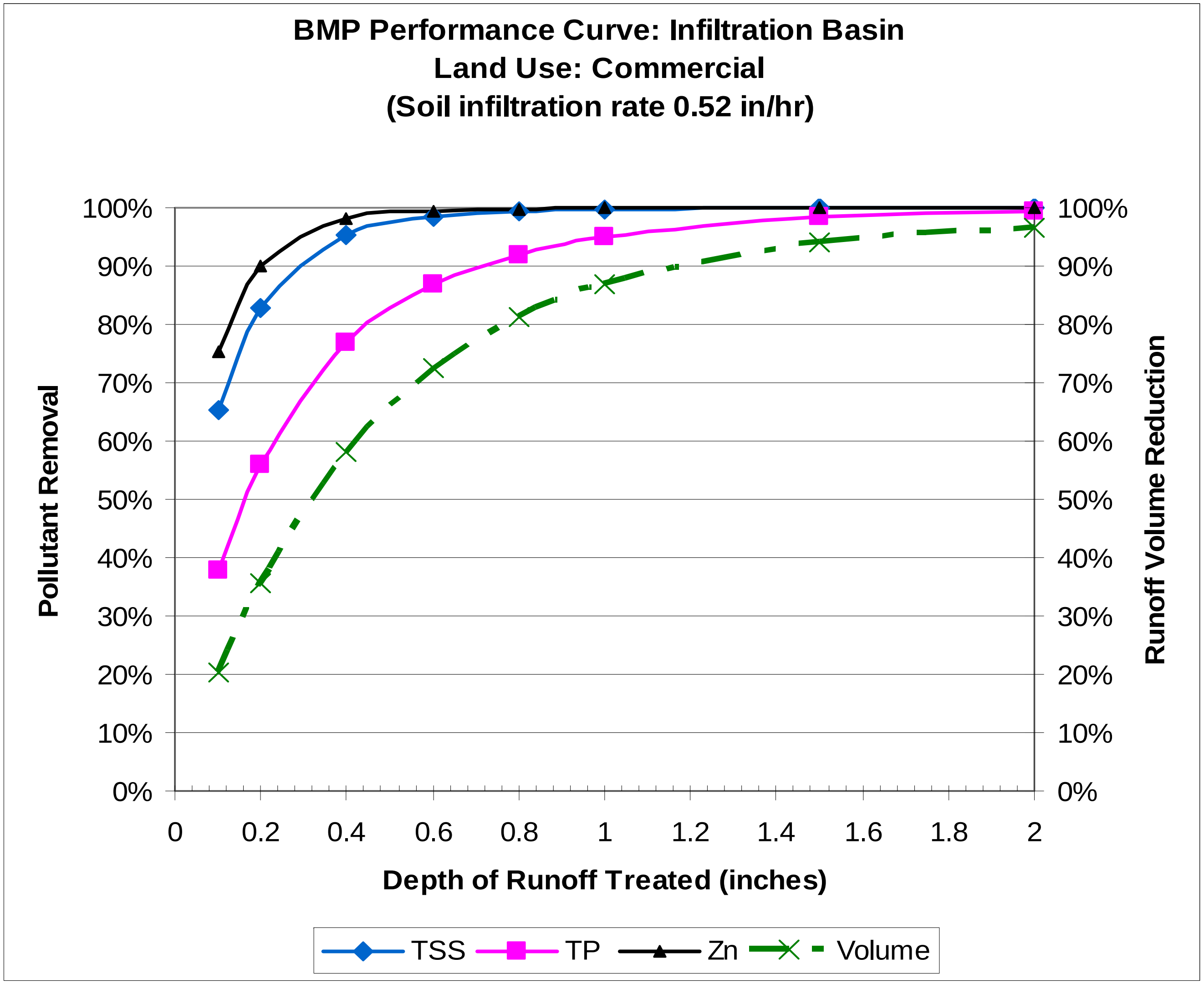
BMP Name: Infiltration Basin

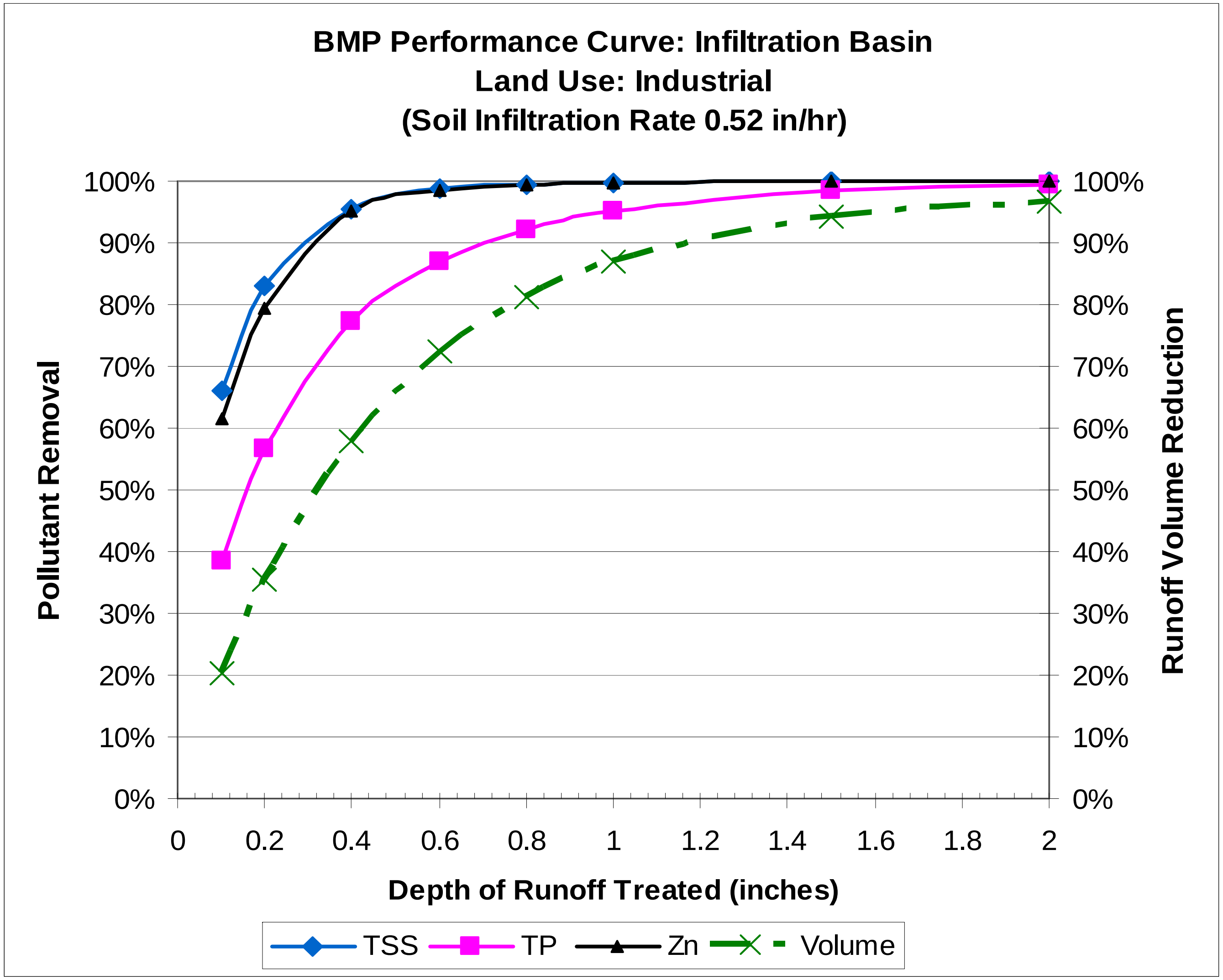
Soil Infiltration Rate: 0.52 in/hr

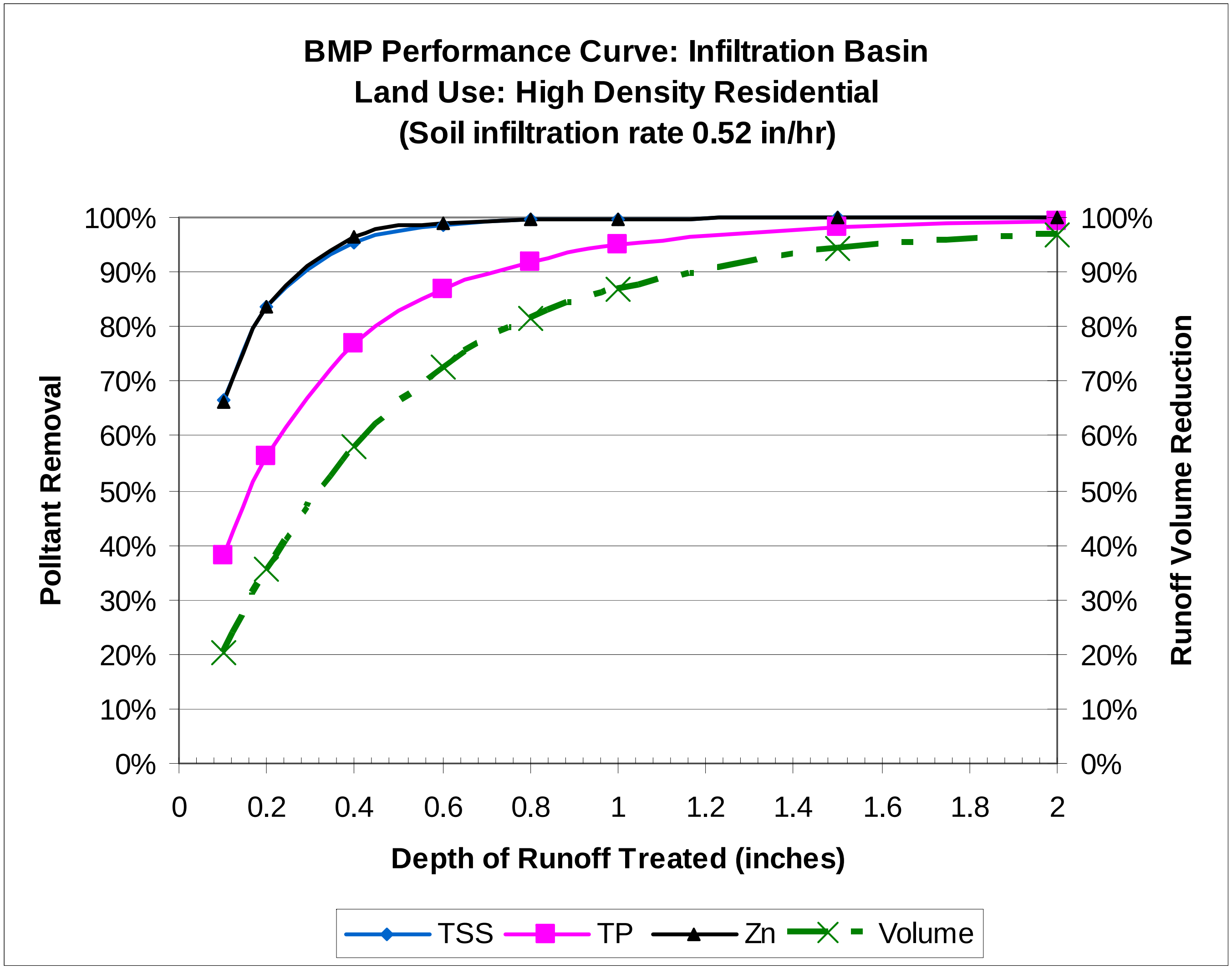
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	65%	83%	95%	99%	99%	100%	100%	100%
	TP	38%	56%	77%	87%	92%	95%	98%	99%
	Zn	75%	90%	98%	99%	100%	100%	100%	100%
Industrial	TSS	66%	83%	95%	99%	100%	100%	100%	100%
	TP	38%	57%	77%	87%	92%	95%	98%	99%
	Zn	62%	80%	95%	98%	99%	100%	100%	100%
High Density Residential	TSS	67%	84%	95%	99%	100%	100%	100%	100%
	TP	38%	56%	77%	87%	92%	95%	98%	99%
	Zn	66%	84%	96%	99%	100%	100%	100%	100%
Medium Density Residential	TSS	72%	87%	97%	99%	100%	100%	100%	100%
	TP	39%	57%	77%	86%	91%	94%	98%	99%
	Zn	40%	59%	80%	90%	94%	97%	100%	100%
Low Density Residential	TSS	70%	85%	95%	98%	99%	100%	100%	100%
	TP	40%	57%	77%	86%	91%	94%	98%	99%
	Zn	34%	54%	75%	86%	92%	96%	99%	100%
Runoff Volume Reduction		20%	36%	58%	73%	81%	87%	94%	97%

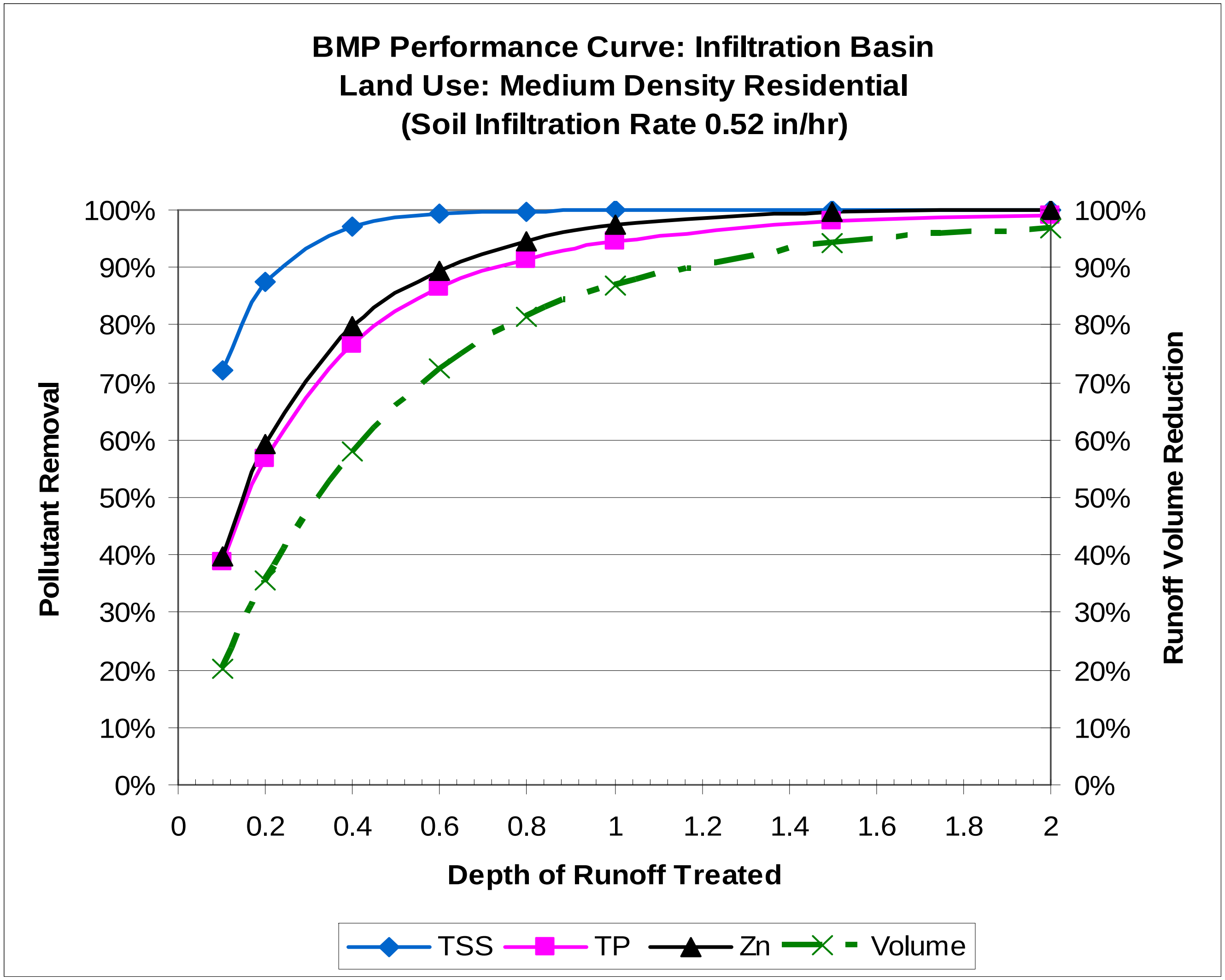
Annual Pollutant Loading Rates

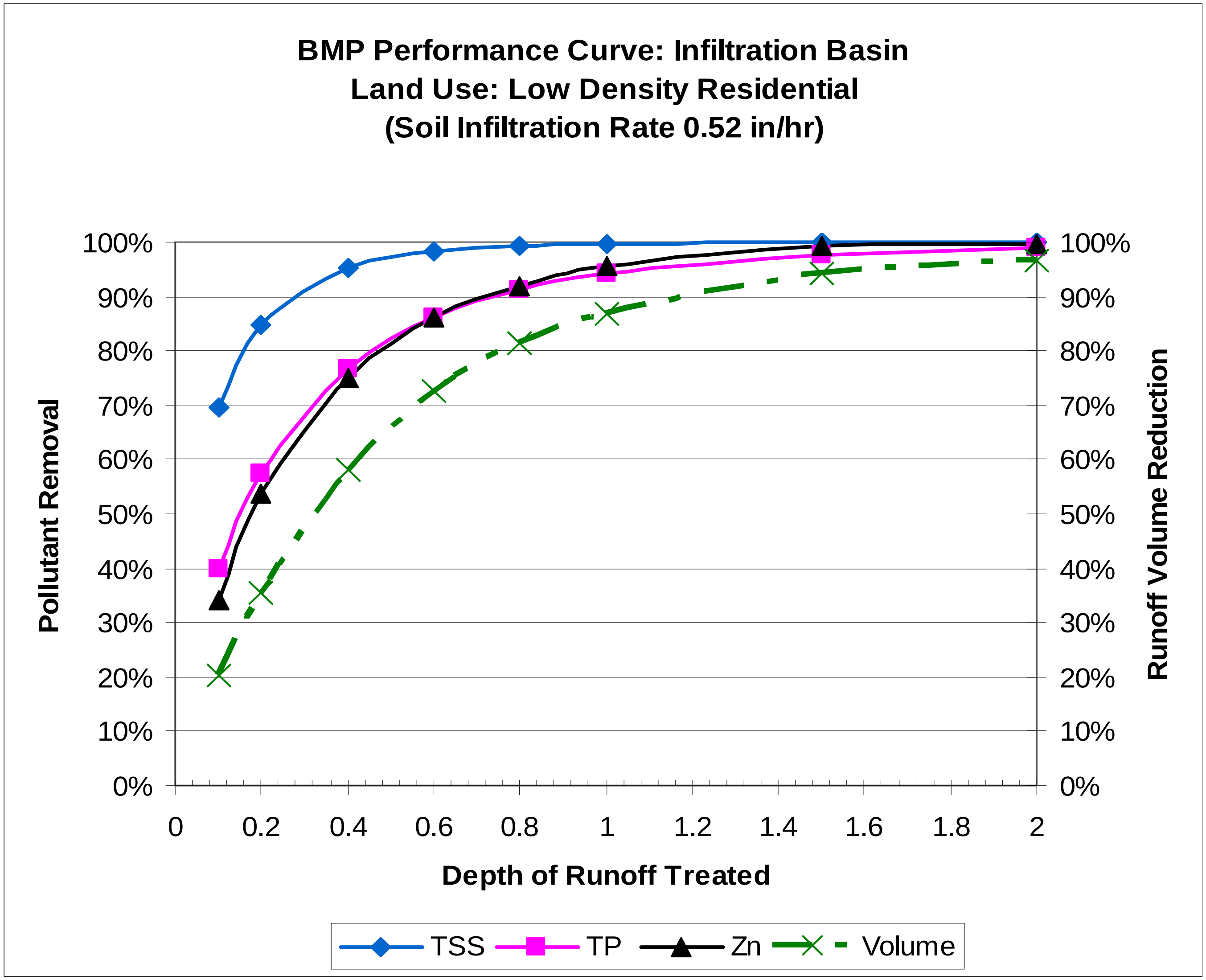
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High Density Residential	465.08	1.10	0.79
Medium Density Residential	274.63	0.55	0.11
Low Density Residential	72.11	0.042	0.043


BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Industrial
(Soil Infiltration Rate 0.52 in/hr)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
Runoff Volume Reduction
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 0.52 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Medium Density Residential
(Soil Infiltration Rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

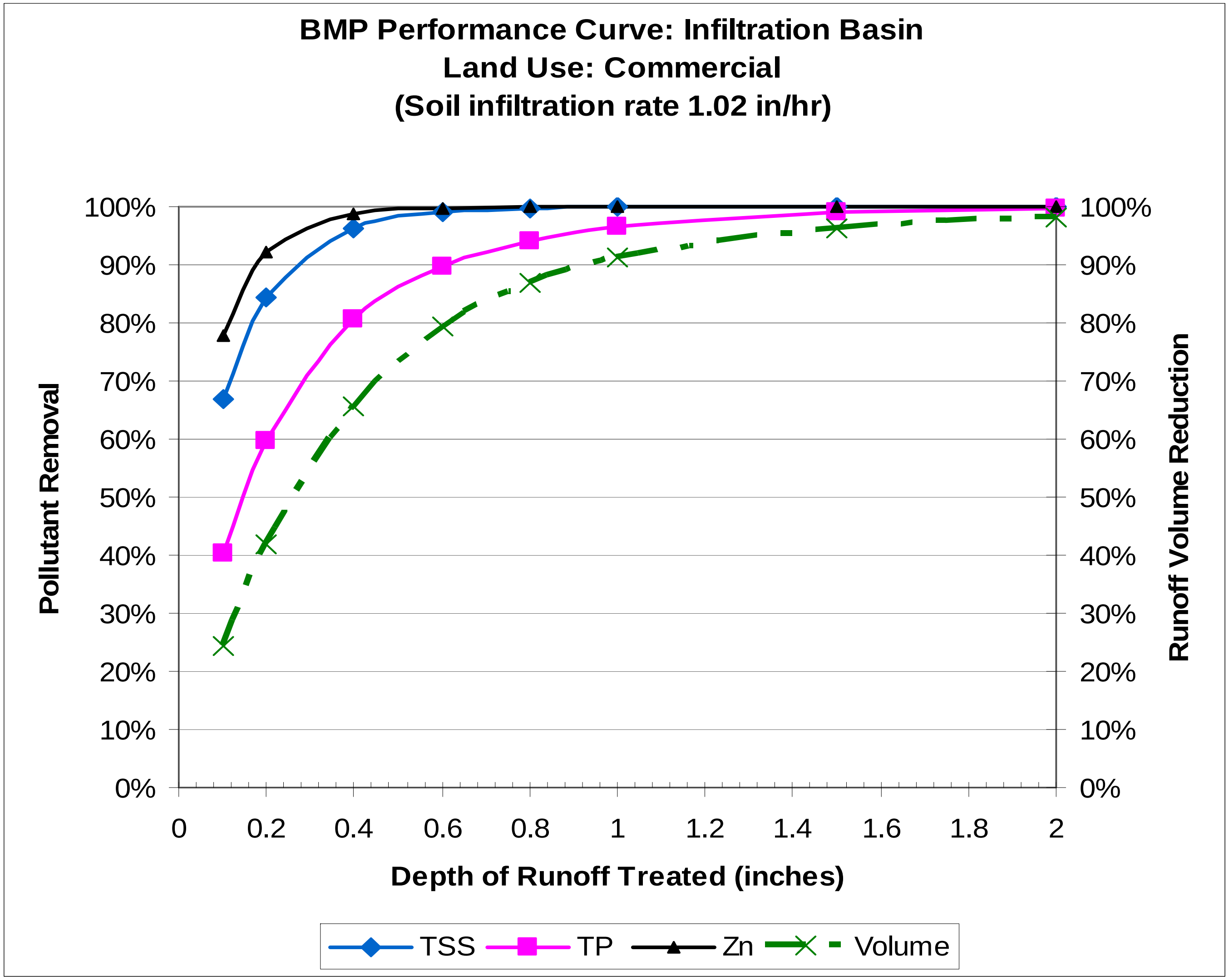
BMP Name: Infiltration Basin

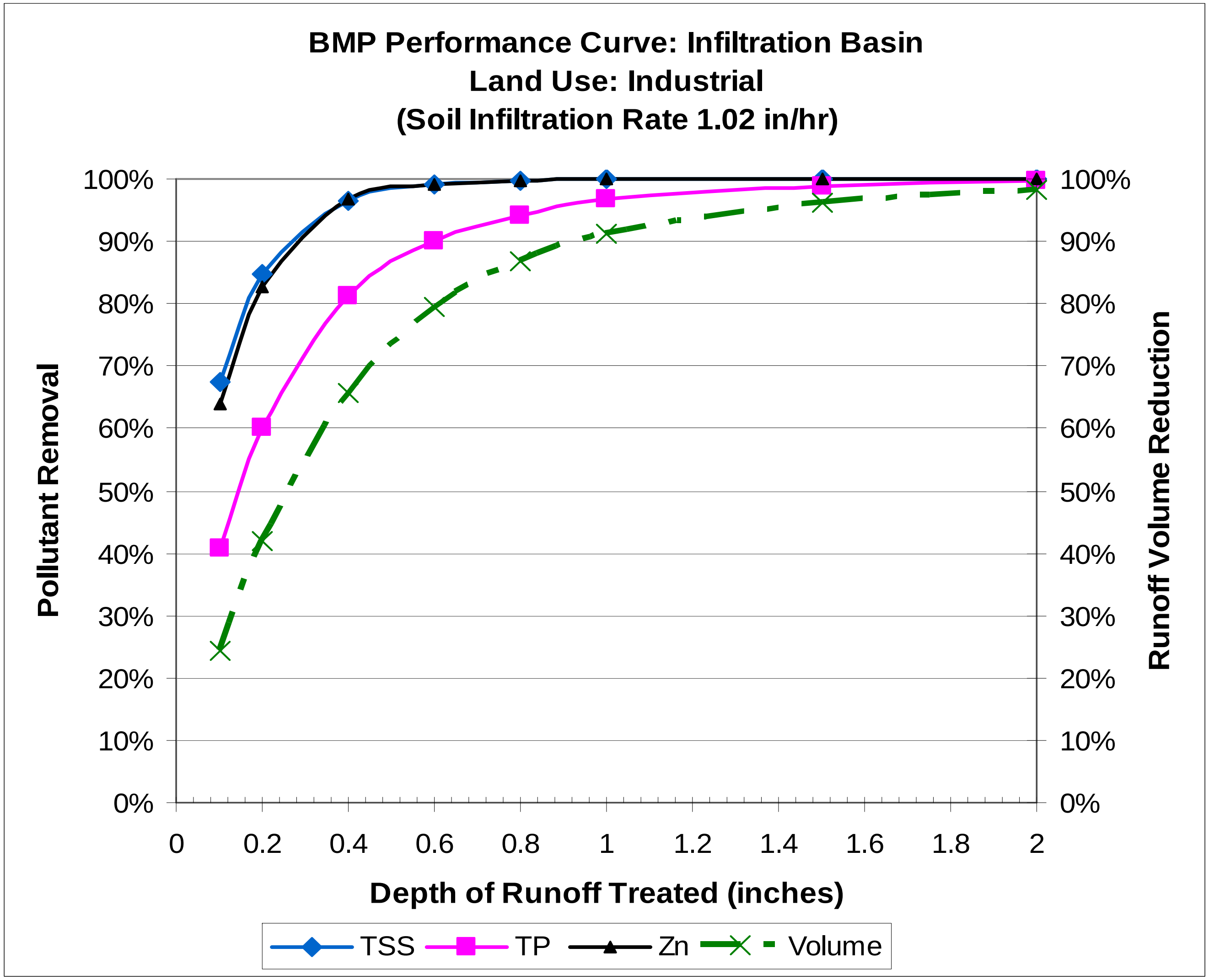
Soil Infiltration Rate: 1.02 in/hr

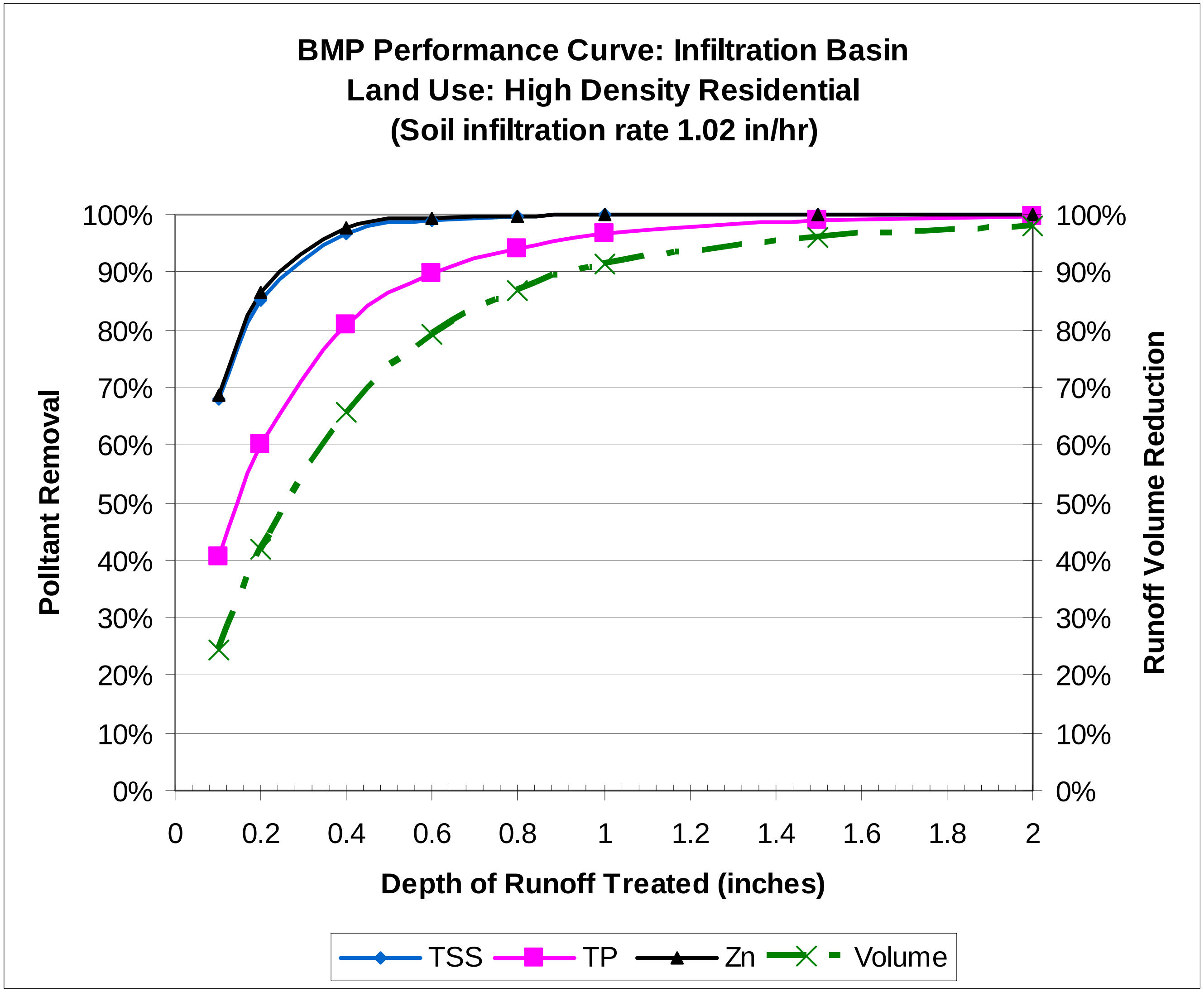
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.5**	**2.0**
Commercial	TSS	67%	84%	96%	99%	100%	100%	100%	100%
	TP	40%	60%	81%	90%	94%	97%	99%	100%
	Zn	78%	92%	99%	100%	100%	100%	100%	100%
Industrial	TSS	68%	85%	96%	99%	100%	100%	100%	100%
	TP	41%	60%	81%	90%	94%	97%	99%	100%
	Zn	64%	83%	97%	99%	100%	100%	100%	100%
High Density Residential	TSS	68%	85%	97%	99%	100%	100%	100%	100%
	TP	41%	60%	81%	90%	94%	97%	99%	100%
	Zn	69%	86%	98%	99%	100%	100%	100%	100%
Medium Density Residential	TSS	74%	89%	98%	99%	100%	100%	100%	100%
	TP	41%	60%	81%	89%	94%	96%	99%	100%
	Zn	41%	62%	83%	92%	97%	99%	100%	100%
Low Density Residential	TSS	71%	86%	96%	99%	100%	100%	100%	100%
	TP	42%	61%	81%	89%	93%	96%	98%	99%
	Zn	36%	56%	79%	89%	94%	97%	100%	100%
Runoff Volume Reduction		24%	42%	66%	79%	87%	91%	96%	98%

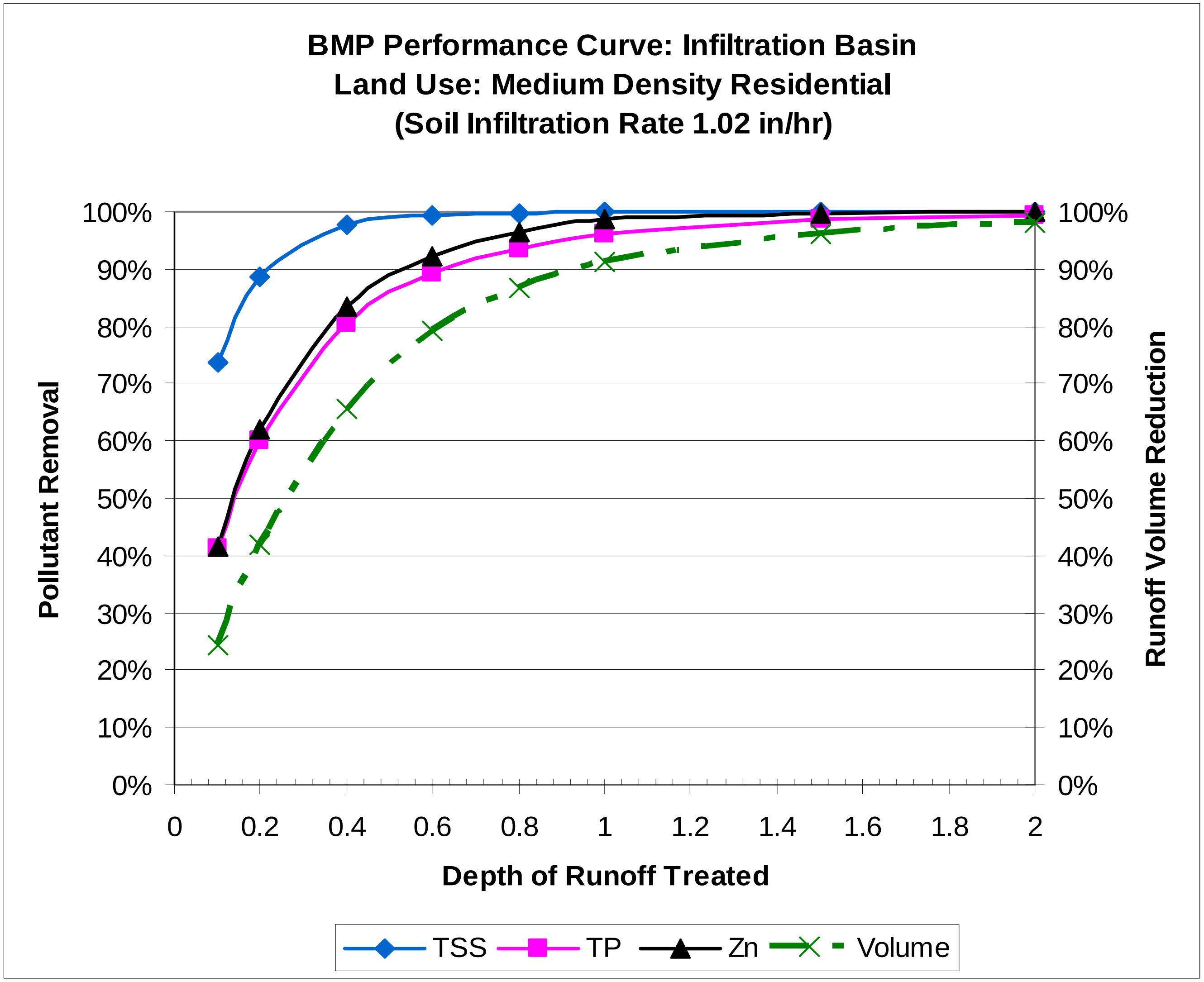
Annual Pollutant Loading Rates

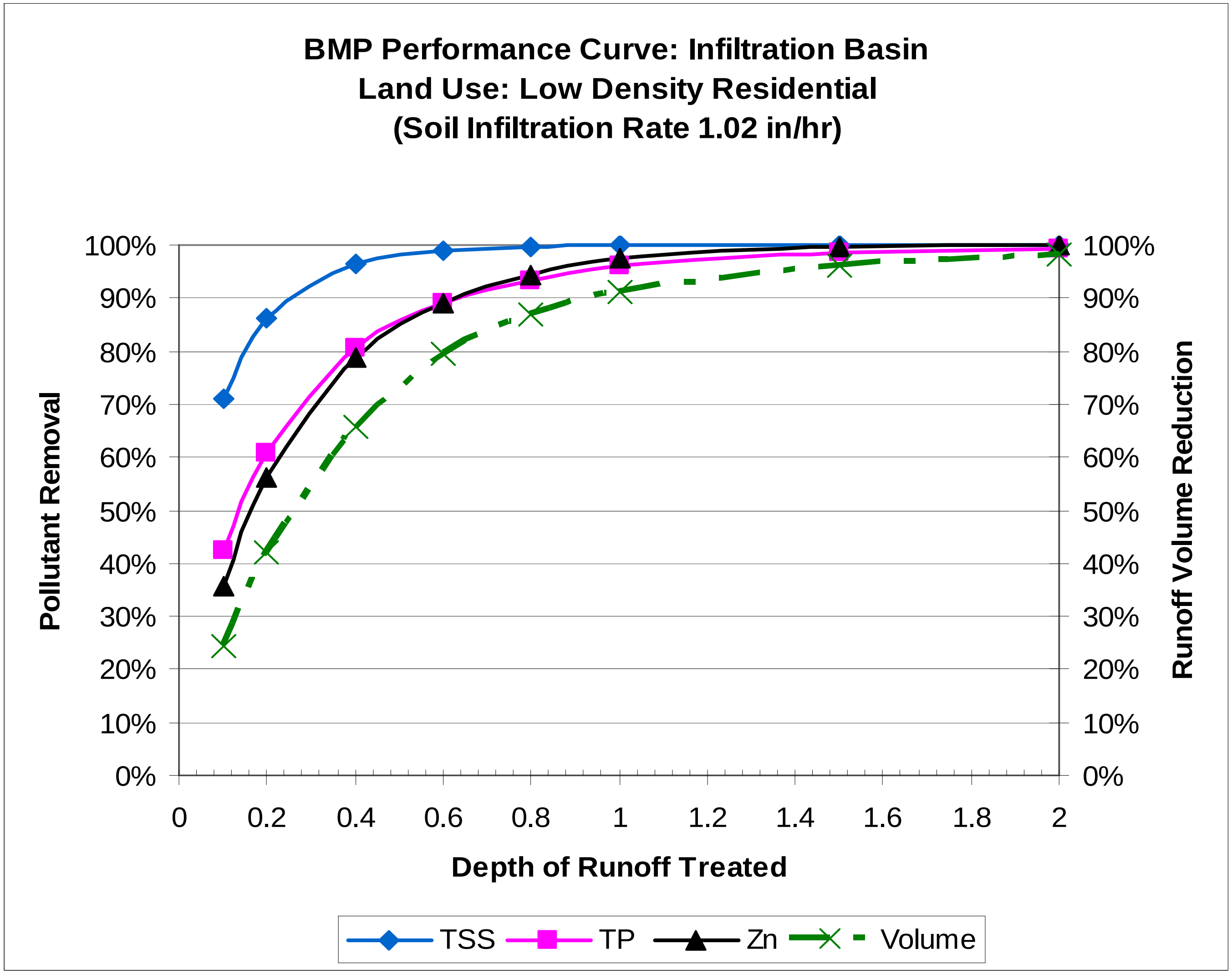
Land use	Pollutant load (lbs/acre-year)		
	TSS	**TP**	**Zn**
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High Density Residential	465.08	1.10	0.79
Medium Density Residential	274.63	0.55	0.11
Low Density Residential	72.11	0.042	0.043


BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Industrial
(Soil Infiltration Rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 1.02 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Medium Density Residential
(Soil Infiltration Rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin

BMP Performance Table

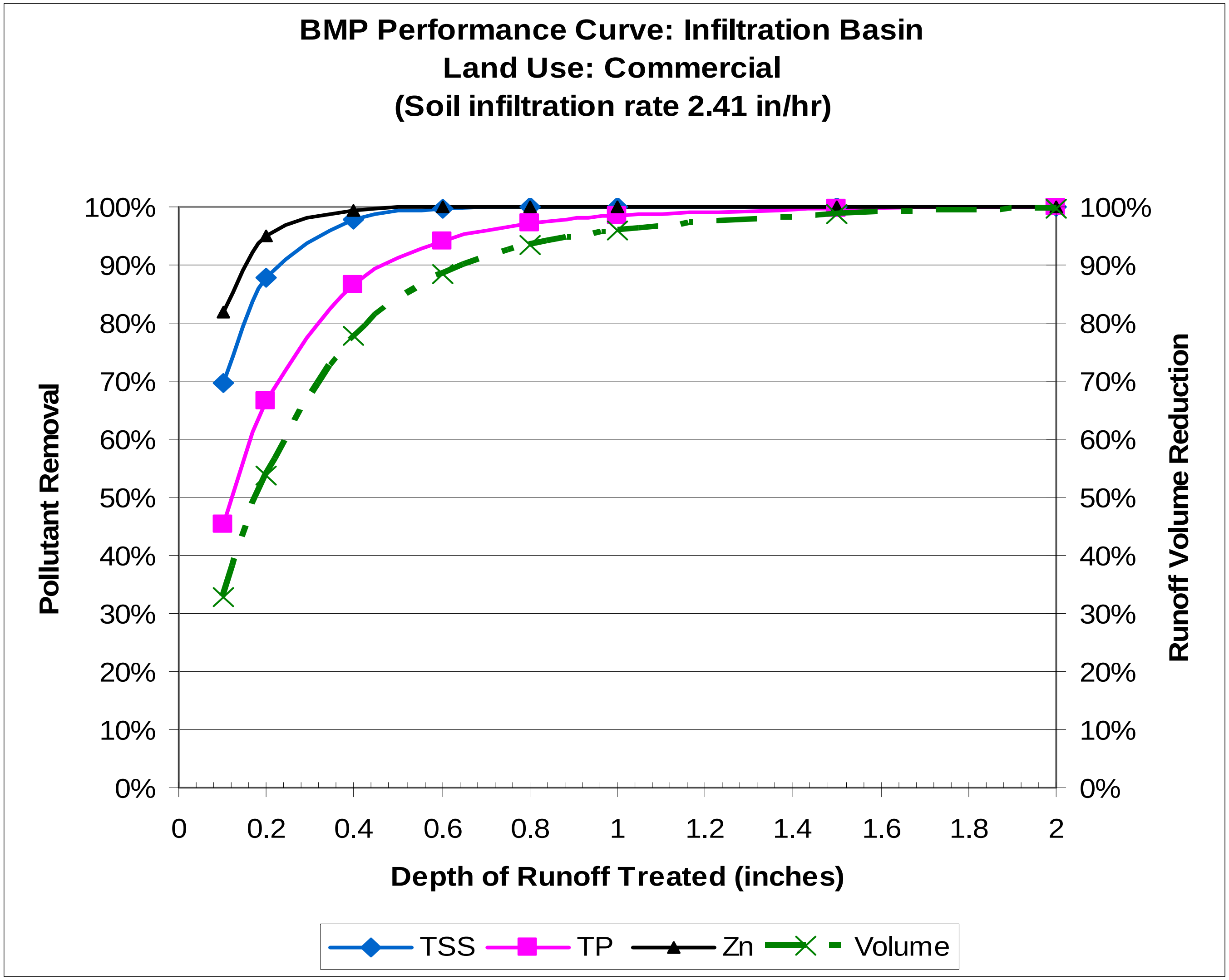
BMP Name: Infiltration Basin

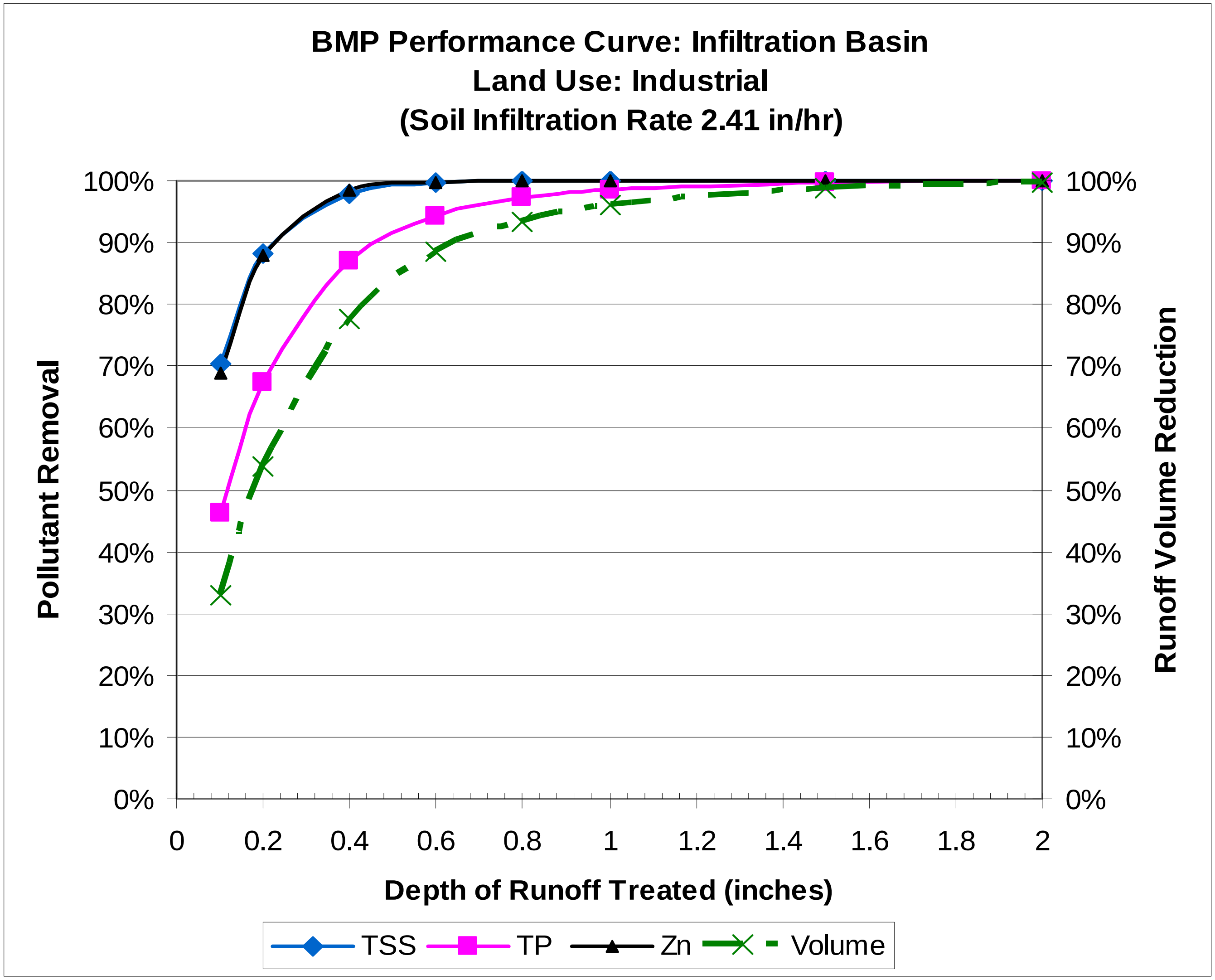
Soil Infiltration Rate: 2.41 in/hr

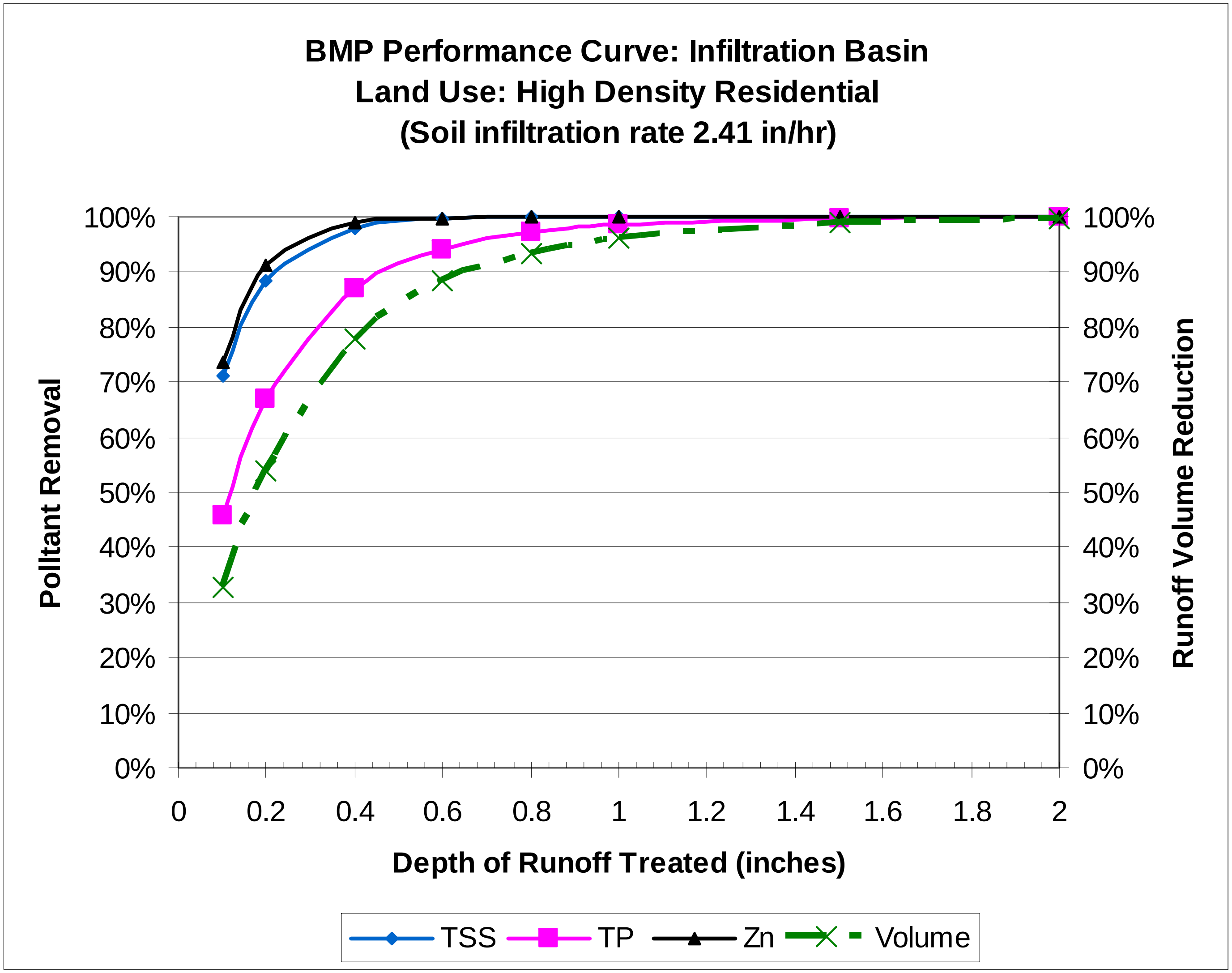
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	**0.2**	**0.4**	**0.6**	**0.8**	**1**	**1.5**	**2**
Commercial	TSS	70%	88%	98%	100%	100%	100%	100%	100%
	TP	45%	67%	87%	94%	97%	98%	100%	100%
	Zn	82%	95%	100%	100%	100%	100%	100%	100%
Industrial	TSS	70%	88%	98%	100%	100%	100%	100%	100%
	TP	46%	67%	87%	94%	97%	99%	100%	100%
	Zn	69%	88%	99%	100%	100%	100%	100%	100%
High Density Residential	TSS	71%	88%	98%	100%	100%	100%	100%	100%
	TP	46%	67%	87%	94%	97%	98%	100%	100%
	Zn	74%	91%	99%	100%	100%	100%	100%	100%
Medium Density Residential	TSS	76%	91%	99%	100%	100%	100%	100%	100%
	TP	46%	67%	87%	94%	97%	98%	100%	100%
	Zn	45%	68%	89%	96%	99%	100%	100%	100%
Low Density Residential	TSS	74%	89%	98%	99%	100%	100%	100%	100%
	TP	48%	68%	87%	94%	97%	98%	100%	100%
	Zn	38%	61%	84%	94%	98%	99%	100%	100%
Runoff Volume Reduction		33%	54%	78%	88%	93%	96%	99%	100%

Annual Pollutant Loading Rates

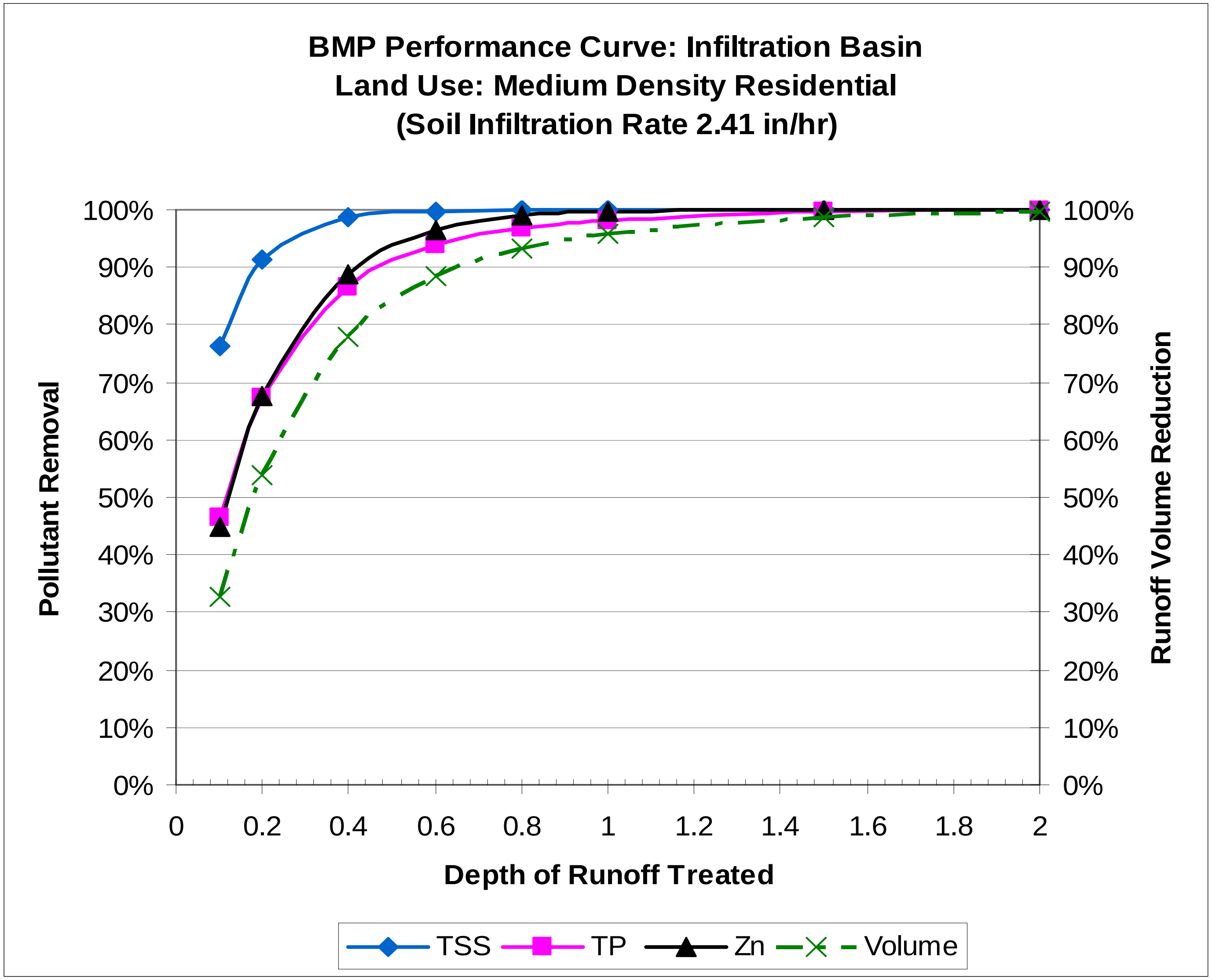
Land use	Pollutant load (lbs/acre-year)		
	TSS	**TP**	**Zn**
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High Density Residential	465.08	1.10	0.79
Medium Density Residential	274.63	0.55	0.11
Low Density Residential	72.11	0.042	0.043

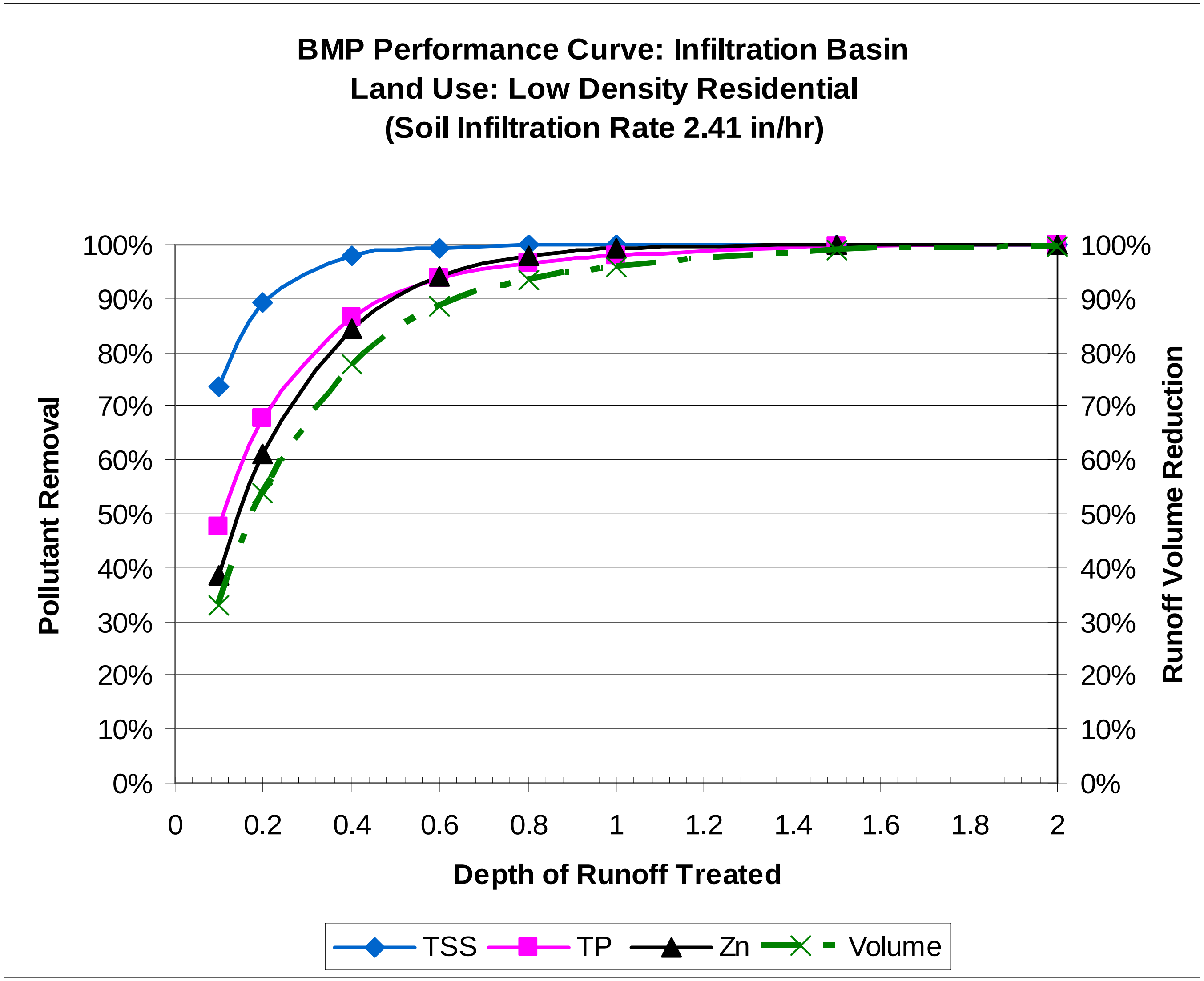

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Industrial
(Soil Infiltration Rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 2.41 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin




BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

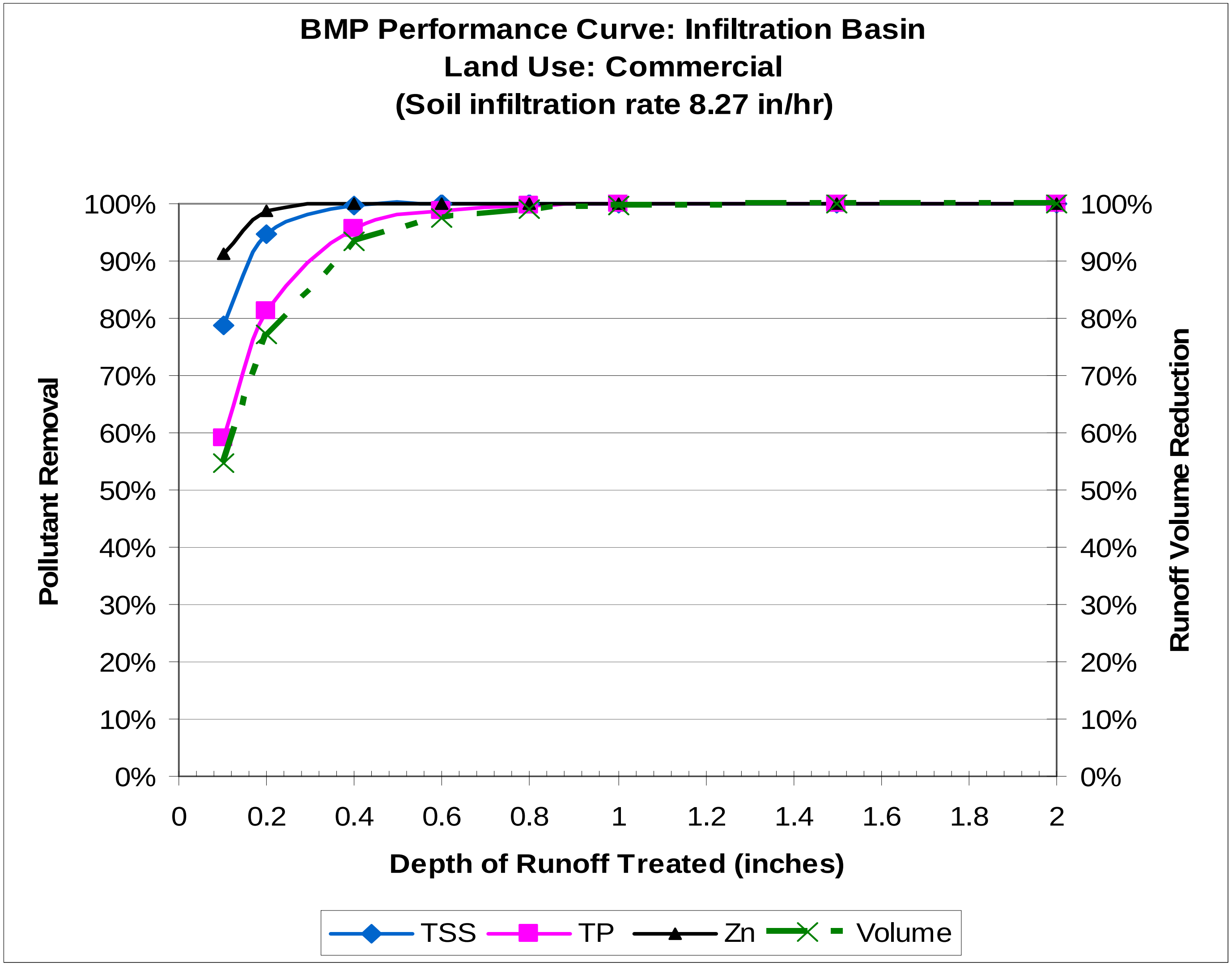
BMP Name: Infiltration Basin

Soil Infiltration Rate: 8.27 in/hr

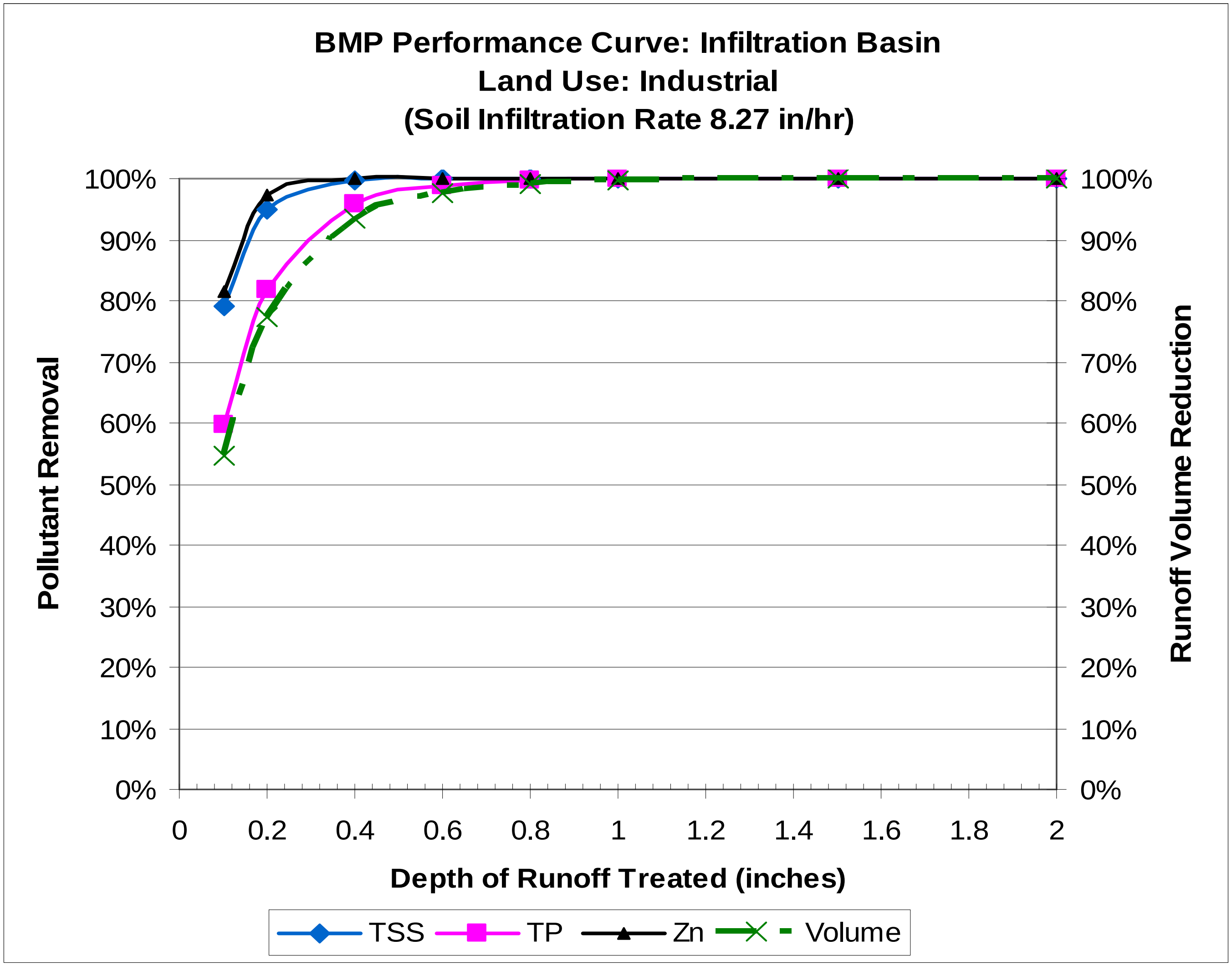
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	**0.2**	**0.4**	**0.6**	**0.8**	**1**	**1.5**	**2**
Commercial	TSS	79%	95%	100%	100%	100%	100%	100%	100%
	TP	59%	81%	96%	99%	100%	100%	100%	100%
	Zn	91%	99%	100%	100%	100%	100%	100%	100%
Industrial	TSS	79%	95%	100%	100%	100%	100%	100%	100%
	TP	60%	82%	96%	99%	100%	100%	100%	100%
	Zn	81%	97%	100%	100%	100%	100%	100%	100%
High Density Residential	TSS	80%	95%	100%	100%	100%	100%	100%	100%
	TP	60%	81%	96%	99%	100%	100%	100%	100%
	Zn	85%	98%	100%	100%	100%	100%	100%	100%
Medium Density Residential	TSS	84%	96%	100%	100%	100%	100%	100%	100%
	TP	60%	82%	96%	99%	100%	100%	100%	100%
	Zn	55%	81%	98%	100%	100%	100%	100%	100%
Low Density Residential	TSS	82%	95%	99%	100%	100%	100%	100%	100%
	TP	62%	82%	96%	98%	99%	100%	100%	100%
	Zn	47%	73%	96%	99%	100%	100%	100%	100%
Runoff Volume Reduction		55%	77%	93%	98%	99%	100%	100%	100%

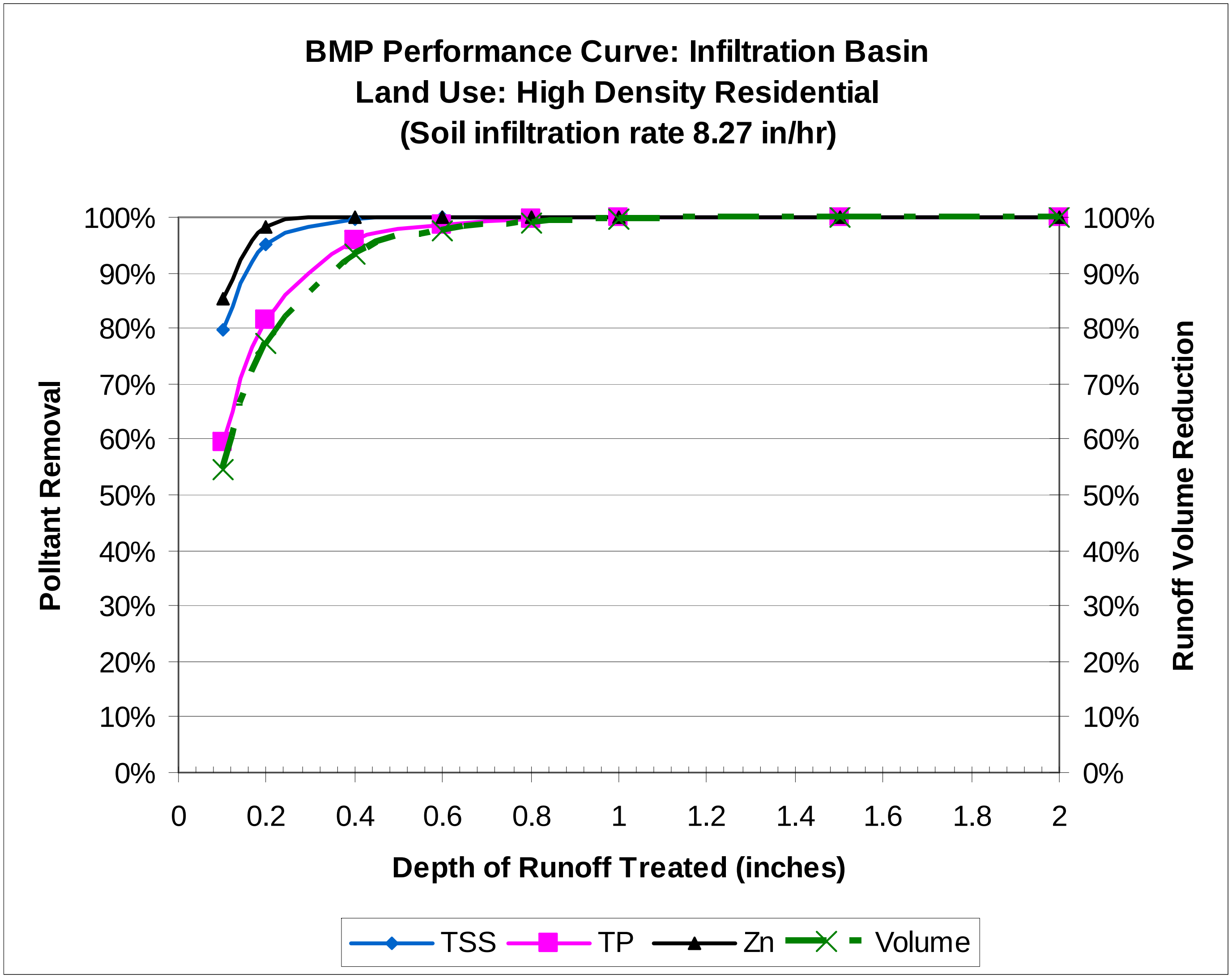
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	**TP**	**Zn**
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High Density Residential	465.08	1.10	0.79
Medium Density Residential	274.63	0.55	0.11
Low Density Residential	72.11	0.042	0.043


BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 8.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

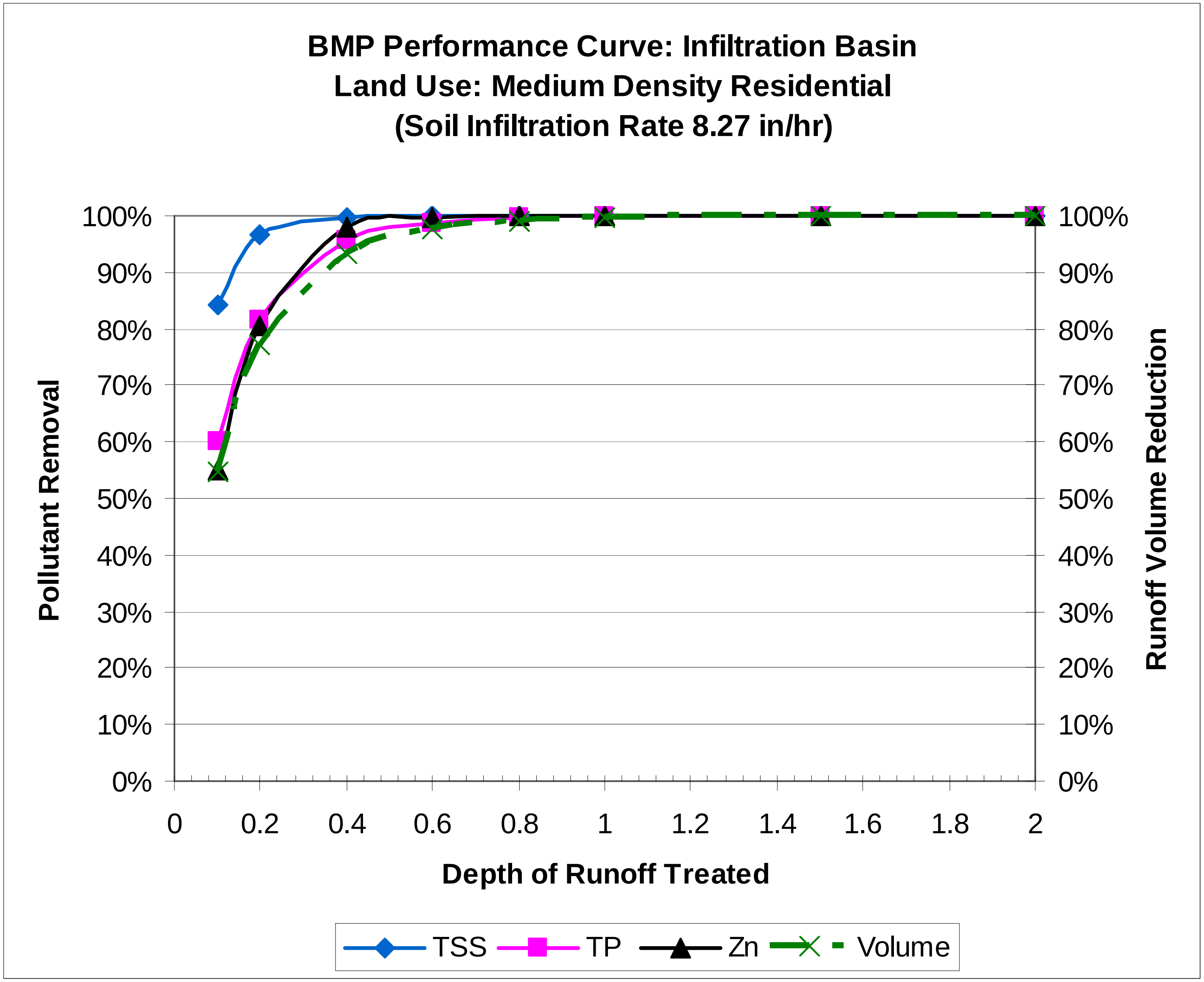
BMP Performance Curve: Infiltration Basin

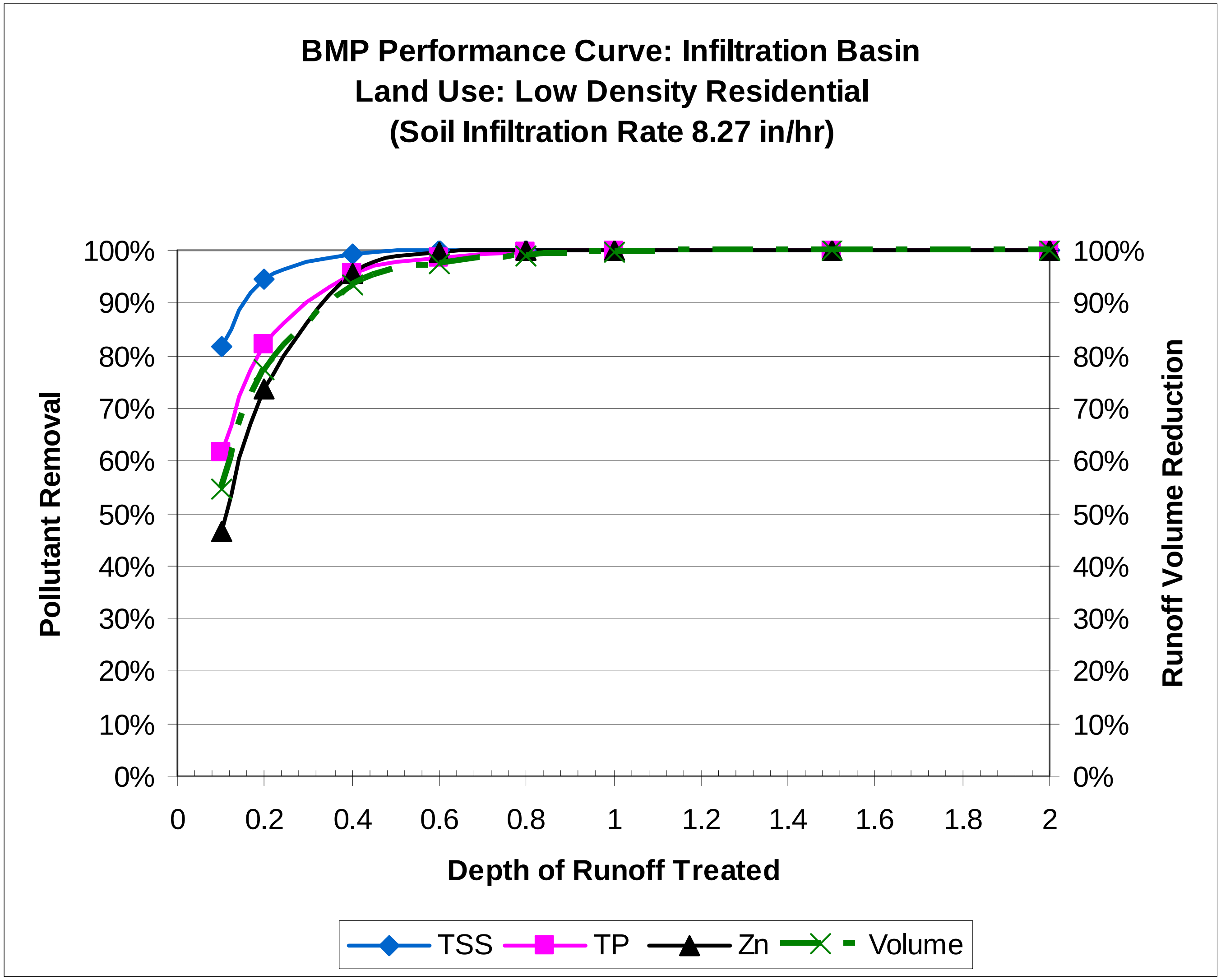




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 8.27 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin




BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 8.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Curve: Gravel Wetland

