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Coastal Stormwater Management Through Green Infrastructure: A Handbook for Municipalities

Environmental Protection Agency

Massachusetts Bay National Estuary Program

Coastal Stormwater Management Through Green Infrastructure

A Handbook for Municipalities

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Cover Photo

Credit: Maureen Thomas, Town of Kingston, MA

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1. Executive Summary

Coastal Stormwater Management through Green Infrastructure: A Handbook for Municipalities (Handbook) is designed to assist coastal municipalities within the Massachusetts Bays Program (MassBays) area to incorporate green infrastructure into their stormwater management planning as they respond to MS4 stormwater permit requirements, review development proposals, and retrofit existing municipal facilities and sites. The MassBays Program can assist those municipalities in using this Handbook to facilitate the use of green infrastructure and address stormwater runoff.

The Handbook can also be applied more broadly by municipal infrastructure and resource managers located in other States to provide them with a proven approach to planning for green infrastructure implementation including a process for: 1) watershed assessment, 2) site identification and prioritization, 3) site planning, 4) selecting appropriate green infrastructure practices, 5) developing conceptual plans, and 6) effective plan review. Users can follow this handbook sequentially or use portions of the handbook as needed for new or existing development situations.

Green Infrastructure Handbook Overview

Assess Watershed (Chapter 2)
Identify opportunities where green infrastructure can be used to provide water quantity and quality benefits to restore, protect, and enhance the natural hydrology and ecosystem functions in the watershed.

Identify Green Infrastructure Opportunities (Chapter 3)
Determine the highest priority sites in a given municipality to provide the greatest water quality benefits.

Site Assessment, Planning, and Design (Chapter 4)
Use green infrastructure planning practices, including land use planning, site assessment, retrofit considerations, and site design.

Identify Green Infrastructure Practices (Chapter 5)
Select the appropriate green infrastructure practice(s) using a BMP Matrix.

Green Infrastructure Review Process (Chapter 6)
Design review to verify proper design concepts to ensure successful construction and long-term operation.

1.1. What is Green Infrastructure?

Green infrastructure is a design strategy for handling runoff that reduces the volume and distributes flows by using vegetation, soils, and natural processes to manage water and create healthier urban and suburban environments. This is often best accomplished by creating a series of smaller retention or detention areas that allow localized filtration utilizing a series of distributed treatment practices rather than carrying runoff to a remote collection area for treatment in regional or centralized facilities (Lloyd et al. 2002). At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up

and storing water in a series of distributed practices, such as rain gardens, permeable pavements, and green roofs. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development* (LID).

Green infrastructure strategies fall under two broad categories: planning practices and best management practices (BMPs). Common site planning practices include site design planning based on natural land contours and decreasing the impervious surface. Green infrastructure planning practices include the following:

- Reducing impervious surfaces
- Disconnecting impervious areas
- Conserving natural resources
- Using cluster/consolidated development
- Using xeriscaping and water conservation practices

Green infrastructure practices use natural, vegetative processes to retain and infiltrate stormwater to the extent feasible. Common BMPs used in green infrastructure include:

- Vegetated filter strips
- Bioretention
- Constructed stormwater wetlands
- Tree box filters
- Green roofs
- Permeable pavement

Green infrastructure typically incorporates multiple practices using the natural features of the site in conjunction with the goal of the site development. Multiple practices can be incorporated into the site development to complement and enhance the proposed layout, while also providing water quality treatment and volume reduction. These practices are discussed in detail in Section 5 of this handbook.

Green infrastructure offers a great degree of design flexibility, which makes it suitable for a wide variety of sites and applications. Green infrastructure practices can often be integrated into a site utilizing existing configurations including incorporating bioretention into landscaped areas, permeable pavement in parking stalls or bike lanes, and green roofs on the rooftops of buildings. Specific to coastal Massachusetts, limited space and high groundwater tables may prohibit the use of conventional centralized stormwater management practices that require large surface areas and deep storage capacity. Many green infrastructure practices can be designed to maximize water quality and quantity benefits within a small footprint by distributing stormwater management practices and special design considerations can be implemented to reduce ponding depths to compensate for limited distance to groundwater or to prevent direct discharge into the groundwater (e.g., installation of an underdrain system, Chapter 5 of this manual).

Larger scale green infrastructure approaches may also incorporate natural features on the landscape, such as wetlands, former wetland sites, or floodplains. In these cases, the design may involve land management decisions including acquisition, easement designations, wetland restoration and protection, and property buyout programs in flood prone areas. These measures can enhance the role natural features play in storing rainfall, reducing peak runoff during storms, reducing the effects of erosion, stabilizing soils, improving water quality, and sustaining surrounding aquatic environments. The Greenseams program in Milwaukee, WI illustrates a large scale green infrastructure alternative.

1.2. Benefits of Green Infrastructure

Green infrastructure restores the natural hydrologic processes of infiltration, percolation, and evapotranspiration to reduce the adverse effects of urban stormwater runoff on receiving water bodies. **Green infrastructure practices have been shown to cost-effectively reduce the effects of stormwater runoff by reducing pollutants such as sediment, bacteria, metals, nitrogen, and phosphorus; reduce maintenance requirements; and provide multiple environmental, social, and economic benefits (Kloss and Calarusse 2006).** Some of the additional environmental, social, and economic benefits of green infrastructure are listed below.

Water Quality Benefits. Green infrastructure principles and practices are designed to encourage percolation and ground water recharge and can provide volume reduction. Green infrastructure practices mainly use the interaction of the chemical, physical, and biological processes between soils and water to filter out sediments and sorb constituents from stormwater. As stormwater percolates into the ground, the soil captures the dissolved and suspended material in stormwater. When infiltration is not feasible, water quality improvements can still be achieved through filtration utilizing sedimentation, straining, and sorption processes as stormwater passes through small pore spaces (FHWA 2002).

When properly designed and maintained, green infrastructure has proven effective at reducing nutrients and bacteria in stormwater runoff, two classes of pollutants of particular concern to coastal waters. Due to water quality impairments linked to stormwater runoff pollution, many of Massachusetts' coastal resources, including shellfish beds and bathing beaches, suffer closures. The implementation of green infrastructure to manage and treat stormwater runoff has the potential to reduce closures and improve the health of coastal resources. A summary of pollutant reduction efficiencies for a variety of green infrastructure practices is included in Section 5.3.

Increased enjoyment of surroundings. Implementing green infrastructure practices to enhance vegetation, preserve parking within the right-of-way (ROW), and add open or park space will help create a more pedestrian-friendly environment that encourages walking and physical activity. A large study of inner-city Chicago found that residents would use their courtyard more if trees were planted (Kuo 2003) and residents living in greener, high-rise apartment buildings reported significantly more use of the area just outside their building (Hastie 2003; Kuo 2003). Research has found that people in greener neighborhoods judge distances to be shorter and make more walking trips (Wolf 2008).

Increased safety and reduced crime. Researchers examined the relationship between vegetation and crime for 98 apartment buildings in an inner-city neighborhood and found the greener a building's surroundings, the fewer total crimes (including violent and property crimes) and that levels of nearby

vegetation explained 7 to 8 percent of the variance in crimes reported by building (Kuo and Sullivan 2001b). In investigating the link between green space and its effect on aggression and violence study found that levels of aggression and violence were significantly lower among women who had some natural areas outside their apartments (Kuo and Sullivan 2001a). Generally, when properly designed, narrower, green streets increase safety by decreasing vehicle speeds and make neighborhoods safer for pedestrians (Wolf 1998; Kuo and Sullivan 2001b).

Increased sense of well-being. There is a large body of literature indicating that green space makes places more inviting and attractive and enhances people's sense of well-being. People living and working with a view of natural landscapes appreciate the various textures, colors, and shapes of native plants, and the progression of hues throughout the seasons (Northeastern Illinois Planning Commission 2004). Desk workers who can see nature from their desks experience 23 percent less time off sick than those who cannot see nature and report a greater job satisfaction (Wolf 1998). Habitat created by green infrastructure attracts birds, butterflies, and other wildlife that add to the aesthetic beauty and appeal of green spaces and natural landscaping. "Attention restorative theory" suggests that exposure to nature reduces mental fatigue, with the rejuvenating effects coming from a variety of natural settings, including community parks and views of nature through windows.

Reduced stormwater from preservation of open space. Adoption of green infrastructure into a site facilitates preservation of open space. This reduces the amount of impervious cover and stormwater runoff by retaining natural conditions that allow stormwater to infiltrate into the ground. In addition to the reduction of stormwater runoff, open space can also treat stormwater runoff with little maintenance needed (Massachusetts Land Trust Coalition).

Increased property values. Many aspects of green infrastructure can increase property values by improving habitat, aesthetics, drainage, and recreation opportunities that can help restore, revitalize, and encourage growth in economically distressed areas. Table 1-1 summarizes the recent studies that have estimated the effect that green infrastructure or related practices have on property values.

Table 1-1. Studies estimating percent increase in property value from green infrastructure

Source	Percent Increase in Property Value	Notes
Ward et al. (2008)	3.5%–5%	Estimated effect of green infrastructure on adjacent properties relative to those farther away in King County (Seattle), Washington.
Shultz and Schmitz (2008)	0.7%–2.7%	Referred to effect of clustered open spaces, greenways, and similar practices in Omaha, Nebraska.
Wachter and Bucchianer (2008)	2%	Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia.
Anderson and Cordell (1988)	3.5%–4.5%	Estimated value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer), Athens-Clarke County, Georgia.
Voicu and Been (2009)	9.4%	Refers to property within 1,000 feet of a park or garden and within 5 years of park opening; effect increases over time.

Source	Percent Increase in Property Value	Notes
Espey and Owasu-Edusei (2001)	11%	Refers to small, attractive parks with playgrounds within 600 feet of houses.
Pincetl et al. (2003)	1.5%	Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third acre garden or park) within a radius of 200 to 500 feet from the house.
Hobden et al. (2004)	6.9%	Refers to greenway adjacent to property.
New Yorkers for Parks and Ernst & Young (2003)	8%–30%	Refers to homes within a general proximity to parks.

1.3. Regulatory Background

Several regulatory programs impact stormwater management and green infrastructure decisions in the State of Massachusetts, including:

- *Massachusetts Stormwater Policy and Stormwater Management Standards* – Developed by the Massachusetts Department of Environmental Protection (MassDEP), these standards apply when a wetlands or 401 permit is required. The ten stormwater management standards address issues such as groundwater recharge, post-development peak discharge rates, and redevelopment.
- *Small Municipal Separate Storm Sewer System Permit (MS4)* – currently in draft and revision by EPA Region 1, the "small communities" MS4 permit requires nearly all of MassBays communities to develop a stormwater program that addresses six minimum control measures, including removing barriers to application of green infrastructure principles.
- *Construction General Permit (CGP)* – issued by EPA, this permit applies to all projects (including municipal construction projects) disturbing greater than one acre of land. Projects are required to develop a stormwater pollution prevention plan (SWPPP) and implement practices that control stormwater runoff from active construction.
- *Multi-Sector General Permit (MSGP)* – issued by EPA, this permit applies to certain categories of industrial facilities and requires the development of a SWPPP and implementation of BMPs to control stormwater runoff from industrial areas.

Additional information about these regulatory programs can be found on the MassDEP stormwater website (http://www.mass.gov/eea/agencies/massdep/water/wastewater/stormwater.html).

1.4. Green Infrastructure Maintenance

The major goal of green infrastructure operation and maintenance is to ensure that BMPs are meeting the specified design criteria for stormwater flow rate, volume, and water quality control functions. If structural green infrastructure systems are not properly maintained, effectiveness can be reduced, resulting in water quality impacts. Routine maintenance and any need-based repairs for a structural

BMP must be completed according to schedule or as soon as practical after a problem is discovered. Deferred BMP maintenance could result in detrimental effects on the landscape and increased potential for water pollution and local flooding. Table 5-1 presents relative maintenance costs for different categories and sizes of BMPs.

Training should be included in program development to ensure that maintenance staff has the proper knowledge and skills. Most structural BMP maintenance work—such as mowing, removing trash and debris, and removing sediment—is nontechnical and is already performed by property maintenance personnel. More specialized maintenance training might be needed for more sophisticated systems. Appendix C presents detailed information on proper BMP operation and maintenance.

With proper green infrastructure BMP maintenance, many benefits can be realized. The following section highlights some of the major benefits of green infrastructure.

1.5. Incorporating Green Infrastructure into Existing Municipal Programs and Facilities

Many communities in the Massachusetts Bays region are required to develop stormwater management plans to comply with stormwater Phase II permit requirements, which include the development of a program to address stormwater management in new development and redevelopment (post-construction stormwater management). Municipalities can incorporate green infrastructure concepts into their post-construction program by:

- **Review your existing codes and ordinances**. Some municipal codes can include barriers to green infrastructure implementation. Review your codes by using EPA's Water Quality Scorecard (http://www.epa.gov/dced/water_scorecard.htm) or a similar checklist to identify barriers and potential changes to your code.
- **Establish a clear post-construction retention standard**. Implement the Massachusetts stormwater standards and encourage on-site retention to the extent practicable.
- **Encourage green infrastructure practices**. Chapter 5 of this Handbook describes common green infrastructure practices that should be encouraged by municipal programs.
- **Incorporate green infrastructure into municipal capital improvement projects**. Lead by example by including green infrastructure practices in new municipal projects, such as incorporating bioretention into road or sidewalk projects.
- **Develop a green infrastructure review process**. Chapter 6 of this Handbook describes a green infrastructure review process, including incentives.
- **Review existing municipal facilities to determine if green infrastructure controls can be added**. Existing municipal facilities may have opportunities to include green infrastructure practices with fairly minor changes. For example, a bioretention area could be added where an existing grass swale exists.

- **Plan for maintenance of green infrastructure practices**. Address maintenance by identifying who will be maintaining the green infrastructure practices and requiring an operation and maintenance plan.

For specific development projects, MassDEP's plan review and permitting process requires a Stormwater Report to be submitted to document compliance with the state's Stormwater Management Standards (as detailed in Chapter 3, Volume 1 of the *Massachusetts Stormwater Handbook* [2008]). Additional information on the plan review process is in Section 6.1 of this handbook.

Also, EPA compiled a set of resources for planning for green infrastructure, including:

- Design and implementation resources to help practitioners better design, install, and maintain practices: http://water.epa.gov/infrastructure/greeninfrastructure/gi_design.cfm
- Modeling tools to assess green infrastructure performance, costs, and benefits: http://water.epa.gov/infrastructure/greeninfrastructure/gi_modelingtools.cfm
- EPA offers a Green Infrastructure Webcast Series and other training resources on their "Where Can I Get More Training?" website: http://water.epa.gov/infrastructure/greeninfrastructure/gi_training.cfm

1.6. Massachusetts Bays National Estuary Program Technical Assistance

The Massachusetts Bays (MassBays) Program was formed in 1988, and became a National Estuary Program (NEP) in 1990. Its mission is to facilitate partnerships that prompt local, state, and federal action and stewardship, by convening stakeholders on the local and regional level, providing scientific basis for management decisions, and informing decision makers about problems and solutions.