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

September 2008

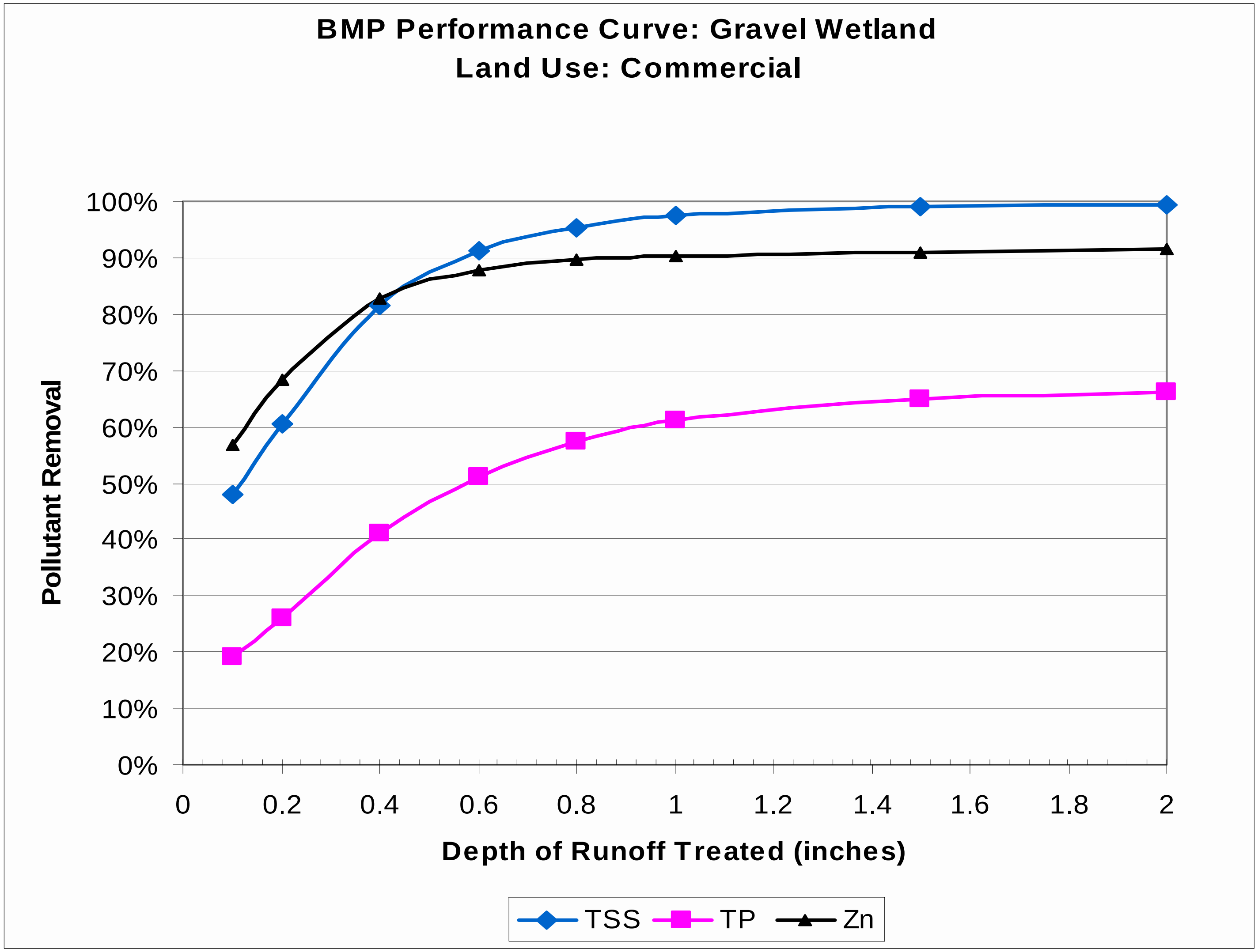
BMP Performance Table

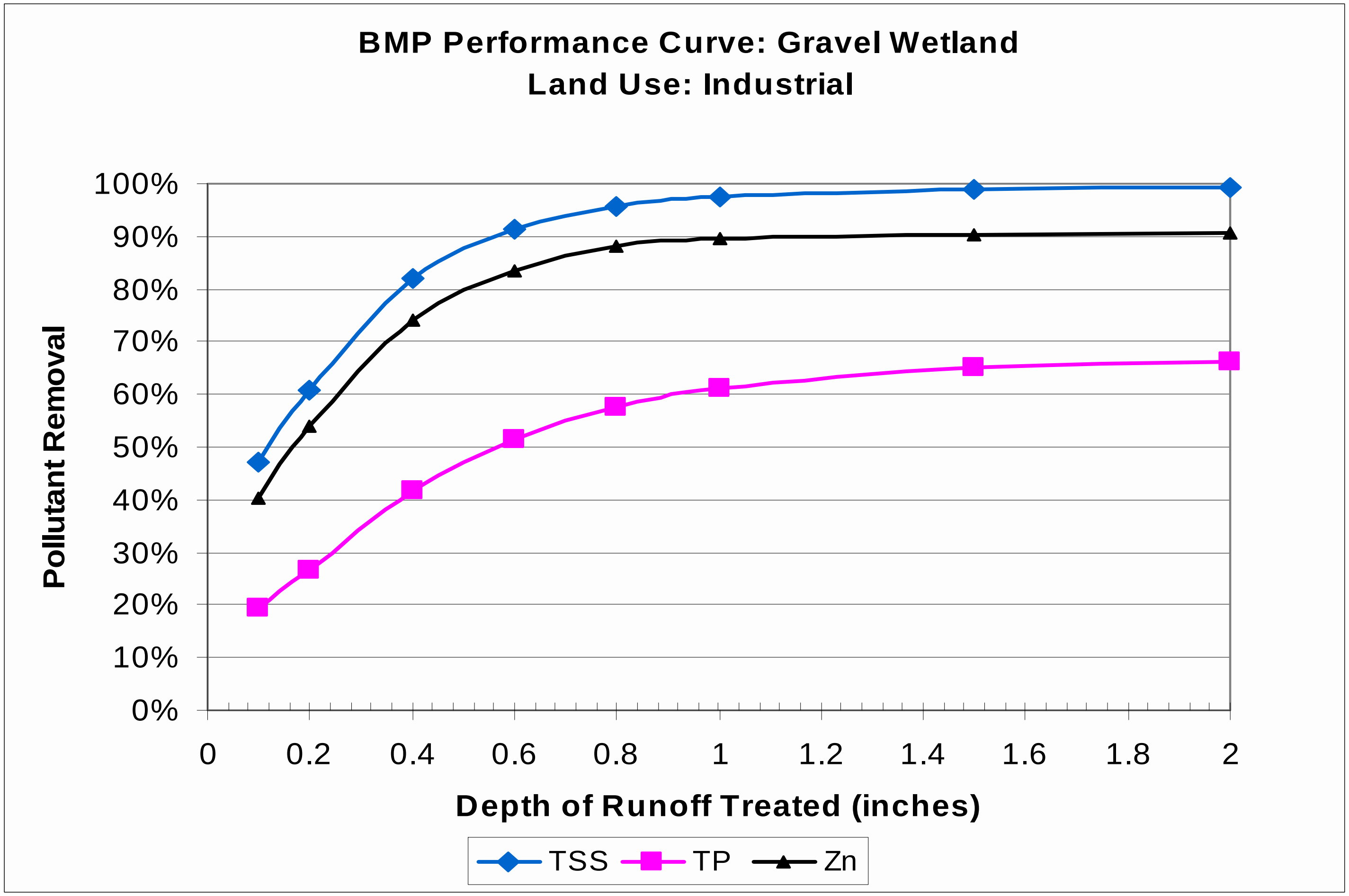
BMP Name: Gravel Wetland

Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	48%	61%	82%	91%	95%	97%	99%	99%
	TP	19%	26%	41%	51%	57%	61%	65%	66%
	Zn	57%	68%	83%	88%	90%	90%	91%	92%
Industrial	TSS	47%	61%	82%	91%	96%	97%	99%	99%
	TP	19%	27%	42%	51%	58%	61%	65%	66%
	Zn	40%	54%	74%	84%	88%	90%	90%	91%
High-Density Residential	TSS	47%	62%	82%	92%	96%	98%	99%	99%
	TP	19%	26%	41%	51%	57%	61%	65%	66%
	Zn	46%	59%	78%	86%	89%	90%	91%	91%
Medium-Density Residential	TSS	53%	68%	86%	94%	97%	98%	99%	99%
	TP	20%	27%	42%	51%	57%	61%	65%	66%
	Zn	21%	32%	52%	67%	76%	82%	89%	91%
Low-Density Residential	TSS	51%	65%	83%	92%	96%	97%	99%	99%
	TP	21%	28%	42%	51%	57%	61%	64%	66%
	Zn	16%	26%	46%	61%	71%	78%	87%	90%

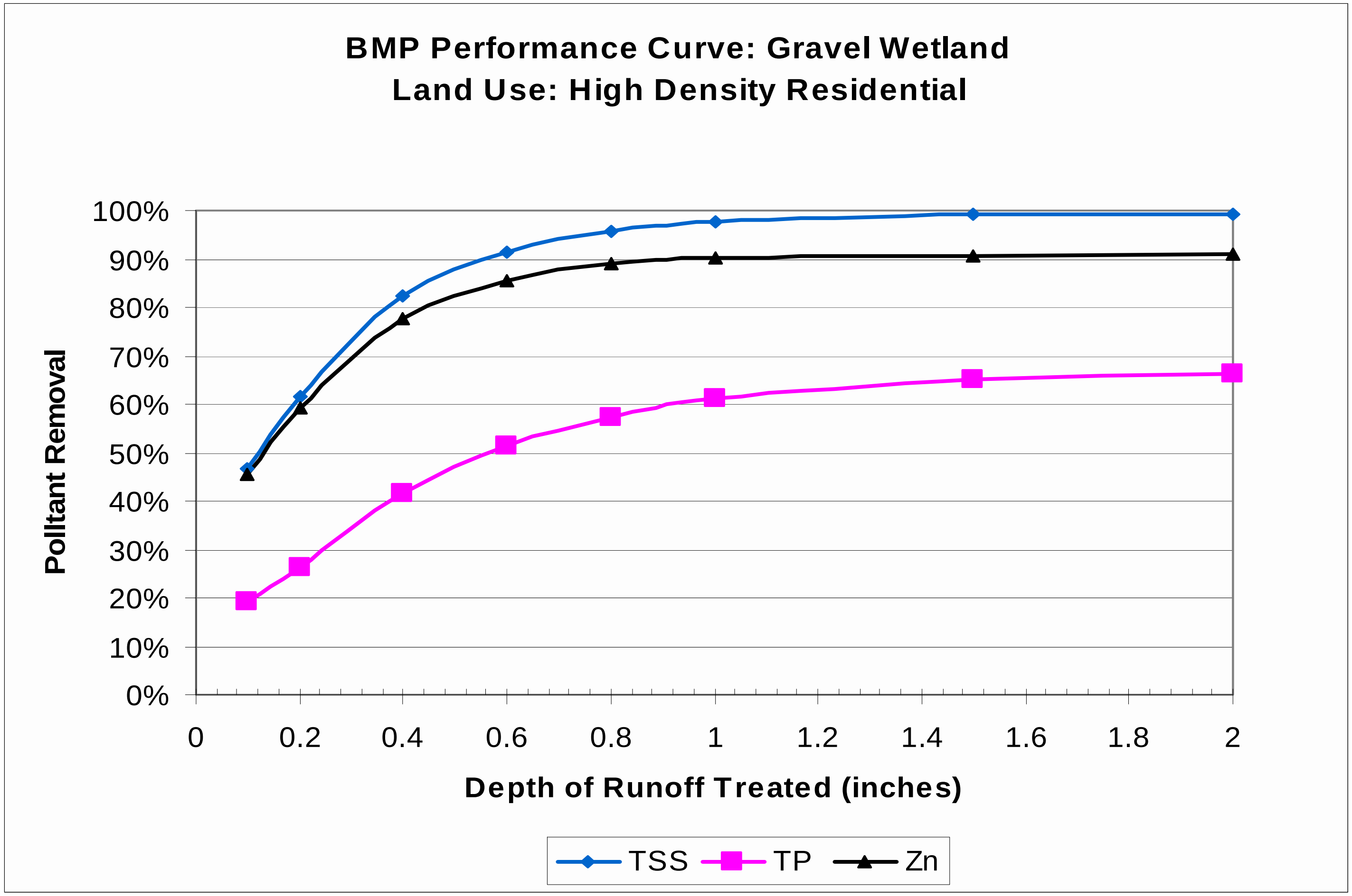
Annual Pollutant Loading Rates

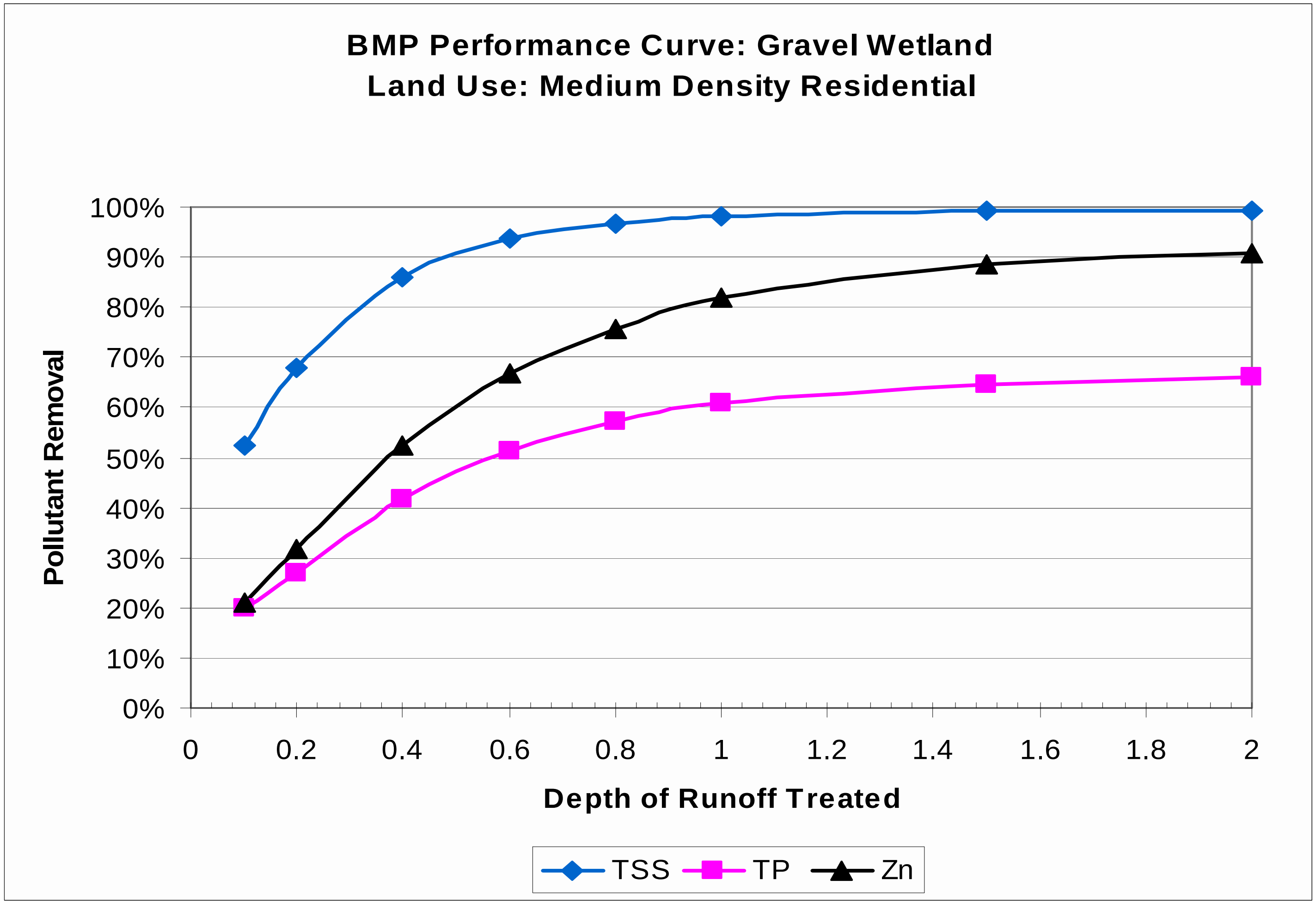
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043


BMP Performance Curve: Gravel Wetland
Land Use: Commercial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

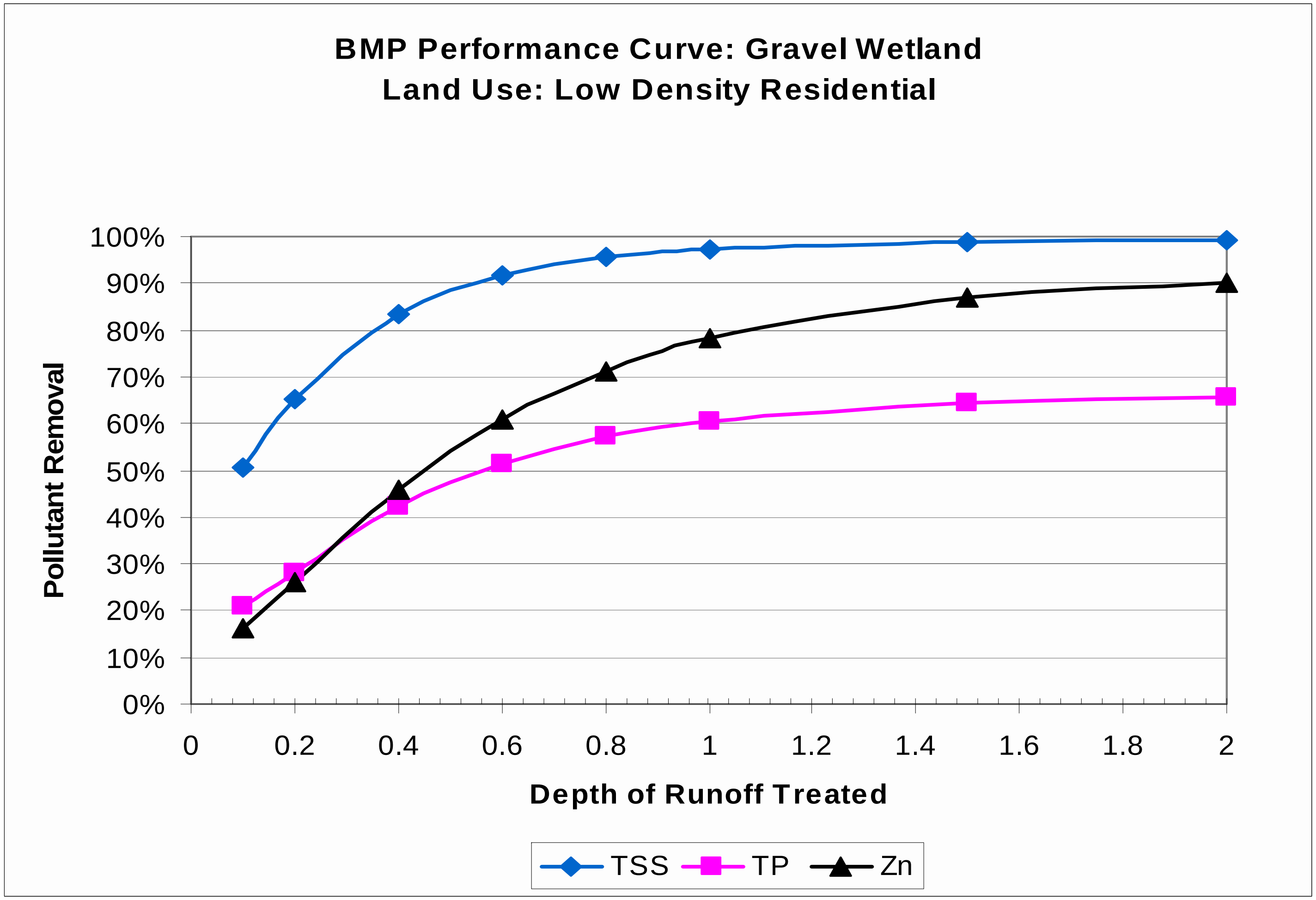

BMP Performance Curve: Gravel Wetland
Land Use: Industrial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

BMP Performance Curve: Gravel Wetland




BMP Performance Curve: Gravel Wetland
Land Use: Medium Density Residential
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn

BMP Performance Curve: Gravel Wetland



BMP Performance Curve: Bioretention

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

September 2008

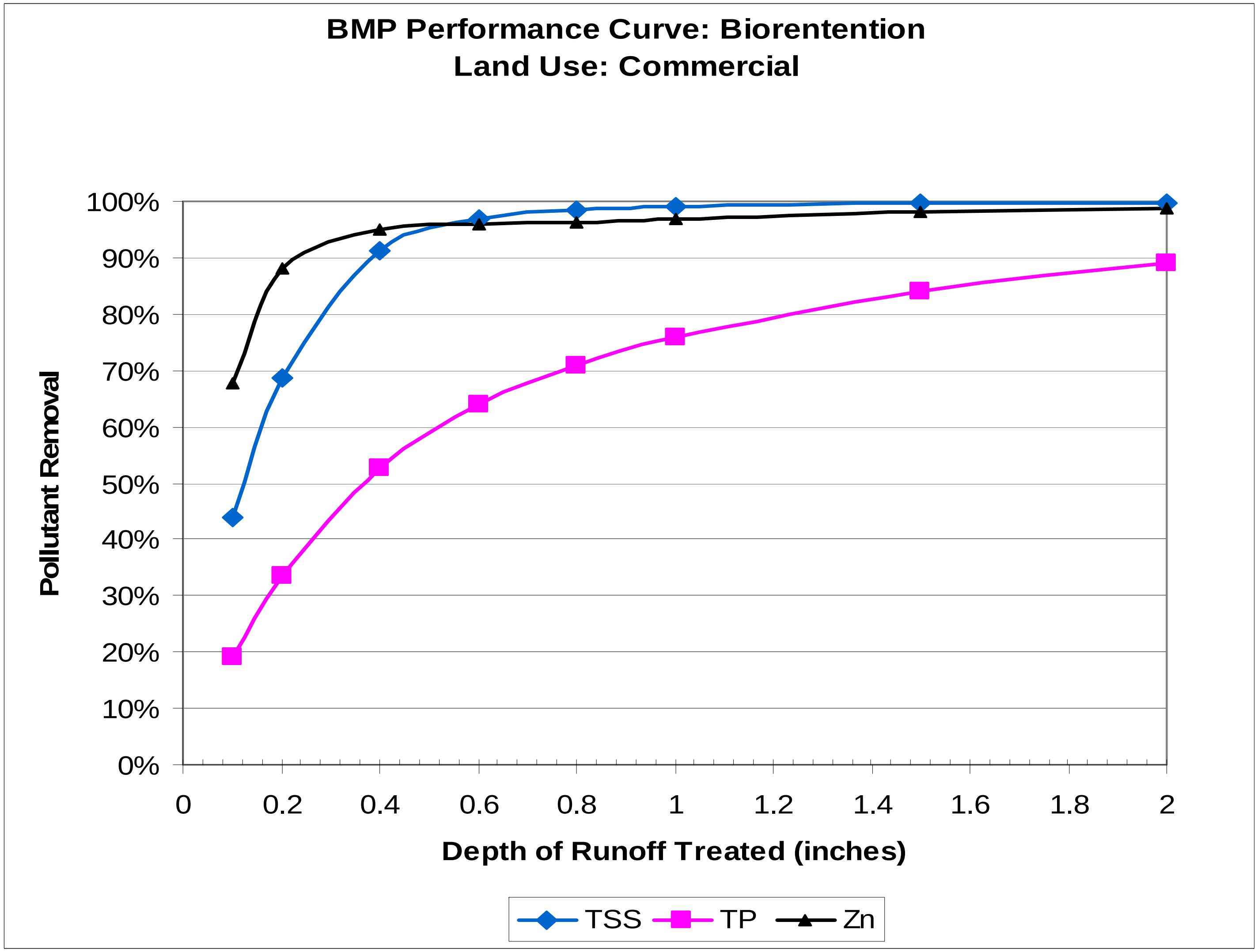
BMP Performance Table

BMP Name: Bioretention

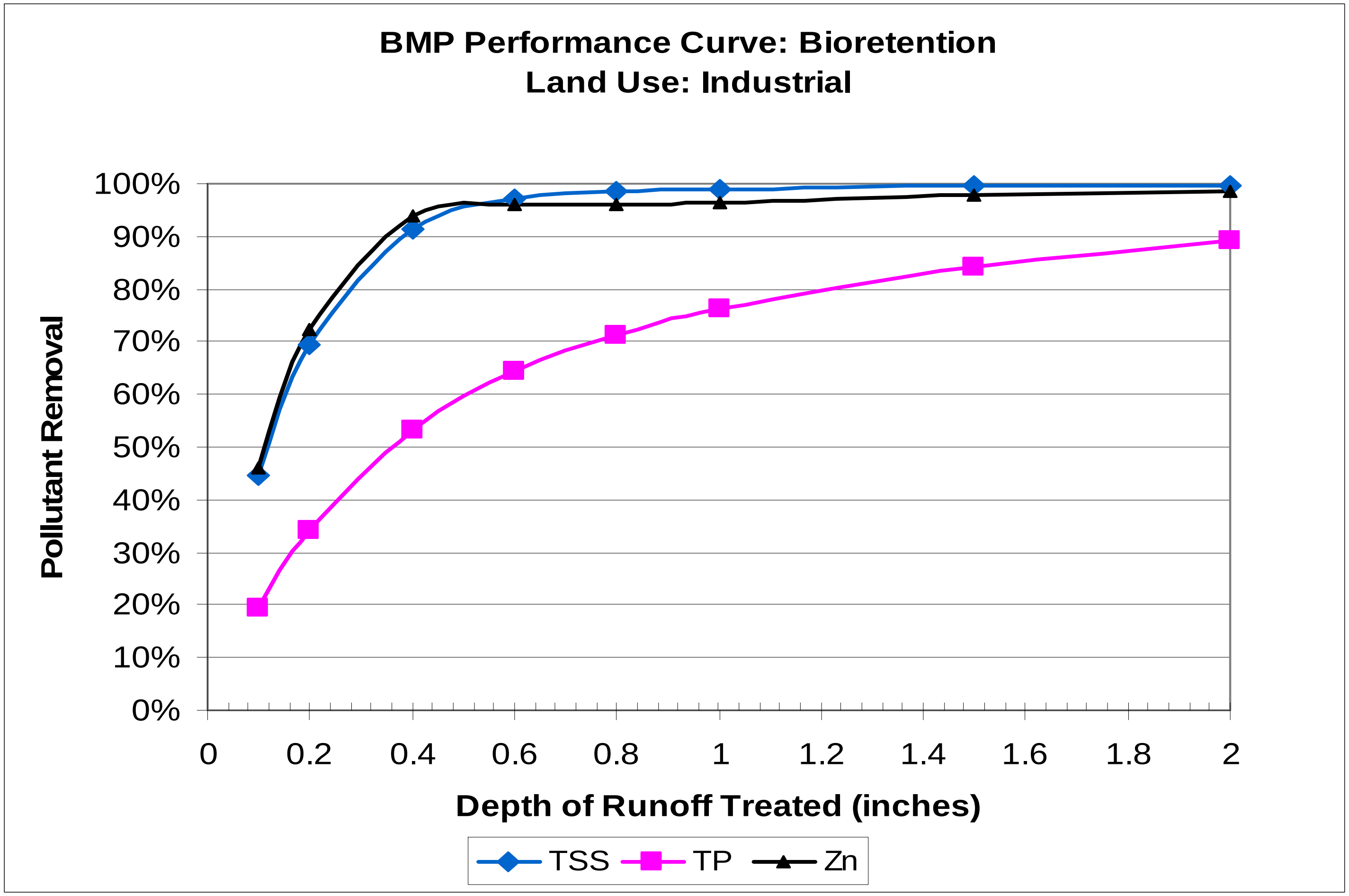
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	44%	69%	91%	97%	98%	99%	100%	100%
	TP	19%	33%	53%	64%	71%	76%	84%	89%
	Zn	68%	88%	95%	96%	96%	97%	98%	99%
Industrial	TSS	45%	70%	91%	97%	98%	99%	100%	100%
	TP	20%	34%	53%	64%	71%	76%	84%	89%
	Zn	46%	72%	94%	96%	96%	96%	98%	99%
High-Density Residential	TSS	46%	70%	92%	97%	99%	99%	100%	100%
	TP	19%	34%	53%	64%	71%	76%	84%	89%
	Zn	53%	79%	95%	96%	96%	97%	98%	99%
Medium-Density Residential	TSS	54%	78%	94%	98%	99%	99%	100%	100%
	TP	20%	34%	53%	63%	70%	75%	83%	88%
	Zn	23%	41%	68%	83%	92%	95%	97%	97%
Low-Density Residential	TSS	52%	73%	91%	96%	98%	99%	99%	100%
	TP	21%	35%	52%	62%	68%	73%	81%	86%
	Zn	17%	33%	59%	76%	88%	93%	97%	97%

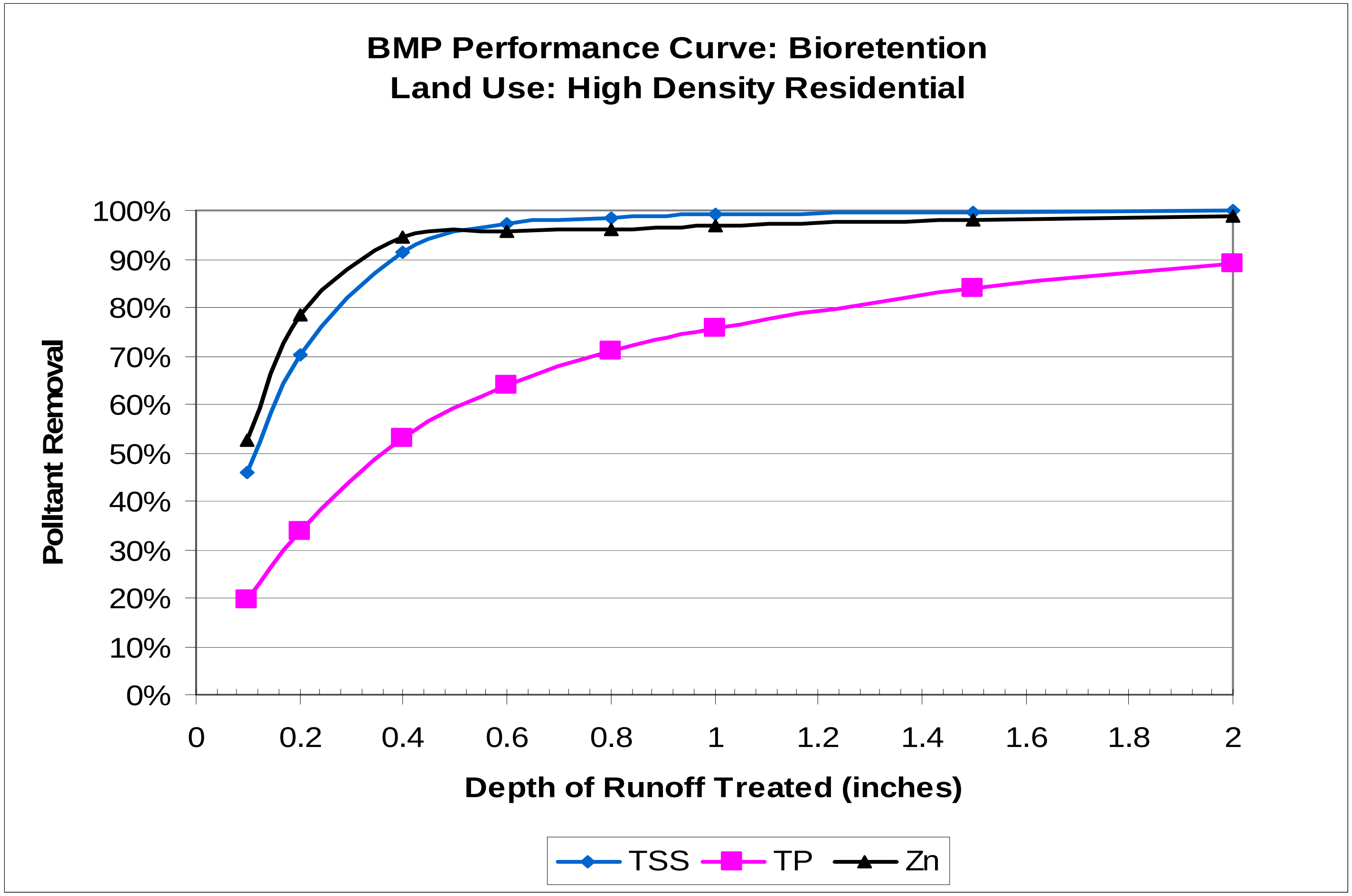
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

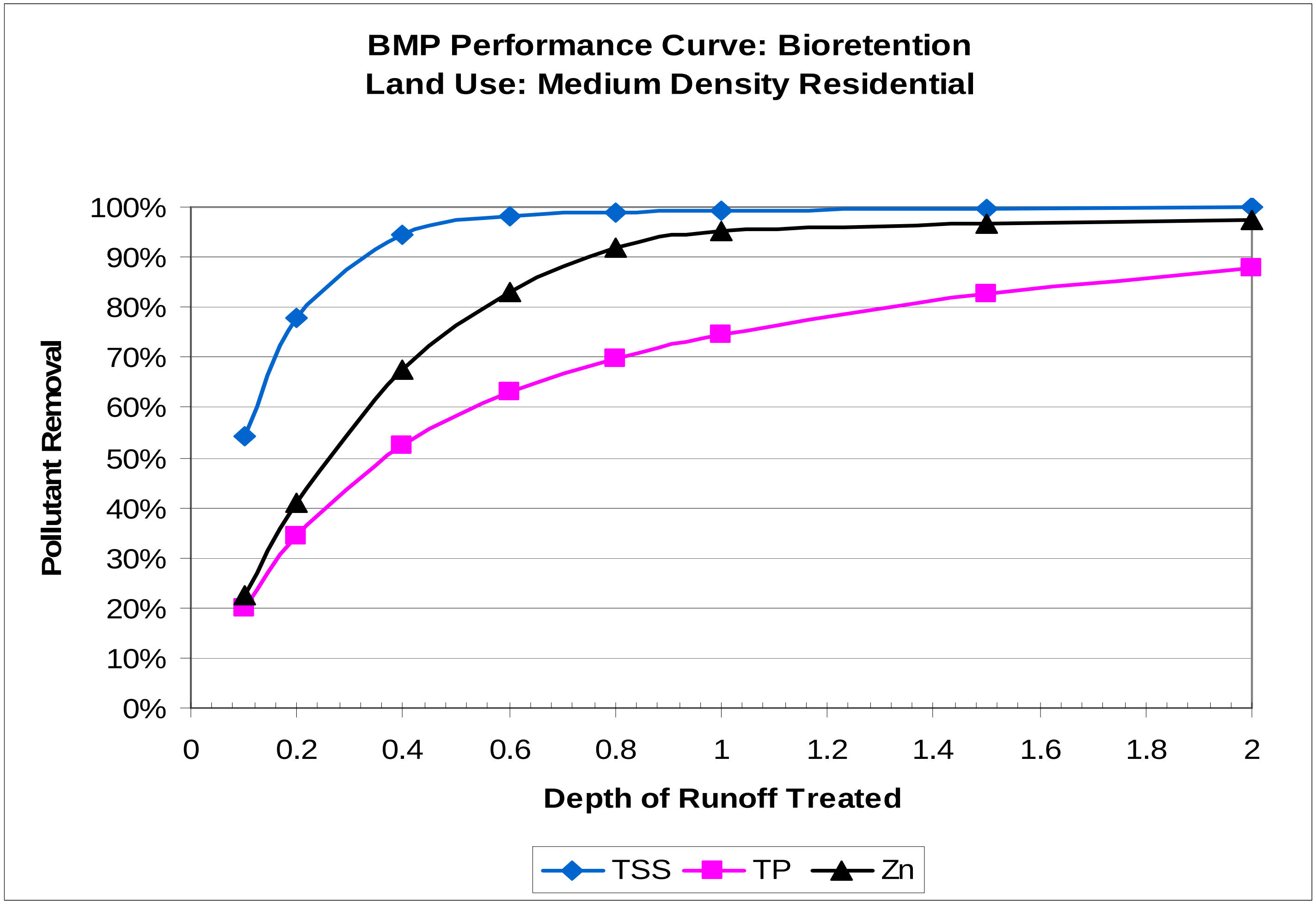

BMP Performance Curve: Biorentention
Land Use: Commercial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

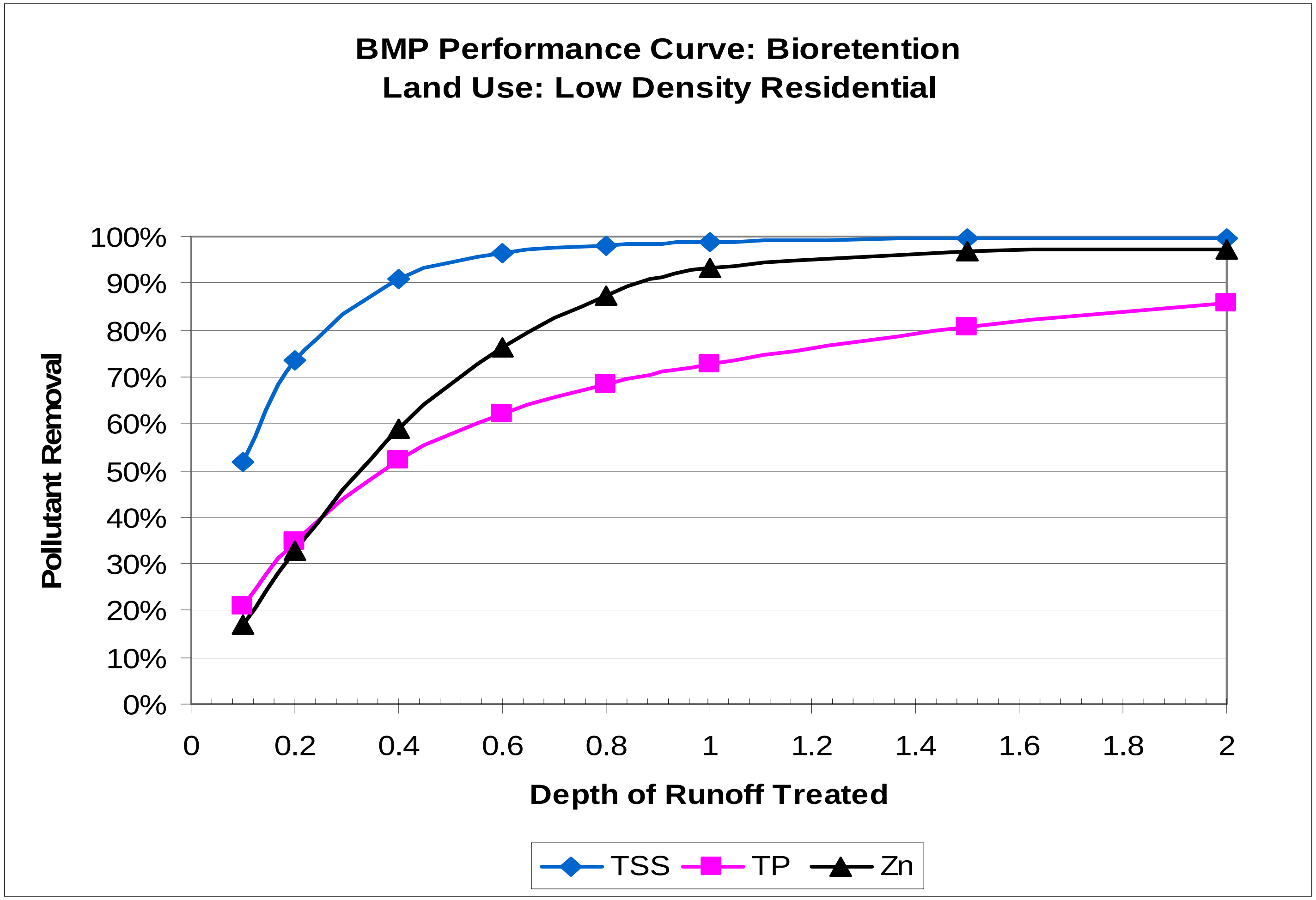
BMP Performance Curve: Bioretention




BMP Performance Curve: Bioretention
Land Use: High Density Residential
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Polltant Removal
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

BMP Performance Curve: Bioretention




BMP Performance Curve: Bioretention
Land Use: Low Density Residential
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn

BMP Performance Curve: Grass Swale

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

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Fairfax, VA 22030

September 2008

BMP Performance Table

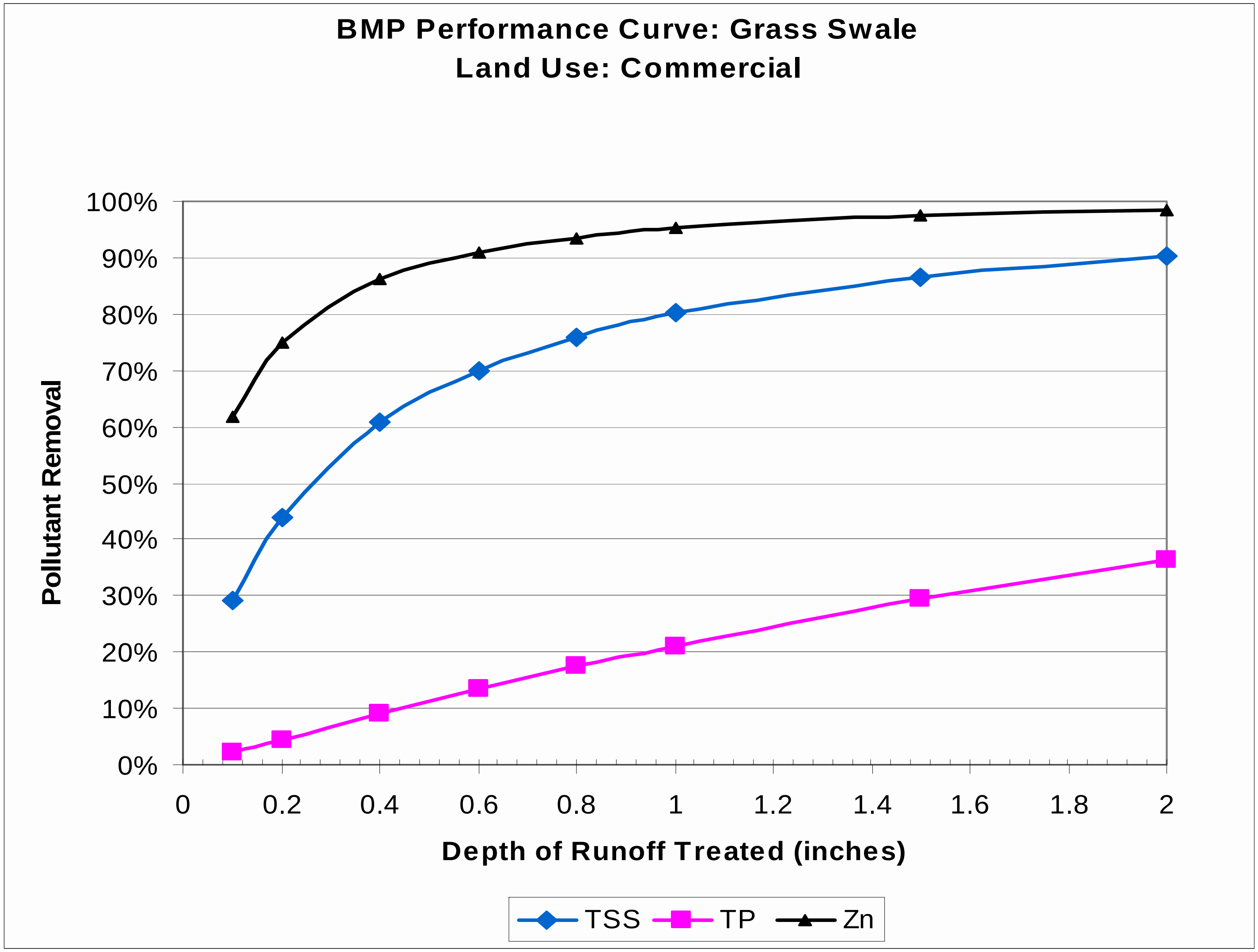
BMP Name: Grass Swale

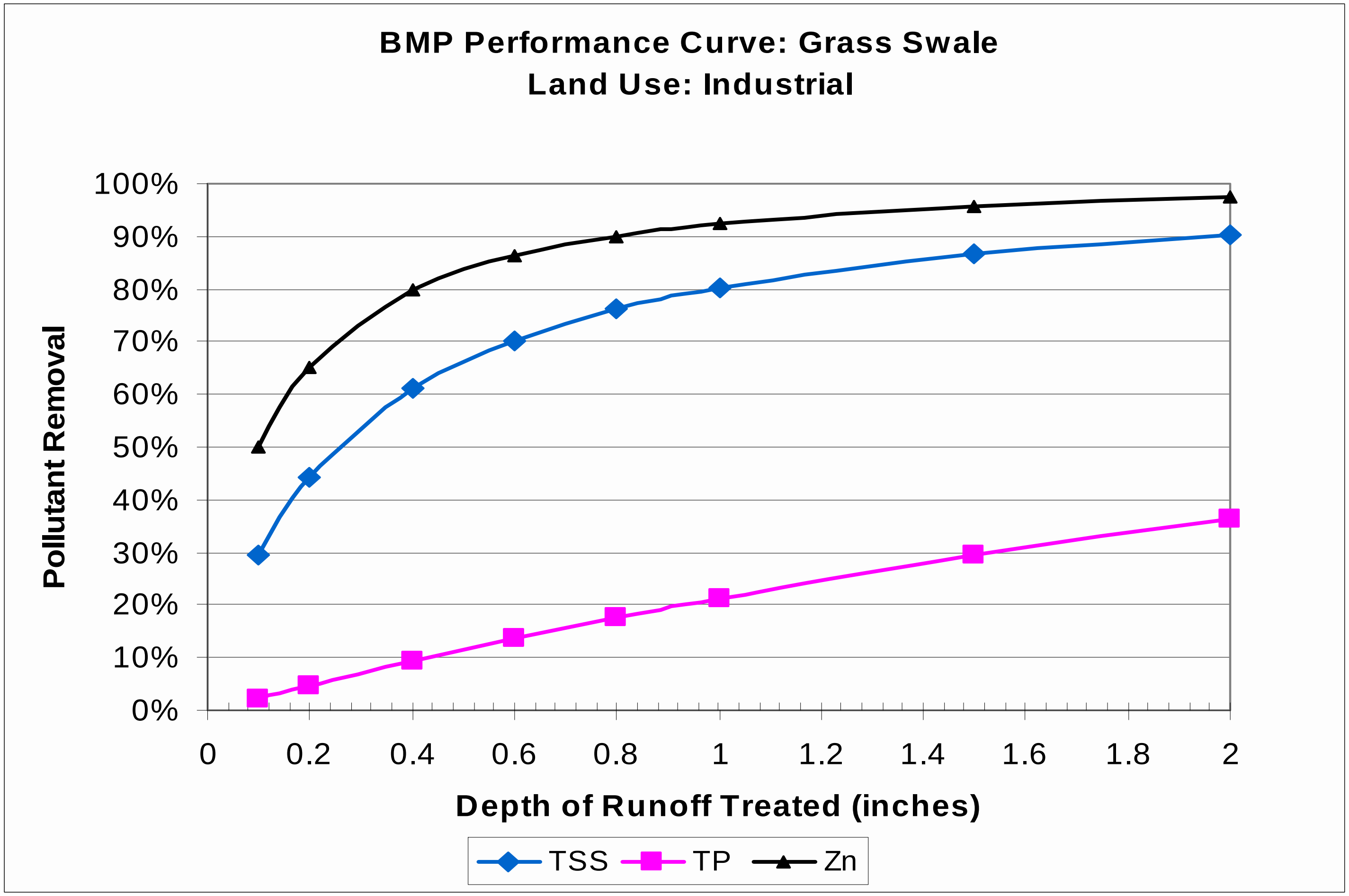
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.5**	**2.0**
Commercial	TSS	29%	44%	61%	70%	76%	80%	87%	90%
	TP	2%	5%	9%	13%	17%	21%	29%	36%
	Zn	62%	75%	86%	91%	94%	95%	97%	99%
Industrial	TSS	30%	44%	61%	70%	76%	80%	87%	90%
	TP	2%	5%	9%	13%	17%	21%	29%	36%
	Zn	50%	65%	80%	86%	90%	92%	96%	97%
High-Density Residential	TSS	30%	45%	62%	71%	77%	81%	87%	91%
	TP	2%	5%	9%	13%	17%	21%	29%	36%
	Zn	54%	69%	82%	88%	91%	93%	96%	98%
Medium-Density Residential	TSS	34%	49%	65%	74%	79%	83%	89%	92%
	TP	2%	5%	9%	13%	17%	21%	29%	36%
	Zn	32%	48%	66%	75%	81%	85%	91%	94%
Low-Density Residential	TSS	34%	48%	64%	73%	78%	82%	88%	91%
	TP	2%	5%	9%	13%	17%	21%	29%	36%
	Zn	27%	41%	60%	71%	78%	82%	89%	93%

Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	**TP**	**Zn**
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

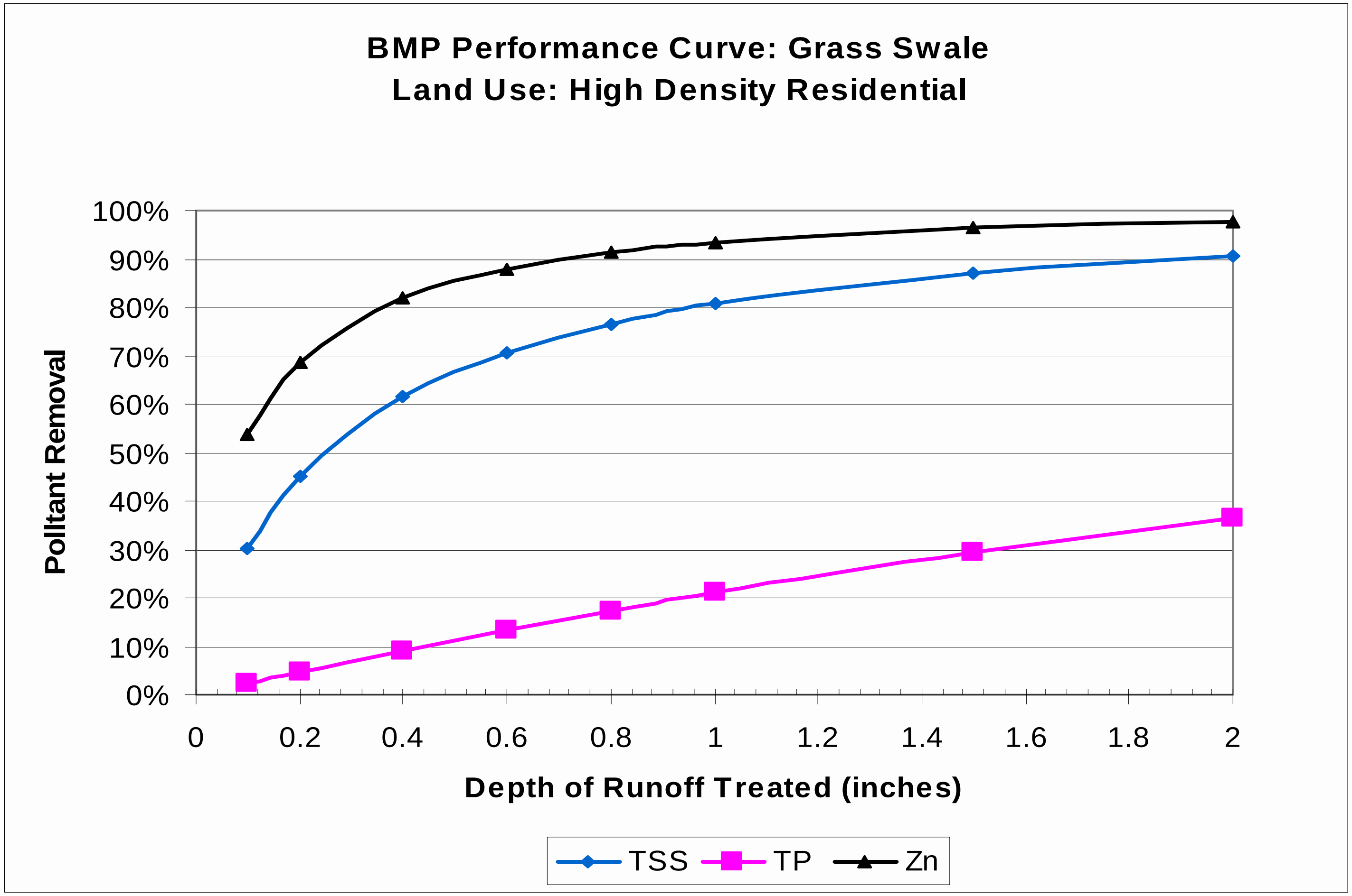
BMP Performance Curve: Grass Swale

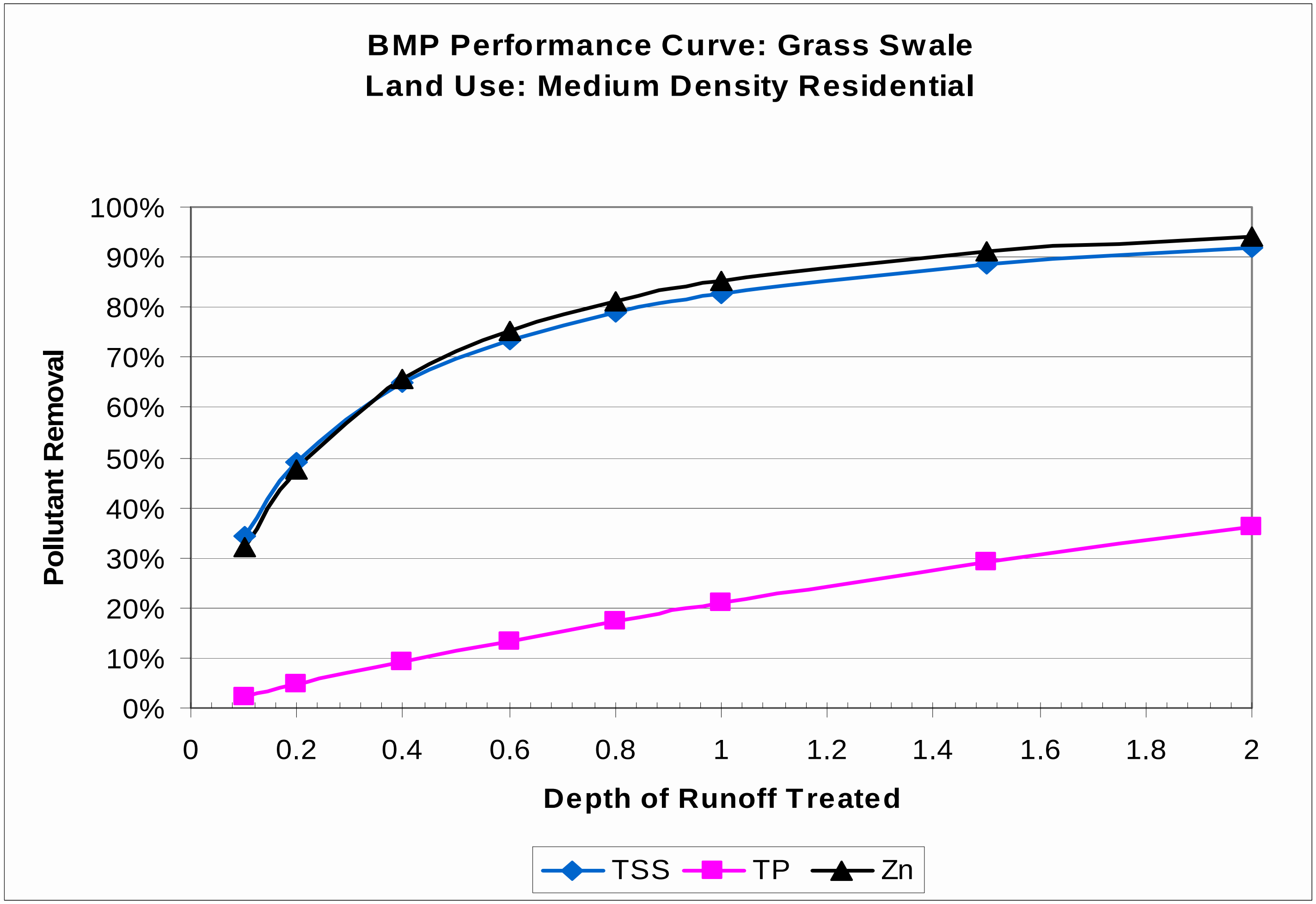


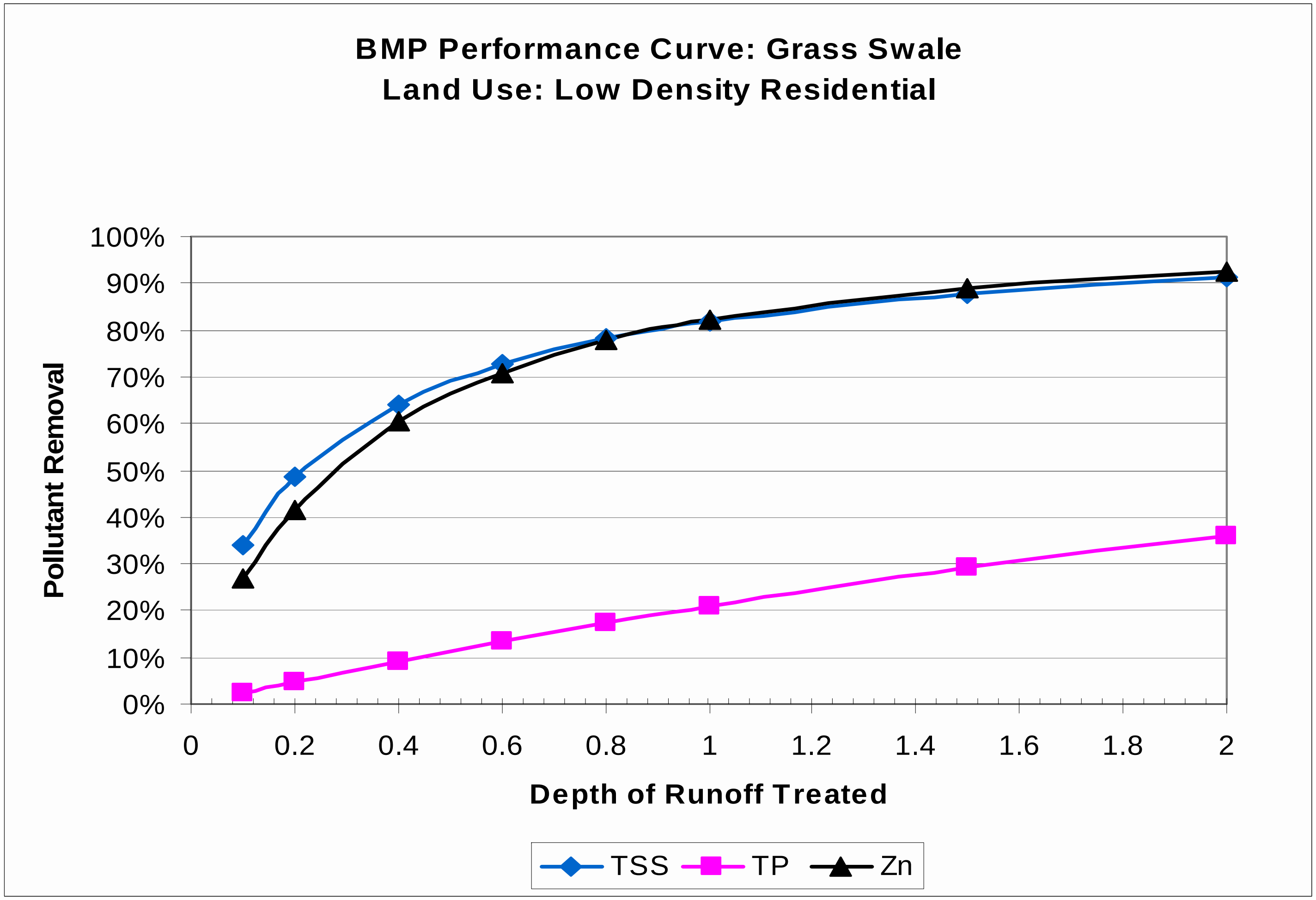


BMP Performance Curve: Grass Swale
Land Use: Industrial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

BMP Performance Curve: Grass Swale




BMP Performance Curve: Grass Swale
Land Use: Medium Density Residential
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn


BMP Performance Curve: Grass Swale
Land Use: Low Density Residential
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn

BMP Performance Curve: Wet Pond

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

September 2008

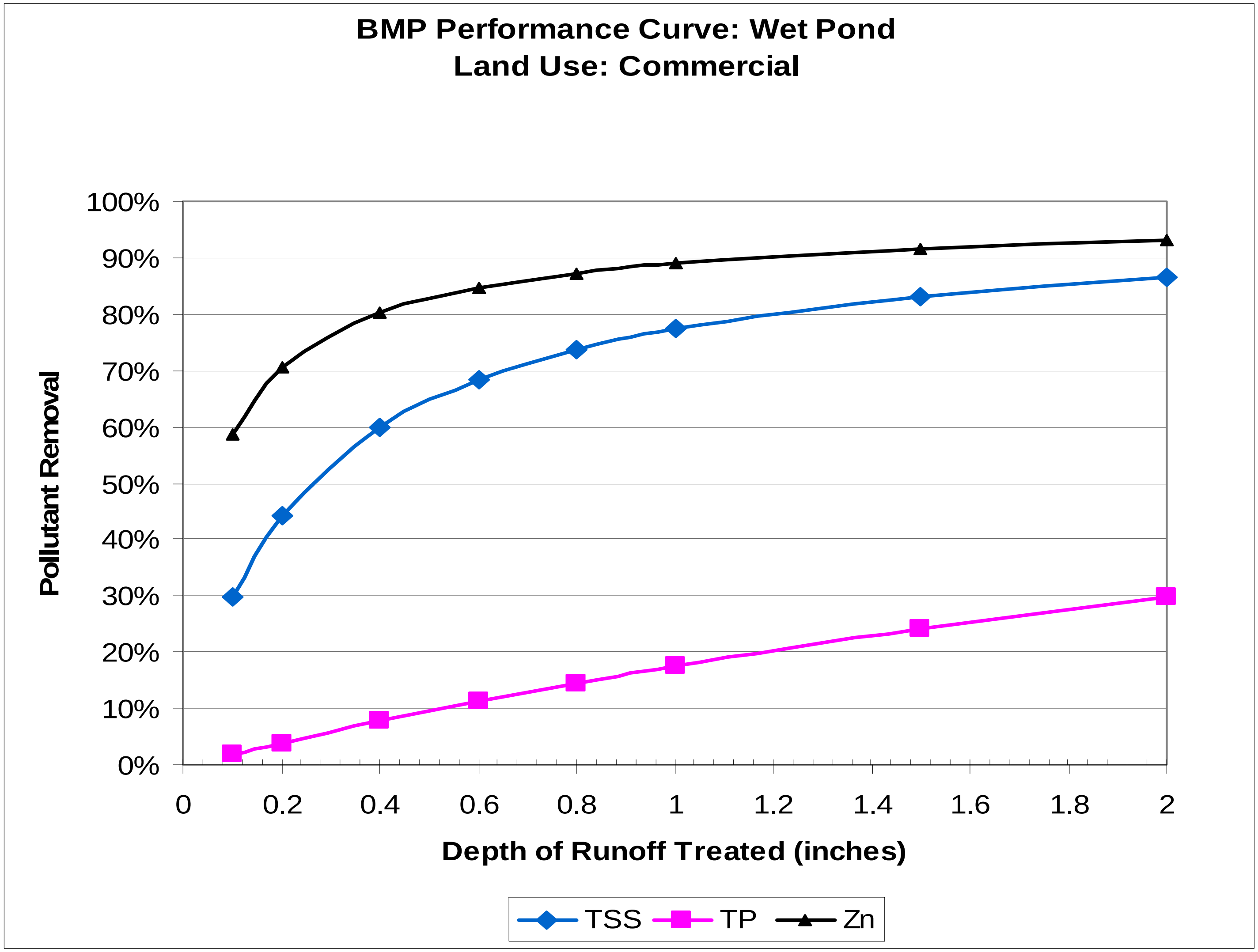
BMP Performance Table

BMP Name: Wet Pond

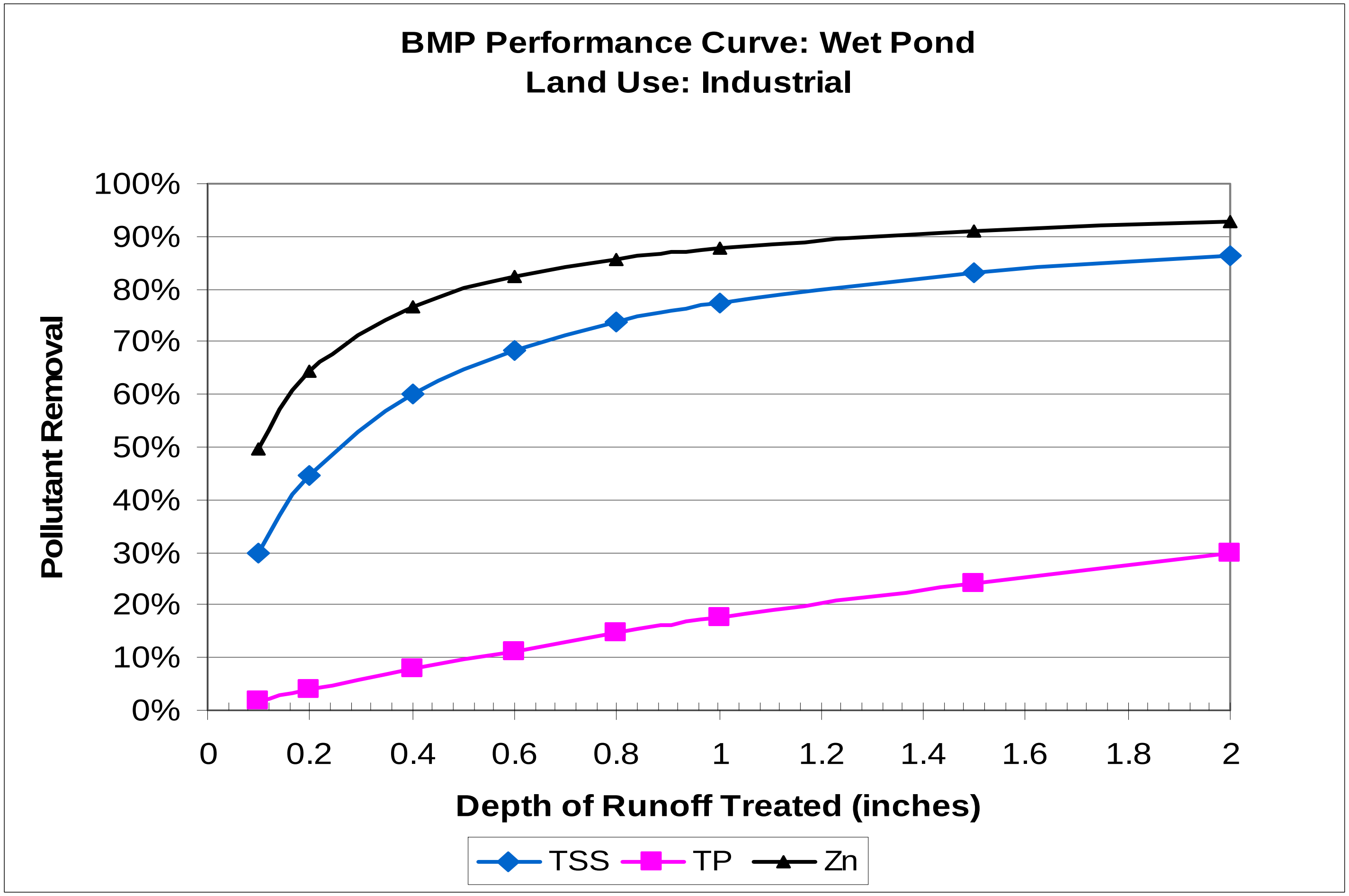
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	30%	44%	60%	68%	74%	77%	83%	86%
	TP	2%	4%	8%	11%	15%	18%	24%	30%
	Zn	59%	71%	80%	85%	87%	89%	92%	93%
Industrial	TSS	30%	45%	60%	69%	74%	78%	83%	87%
	TP	2%	4%	8%	11%	15%	18%	24%	30%
	Zn	50%	64%	77%	82%	86%	88%	91%	93%
High-Density Residential	TSS	30%	44%	60%	69%	74%	78%	83%	87%
	TP	2%	4%	8%	11%	15%	18%	24%	30%
	Zn	53%	71%	78%	83%	86%	88%	91%	93%
Medium-Density Residential	TSS	34%	48%	62%	70%	75%	78%	84%	87%
	TP	2%	4%	8%	11%	14%	17%	24%	30%
	Zn	33%	49%	65%	73%	78%	82%	87%	90%
Low-Density Residential	TSS	33%	47%	61%	69%	74%	78%	83%	86%
	TP	2%	4%	8%	11%	14%	17%	24%	30%
	Zn	28%	43%	60%	69%	75%	79%	85%	89%

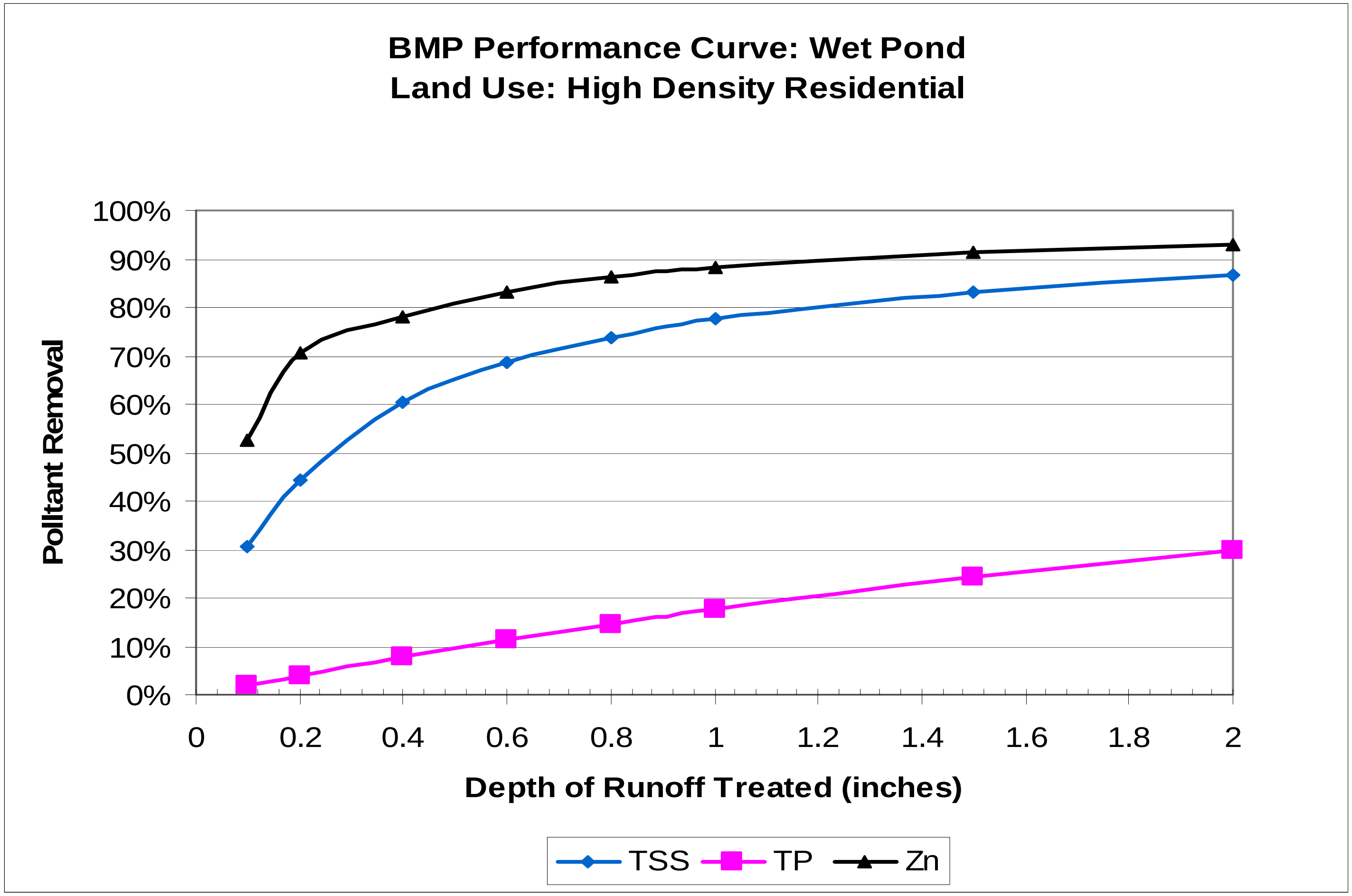
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

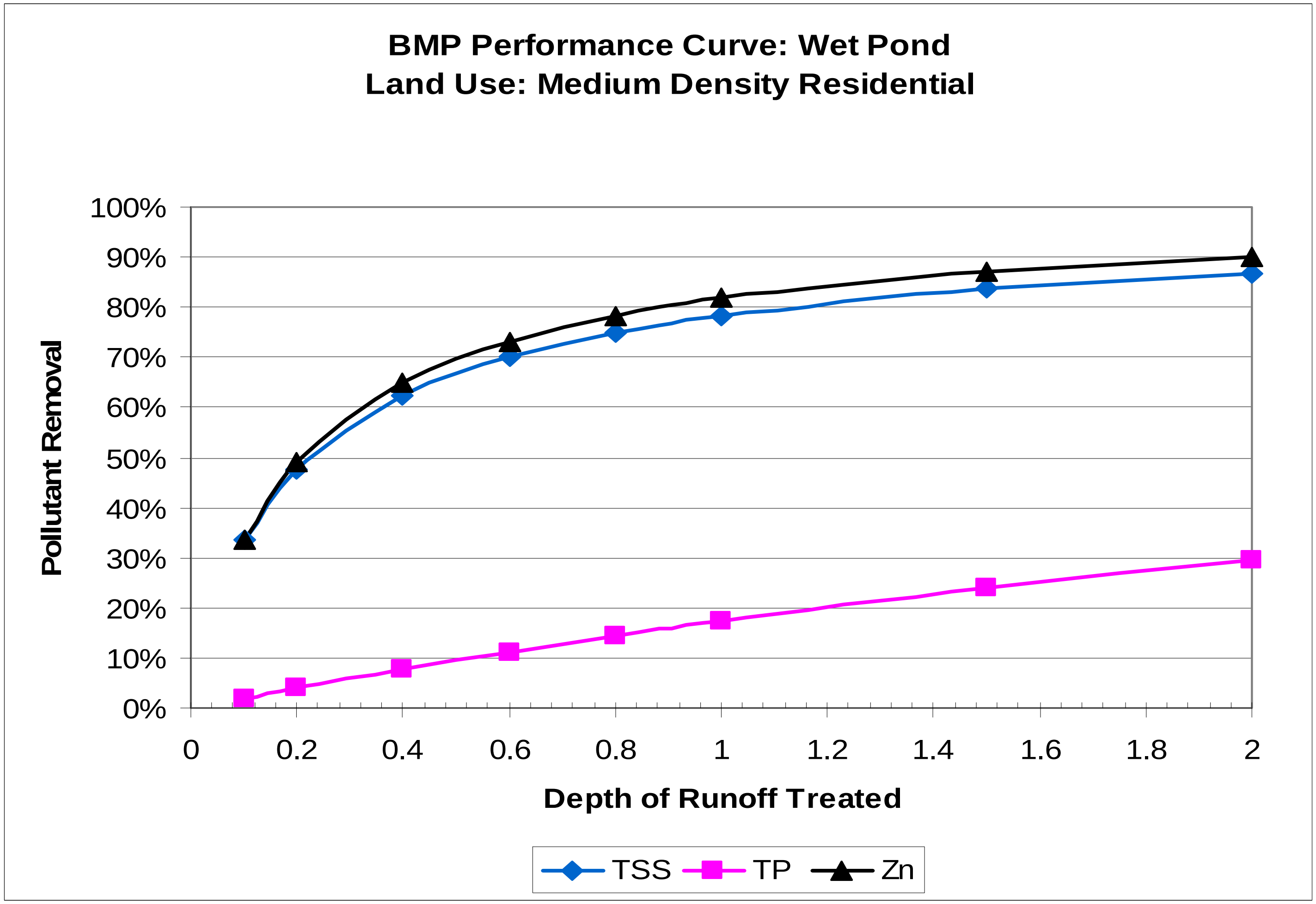

BMP Performance Curve: Wet Pond
Land Use: Commercial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

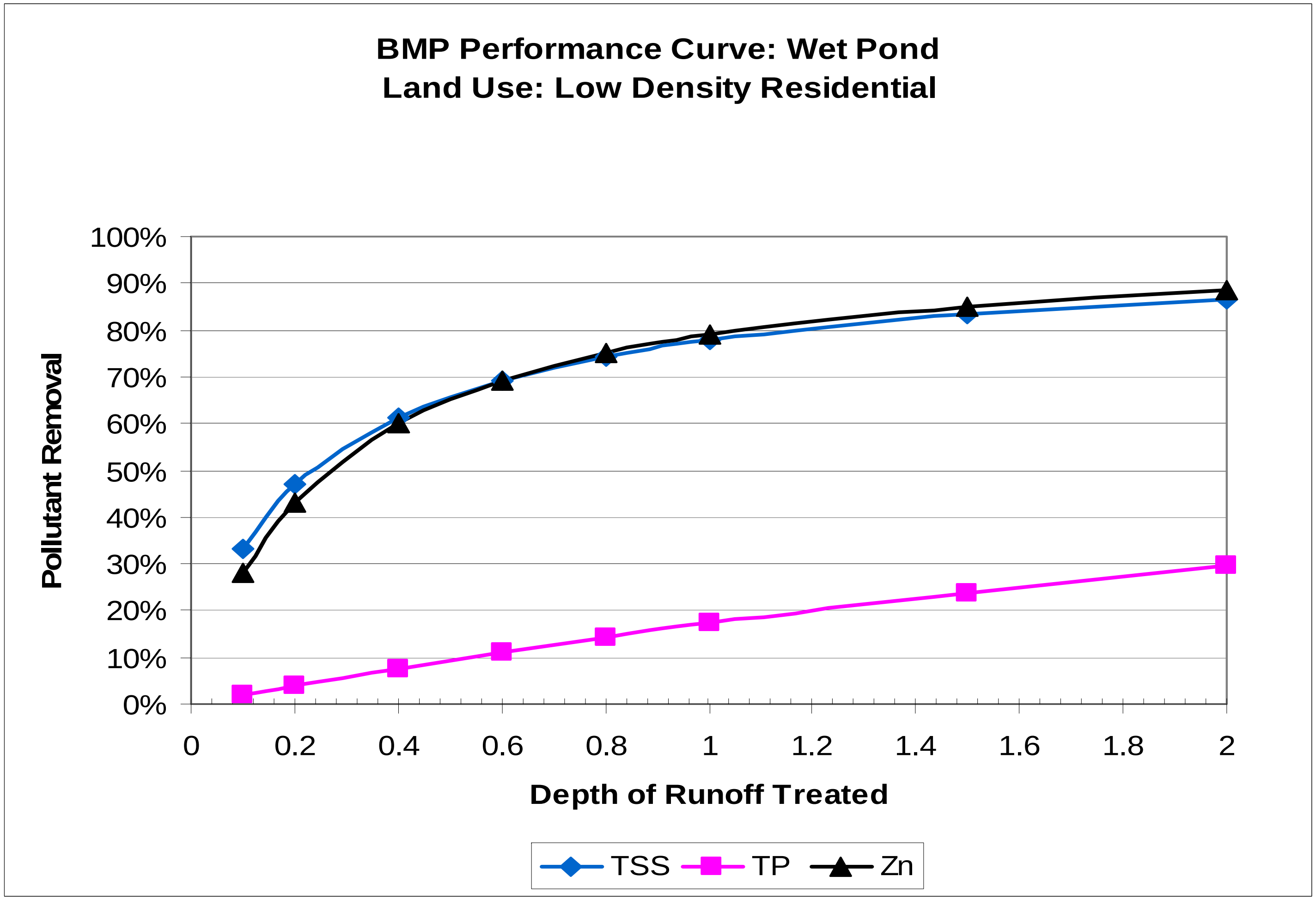
BMP Performance Curve: Wet Pond




BMP Performance Curve: Wet Pond
Land Use: High Density Residential
Polltant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

BMP Performance Curve: Wet Pond




BMP Performance Curve: Wet Pond
Land Use: Low Density Residential
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn

BMP Performance Curve: Dry Pond

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

September 2008

BMP Performance Table

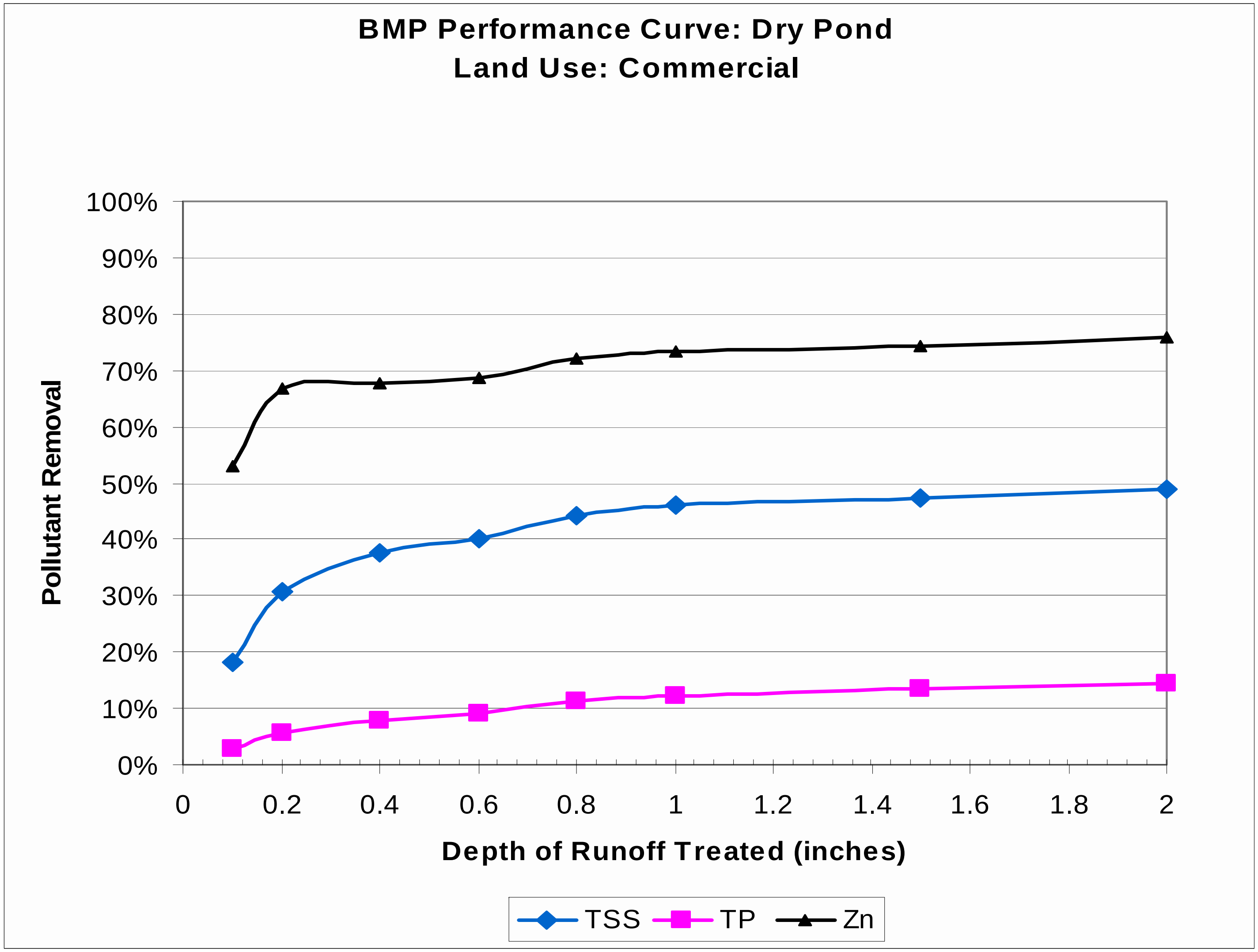
BMP Name: Dry Pond

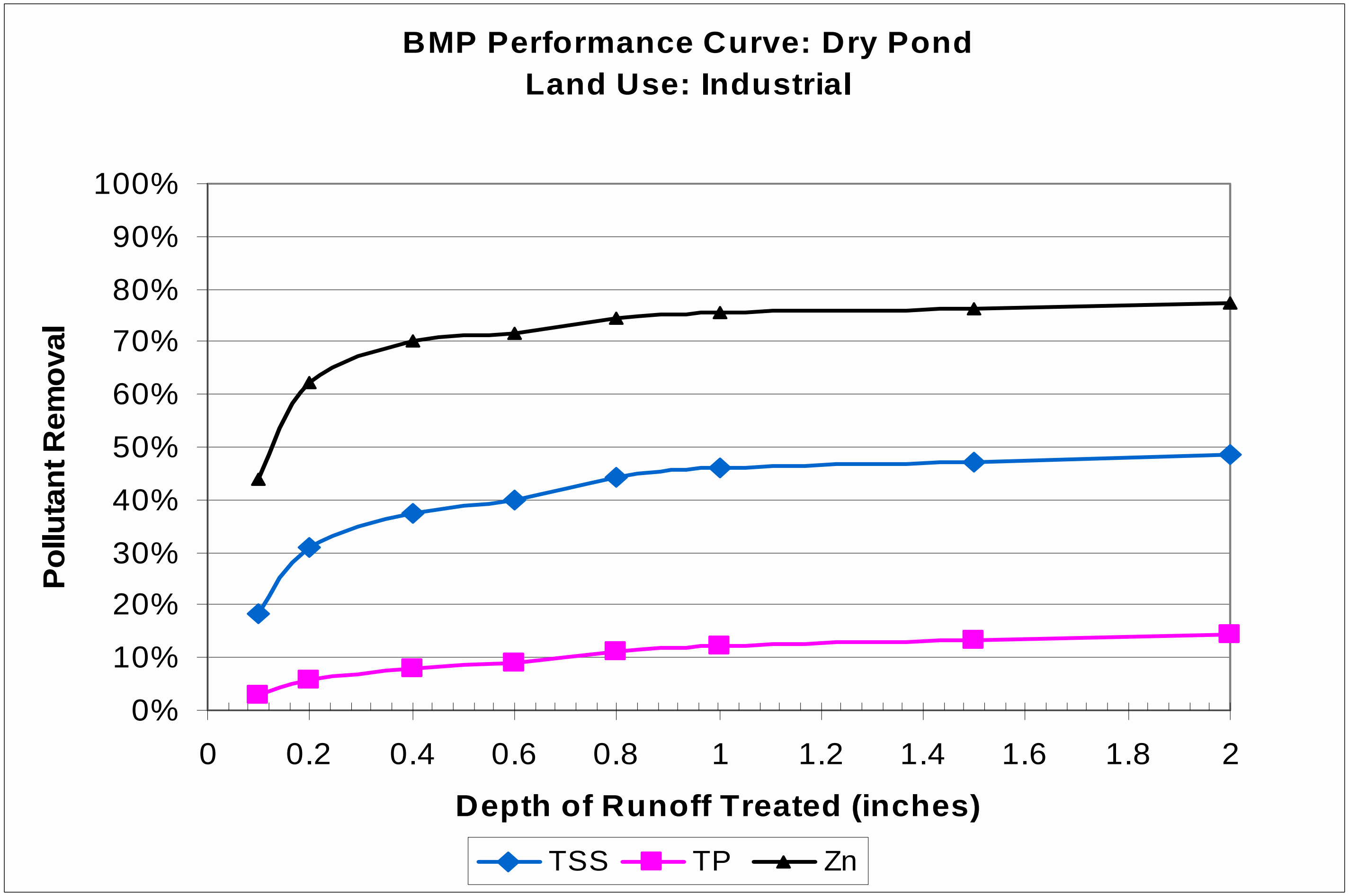
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.5**	**2.0**
Commercial	TSS	18%	31%	38%	40%	44%	46%	47%	49%
	TP	3%	6%	8%	9%	11%	12%	13%	14%
	Zn	53%	67%	68%	69%	72%	73%	74%	76%
Industrial	TSS	18%	31%	38%	40%	44%	46%	47%	49%
	TP	3%	6%	8%	9%	11%	12%	13%	14%
	Zn	44%	62%	70%	71%	75%	76%	76%	77%
High-Density Residential	TSS	18%	31%	37%	40%	44%	46%	47%	49%
	TP	3%	6%	8%	9%	11%	12%	13%	14%
	Zn	47%	65%	70%	70%	74%	75%	76%	77%
Medium-Density Residential	TSS	20%	32%	37%	39%	43%	45%	46%	48%
	TP	3%	6%	8%	9%	11%	12%	13%	14%
	Zn	27%	45%	62%	71%	76%	79%	80%	81%
Low-Density Residential	TSS	20%	31%	37%	39%	43%	45%	47%	48%
	TP	3%	6%	8%	9%	11%	12%	13%	14%
	Zn	22%	39%	59%	69%	75%	78%	81%	82%

Annual Pollutant Loading Rates

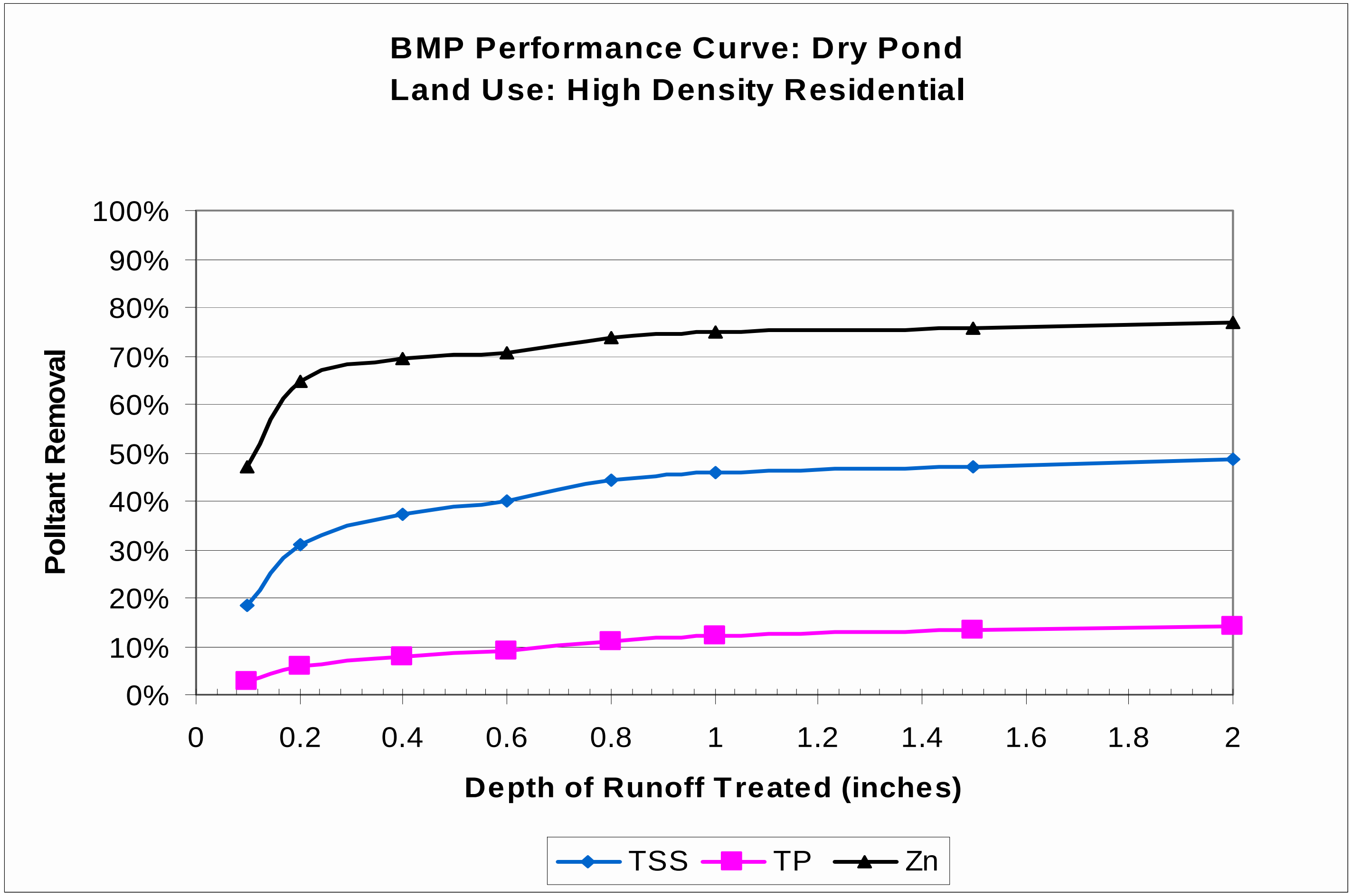
Land use	Pollutant load (lbs/acre-year)		
	TSS	**TP**	**Zn**
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

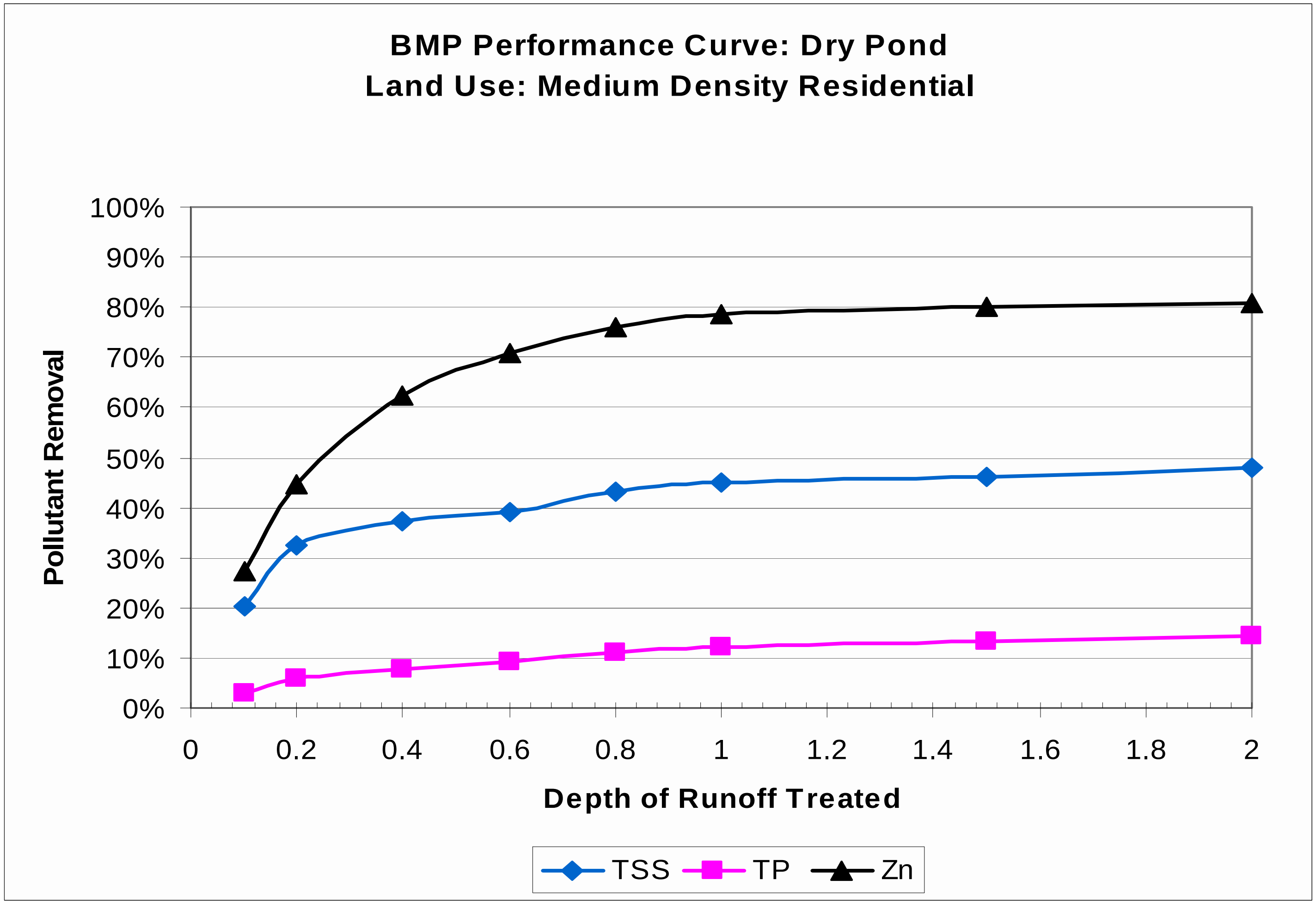
BMP Performance Curve: Dry Pond



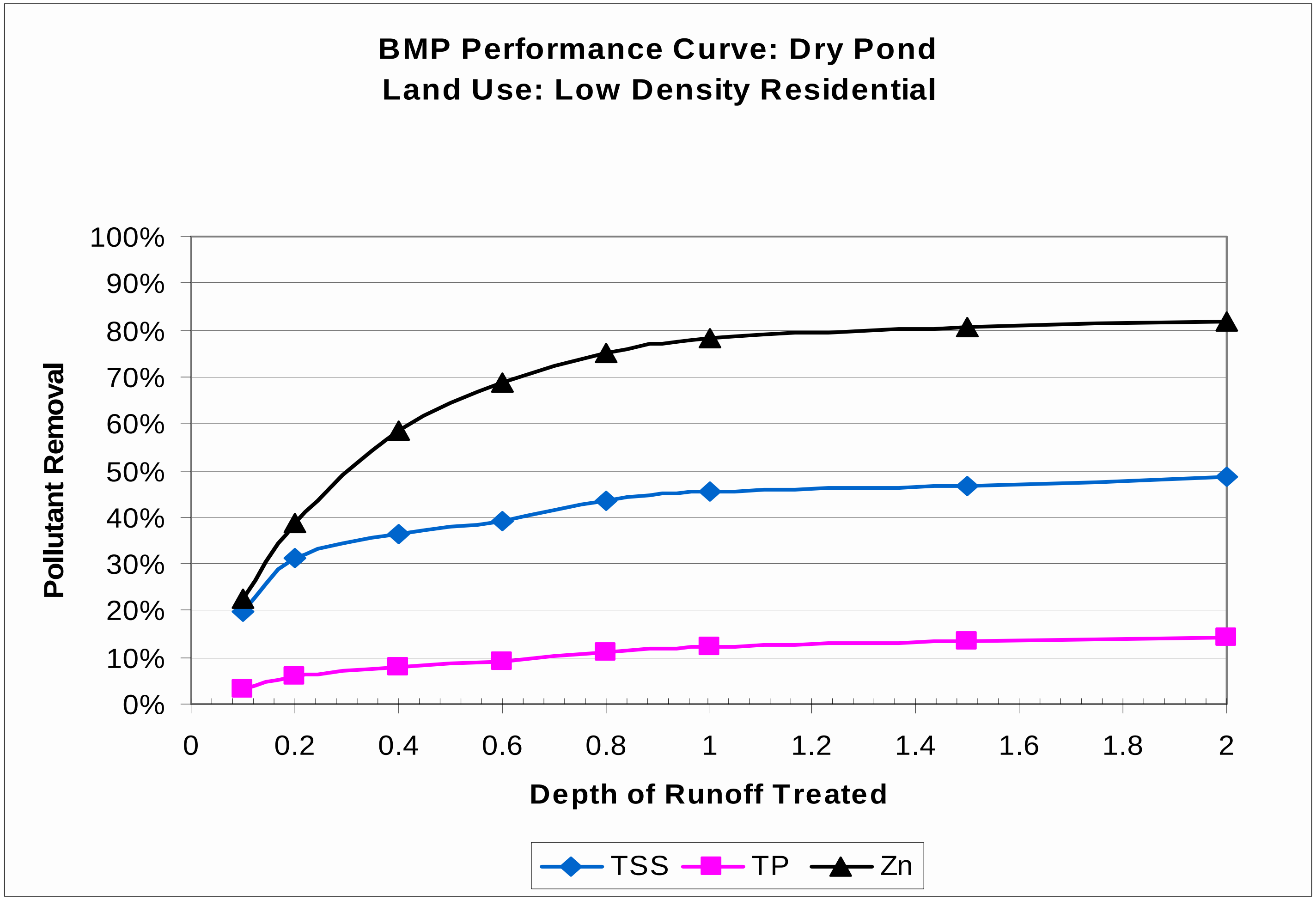

BMP Performance Curve: Dry Pond
Land Use: Industrial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn

BMP Performance Curve: Dry Pond




BMP Performance Curve: Dry Pond
Land Use: Medium Density Residential
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn

BMP Performance Curve: Dry Pond



BMP Performance Curve: Porous Pavement

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

September 2008

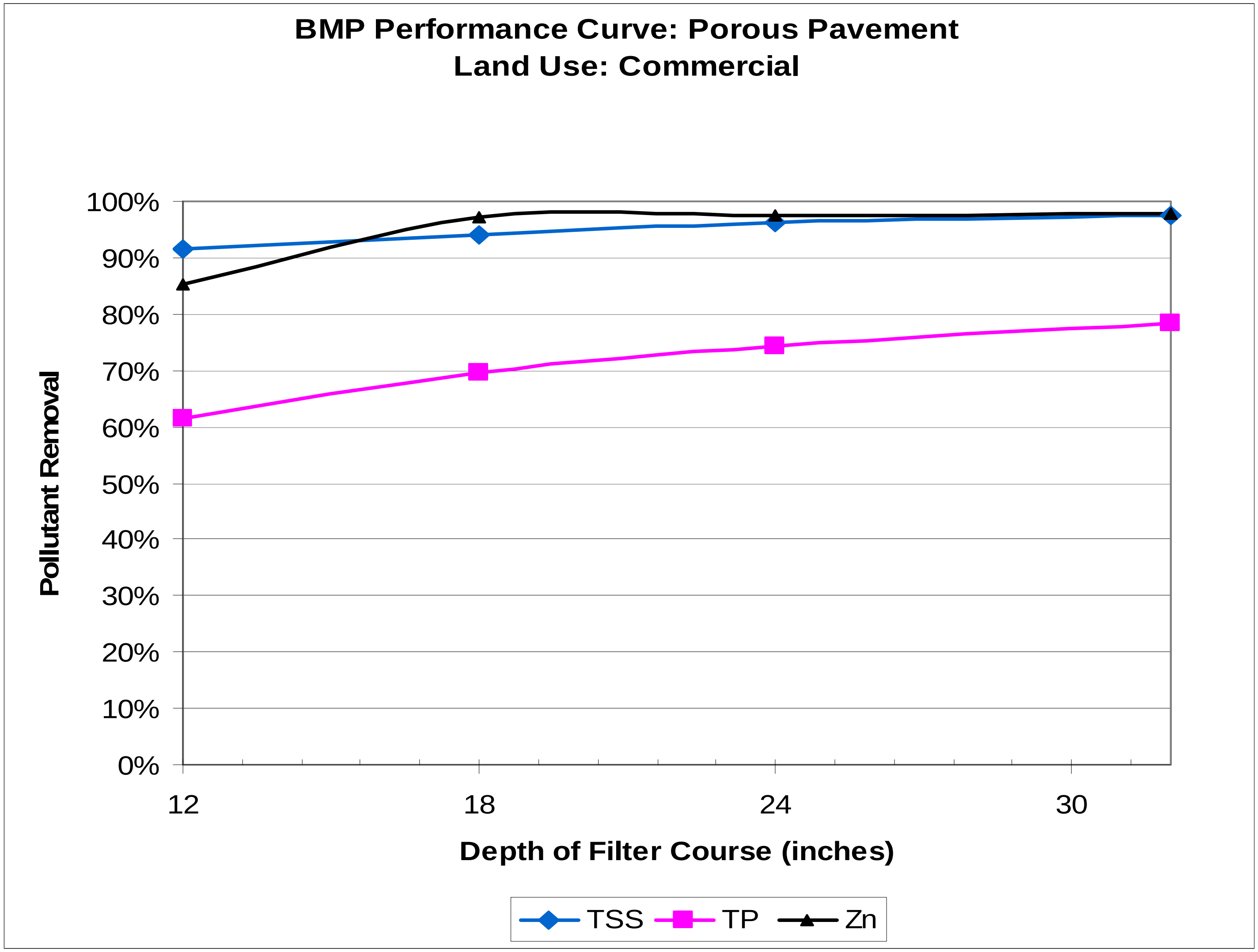
BMP Performance Table

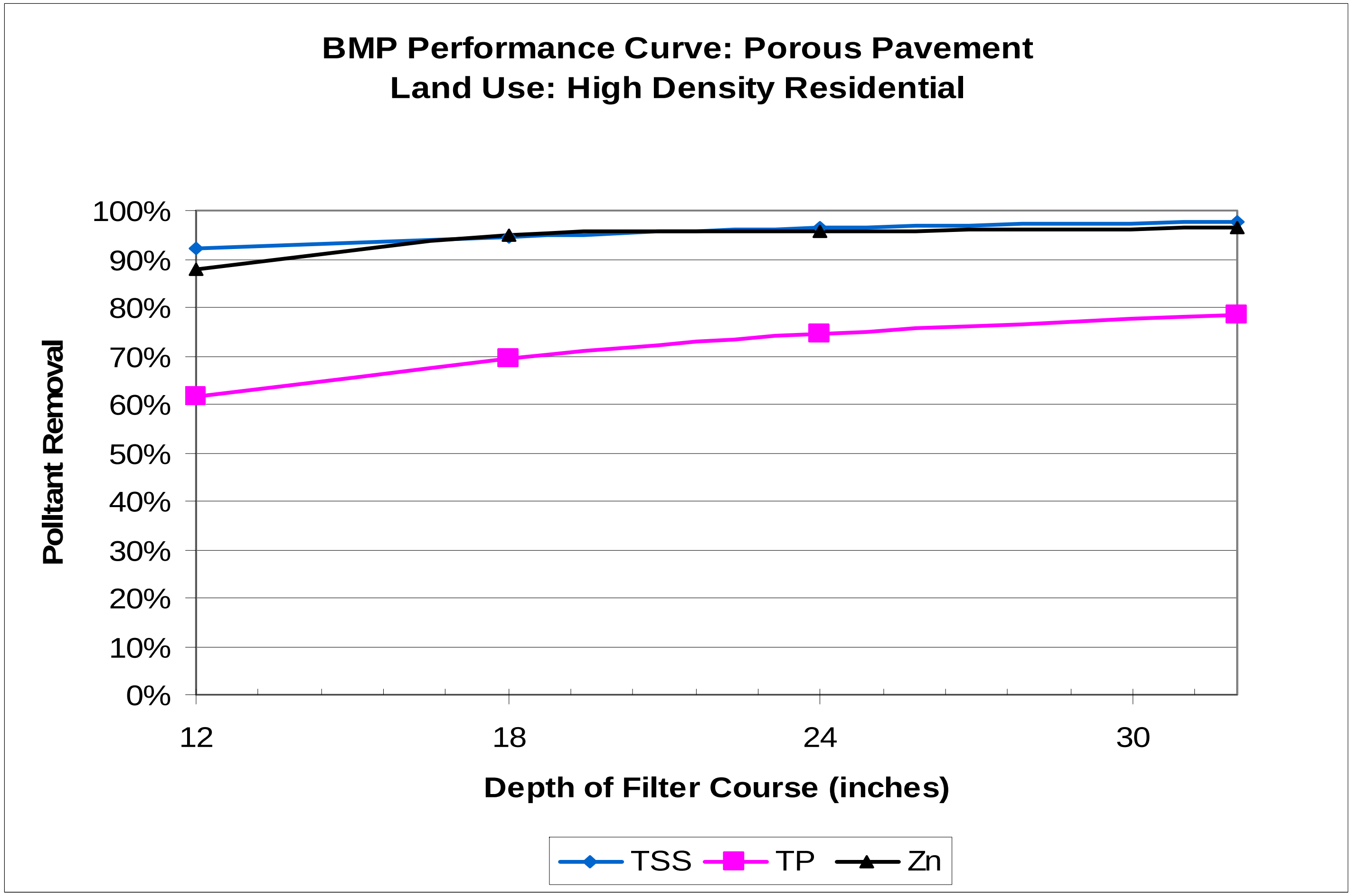
BMP Name: Porous Pavement

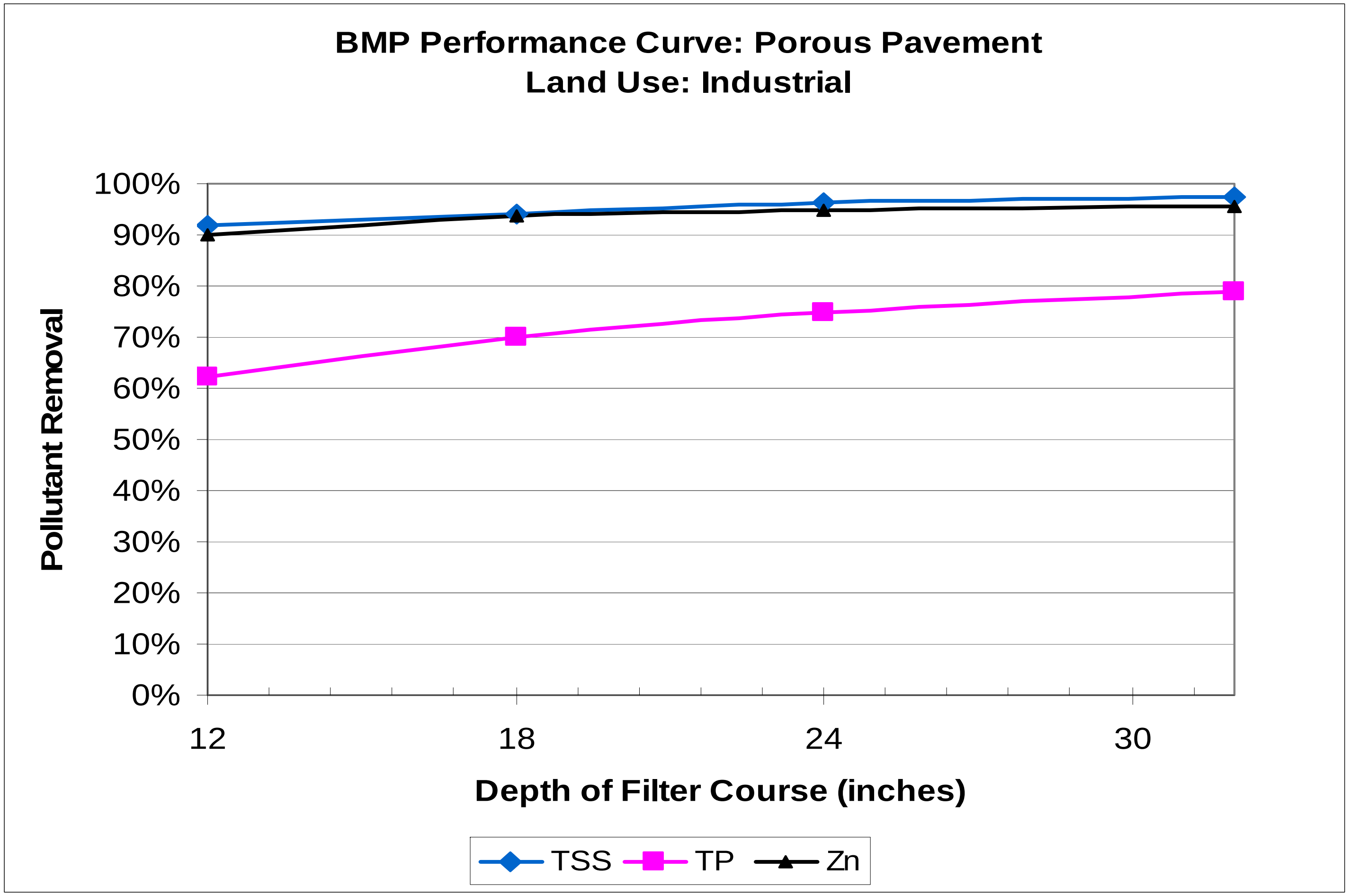
Land Use	Pollutant	Depth of Filter Course Layer (inches)			
		12	18	24	32
Commercial	TSS	92%	94%	96%	97%
	TP	62%	69%	74%	78%
	Zn	85%	97%	97%	98%
Industrial	TSS	92%	94%	96%	98%
	TP	62%	70%	75%	79%
	Zn	90%	94%	95%	95%
High-Density Residential	TSS	92%	94%	96%	98%
	TP	62%	70%	74%	78%
	Zn	88%	95%	96%	96%
Medium-Density Residential	TSS	95%	97%	98%	99%
	TP	61%	68%	73%	77%
	Zn	70%	71%	75%	79%
Low-Density Residential	TSS	92%	94%	96%	97%
	TP	60%	67%	71%	75%
	Zn	63%	64%	69%	74%

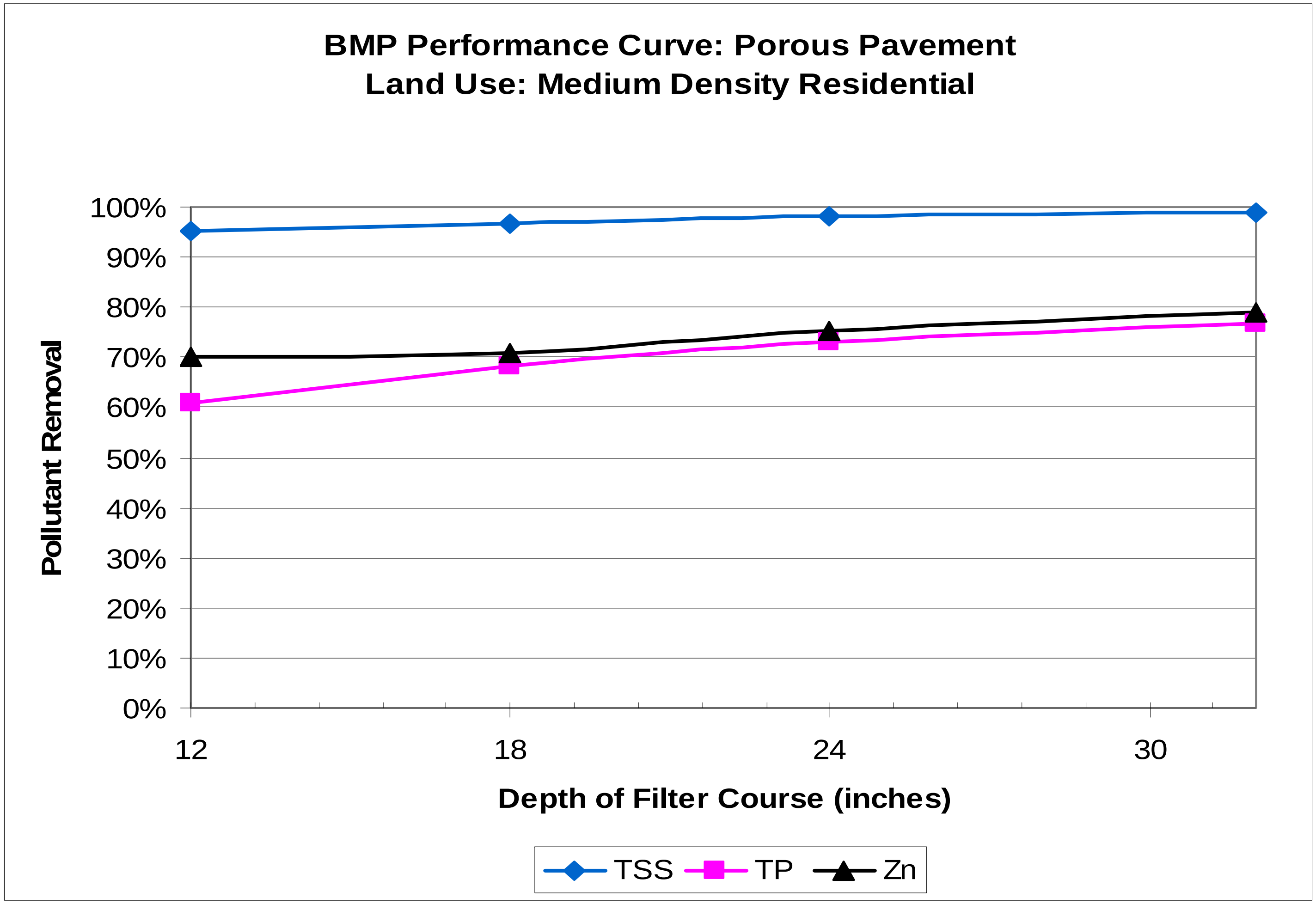
Annual Pollutant Loading Rates

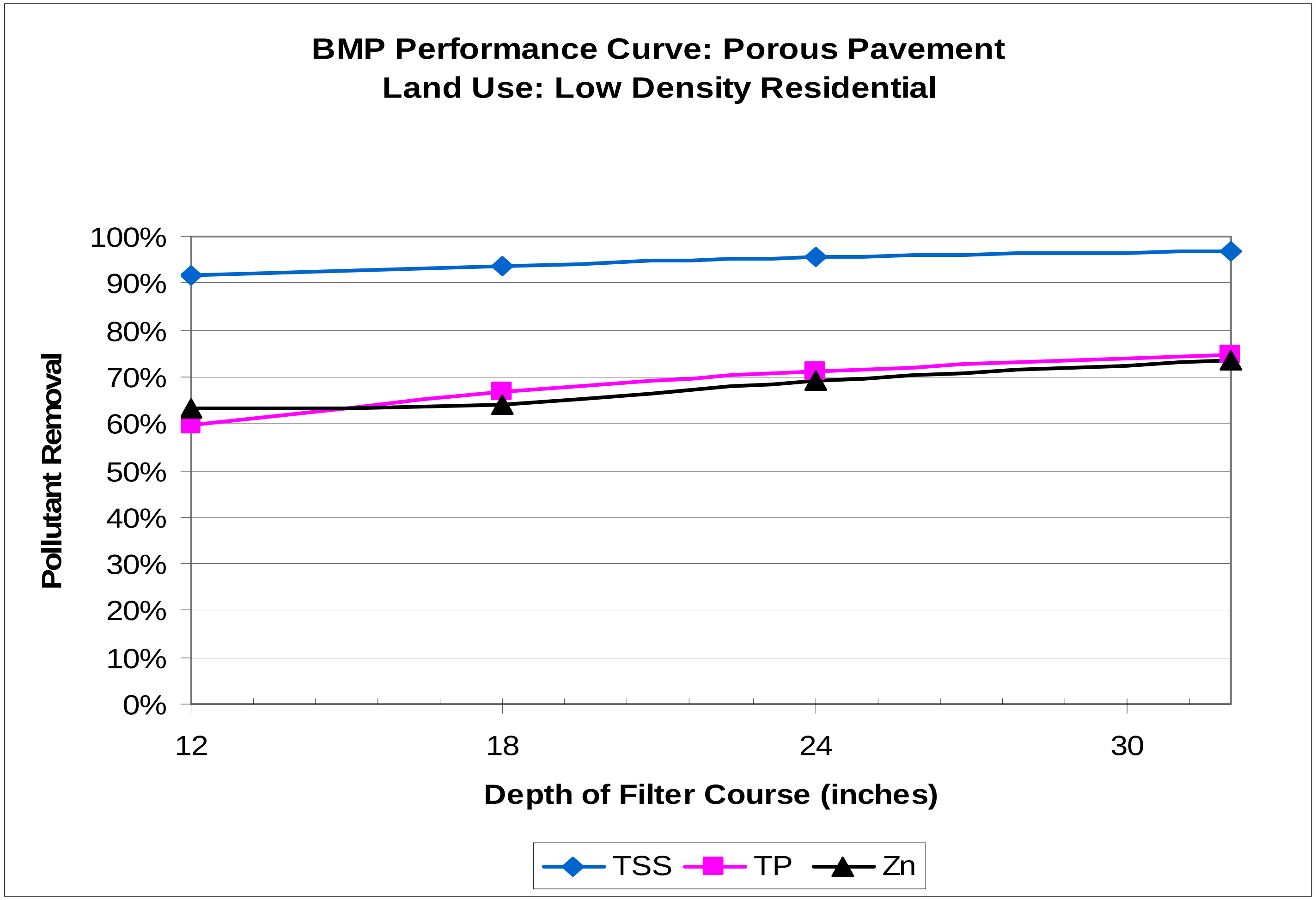
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043


BMP Performance Curve: Porous Pavement
Land Use: Commercial
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
12
18
24
30
Depth of Filter Course (inches)
TSS
TP
Zn


BMP Performance Curve: Porous Pavement
Land Use: High Density Residential
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Polltant Removal
12
18
24
30
Depth of Filter Course (inches)
TSS
TP
Zn


BMP Performance Curve: Porous Pavement
Land Use: Industrial
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
12
18
24
30
Depth of Filter Course (inches)
TSS
TP
Zn


BMP Performance Curve: Porous Pavement
Land Use: Medium Density Residential
Pollutant Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
12
18
24
30
Depth of Filter Course (inches)
TSS
TP
Zn


BMP Performance Curve: Porous Pavement
Land Use: Low Density Residential
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
12
18
24
30
Depth of Filter Course (inches)
TSS
TP
Zn

APPENDIX C: BMP PERFORMANCE CURVES FOR INFILTRATION BASIN-SIMPLE DYNAMIC METHOD

Note: During the development of the following infiltration basin performance curves (December 2008), the “Simple Dynamic” method was used to calculate the BMP surface areas. The calculation method was updated (and subsequently the infiltration performance curves, in Appendix B) with the “Static” method in the March 2010 revision. Here the infiltration basin performance curves based on the “Simple Dynamic” method are included for record purposes.