MassBays is one of 28 NEPs established and funded by EPA under §320 of the Clean Water Act (CWA). Each NEP is led by a Management Committee made up of diverse stakeholders including citizens, local, state, and federal agencies, as well as with non-profit and private sector entities. Using a consensus-building approach and collaborative decision-making process, the Committee devises a long-term plan – a Comprehensive Conservation and Management Plan (CCMP) – that contains specific targeted actions tailored to the local priorities, designed to address water quality, habitat, and living resource challenges as identified in CWA §320. Stormwater runoff is one of the largest sources of pollution faced by MassBays and other NEPs.

Each NEP works within a geographic boundary or study area. The MassBays study area encompasses approximately 1,100 linear miles of coastline, from the tip of Provincetown to the New Hampshire border, and serves 50 coastal communities (Massachusetts EEA 2014). This includes Massachusetts Bay and Cape Code estuaries. The area contains many important coastal resources such as shellfish beds, salt marshes, seagrass beds, diadromous fish runs, and shorebird habitat and nesting sites. These habitats support sensitive species and provide recreational and environmental benefits such as filtering pollutants, serving as spawning and nursery areas, and buffering against storm damage. Polluted runoff from Stormwater – excess nutrients, sediment, and chemicals – compromises these natural habitats.

The MassBays Program is organized into 5 coastal subregions to facilitate implementation of its goals and objectives. The 5 coastal subregions are (from north to south as shown in Figure 1-1): Upper North Shore, Lower North Shore, Metro Boston, South Shore, and Cape Cod. A coordinator contracted in each region provides technical and other assistance to local partners (Regional Coordinators). MassBays Central staff – an Executive Director, Staff Scientist, and Communications Coordinator – are hosted by the Massachusetts Office of Coastal Zone Management.

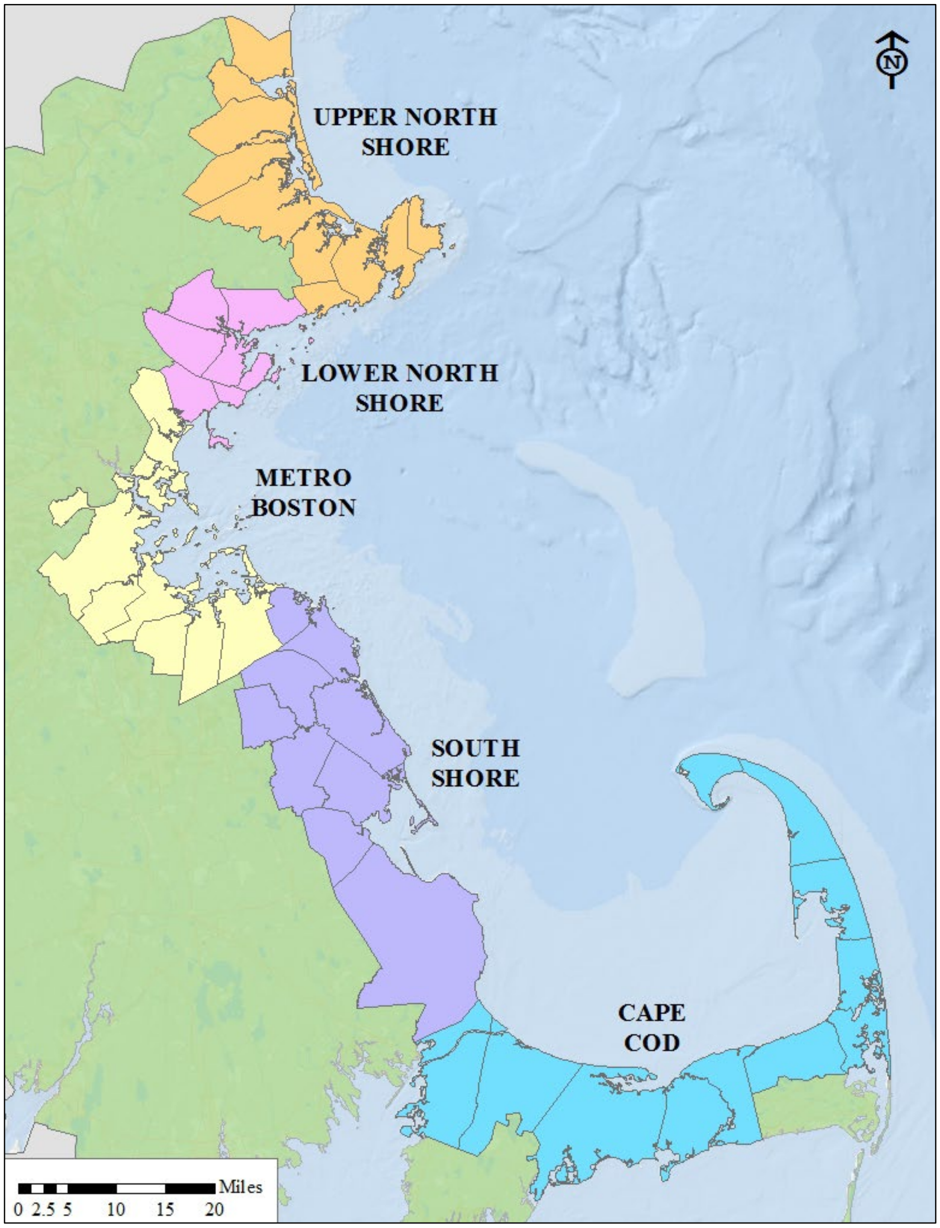

Figure 1-1. Massachusetts Bays Program Regions

MassBays can provide a range of support to municipal officials in its program areas to improve water quality and address stormwater such as helping municipalities use this Handbook to facilitate the use of green infrastructure. Through MassBays Regional Coordinators, you can receive technical support, access embayment-specific water quality assessments and planning documents, and find connections to state and federal funding agencies.

MassBays has a successful "Greenscapes" outreach and education program (greenscapes.org) for homeowners and landscaping companies, and provides direct technical assistance to municipalities to implement estuary-friendly stormwater treatment and control. Visit www.massbays.org and use the "Contact Us" link to find information for your local MassBays Program Regional Coordinator for assistance.

1.7. Case Study: Jones River Estuary and Kingston Bay Stormwater Assessment Project

Historically, Kingston Bay harbored a thriving shellfishing industry. But over time, deteriorating water quality resulted in restrictions on shellfish harvesting. To restore what once was, the town of Kingston applied for and received funding from MassBays in 2011 to evaluate the feasibility of installing green infrastructure at stormwater outfalls that discharge into the Jones River and Kingston Bay. Kingston's Conservation Agent worked with her counterpart in the town of Duxbury to lay out the process detailed in this handbook.

Kingston contracted with local consulting firm ATP Environmental and identified nineteen outfalls into the Jones River and related tributaries controlled by the Town. The outfalls were mapped and an estimate was made of the "first flush" volume related to each. Distance from the mouth of the river, in river miles, and distance from the Jones River itself were both determined as a way of assessing potential for adverse impacts to the river and Kingston Bay. Two other outfalls controlled by Mass Highways on Route 3 and discharging to the Jones River were also identified by the Town as outfalls of interest.

ATP recommended that 10 outfalls be sampled based upon the "first flush" volume generated from one inch of runoff and the proximity of the discharge to Kingston Bay. One inch of runoff was used because shellfish areas in Kingston Bay represent the natural resource of concern. Outfalls with elevated first flush volumes discharging at or near the mouth of the River, or that were high in volume within 2 miles from the mouth of the River, were selected to be sampled under two storm events. The Town added three other local outfalls based upon their observations in the past, and two outfalls managed by Mass DOT.

Two rounds of wet weather sampling were performed in fall of 2011. Samples in both rounds were analyzed for bacteria (fecal coliform and enterococci), and total suspended solids. The results of the two sampling rounds were plotted and analyzed. Because of the wide disparity of bacteria values between events at some locations, it was decided to calculate the geometric mean of values, rather than a simple average, to assess the level of contamination. The geometric mean for fecal coliform counts ranged from 52 cfu/100 ml to 13,856 cfu/100 ml with an average of 5,417 cfu/100 ml for all fifteen sample sites. The geometric mean for enterococci ranged from 856 cfu/100 ml to 39,950 with an average of 16,962 cfu/100 ml for all fifteen sample sites. Total suspended solids values ranged from 6 mg/l to 33 mg/l with

an average value of 17 mg/l across all fifteen sites. (Note: TSS values represent arithmetic average values, not geometric mean values, because TSS values between sample rounds did not vary significantly).

ATP performed an analysis to determine which of the Town-controlled outfalls represents the greatest measurable threat to the shellfish areas in Kingston Bay at the mouth of the Jones River. A mass balance was performed for each outfall using the three laboratory measured parameters selected for the study (geometric mean or arithmetic average, as appropriate) and multiplying each by the “first flush” volume. The greatest mass of fecal coliform units was measured at 9,995 million units. The greatest mass of enterococci bacteria were 49,311 million units. The greatest volume of total suspended solids was 22,166 grams. The respective average values were 3,675 million units fecal, 11,568 million units enterococci, and 8,861 grams TSS.

To reduce the number of outfalls be subject to preliminary design, ATP developed a relatively simple matrix analysis incorporating four parameters: Pollutant Level (mass fecal units and mass enterococci units); Proximity to Kingston Bay; and Constructability. Constructability refers to the probability that a subsurface leaching system can be built with volume suitable to manage the first flush and was based, in part, on the apparent public land available and soil characteristics as gleaned from the most recent NRCS mapping. Within the matrix, each outfall was assigned a value from one to five for each of the four parameters with 1 being not significant and 5 being significant. The individual scores were then added up with the highest value representing outfalls that should move forward to preliminary design.

In an effort to begin the process of mitigating stormwater impacts, conceptual designs were developed for ten catchment areas. Using first flush volumes calculated, a site specific BMP system that would remove suspended solids and fecal coliform using infiltration systems, both surface and subsurface, was developed. System headworks were sized to hold 10% of the first flush volume for settling purposes. Consistent with the Massachusetts Stormwater Handbook, infiltration systems were sized using TR-55 analyses based upon the first flush (1” of runoff) which serves as the Required Water Quality Volume. The “Dynamic Field” method was used to determine system size based upon an estimate of permeability from the soils data gathered from NRCS sources.

Depending upon soil types and estimated depth to water table, surface and subsurface infiltration systems were analyzed. In shallow-to-groundwater areas, such as near to outfalls, vegetated swales, surface filtration systems, and rain gardens were proposed. Where first flush volumes were large, upgradient subsurface systems were selected for conceptual design to capture flow and minimize the footprint of surface systems. Subsurface systems were selected in locations where soils were permeable, groundwater was deemed to be at depth, and/or where space was tight. In some locations a network of existing catchbasins and drain manholes were worked into the conceptual design, while elsewhere, no system existed apart from a simple catchbasin/outfall complex. Typical sedimentation units were comprised of drain manholes with 4’ sumps and septic tanks ranging in size from 1000 gallons to 1500 gallons. Conceptual infiltration systems were predicated upon units manufactured by Cultec with varying heights and sizes. Surface filtration systems sometimes were proposed to be constructed using imported sand with underdrainage where soils were deemed not sufficiently permeable.

Source: Maureen Thomas, Town of Kingston

Figure 1-2. Rain garden off of Delano Ave. in Kingston, MA.

Based upon the conceptual designs, a materials quantity takeoff was performed and a construction cost estimate developed for each location. Construction costs were increased by 15% to cover contingencies and 25% to cover the cost of services for final design and construction inspection. The total construction cost, including final engineering design, construction, and construction inspection for all ten locations was $556,392.

Based upon the matrix analysis results two sites were selected for preliminary design. Tasks to raise a design from “conceptual” to “preliminary” included a detailed topographic and utility survey plotted to 20-scale, and refined design to ensure clearance with existing watermains, sewage forcemains, and service connections. Two drawings were completed for the Preliminary Designs. No stormwater infrastructure exists at either location so all systems were designed to bypass flows in excess of the first flush along the street as flows currently do.

Source: Maureen Thomas, Town of Kingston

Figure 1-3. Rain garden off of Delano Ave. in Kingston, MA during a storm event.

Preliminary design at the paved swale on Delano Avenue was proposed to be comprised of a trench drain at the toe of the road, two 5’ drain manholes with 4’ sumps, and two 18’ diameter rain gardens. The site is fairly tight with poor soils and narrow public land but it appears, based upon current understanding of property lines, that a rain garden of some configuration is possible on both sides of the proposed trench drain. Final design will ensure that, once the rain gardens are full, flows in excess of the first flush will pass over the trench drain and enter the Jones River as they currently do. The final design will also seek to manage any scour that might occur from the new system by specifying some combination of riprap and hardy vegetation down gradient. Based on the preliminary designs, a total construction cost estimate of $268,778 has been calculated for the two catchment areas. The total construction cost includes 10% for construction contingencies and 25% for services related to design and construction inspection. The total construction cost estimate to mitigate all twelve outfalls is $825,170.

1.8. Handbook Components

The checklist on the next page lists the major chapters of this Handbook, describes the goals of each chapter, and lists the major activities within each chapter. Readers can also use this checklist to follow a proven process to plan for implementing a green infrastructure approach, or refer directly to specific chapters that meet their needs and are the most relevant to their situation.

INCORPORATING GREEN INFRASTRUCTURE INTO STORMWATER MANAGEMENT PLANNING

WATERSHED ASSESSMENT (CH. 2)

Chapter Goal: To provide background on the regulatory requirements related to stormwater management, conditions in the geographic region, contents of the Handbook, and green infrastructure concepts.

	Identify stakeholders and roles.
	Identify study watershed or subwatershed.
	Identify existing hydrologic and hydraulic data.
	Characterize known pollutant loadings.
	Identify existing BMPs and green infrastructure practices.
	Identify additional data needs.

IDENTIFYING GREEN INFRASTRUCTURE OPPORTUNITIES (CH. 3)

Chapter Goal: To evaluate and prioritize each potential parcel and street segment for the potential implementation of green infrastructure concepts and practices.

	Identify target subwatershed(s).
	Complete primary screening of potential BMP locations.
	Complete secondary screening and prioritization.

SITE ASSESSMENT, PLANNING, AND DESIGN (CH. 4)

Chapter Goal: To apply green infrastructure principles, concepts, and practices for a retrofit, redevelopment, or new development site.

	Review site planning and design principles.
	Incorporate green infrastructure principles and concepts in a site design.
	Prepare conceptual design plans.

GREEN INFRASTRUCTURE PRACTICES (CH. 5)

Chapter Goal: To provide an overview of green infrastructure practices with guidance on selecting the appropriate practice(s) for the selected site design.