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method

Prepared for:

United States Environmental Protection Agency – Region 1
One Congress Street, Suite 1100
Boston, MA 02114

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

September 2008

BMP Performance Table

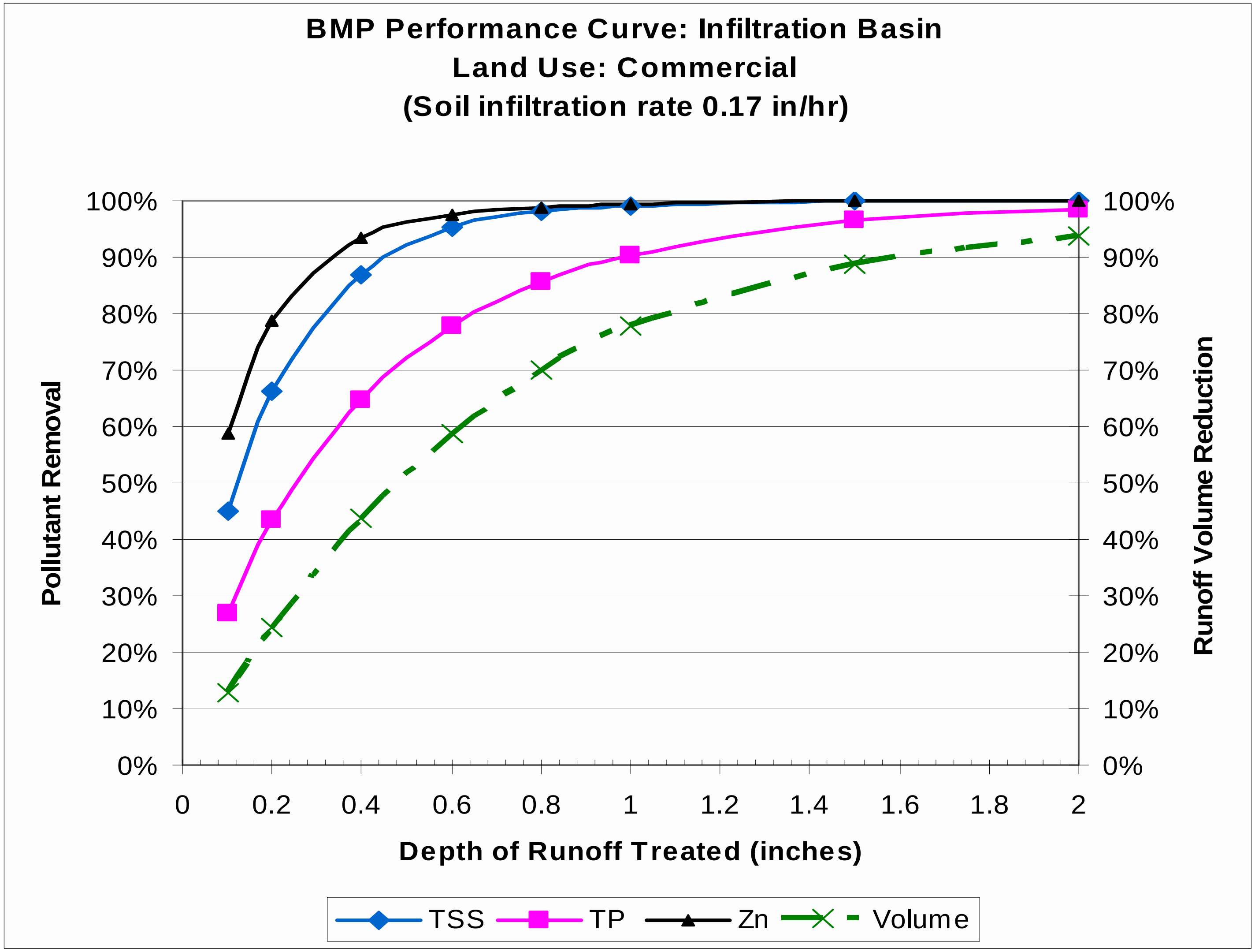
BMP Name: Infiltration Basin-Simple Dynamic Method

Soil Infiltration Rate: 0.17 in/hr

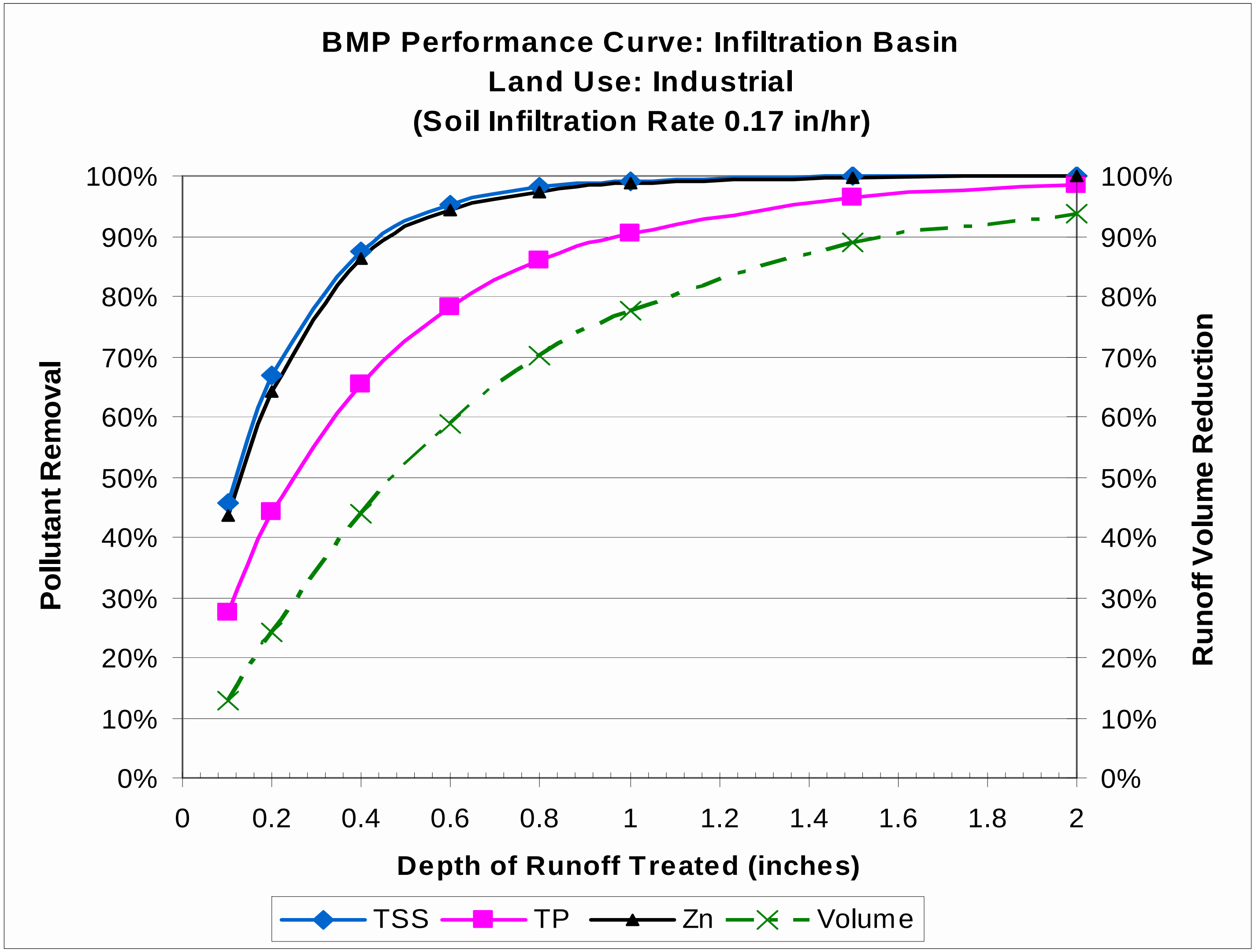
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	45%	66%	87%	95%	98%	99%	100%	100%
	TP	27%	43%	65%	78%	86%	90%	96%	98%
	Zn	59%	79%	93%	97%	99%	99%	100%	100%
Industrial	TSS	46%	67%	87%	95%	98%	99%	100%	100%
	TP	27%	44%	65%	78%	86%	91%	97%	98%
	Zn	43%	64%	86%	94%	97%	99%	100%	100%
High-Density Residential	TSS	46%	68%	88%	95%	98%	99%	100%	100%
	TP	27%	44%	65%	78%	86%	90%	96%	98%
	Zn	48%	69%	89%	96%	98%	99%	100%	100%
Medium-Density Residential	TSS	53%	74%	91%	97%	99%	100%	100%	100%
	TP	28%	44%	65%	78%	85%	90%	96%	98%
	Zn	25%	42%	64%	78%	87%	92%	98%	99%
Low-Density Residential	TSS	51%	70%	88%	95%	98%	99%	100%	100%
	TP	29%	45%	65%	77%	85%	89%	95%	98%
	Zn	20%	35%	58%	73%	82%	89%	97%	99%
Runoff Volume Reduction		13%	24%	44%	59%	70%	78%	89%	94%

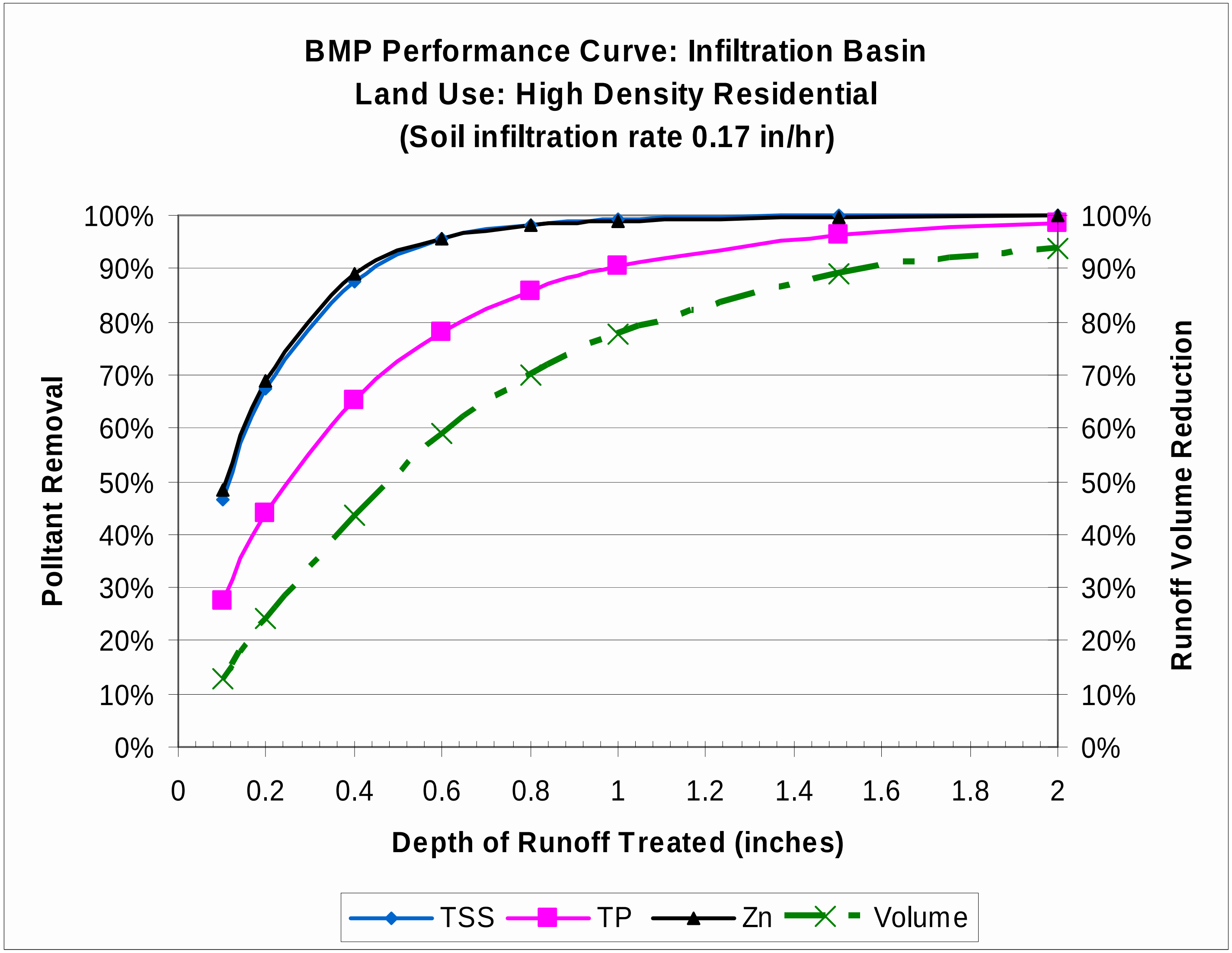
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

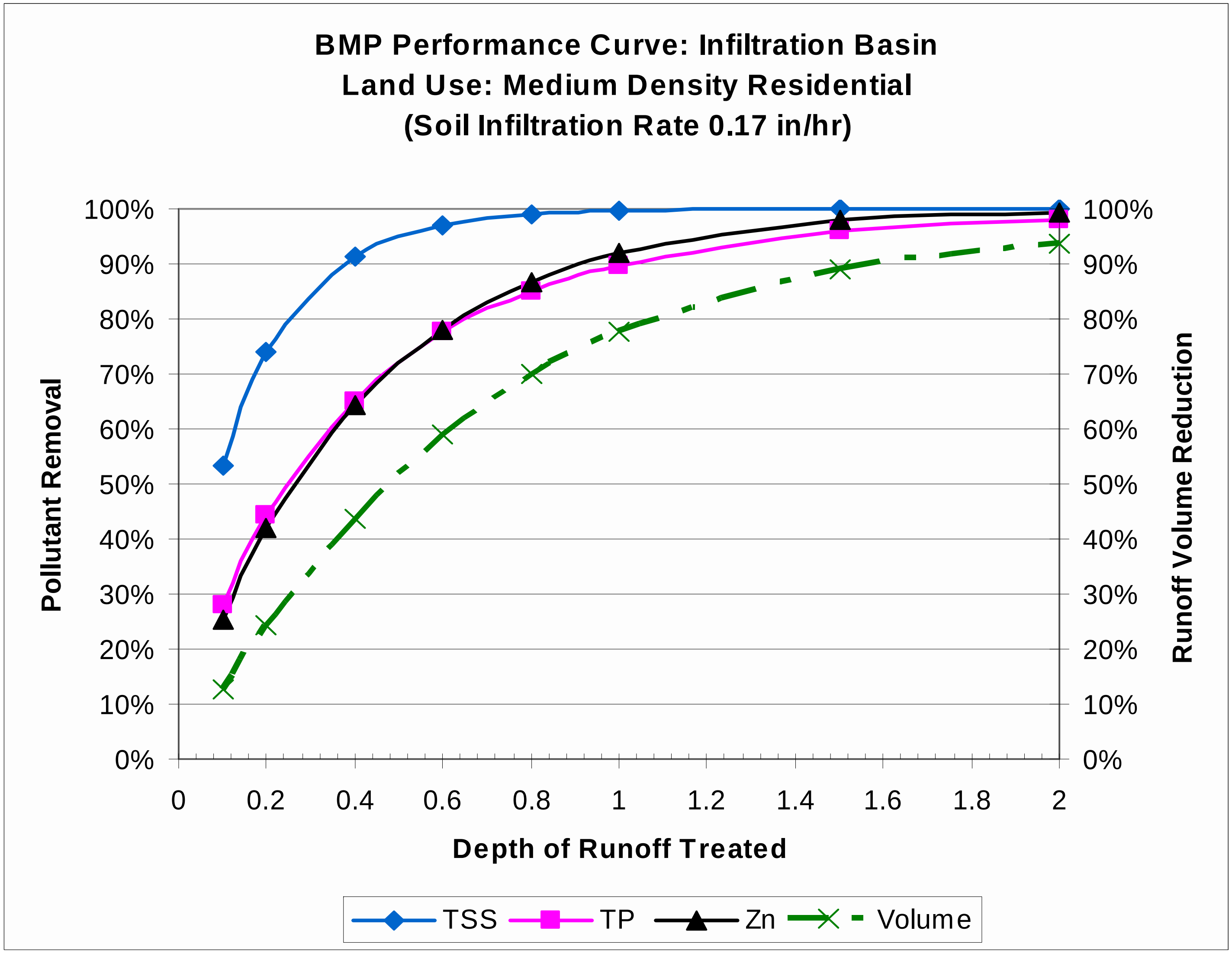

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

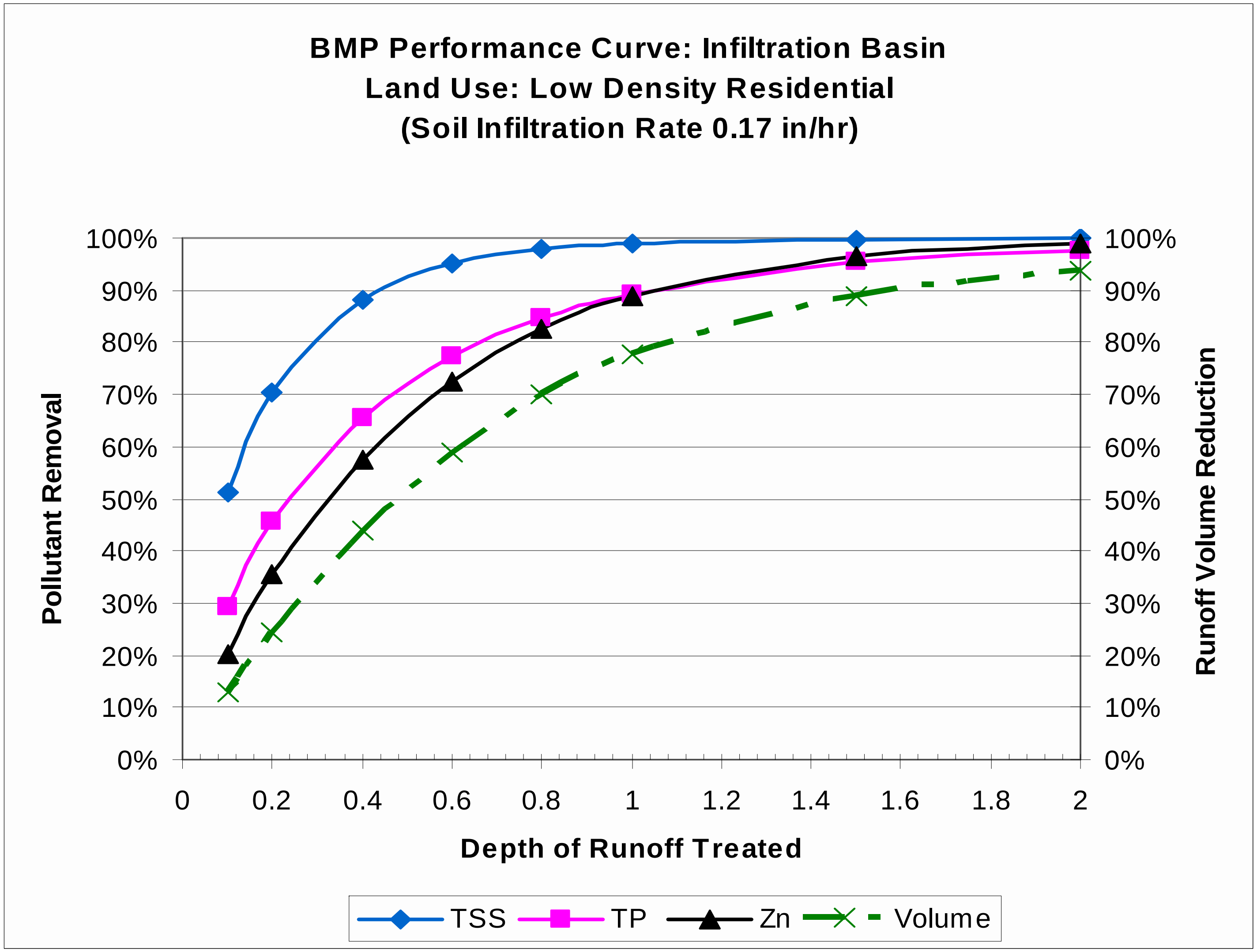
BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 0.17 in/hr)
Polltant Removal
Runoff Volume Reduction
Depth of Runoff Treated (inches)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 0.17 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method

BMP Performance Table

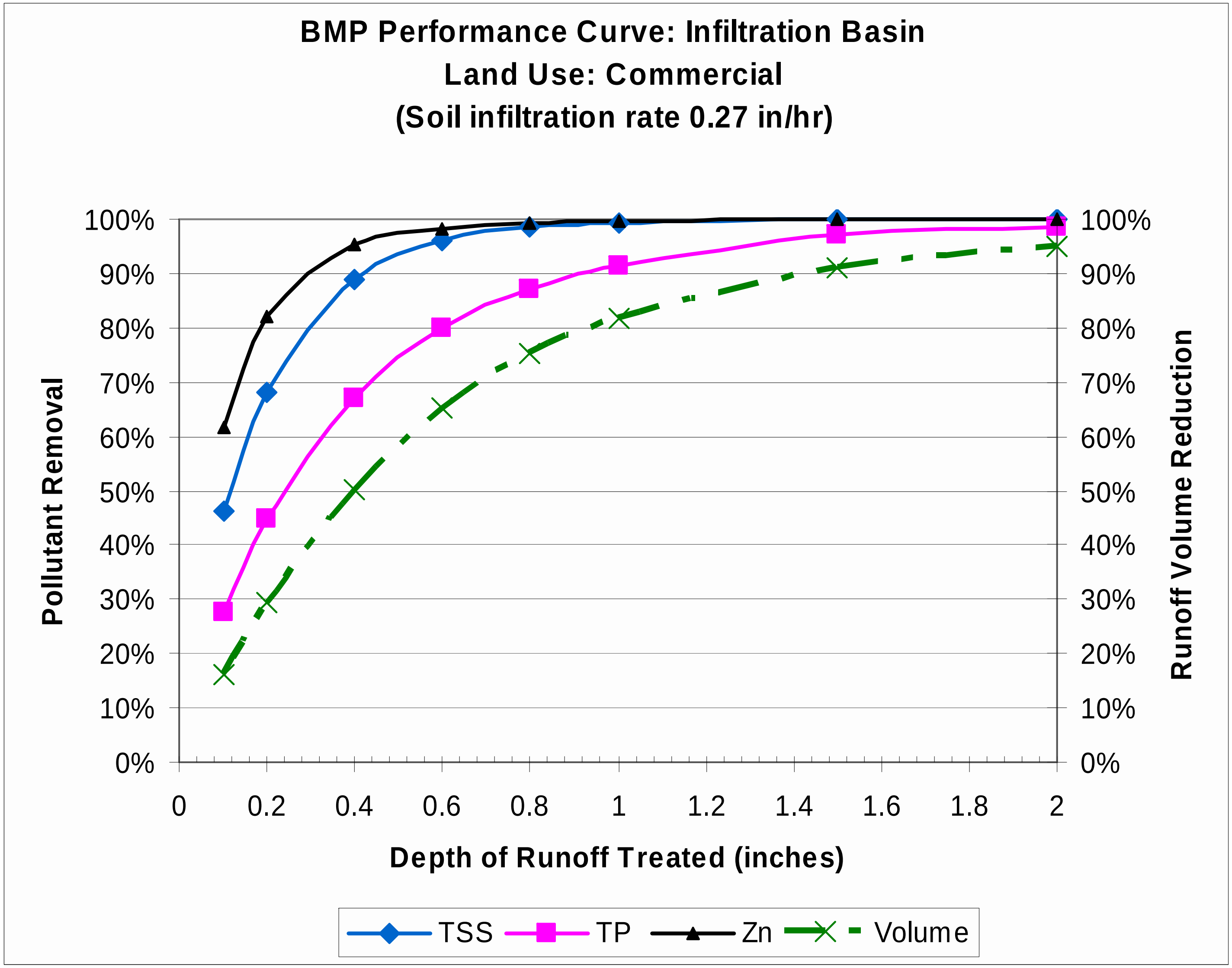
BMP Name: Infiltration Basin-Simple Dynamic Method

Soil Infiltration Rate: 0.27 in/hr

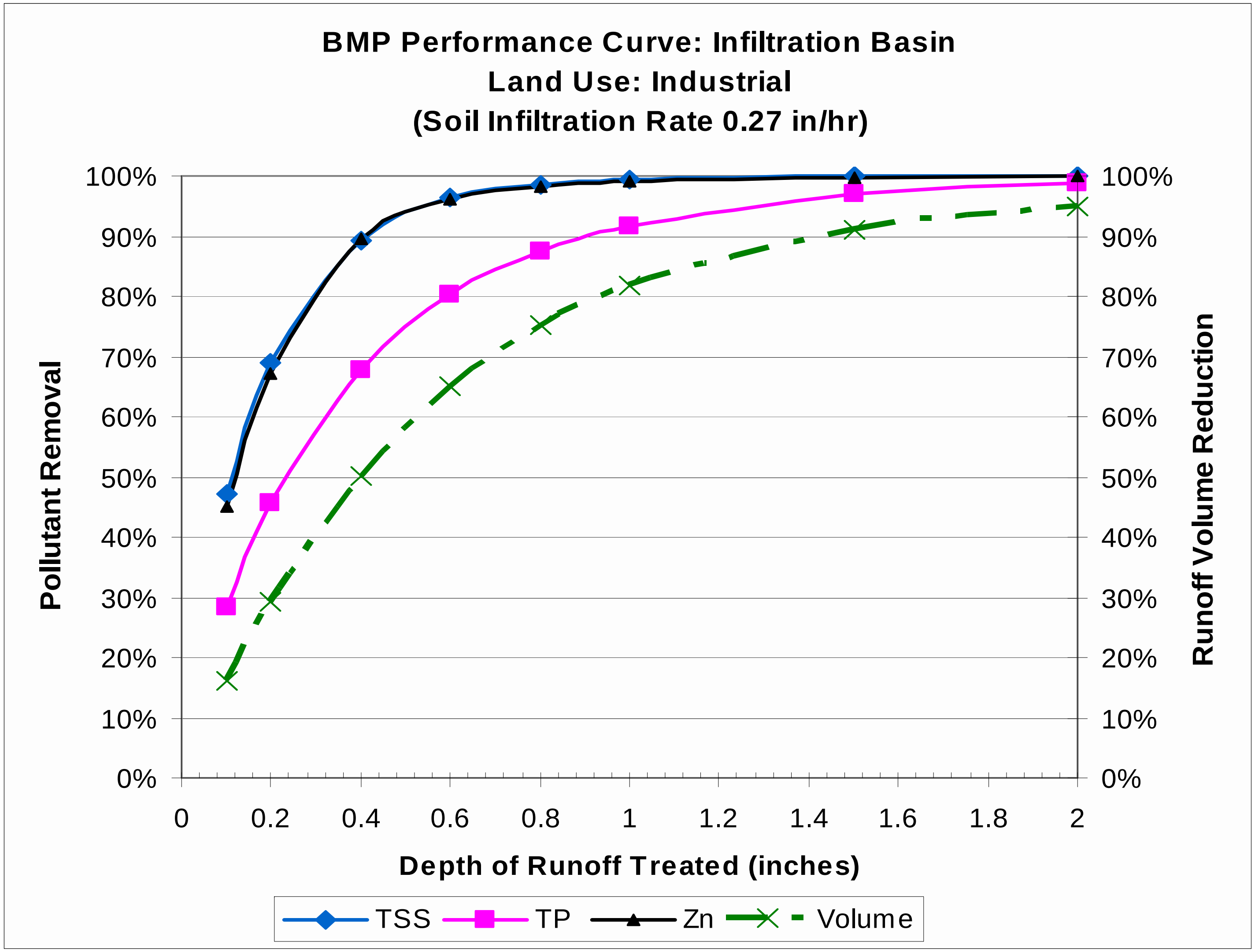
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	46%	68%	89%	96%	99%	99%	100%	100%
	TP	28%	45%	67%	80%	87%	92%	97%	99%
	Zn	62%	82%	95%	98%	99%	100%	100%	100%
Industrial	TSS	47%	69%	89%	96%	99%	99%	100%	100%
	TP	28%	46%	68%	80%	88%	92%	97%	99%
	Zn	45%	67%	89%	96%	98%	99%	100%	100%
High-Density Residential	TSS	48%	70%	89%	96%	99%	99%	100%	100%
	TP	28%	45%	67%	80%	87%	92%	97%	99%
	Zn	50%	72%	92%	97%	99%	99%	100%	100%
Medium-Density Residential	TSS	55%	76%	93%	98%	99%	100%	100%	100%
	TP	29%	46%	67%	80%	87%	91%	97%	98%
	Zn	26%	43%	67%	81%	89%	94%	99%	100%
Low-Density Residential	TSS	53%	72%	90%	96%	98%	99%	100%	100%
	TP	30%	47%	68%	80%	86%	91%	96%	98%
	Zn	21%	36%	60%	75%	85%	90%	97%	99%
Runoff Volume Reduction		16%	29%	50%	65%	75%	82%	91%	95%

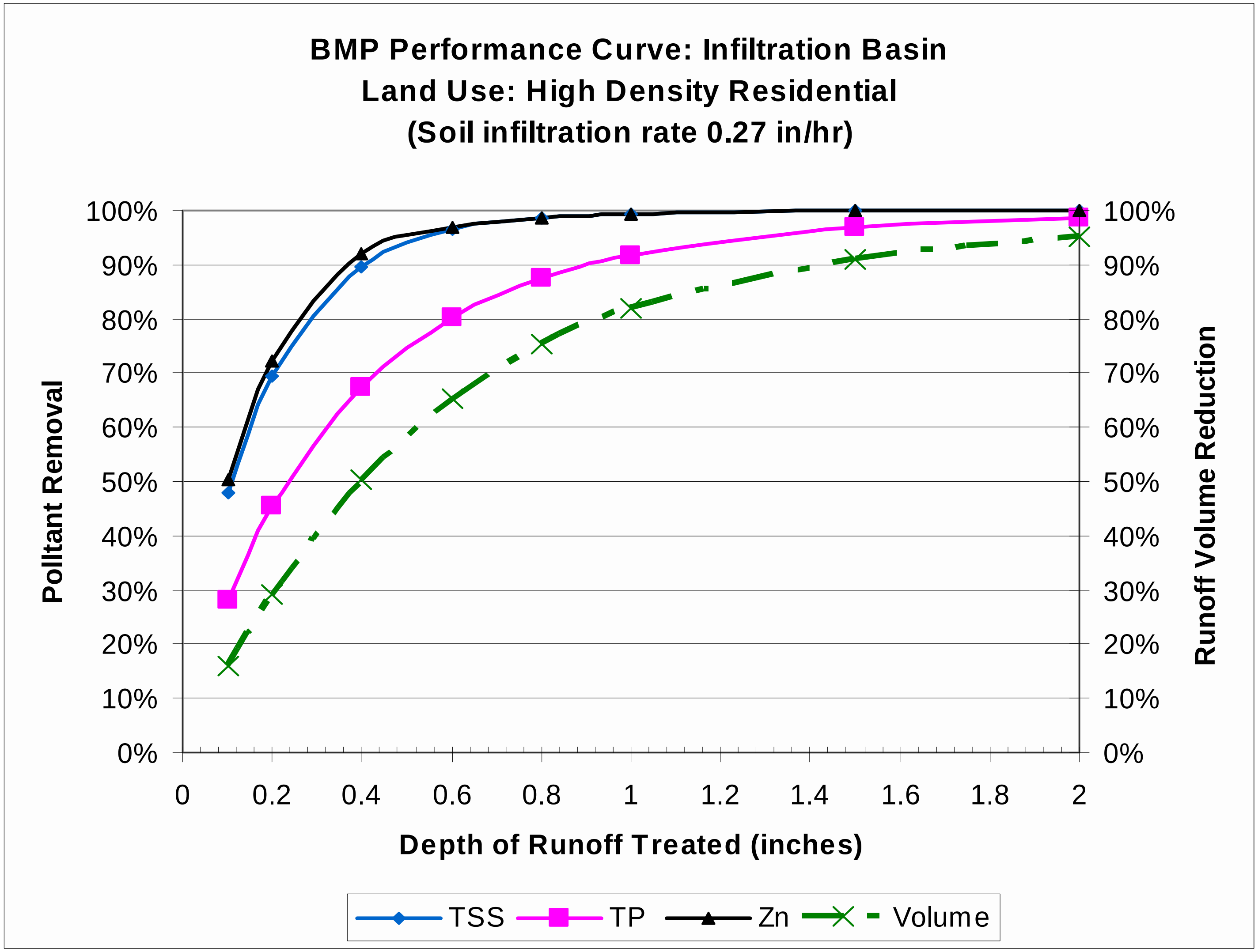
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

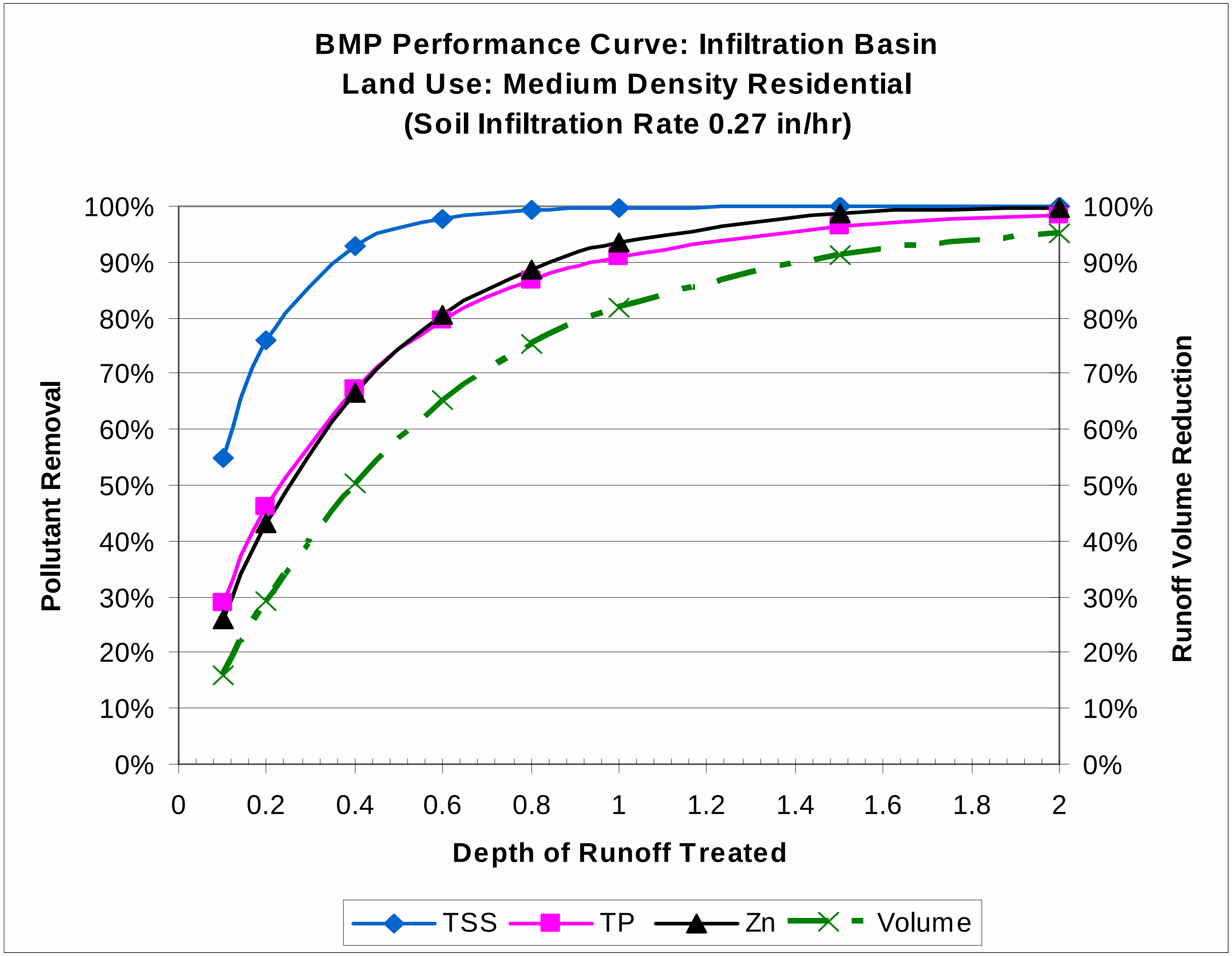

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 0.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

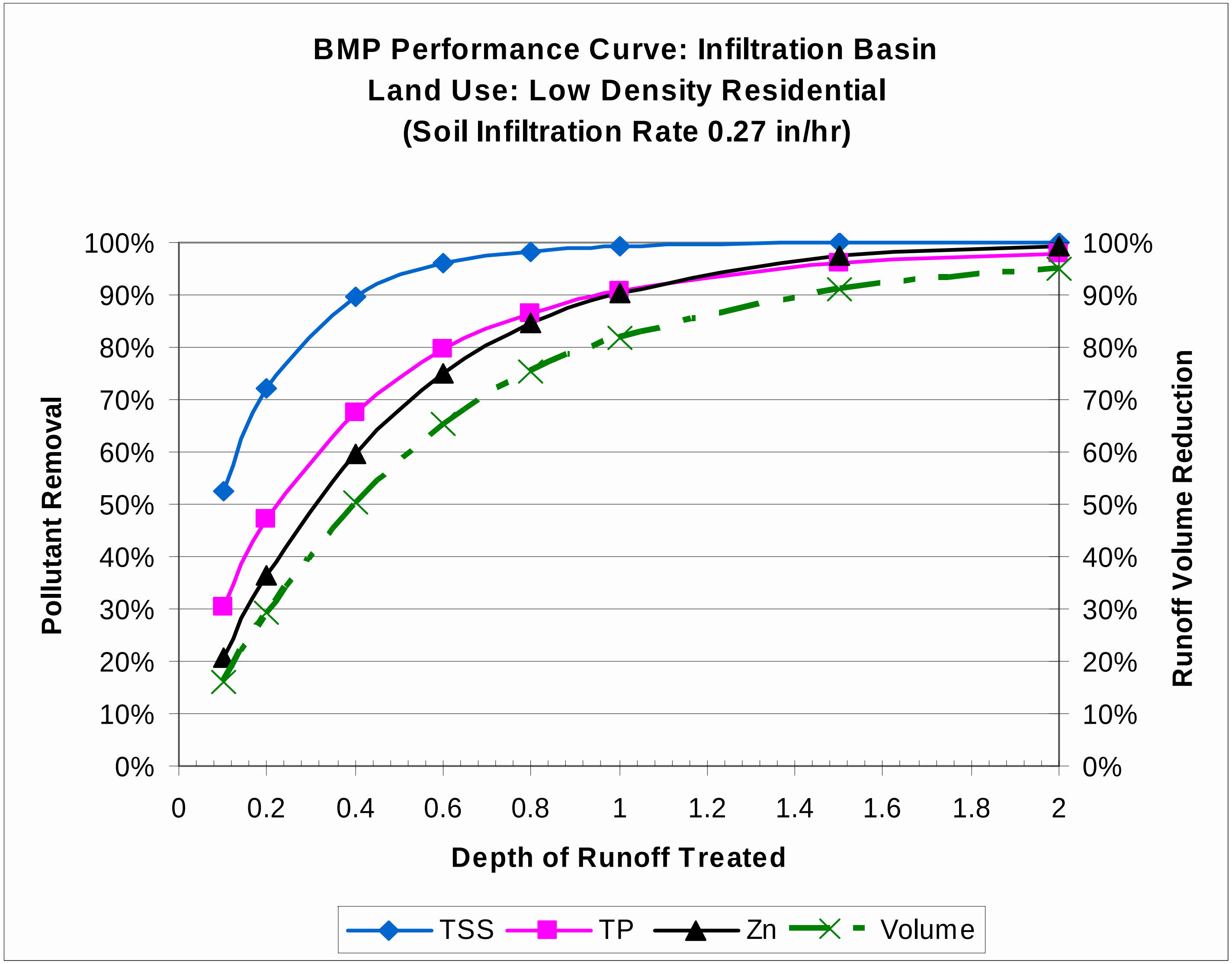
BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 0.27 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 0.27 in/hr)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pollutant Removal
Runoff Volume Reduction
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

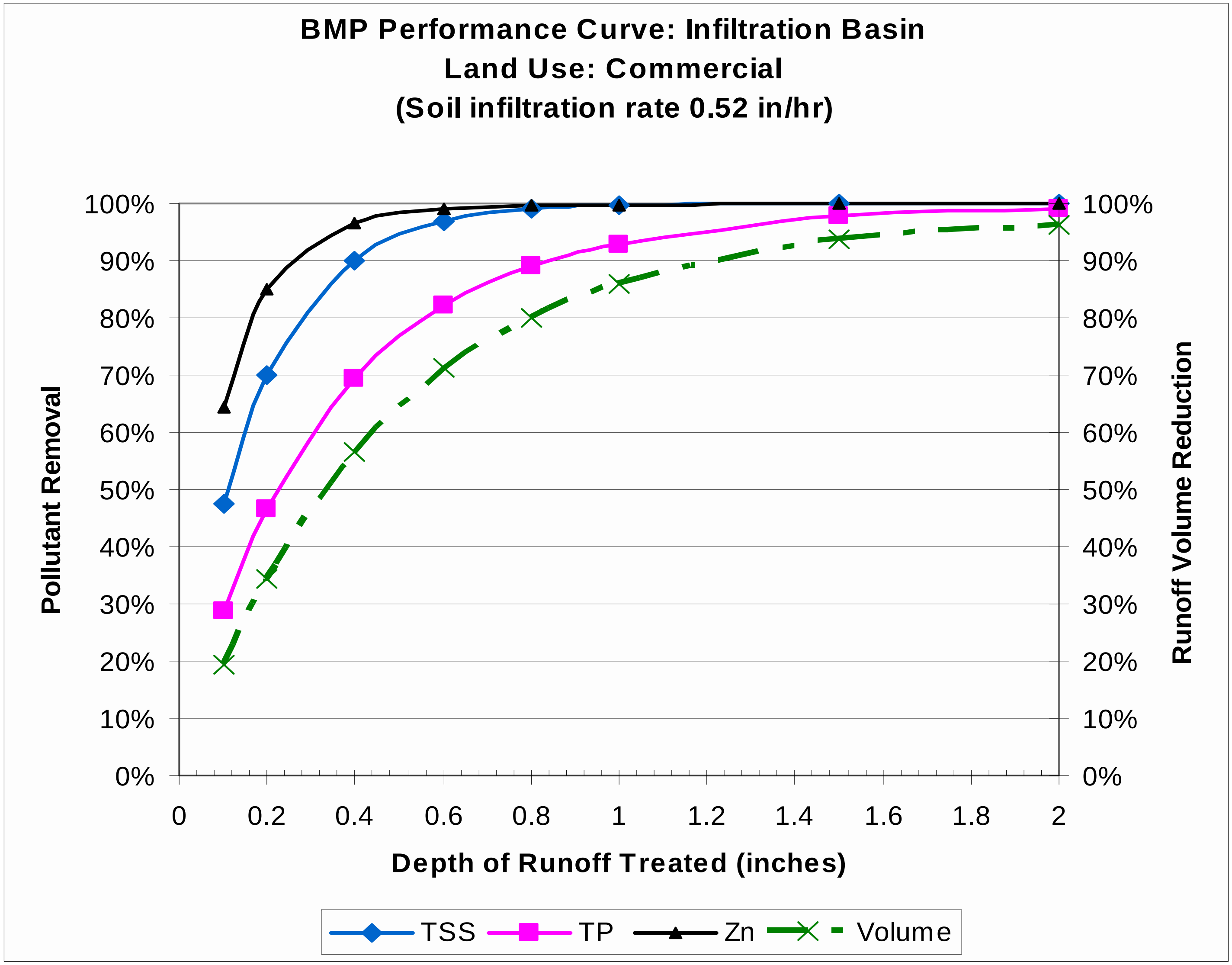
BMP Name: Infiltration Basin-Simple Dynamic Method

Soil Infiltration Rate: 0.52 in/hr

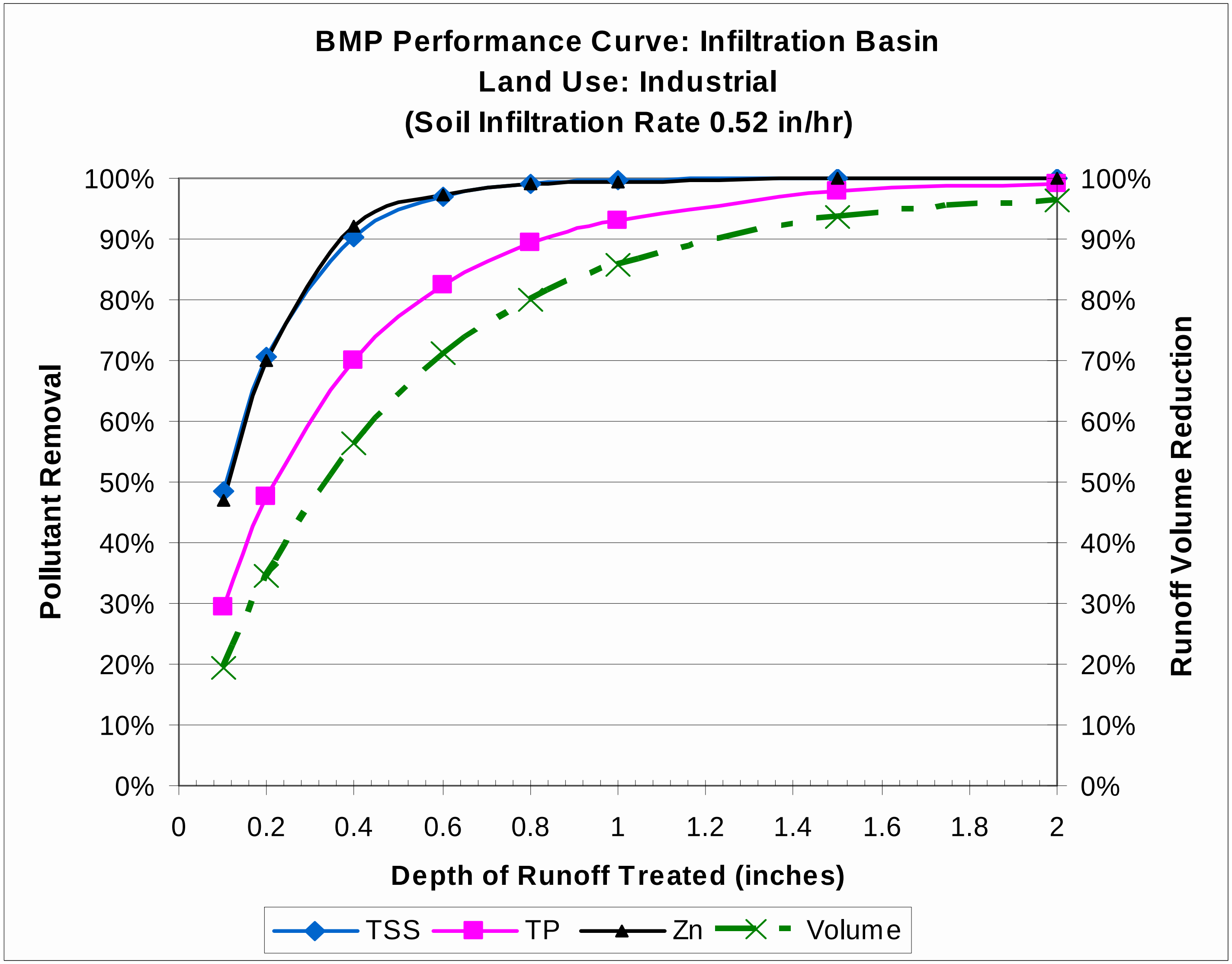
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.5**	**2.0**
Commercial	TSS	48%	70%	90%	97%	99%	100%	100%	100%
	TP	29%	47%	69%	82%	89%	93%	98%	99%
	Zn	64%	85%	97%	99%	100%	100%	100%	100%
Industrial	TSS	48%	71%	90%	97%	99%	100%	100%	100%
	TP	29%	47%	70%	83%	89%	93%	98%	99%
	Zn	47%	70%	92%	97%	99%	100%	100%	100%
High-Density Residential	TSS	49%	71%	91%	97%	99%	100%	100%	100%
	TP	29%	47%	70%	82%	89%	93%	98%	99%
	Zn	52%	75%	94%	98%	99%	100%	100%	100%
Medium-Density Residential	TSS	56%	77%	94%	98%	99%	100%	100%	100%
	TP	30%	48%	70%	82%	89%	92%	97%	99%
	Zn	27%	45%	69%	83%	91%	95%	99%	100%
Low-Density Residential	TSS	54%	74%	91%	97%	99%	99%	100%	100%
	TP	31%	49%	70%	82%	88%	92%	97%	98%
	Zn	21%	38%	62%	77%	87%	92%	99%	100%
Runoff Volume Reduction		20%	34%	57%	71%	80%	86%	94%	96%

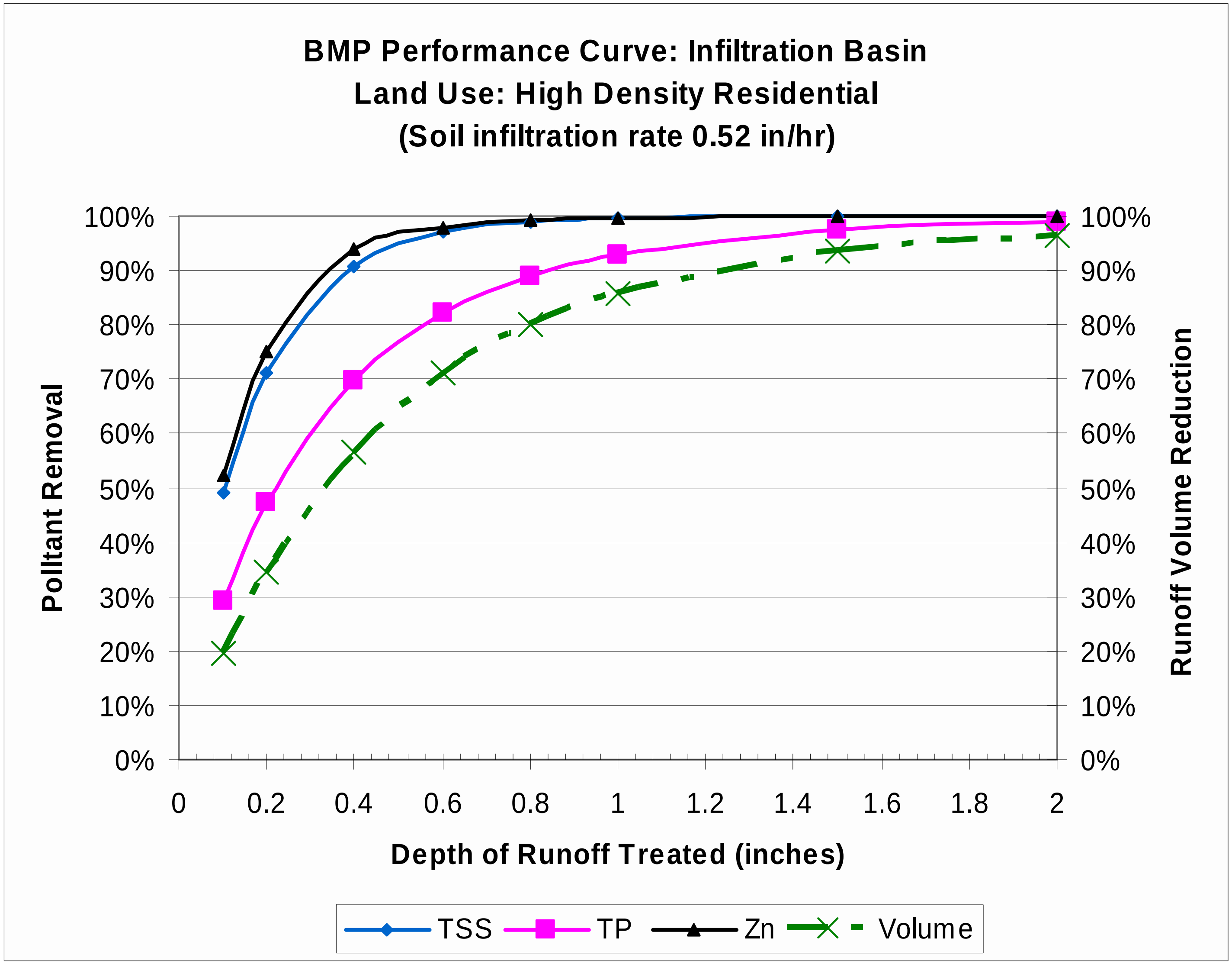
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	**TP**	**Zn**
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

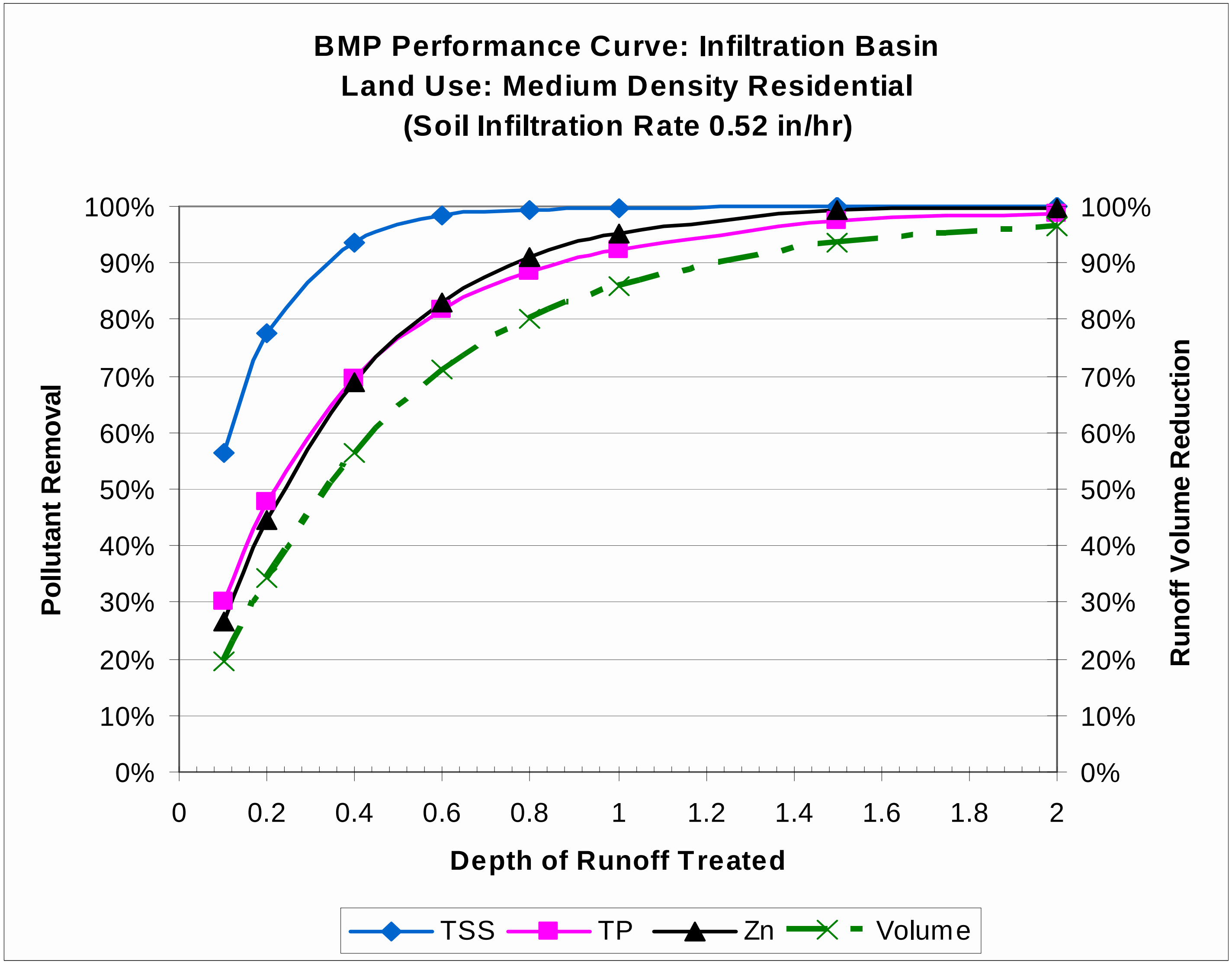

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

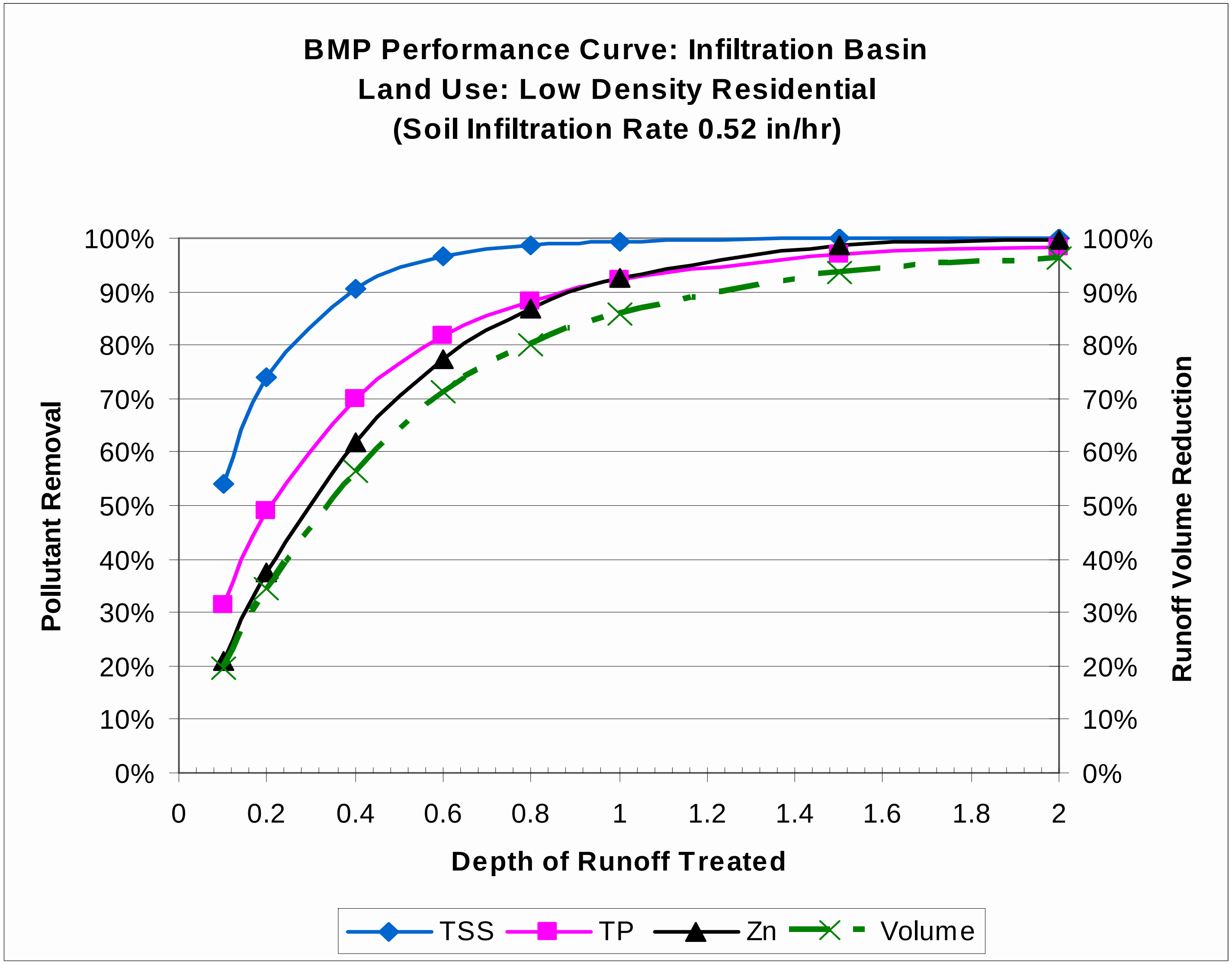
BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 0.52 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method





BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 0.52 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Table

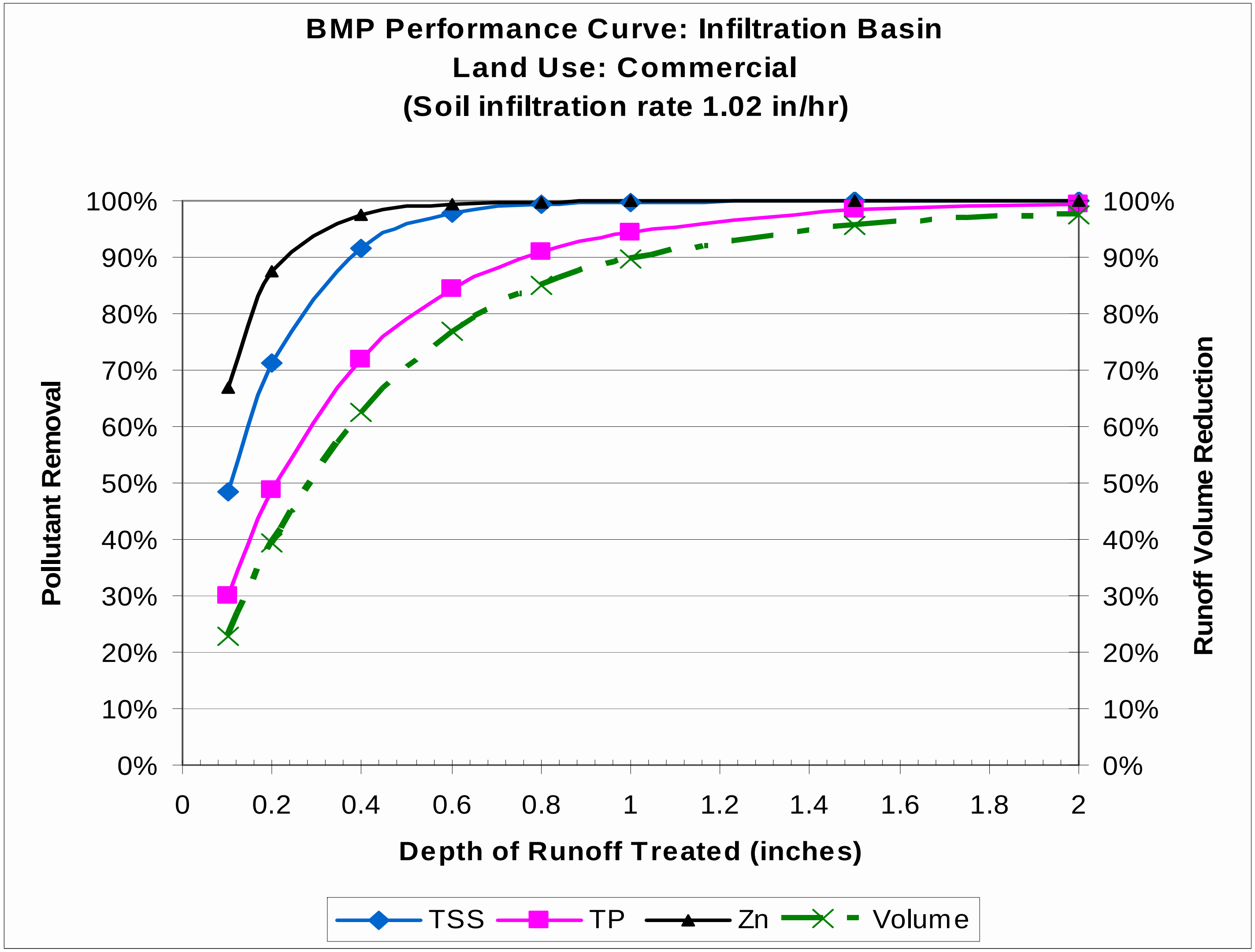
BMP Name: Infiltration Basin-Simple Dynamic Method

Soil Infiltration Rate: 1.02 in/hr

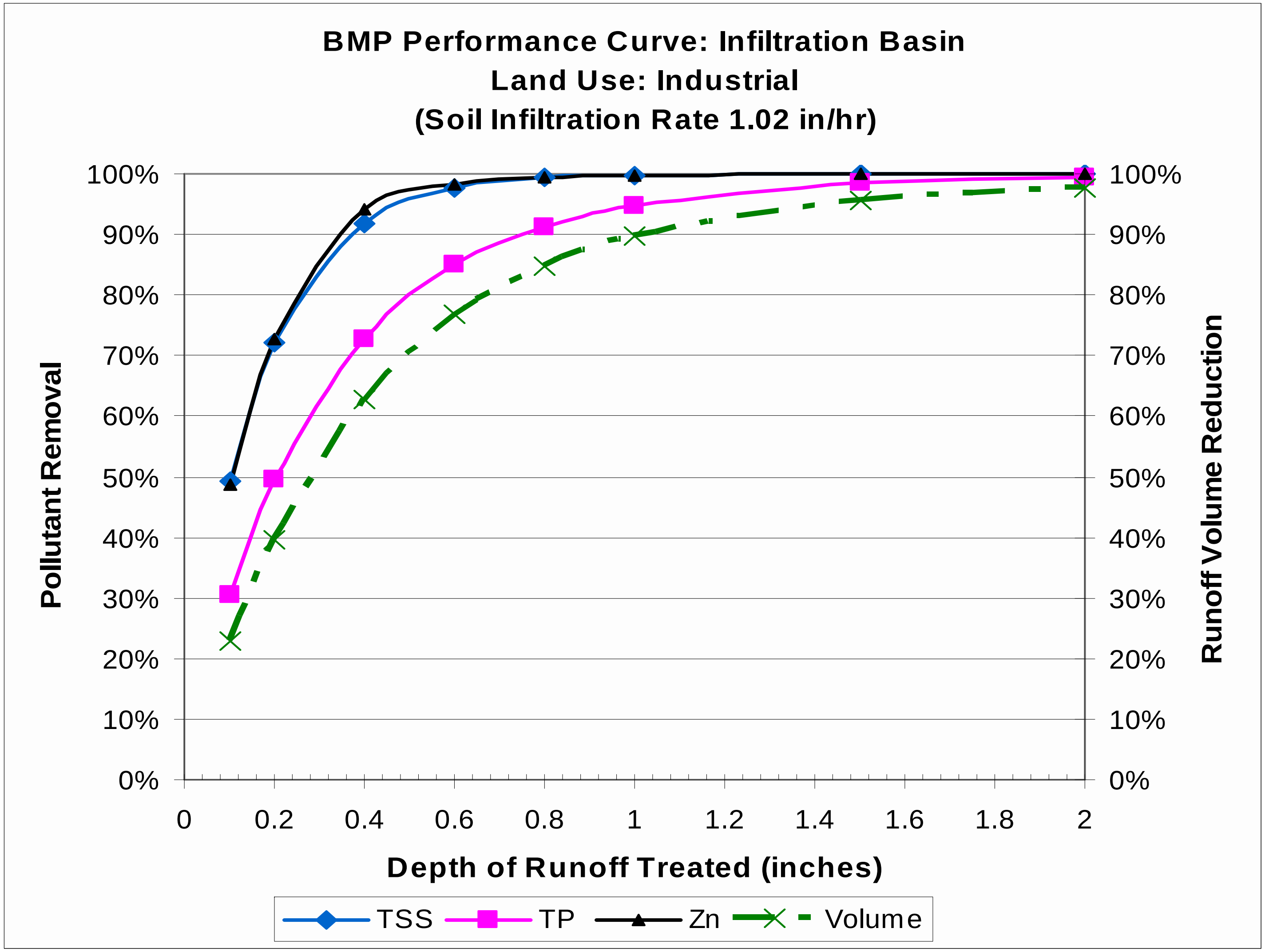
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Commercial	TSS	49%	71%	92%	98%	99%	100%	100%	100%
	TP	30%	49%	72%	85%	91%	94%	98%	99%
	Zn	67%	88%	98%	99%	100%	100%	100%	100%
Industrial	TSS	49%	72%	92%	98%	99%	100%	100%	100%
	TP	31%	49%	73%	85%	91%	95%	98%	99%
	Zn	49%	73%	94%	98%	99%	100%	100%	100%
High-Density Residential	TSS	50%	73%	92%	98%	99%	100%	100%	100%
	TP	30%	49%	72%	85%	91%	95%	98%	99%
	Zn	54%	78%	96%	99%	100%	100%	100%	100%
Medium-Density Residential	TSS	58%	79%	95%	99%	100%	100%	100%	100%
	TP	31%	50%	72%	84%	91%	94%	98%	99%
	Zn	27%	46%	71%	86%	93%	97%	100%	100%
Low-Density Residential	TSS	55%	75%	92%	97%	99%	100%	100%	100%
	TP	33%	51%	73%	84%	90%	94%	98%	99%
	Zn	22%	39%	64%	80%	90%	95%	99%	100%
Runoff Volume Reduction		23%	39%	63%	77%	85%	90%	95%	98%

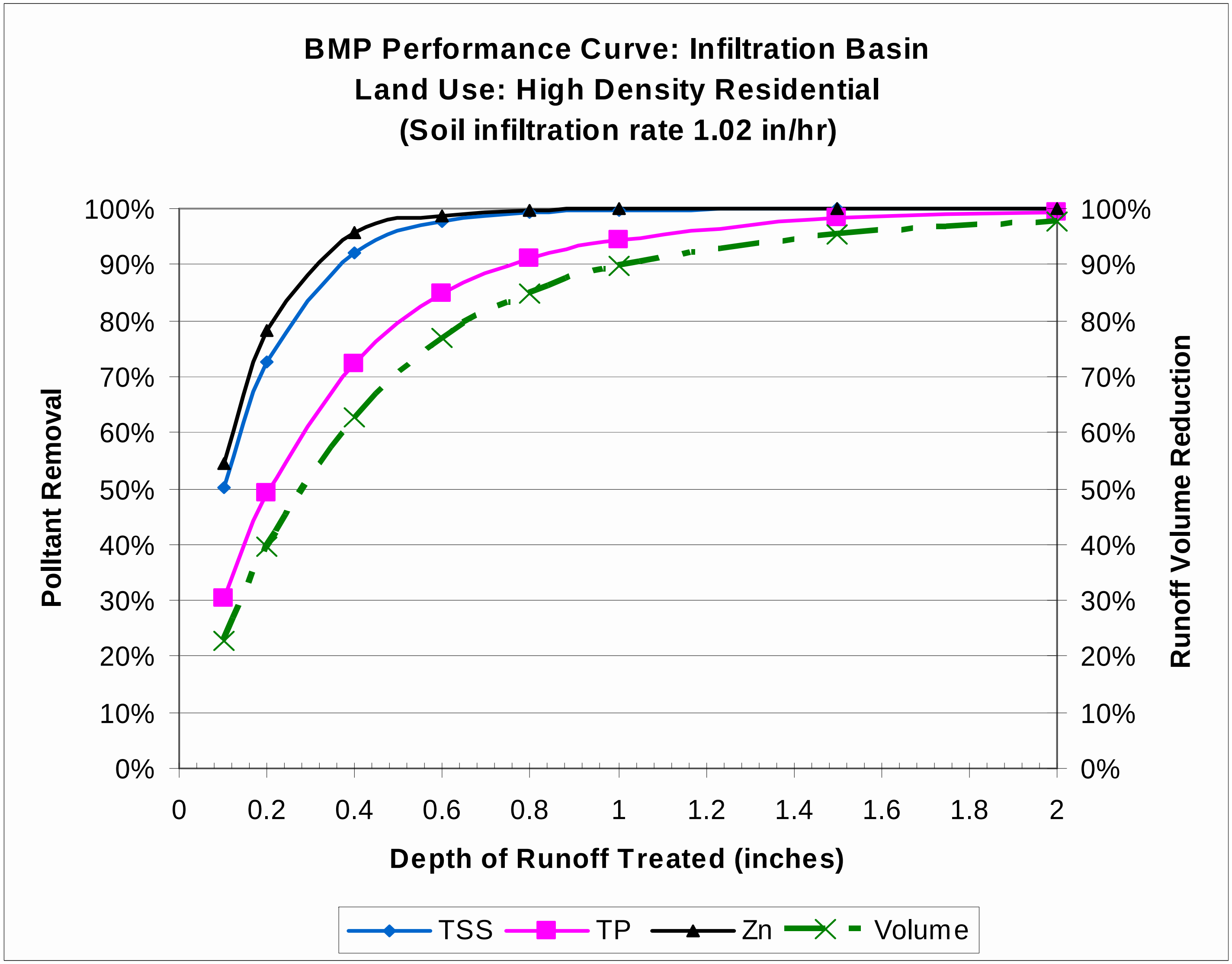
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

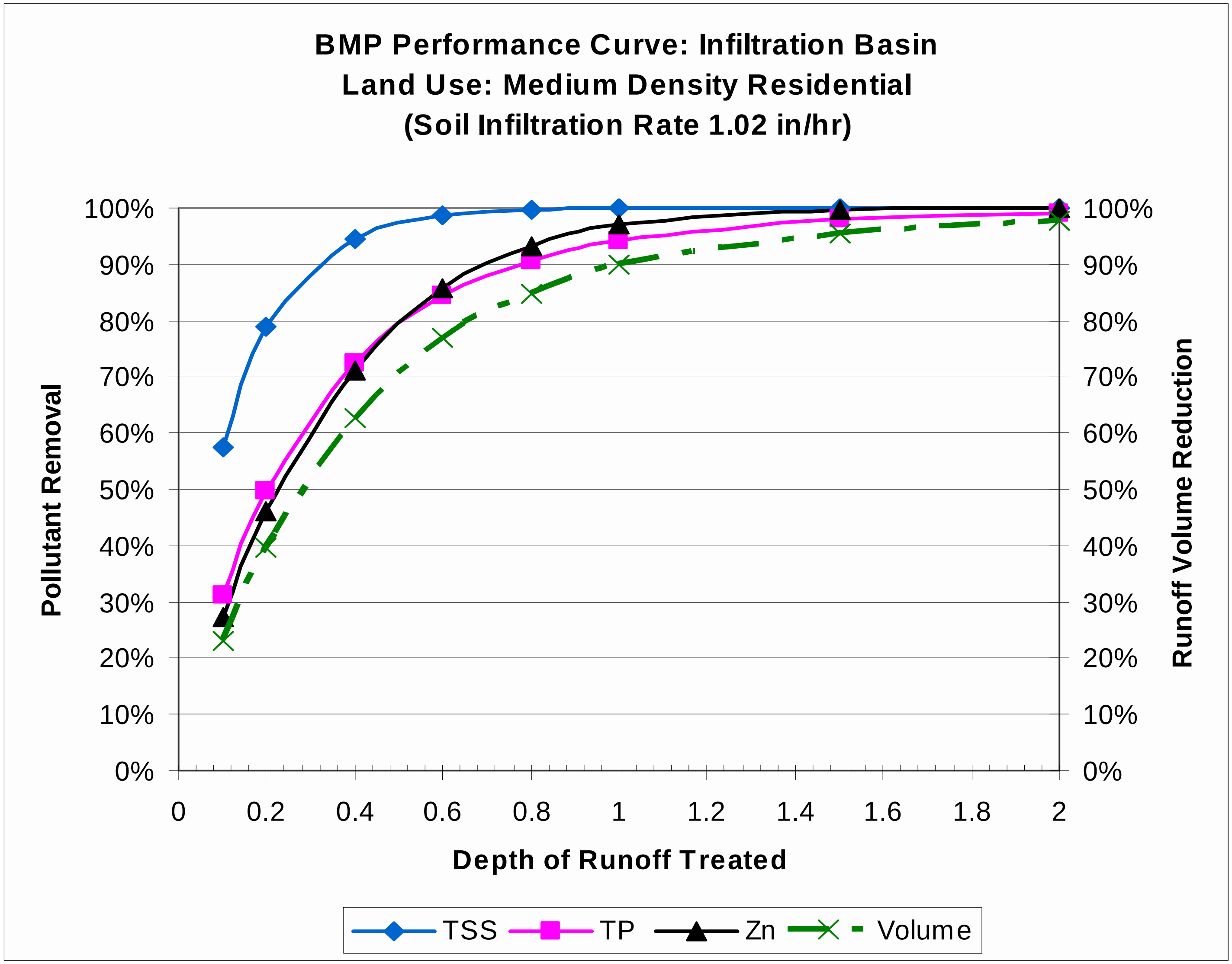

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

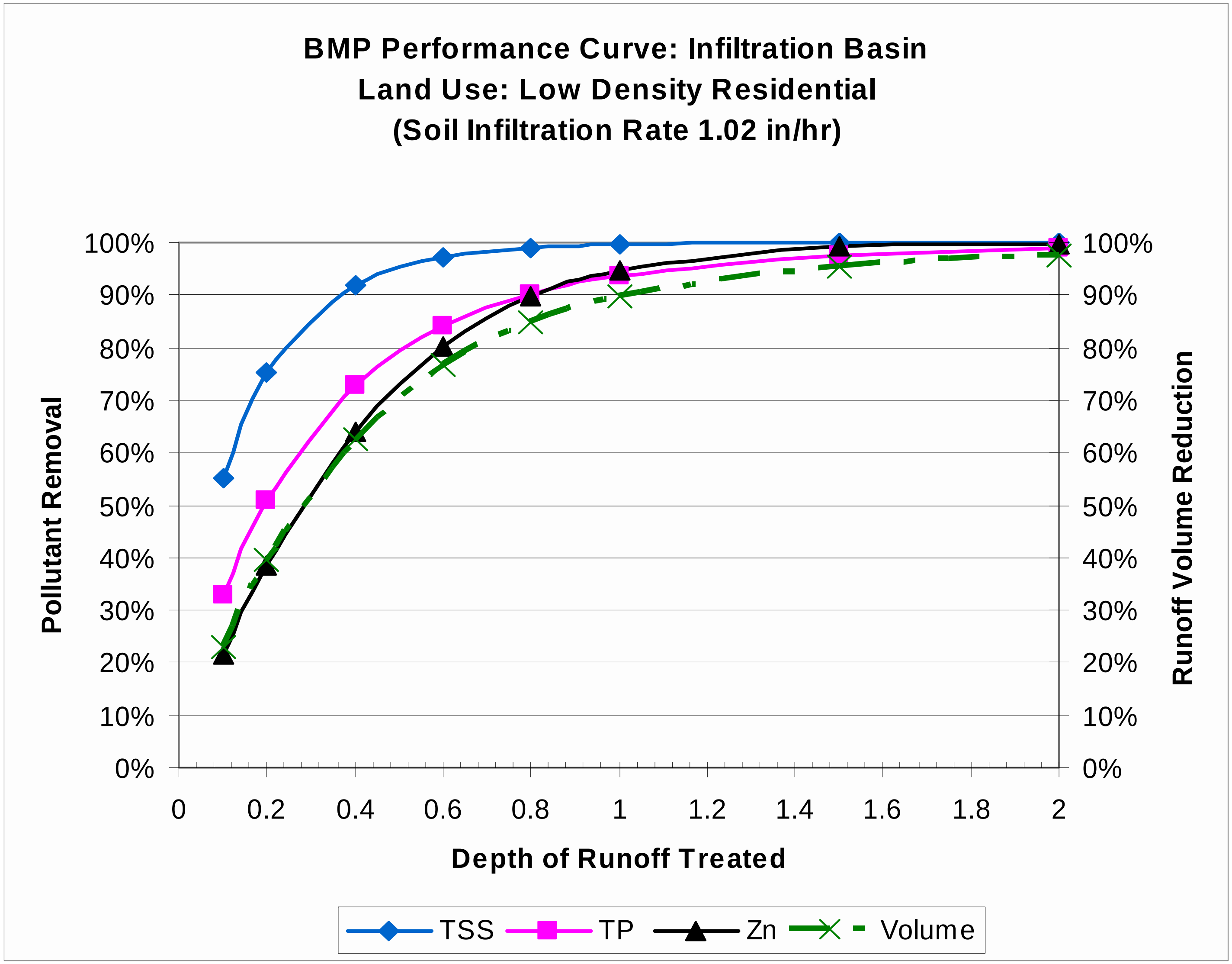
BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 1.02 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 1.02 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method