	Use “BMP Selection Matrix” to select green infrastructure BMPs.
	Size green infrastructure BMPs.
	Review common green infrastructure practices.
	Utilize resources referenced to develop a full design.
	Consider potential BMP construction and post-construction issues.

GREEN INFRASTRUCTURE REVIEW PROCESS (CH. 6)

Chapter Goal: To achieve effective implementation of green infrastructure concepts and practices by developing effective and complete design plans and providing incentives for implementing green infrastructure practices.

	Incorporate a process for reviewing and approving green infrastructure.
	Provide incentives to encourage green infrastructure.

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2. Watershed Assessment

A watershed assessment helps to identify opportunities where green infrastructure can be used to provide water quantity and quality benefits to restore, protect, and enhance the natural hydrology and ecosystem functions in the watershed; in this case, the Massachusetts coastal region (see Figure 1-1). It includes an overview of multiple existing data resources. Additional detailed information for the steps presented below is presented in Appendix A.

The overall goal of a watershed assessment is to identify opportunities where green infrastructure can be used to provide water quantity and quality benefits to restore, protect, and enhance the natural hydrology and ecosystem functions in the watershed. The purpose of a watershed assessment is therefore to:

- Evaluate current water quality conditions to determine overall health of streams.
- Identify sources of current water quality impairments.
- Address land use changes and predict effects future growth will have on water quality.
- Link activities in the watershed with impacts to water quality, hydrology, and habitat.
- Develop management strategies to restore and maintain water quality.

There is no "one size fits all" approach when it comes to watershed assessments. Watershed assessments have varying levels of complexity depending on specific objectives, availability and quantity/quality of existing data, results from previous studies, budget and funding, schedule, watershed size, number of stakeholders and level of involvement, and other factors. However, all watershed assessments should ask the following questions:

> *The watershed assessment addresses the following major questions:*
> (1) What are the most important impacts in the watershed?
> (These include adverse impacts to water quality and hydrology.)
> (2) What are the major stressors and sources linked to these impacts?
> (3) Where in the watershed should green infrastructure efforts be focused?

Watershed assessments are typically initiated when an opportunity for restoration or enhancement is recognized, or in response to a perceived problem related to a local water body. The sections below provide an outline of the comprehensive watershed assessment approach and the types of data and analyses required. Project-specific objectives and other factors described above will determine which of the following categories should be included in the assessment and which are not relevant. Figure 2-1 outlines the components involved in the watershed assessment process, to be discussed in the following sections. Detailed information on watershed assessment is provided in Appendix A. Note that the watershed assessment is not a step-wise process – users can begin where it makes the most sense for their particular situation (for example, collecting data before identifying the stakeholders).

MassBays provides an interactive map with access to more than 500 documents dated 1996 to 2013 on its website at http://www.mass.gov/eea/agencies/mass-bays-program/estuaries/. For each of the 47 embayments in the MassBays region, you will find a wealth of downloadable assessments and

recommendations for action categorized by five topics: water quality, estuarine habitat protection, continuity of estuarine habitat, invasive species, and climate change/vulnerability. This online resource is a good first stop to find existing information about the subject watershed.

Part 1: Identify Stakeholders and Roles
Identify potential stakeholders and roles to engage the community and earn support for projects.

Part 2: Identify Study Watershed

- Define the watershed or subwatershed boundary.
  - *This establishes the limits of the study.*
- Locate or create a geographic information systems (GIS) representation of the watershed.
  - *This will facilitate watershed assessment (Section 2) and prioritization (Section 3).*

Part 3: Identify Existing Hydrologic and Hydraulic Data
Search for existing data and studies that help characterize existing conditions in the study watershed. Starting with a GIS-based desktop analysis can help reduce time and resources spent in the field.

- Locate water bodies in the study watershed.
  - *Identify waters that receive stormwater runoff and may benefit from BMPs.*
- Characterize land use and land cover.
  - *This will help determine potential for runoff and pollutant loading.*
- Identify areas of impervious coverage.
  - *These areas have the highest runoff rates (per unit area) compared to other land cover and could provide retrofit opportunities.*
- Characterize topography.
  - *Slope impacts the speed and path of stormwater runoff and some BMPs are not appropriate where steep slopes occur.*
- Identify parcel data.
  - *This will help determine land ownership.*
- Locate aerial photography dataset.
  - *This will allow for preliminary screening for BMP opportunities.*

Part 4: Characterize Known Pollutant Loadings
Identify and prioritize stormwater pollutant sources in the study watershed.

- Identify pollutants of concern or interest (beginning with 303(d) and TMDL pollutants).
- Identify potential pollutant sources.
- Estimate pollutant loadings.
  - *Pollutant loadings can be based on monitoring, land use-based estimates, or other methods.*
- Develop site characterizations.
  - *Synthesize information in previous steps to facilitate site prioritization (Section 3).*

Part 5: Identify Existing BMP and Green Infrastructure Practices
Identify any existing or planned green infrastructure projects in the study watershed.

Part 6: Identify Additional Data Needs
Identify data collection that may be necessary to address any data gaps identified in the previous steps. This could include water quality sampling and site visits.

Source: Tetra Tech

Figure 2-1. Components of the watershed assessment process.

2.1. Part 1: Identify and Engage Stakeholders

Formulate watershed assessment team by identifying potential stakeholders in the watershed and their possible roles.

A good watershed assessment team should include members with a variety of disciplines or specialties. Involving a variety of stakeholders with different backgrounds, experience, and expertise will make it less likely that the assessment will overlook some important watershed factors. A key initial step is to identify potential stakeholders in the watershed and their possible roles. The MassBays Regional Coordinators convene a Local Governance Committee with representatives from multiple local agencies and other community stakeholders; watershed associations and friends groups may also convene stakeholders and can help bring them to the table for planning and siting. As the Massachusetts MS4 permit is put in place, towns will establish MS4 committees typically charged with oversight and development of regional stormwater management programs and could serve important roles in the stakeholder process.

General categories of stakeholders may include:

- Local businesses
- Landowners
- Local, regional, state, and federal agencies including the Department of Transportation
- Environmental groups
- Nonprofit and volunteer organizations
- Watershed and neighborhood associations
- Experts (consultants, engineers, scientists, and academics)
- People with local knowledge

When initiating a watershed assessment, contact a MassBays Regional Coordinator (http://www.mass.gov/eea/agencies/mass-bays-program/regions/) who can provide assistance and connections with federal and state agencies, local nonprofits and community groups, and other towns that have implemented green infrastructure projects.

The importance of earning community support for project goals cannot be overstated. From start to finish, the assessment should make clear how and why various steps were taken. Stakeholders and decision makers are more likely to trust the assessment's conclusions if they understand the reasons why various approaches were taken, or if they were personally involved in gathering data and information.

Possible methods for stakeholder involvement may include:

- Contact the MassBays Program
- Discuss the role of or engage local residents and business owners.

- Work with local stakeholders to develop an understanding of:
  - Awareness of green infrastructure/BMP facilities.
  - Impacts of upstream pollutants and runoff to local waterways.
  - Viable communication channels.
  - Demographic variables.
- Develop outreach plan to increase community support and public awareness of green infrastructure
- Use indirect communication channels such as websites, flyers, and billing inserts.
- Use direct channels such as events, workshops, and in-person visits.
- Develop advertising materials such as brochures, how-to guides, and social media posts.

The main goal of stakeholder involvement is to target and increase public awareness and ultimately increase probability of success of project.