BMP Performance Table

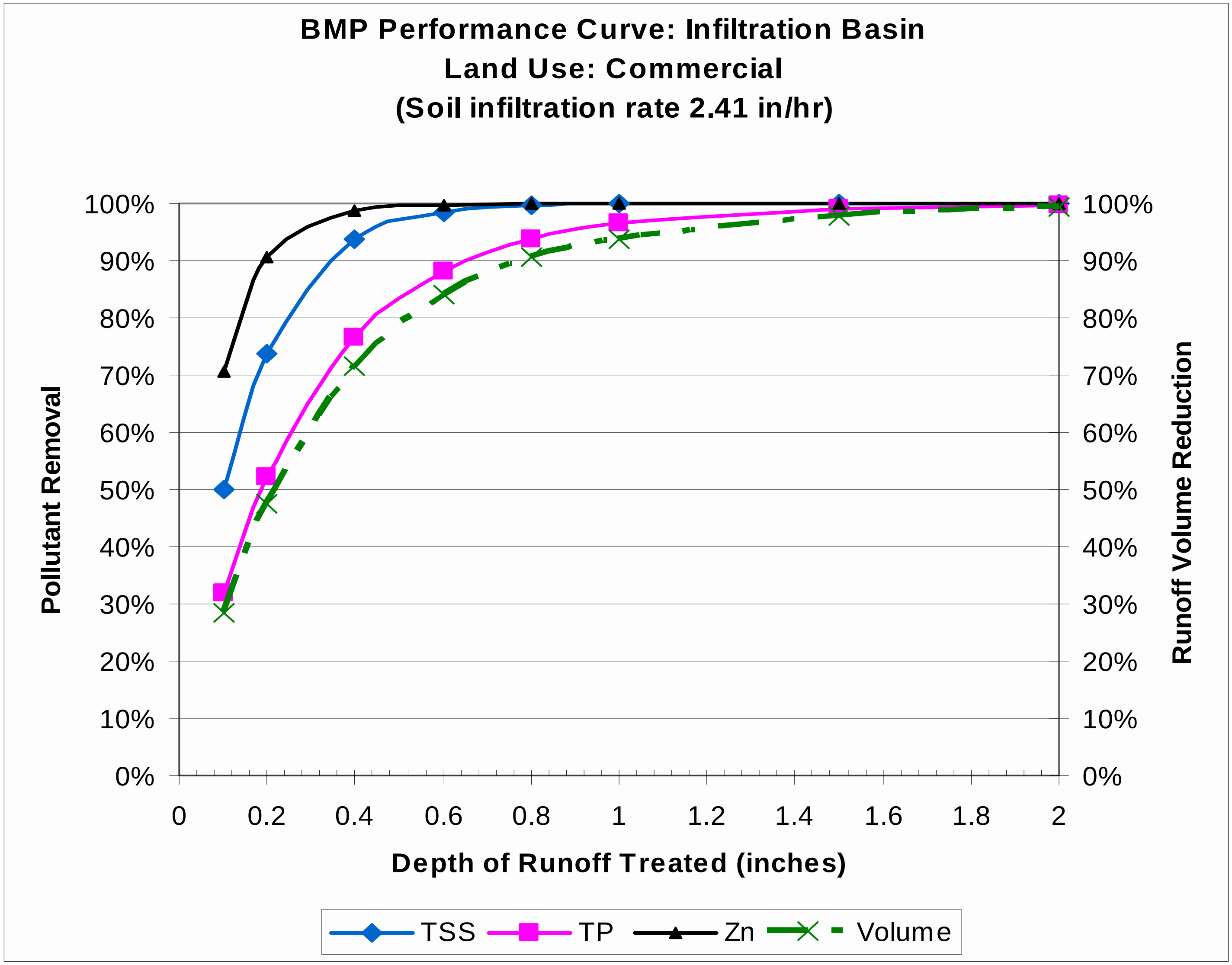
BMP Name: Infiltration Basin-Simple Dynamic Method

Soil Infiltration Rate: 2.41 in/hr

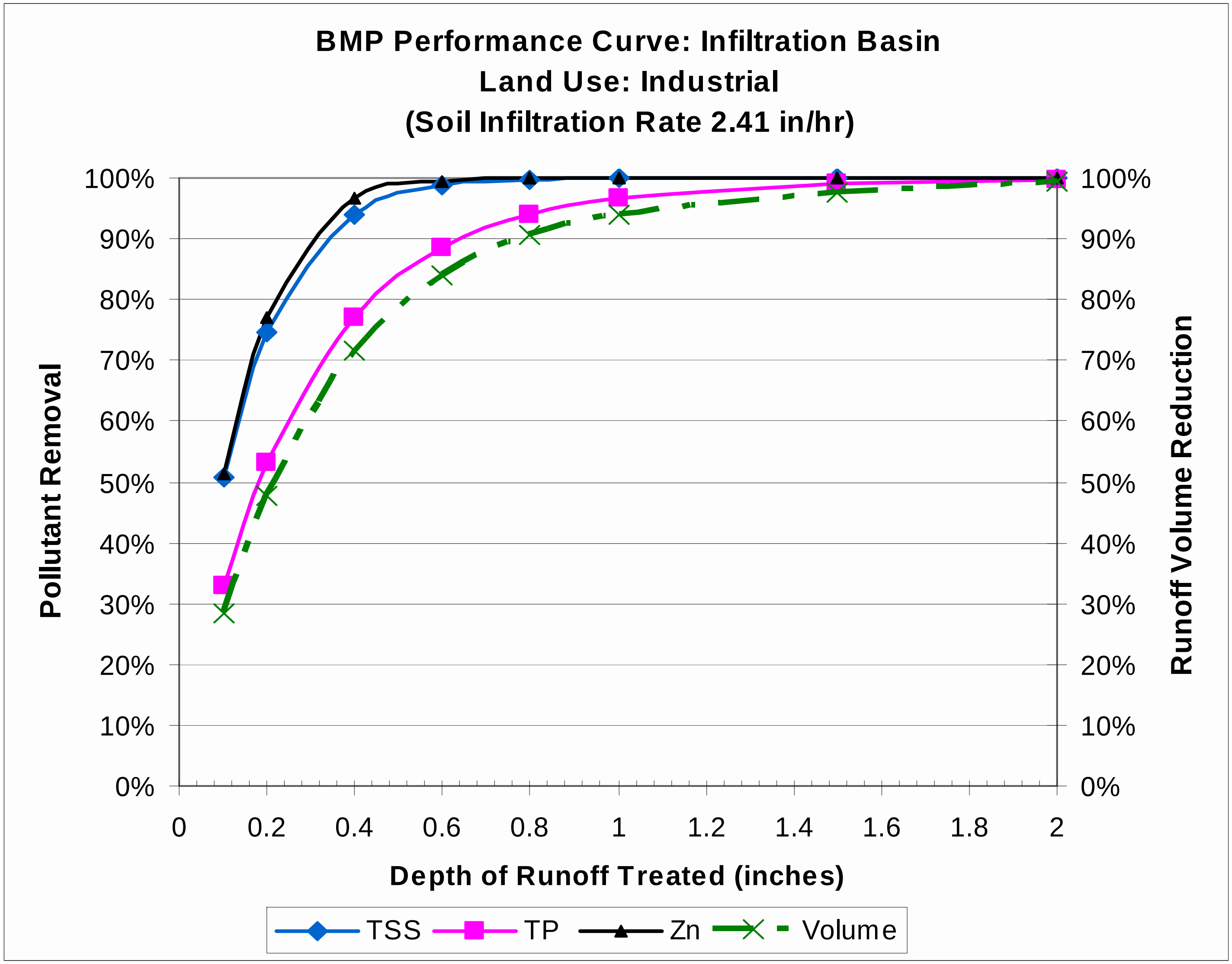
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1	1.5	2
Commercial	TSS	50%	74%	94%	99%	100%	100%	100%	100%
	TP	32%	52%	76%	88%	94%	97%	99%	100%
	Zn	71%	91%	99%	100%	100%	100%	100%	100%
Industrial	TSS	51%	75%	94%	99%	100%	100%	100%	100%
	TP	33%	53%	77%	89%	94%	97%	99%	100%
	Zn	51%	77%	97%	99%	100%	100%	100%	100%
High-Density Residential	TSS	52%	75%	94%	99%	100%	100%	100%	100%
	TP	33%	53%	77%	88%	94%	97%	99%	100%
	Zn	58%	83%	98%	100%	100%	100%	100%	100%
Medium-Density Residential	TSS	59%	81%	96%	99%	100%	100%	100%	100%
	TP	34%	54%	77%	88%	93%	96%	99%	100%
	Zn	28%	48%	75%	90%	97%	99%	100%	100%
Low-Density Residential	TSS	57%	78%	94%	98%	99%	100%	100%	100%
	TP	35%	55%	77%	88%	93%	96%	99%	100%
	Zn	22%	40%	68%	85%	94%	98%	100%	100%
Runoff Volume Reduction		28%	48%	72%	84%	90%	94%	98%	99%

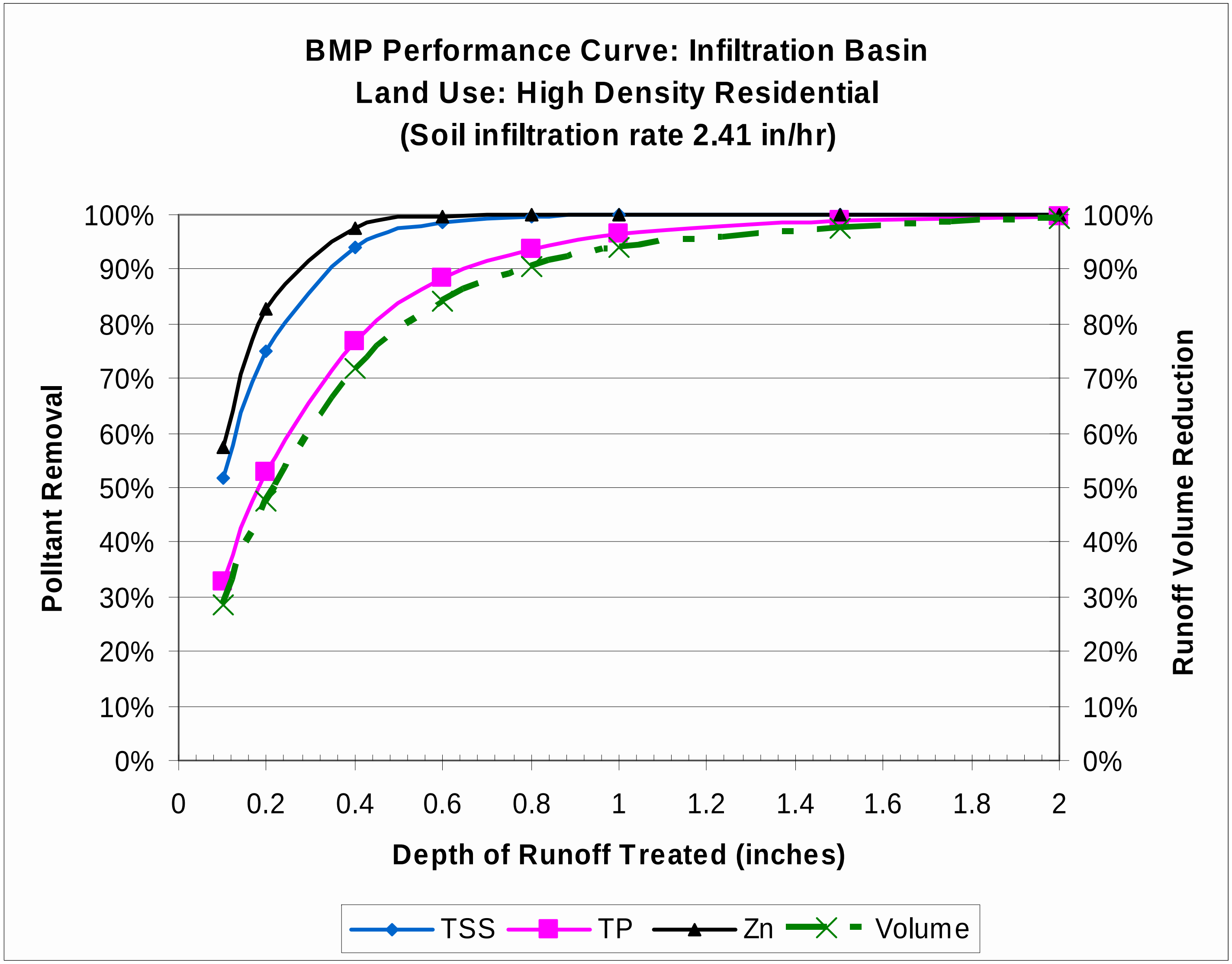
Annual Pollutant Loading Rates

Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

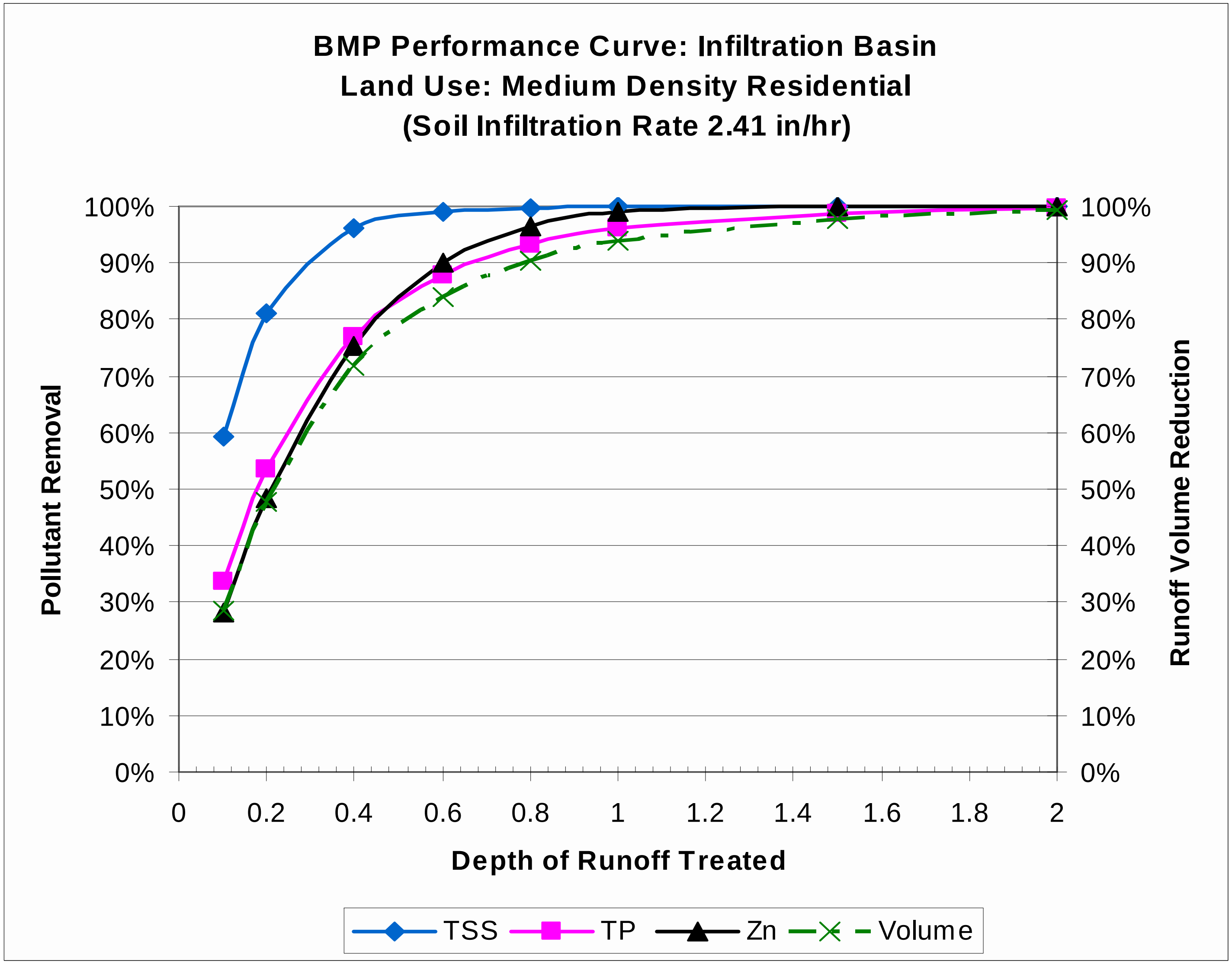

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

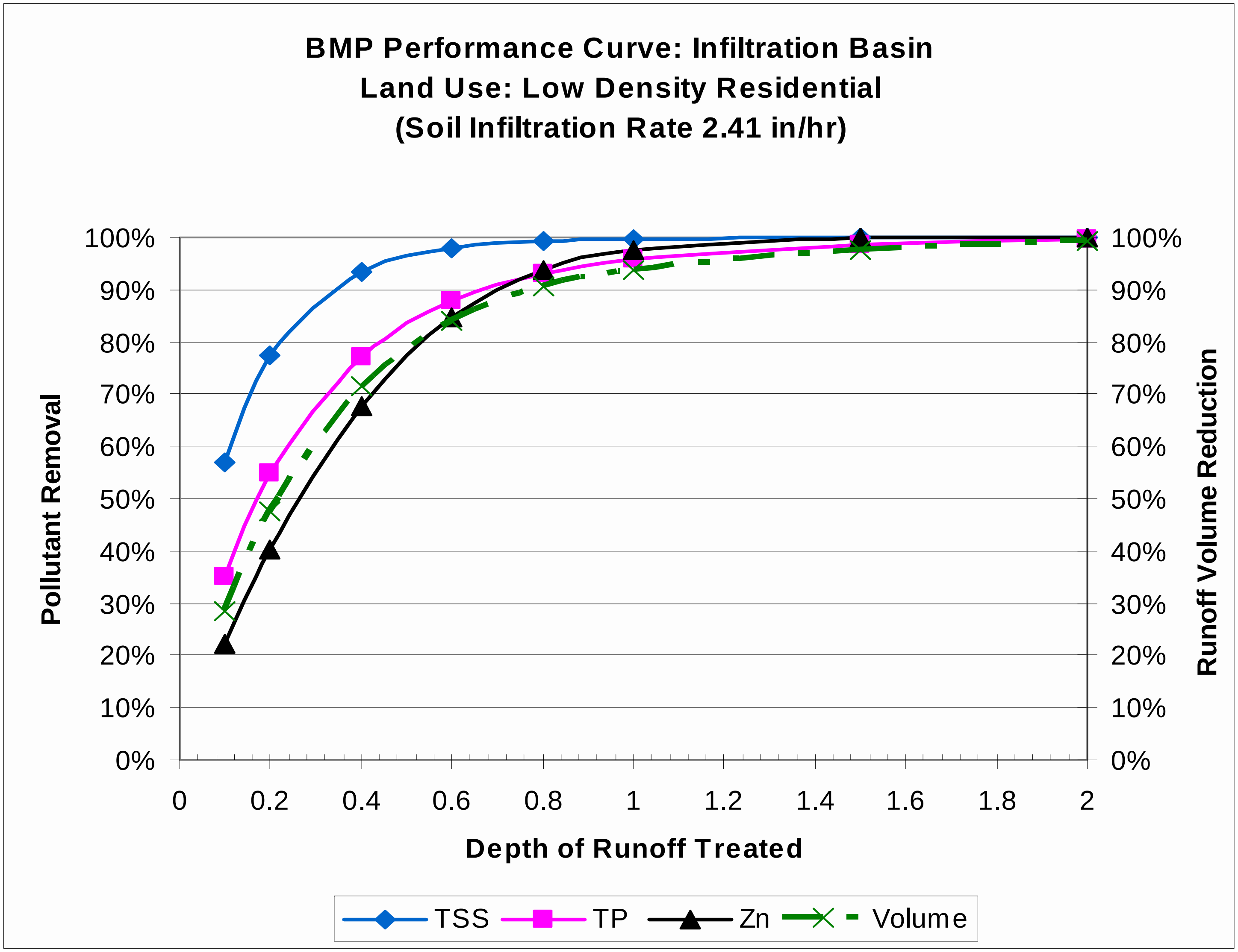
BMP Performance Curve: Infiltration Basin-Simple Dynamic Method




BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 2.41 in/hr)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Polltant Removal
Runoff Volume Reduction
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method





BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 2.41 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method

BMP Performance Table

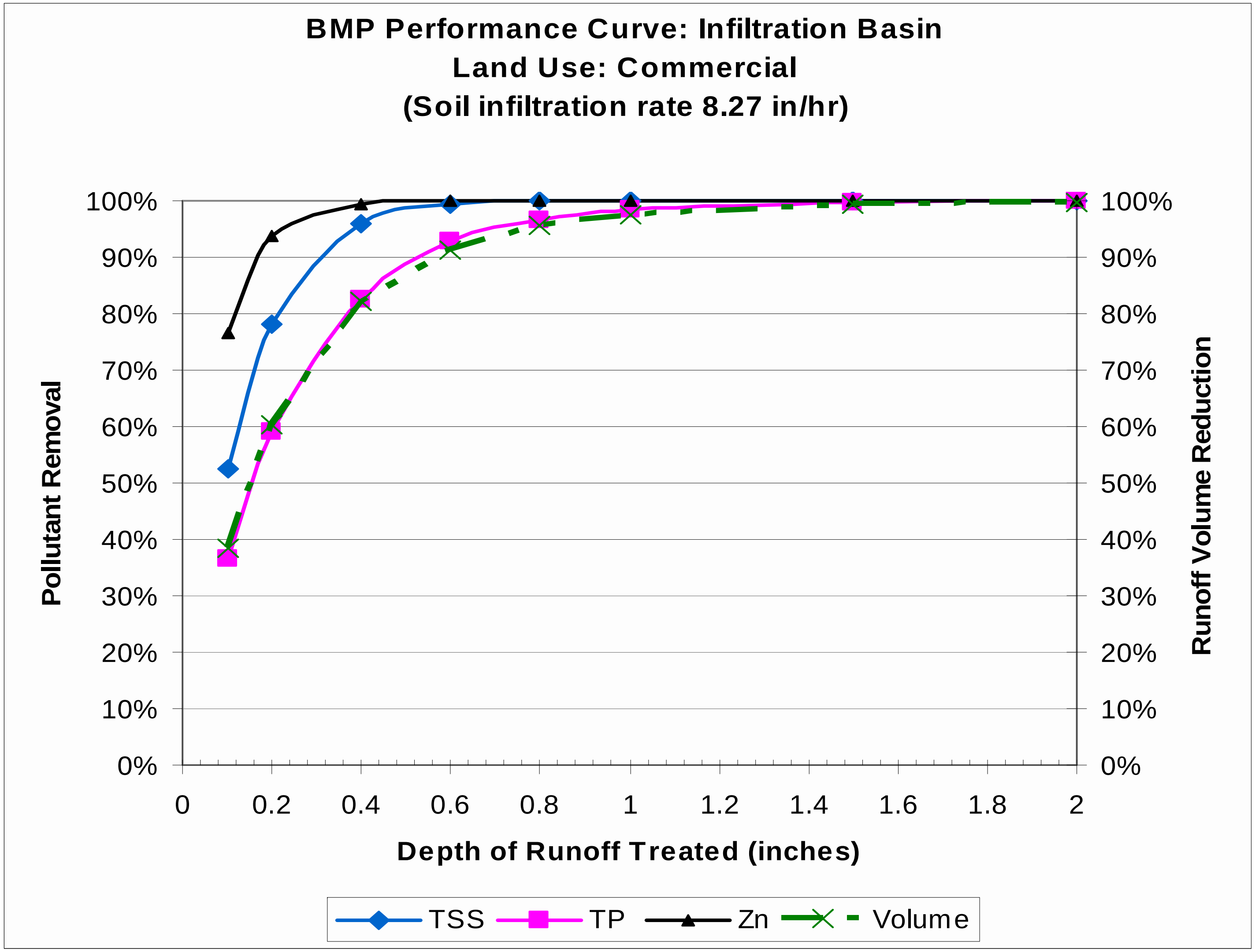
BMP Name: Infiltration Basin-Simple Dynamic Method

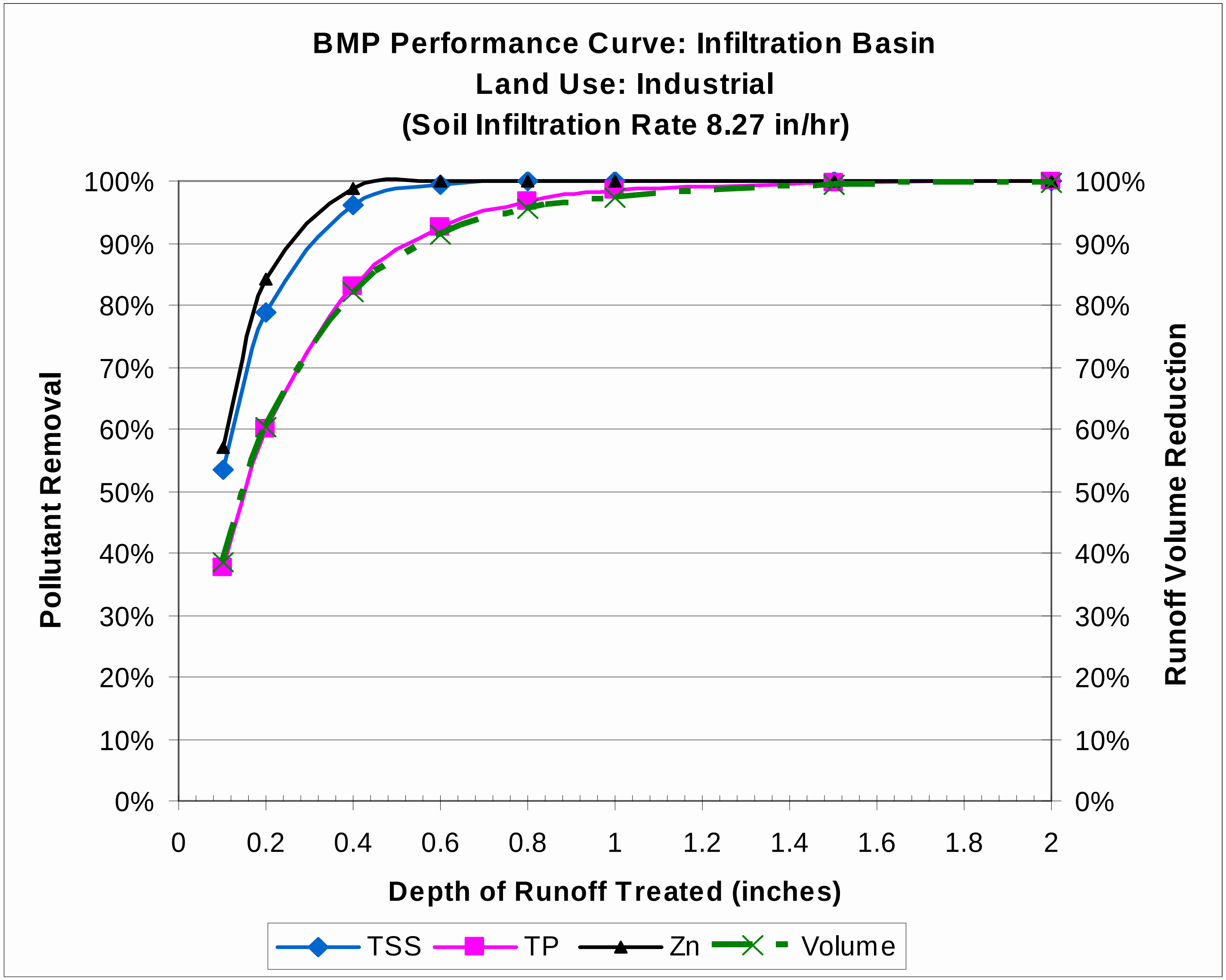
Soil Infiltration Rate: 8.27 in/hr

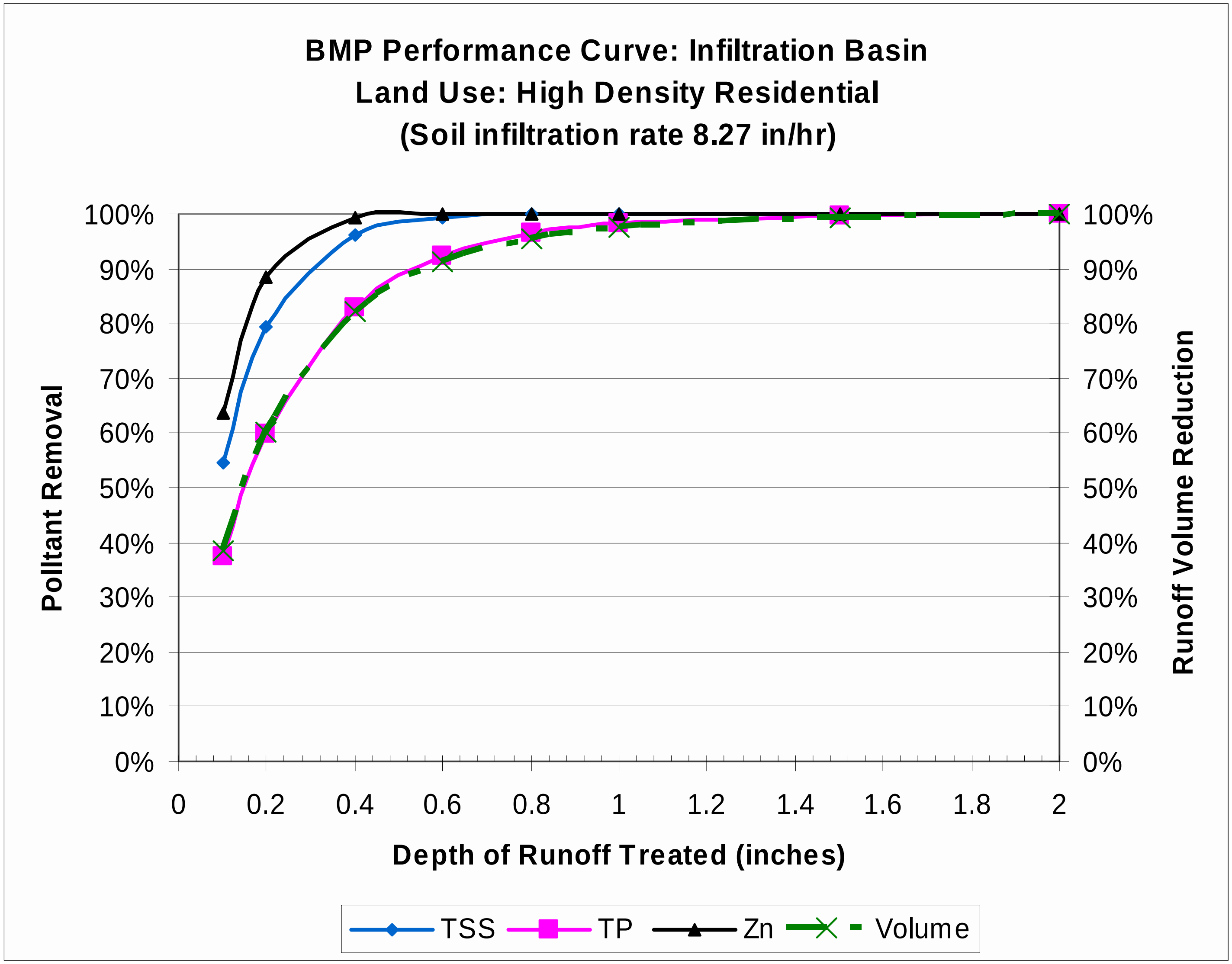
Land Use	Pollutant	Depth of Runoff Treated (inches)							
		0.1	0.2	0.4	0.6	0.8	1	1.5	2
Commercial	TSS	53%	78%	96%	99%	100%	100%	100%	100%
	TP	37%	59%	83%	93%	97%	98%	100%	100%
	Zn	76%	94%	99%	100%	100%	100%	100%	100%
Industrial	TSS	53%	79%	96%	99%	100%	100%	100%	100%
	TP	38%	60%	83%	93%	97%	98%	100%	100%
	Zn	57%	84%	99%	100%	100%	100%	100%	100%
High-Density Residential	TSS	54%	79%	96%	99%	100%	100%	100%	100%
	TP	37%	60%	83%	92%	97%	98%	100%	100%
	Zn	64%	89%	99%	100%	100%	100%	100%	100%
Medium-Density Residential	TSS	62%	85%	97%	100%	100%	100%	100%	100%
	TP	38%	60%	83%	92%	96%	98%	100%	100%
	Zn	31%	53%	81%	95%	99%	100%	100%	100%
Low-Density Residential	TSS	60%	81%	95%	99%	100%	100%	100%	100%
	TP	40%	62%	83%	92%	96%	98%	100%	100%
	Zn	24%	44%	73%	90%	98%	100%	100%	100%
Runoff Volume Reduction		38%	60%	82%	91%	96%	97%	99%	100%

Annual Pollutant Loading Rates

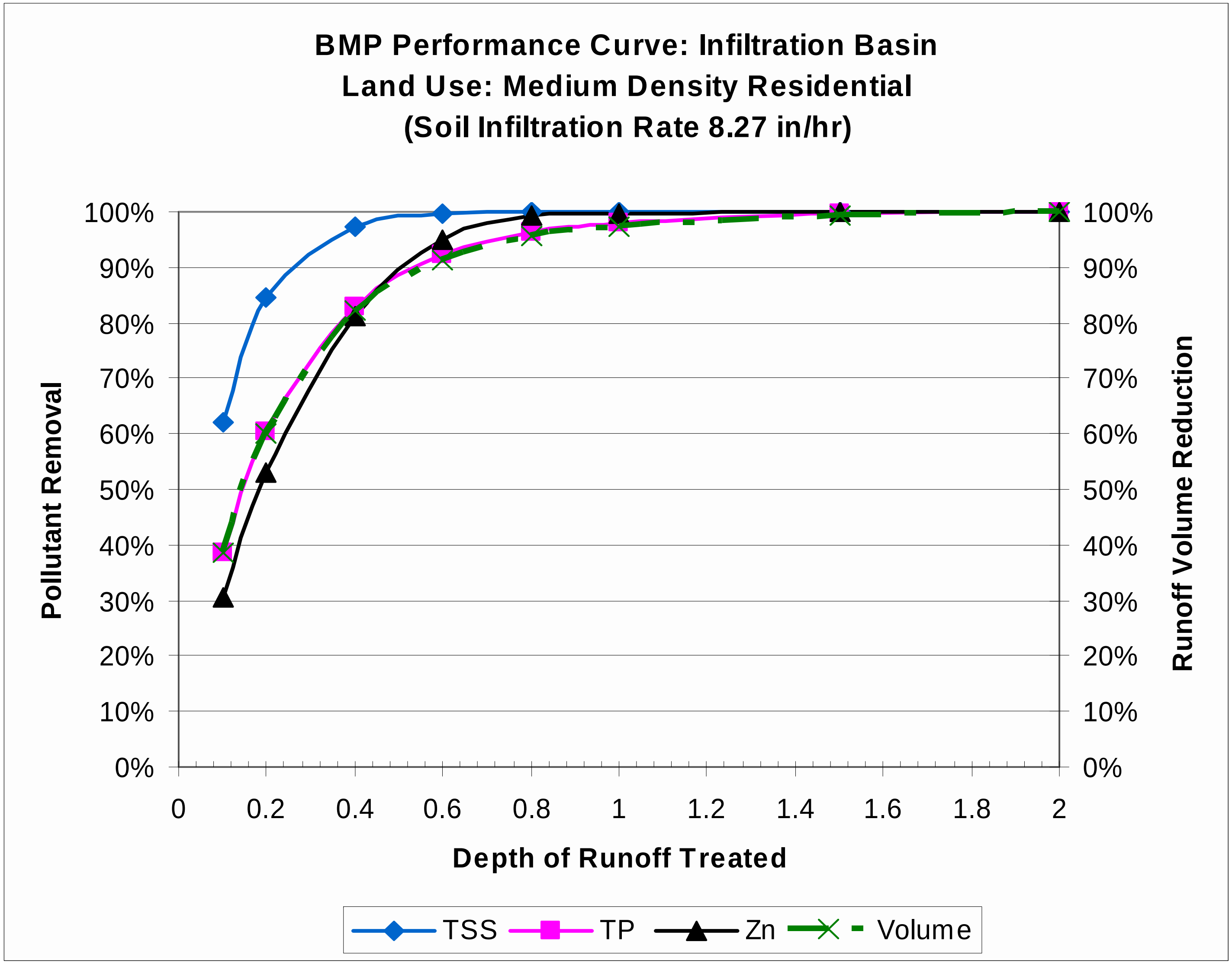
Land use	Pollutant load (lbs/acre-year)		
	TSS	TP	Zn
Commercial	1117.77	1.66	2.33
Industrial	745.22	1.43	0.45
High-Density Residential	465.08	1.10	0.79
Medium-Density Residential	274.63	0.55	0.11
Low-Density Residential	72.11	0.042	0.043

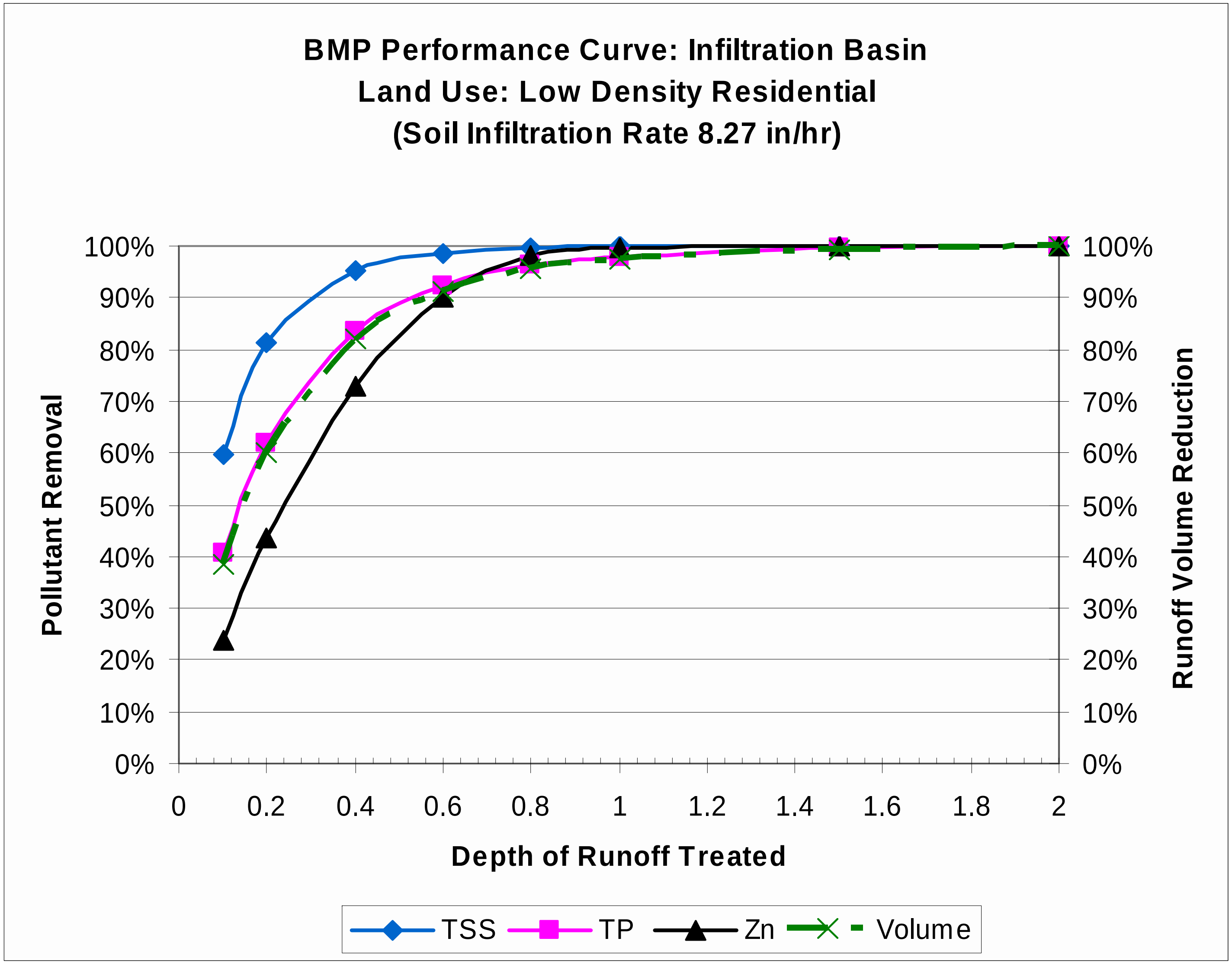

BMP Performance Curve: Infiltration Basin
Land Use: Commercial
(Soil infiltration rate 8.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: Industrial
(Soil Infiltration Rate 8.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume


BMP Performance Curve: Infiltration Basin
Land Use: High Density Residential
(Soil infiltration rate 8.27 in/hr)
Polltant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated (inches)
TSS
TP
Zn
Volume

BMP Performance Curve: Infiltration Basin-Simple Dynamic Method





BMP Performance Curve: Infiltration Basin
Land Use: Low Density Residential
(Soil Infiltration Rate 8.27 in/hr)
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth of Runoff Treated
TSS
TP
Zn
Volume