- EPA published the second edition of their guidance manual ***Getting in Step: Engaging Stakeholders in Your Watershed***. This manual can be very useful for guiding users through the stakeholder involvement process (www.epa.gov/owow/watershed/outreach/documents/stakeholderguide.pdf).
- *Community-Based Watershed Management: Lessons from the National Estuary Program* (www.epa.gov/nep) also contains valuable information about involving the public to address coastal management issues.

2.2. Part 2: Identify Study Watershed

Define the watershed or subwatershed boundary.

As defined by EPA, "a watershed is the area of land where all of the water that is under it or drains off it goes into the same place" (USEPA 2014). Watersheds are also called drainage basins, river basins, or catchments. Watersheds can be very small or very large depending on the point of interest from which they are drawn.

The local municipality leading the green infrastructure evaluation process typically directs the watershed assessment team to focus their study in a particular watershed (or subwatershed) based on existing knowledge of water quality, hydrology, or habitat issues prompting the assessment. If a geographic information system (GIS) based representation of the study watershed has not already been created, this should be completed to facilitate assessment.

In many cases, cooperation among multiple local municipalities is necessary when it comes to green infrastructure implementation because watersheds and subwatersheds typically do not adhere to municipal boundaries. Accordingly, a single watershed or subwatershed could encompass multiple

communities and cooperation among these multiple stakeholders is essential for achieving successful outcomes in that particular watershed.

2.3. Part 3: Identify Existing Hydrologic and Hydraulic Data

Search for existing data that help characterize watershed or catchment hydrology and hydraulics.

Once the study watershed (or subwatershed) has been identified, a key component of the watershed assessment process is to perform a detailed search for existing efforts characterizing the hydrology and hydraulics of the target watershed. This might include previously collected monitoring data, modeling efforts, watershed studies, and watershed management plans. Existing data and studies should be evaluated for their relevance and summarized. Sources of previous watershed assessments and watershed data can include local government, local organizations, and state agencies.

Data and results from previous studies and monitoring efforts can provide information to establish the *baseline conditions* for hydrology and water quality in the watershed. Previous watershed delineations and other assumptions should be evaluated, scrutinized, and confirmed appropriately before using them in the watershed assessment and prioritization. When appropriate, data and results from previous hydrology and hydraulic studies should be updated and supplemented with new data, if new data have become available since the original study.

2.3.1. Types of Data

Relevant hydrologic and hydraulic data can include any pertinent data used to describe hydrologic and hydraulic features of the watershed as well as characteristics that influence watershed hydrology and hydraulics. These data types and potential resources for obtaining data are listed below, with detailed descriptions provided in Appendix A:

- Locations of water bodies including streams, lakes, and wetlands
  - Provides identification of surface waters that receive stormwater runoff and may benefit from BMPs.
- Impervious surface coverage
  - Used to identify potential areas where greatest stormwater runoff occurs.
- Land use and land cover, including vegetation
  - Used to identify potential for runoff and pollution loading.
- Topography (elevation and slope)
  - Elevation and slope determine speed and path of stormwater runoff, and excessive slopes may prohibit green infrastructure installation.
- Soils (types, textures, and hydrologic soil groups)
  - Used to evaluate infiltration capacity.

- Parcel data
  - Used to determine ownership when identifying sites for BMP opportunities.
- Aerial imagery
  - Allows for preliminary screening of sites for BMP opportunities.

2.3.2. GIS Data for Massachusetts

Although there are other sources of spatial (GIS) data for Massachusetts, two of the more robust data acquisition systems are described below. Both databases provide instant online access to free, high-quality geospatial data.

2.3.2.1. MORIS

MORIS (Massachusetts Ocean Resource Information System) is an online spatial data mapping and acquisition tool developed by the Massachusetts Office of Coastal Zone Management (CZM) in partnership with MassGIS (described below), SeaPlan, Applied Science Associates, Charlton Galvarino, and PeopleGIS (MORIS 2014). MORIS features an interactive web-based map application that allows the user to zoom into an area of interest and download a wealth of data layers specific to that area. MORIS contains much of the same data sources as MassGIS (described below), but is of particular interest to MassBays communities due to its coastal focus.

- MORIS is accessed through the mass.gov website: www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris/

2.3.2.2. MassGIS

The Commonwealth of Massachusetts maintains a database of GIS resources through its Office of Geographic Information (MassGIS). Based on information provided by MassGIS, "the state legislature has established MassGIS as the official state agency assigned to the collection, storage, and dissemination of geographic data" and is responsible for coordinating GIS activity in the Commonwealth.

- The MassGIS geospatial library can be found at www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/.
- The MassGIS data system also includes an online viewer ("OLIVER") allowing users to quickly and easily view available data layers for a particular area. It can be found at http://maps.massgis.state.ma.us/map_ol/oliver.php.

2.3.3. Hydrologic and Hydraulic Data Summary

Table 2-1 summarizes relevant data types, descriptions, and possible sources.

Table 2-1. Recommended sources of hydrologic and hydraulic data for watershed assessment

Dataset	Type	Description	Source(s)
Subwatershed boundary	GIS shapefile	Delineation of study watershed	Municipality
Hydrography	GIS shapefile	Locations of surface water features (lakes, ponds, reservoirs, wetlands, rivers, streams)	MORIS, MassGIS
Land use and land cover	GIS shapefile	Land use and land cover	MORIS, MassGIS
Impervious Area	Image file	Impervious surfaces including buildings, roads, and parking lots	MORIS, MassGIS
Roads and streets	GIS shapefile	Transportation (public and private roadways) *(if impervious surface data are insufficient)*	MORIS, MassGIS
Elevation	GIS raster file	Elevation above or below sea level	MORIS, MassGIS
Soils	GIS shapefile	Spatial extent of soil types and HSGs	MassGIS (alternately NRCS)
Parcels	GIS shapefile	Property boundaries and ownership	Municipality, MORIS, MassGIS
Aerial imagery	Image file	True-color aerial photos	MORIS, MassGIS

2.3.4. Additional Data Resources

Additional data resources that can aid in the watershed assessment and characterization may include the following:

- Locations and routing of existing stormwater structures and pipes
  - New BMPs will become part of the existing stormwater infrastructure.
- Streamflow data and locations of streamflow gages
  - Useful for understanding existing hydrologic behavior of the study watershed.
- Climate/rainfall data and locations of climate monitoring stations
  - Used to develop understanding of climate and rainfall which impact BMP performance.
- Water quality data and locations of existing monitoring locations
  - Useful for establishing baseline water quality conditions in the watershed.
- Locations of impaired waters and corresponding impairments, both within the watershed and immediately downstream
  - Used to identify known water quality problems.
- Environmentally sensitive areas, floodplains and floodways, water supplies, and dams
  - These areas require special consideration.

The unique objectives and scope of the individual watershed assessment will determine the extent to which each of these should be investigated and included in the assessment. Detail on each of these resources is provided in Appendix A.

2.3.5. Summary of Additional Data Resources

Table 2-2 summarizes relevant data types, descriptions, and possible sources.

Table 2-2. Recommended additional data for use in watershed assessment

Dataset	Type	Description	Source(s)
Storm drain map	GIS shapefile (if available), other	GIS, digital, or hardcopy map with locations and dimensions of existing storm network including pipes, road crossings, and culverts	Municipality
Climate stations	GIS shapefile	Locations of climactic data monitoring (e.g., NCDC or NOAA, Global Historical Climatology Network [GHCN])	NOAA
Water quality monitoring stations	GIS shapefile	Locations of water quality sampling (e.g., MassDEP DWM)	MassGIS
303(d) waters	GIS shapefile	MassDEP Integrated List of Waters (303(d)) (most recent available)	MORIS, MassGIS
Shellfish sampling stations	GIS shapefile	Stations designated by DMF's Shellfish Project for water quality and shellfish samples	MORIS, MassGIS
Coastal habitat	GIS shapefile	Core/critical habitat delineations	MORIS
ACECs	GIS shapefile	Areas of Critical Environmental Concern	MORIS, MassGIS
Protected open space	GIS shapefile	Conservation lands and recreational facilities	MORIS, MassGIS
NHESP (various)	GIS shapefile	Natural Heritage & Endangered Species Program habitats and natural communities	MORIS, MassGIS
ORWs	GIS shapefile	Outstanding Resource Waters of the state	MORIS, MassGIS
Priority natural vegetation	GIS shapefile	Identified by NHESP as most critical to biological diversity	MORIS, MassGIS
NWI	GIS shapefile	National Wetlands Inventory – extent, types, and locations of wetlands and deepwater habitats	MORIS, MassGIS
FEMA flood hazards	GIS shapefile	1 percent and 0.2 percent annual chance flood boundaries and regulatory floodway	MORIS, MassGIS
Dams	GIS shapefile	Locations of dams from Massachusetts ODS, ground-truthed	MORIS, MassGIS
Public water supplies	GIS shapefile	Public surface and ground water supply sources	MassGIS

2.4. Part 4: Characterize Known Pollutant Loadings

Prioritize pollutant sources and develop a meaningful plan for green infrastructure implementation focused on the highest priority sources in the target watershed or catchment.

The purpose of this exercise is to characterize pollutant sources within the study watershed or catchment. The goal is to build upon existing bodies of knowledge, such as relevant studies and efforts within the target watershed or catchment, using supplemental research and local knowledge. Steps used to identify and summarize known pollutant loadings include:

- Identify pollutants of interest and concern (e.g., 303(d) and TMDL pollutants).
- Identify and characterize pollutant sources.
- Estimate pollutant loadings using existing monitoring data and other methods.
- Develop site characterizations.
- Identify significant data gaps (Section 2.6).
- Identify potential green infrastructure practices to address specific pollutants (this will be addressed in subsequent sections of this guidance).

Site characterizations are essentially a synthesis of the information gathered in the previous steps, and include an evaluation of any known activities that could be impacting stormwater runoff, an estimate of impervious coverage, and the likelihood for discharge of pollutants of interest. Sites with the highest known or suspected pollutant loadings should be prioritized for green infrastructure, or for further monitoring to confirm the loading assumptions, respectively. These sites will be further prioritized for green infrastructure in Section 3.

Supplemental detail on this process is provided in Appendix A. The site characterizations and estimated pollutant loadings will be used to prioritize and target green infrastructure efforts. Higher concentrations of pollutant loading might warrant a greater focus of BMPs.

2.5. Part 5: Identify Existing BMP and Green Infrastructure Practices

Identify existing or planned green infrastructure projects in the watershed or catchment.

Knowledge of any existing or planned projects is critical for developing a green infrastructure plan and assessing the current condition of the watershed or catchment. It is possible that projects already in place are significantly contributing to volume and pollutant load reduction. Further, to distribute green infrastructure opportunities effectively throughout the watershed or catchment, areas in close proximity to existing or planned green infrastructure implementation may be considered lower priority (see Section 3.3). Available resources must be reviewed to identify the location and potential effect of any existing green infrastructure practices or BMPs. All planned and existing BMPs must be considered in the identification and prioritization of potential locations for green infrastructure to maximize the potential water quality impacts of these improvements.

Potential sources of information for identifying existing BMPs include local municipalities, existing databases and inventories, existing maps and GIS data, the Massachusetts Department of Transportation (MassDOT), and physical site assessment.

Some municipalities maintain an electronic database or inventory, sometimes GIS-based, of existing stormwater management practices, principally for maintenance purposes. Municipal employees or local landowners can be good sources of knowledge for locating existing BMPs. It might be possible to obtain existing maps, data, plans, and other information on existing green infrastructure practices directly from municipalities or from local engineers or engineering firms with knowledge of when and where the

BMPs were installed. MassDOT installs and maintains stormwater BMPs for the purpose of meeting stormwater permit requirements related to runoff from state-owned transportation features. MassDOT and local DOT offices might be able to provide information on locations and design of existing BMPs.

2.6. Part 6: Identify Additional Data Needs

Identify any additional data collection that might be necessary to address data gaps identified in the watershed assessment process.

Field observations and additional monitoring may be used to verify assumptions regarding the pollutant loading analysis, or to provide additional data for the watershed assessment and characterization of pollutant sources where data gaps are identified. In watersheds or catchments with extensive existing data resources, additional data collection might not be necessary.

An important consideration is that many grant programs require sufficient water quality data before grants are awarded. This could serve as a key incentive for additional data collection when data gaps have been identified.

2.6.1. Water Quality Sampling

Wet-weather observations and sampling can be used to confirm loading from key sources or drainage areas where previous monitoring data are not available. Components can include water quality and sediment analysis at selected sample sites to determine levels of bacteria, nutrients, organic contaminants and metals or land use characterization to identify potential stressors. A biological analysis can also be included as part of watershed or catchment monitoring, such as detailed habitat, macroinvertebrate, and fish community assessments. The type of water quality sampling employed depends on the specific pollutant(s) of concern and specific impacts to be addressed.

Many watersheds benefit from the presence of local organizations (such as watershed associations) that develop their own volunteer monitoring programs. This can be an effective method for hands-on community contribution to the assessment and can also conserve resources compared to contracting out all of the monitoring work. However, effective training, supervision and scheduling are required for the data to be rendered useful for watershed assessment. Section 2.1 described potential types of watershed groups and other key stakeholders.

2.6.2. Field Reconnaissance

Sites identified as potential locations for green infrastructure as part of the watershed assessment can be further evaluated through field visits to evaluate the accuracy of the GIS analysis and further establish the priority of the site (Section 3). Field reconnaissance typically includes photo documentation and documentation of site characteristics that can impact or prevent BMP design or construction, as well as additional evaluation including:

- **Overall appearance**
  Gather information on overall site characteristics, including any perceived pollutant sources or water quality or quantity concerns. (Refer to potential sources discussed in Appendix A.)
- **Site configuration**
  Elements of the site that will determine the configuration and type of BMP, such as utilities, right-of-way (ROW) width, curb configuration, existing landscaping, current use, and existing drainage patterns.
- **Slope**
  Verify visually to confirm that the slope is appropriate for green infrastructure.

Other factors to consider in the site identification process may include:

- **Design complexity**
  Sites that require a more complex design should be avoided because they could prolong the permitting process and complicate construction. Sites that might require extensive permits from multiple regulatory agencies should also be avoided.
- **Maintenance/accessibility**
  BMPs must be maintained at some level to function as designed. Sites should be evaluated for ease of maintenance access.

2.6.3. Wetlands

Wetlands are valuable, sensitive resources that warrant careful attention in the watershed assessment process. References that can be helpful in evaluating wetlands in the watershed context include:

- EPA Region 5 Wetlands Supplement: Incorporating Wetlands into Watershed Planning
- Watershed Approach Handbook: Improving Outcomes and Increasing Benefits Associated with Wetland and Stream Restoration and Protection Projects

2.7. Part 7: Identify Sources of Funding

EPA also compiled a set of resources to help municipalities better understand the cost-benefits of green infrastructure and to identify funding opportunities. They include:

- Cost-benefit resources to conduct cost benefit analyses of green infrastructure approaches. Completed analyses demonstrate that the value of green infrastructure benefits can exceed those of gray. http://water.epa.gov/infrastructure/greeninfrastructure/gi_costbenefits.cfm
- Funding opportunities including federal funding sources and funding tools that project sponsors can use to tap a variety of federal funding sources.
  http://water.epa.gov/infrastructure/greeninfrastructure/gi_funding.cfm
- Managing Wet Weather with Green Infrastructure Municipal Handbook: Funding Options.
  http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_funding.pdf

- EPA's report, *Getting to Green: Paying for Green Infrastructure: Financing Options and Resources for Local Decision-Makers*, provides a summary of funding mechanisms available to support stormwater management programs or finance individual projects. http://water.epa.gov/nep. The report outlines financing options (mostly applicable to small parcel projects), examples of municipal programs by type of funding source, and a list of additional resources for financing green infrastructure projects.

Several possible funding sources for green infrastructure projects are outlined below. Contact your MassBays Regional Coordinator to discuss possible funding opportunities and options.

MassBays Research and Planning Grants

Agency: Executive Office of Energy and Environmental Affairs (EEA)-Coastal Zone Management (CZM)

Description and Eligible Activities: The MassBays Research and Planning Program provides grants for applied planning and research projects that protect coastal habitat, reduce stormwater pollution, protect shellfish resources, manage local land use and growth, manage municipal wastewater, manage marine invasive species, monitor marine and estuary waters, and adapt to the projected impacts of climate change. Note: the program will be inactive in FY2015, to be evaluated and re-launched in FY2016.

Website: www.massbays.org

Eligible Applicants: Massachusetts cities, towns, and other public entities; academic institutions; and certified 501(c) (3) non-profit organizations.

Clean Water Act S.604b Water Quality Management Planning Grant Program

Agency: Department of Environmental Protection (DEP)

Description and Eligible Activities: Assists regional planning agencies and other eligible recipients in providing water quality assessment and planning assistance to local communities.

Website: http://www.mass.gov/eea/agencies/massdep/water/grants/watersheds-water-quality.html#3

Eligible Applicants: Regional planning agencies, conservation districts, cities and towns

Coastal Pollution Remediation (CPR) Grants

Agency: Executive Office of Energy and Environmental Affairs (EEA)-Coastal Zone Management (CZM)

Description and Eligible Activities: The CPR Program provides funding to municipalities located within the Massachusetts coastal watershed for planning / design and remediation including construction and implementation to reduce stormwater pollution from paved surfaces, or for commercial boat waste pumpout facilities. Municipalities may request up to $125,000 for stormwater planning /design /remediation or commercial boat pumpout projects.

Website: http://www.mass.gov/eea/agencies/czm/program-areas/coastal-water-quality/cpr/

Eligible Applicants: Municipalities located in the greater Massachusetts Coastal Watershed (see http://www.mass.gov/eea/agencies/czm/program-areas/coastal-water-quality/cpr/coastal-watershed-communities.html)

Clean Water Act S.319 grants

Agency: Department of Environmental Protection (DEP)

Description: This grant program is authorized under Section 319 of the federal Clean Water Act for implementation projects that address the prevention, control, and abatement of nonpoint source (NPS) pollution. In general, eligible projects must: implement measures that address the prevention, control, and abatement of NPS pollution; target the major source(s) of nonpoint source pollution within a watershed/subwatershed; contain an appropriate method for evaluating the project results; and must address activities that are identified in the Massachusetts NPS Management Plan. Proposals may be submitted by any interested Massachusetts public or private organization. To be eligible to receive funding, a 40% non-federal match is required from the grantee

Website: http://www.mass.gov/eea/agencies/massdep/water/grants/watersheds-water-quality.html#2

Eligible Applicants: Any Massachusetts public or private organization.

Massachusetts Environmental Trust

Agency: Executive Office of Energy and Environmental Affairs (EEA)

Description and Eligible Activities: The Trust supports cooperative efforts to restore, protect, and improve water and water-related resources of the Commonwealth. Grants funds are generated through the sale of environment themed license plates.

Website: http://www.mass.gov/eea/met

Eligible Applicants: Eligible organizations generally include 501(c)(3) nonprofit organizations and municipalities. Unincorporated organizations may apply provided that they have an eligible fiscal sponsor.

Rivers and Harbors Grant Program

Agency: Department of Conservation and Recreation (DCR)

Description: Grants requiring matching funds for studies, surveys, design & engineering, environmental permitting and construction that addresses problems on coastal & inland waterways, lakes, ponds and great ponds. Grants are awarded in the following categories: 1) Coastal Waterways - for commercial and recreational navigation safety & to improve coastal habitat by improving tidal interchange; 2) Inland Waterways - to improve recreational use, water quality & wildlife habitats; 3) Erosion Control - to protect public facilities and reduce downstream sedimentation; 4) Flood Control - to reduce flood potentials.

Contact: Kevin P. Mooney, (781) 740-1600 x103

Wetlands and River Restoration and Revitalization Priority Projects

Agency: Department of Fish and Game (DFG)

Description and Eligible Activities: These grants support sustainable river and wetland restoration projects that restore natural processes, remove ecosystem stressors, increase the resilience of the ecosystem, support river and wetland habitat, and promote passage of fish and wildlife through dam and other barrier removal. Support is also provided for urban stream revitalization projects that improve the inter-connection between water quality, aquatic ecology, physical river structure and land use, taking into consideration the social, cultural and economic landscape.

Website: http://www.mass.gov/eea/agencies/dfg/der/aquatic-habitat-restoration/river-restoration/

Eligible Applicants: Open to public agencies and (c) (3) certified non-profit organizations, including, but not limited to state agencies, cities and towns, regional planning agencies, watershed organizations, and land trusts.

Buzzards Bay Watershed Municipal Mini-grant Program

Agency: Executive Office of Energy and Environmental Affairs (EEA)-Coastal Zone Management (CZM)

Description and Eligible Activities: The Buzzards Bay National Estuary Program offers these grants to assist interested Buzzards Bay watershed municipalities in the protection of open space, rare and endangered species habitat, and freshwater and saltwater wetlands, and to help restore tidally restricted salt marshes, to purchase oil spill containment equipment, to restore fish runs, and to remediate stormwater discharges threatening water quality. These funds have been made available in accordance with US EPA National Estuary Program Cooperative Agreements and are part of an ongoing Buzzards Bay Watershed Municipal Grant Program implemented by the Buzzards Bay National Estuary Program.

Website: www.buzzardsbay.org

Eligible Applicants: Eligible towns include Fall River, Westport, Dartmouth, New Bedford, Acushnet, Fairhaven, Rochester, Mattapoisett, Marion, Wareham, Middleborough, Carver, Plymouth, Bourne, Falmouth, and Gosnold. However, specific restoration and protection projects must lie principally within the Buzzards Bay watershed.

Catalog of Federal Funding Sources for Watershed Protection (searchable database)

Website: https://ofmpub.epa.gov/apex/watershedfunding/f?p=fedfund:1

2.8. References

MORIS (Massachusetts Ocean Resource Information System). 2014. Accessed June 2014. http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris/

USEPA (U.S. Environmental Protection Agency). 2013. *Getting in Step: Engaging Stakeholders in Your Watershed (2nd edition).* EPA 841-B-11-001. U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch (4503T), Washington, DC. http://cfpub.epa.gov/npstbx/files/stakeholderguide.pdf.

USEPA (U.S. Environmental Protection Agency). 2014. *What is a Watershed?* U.S. Environmental Protection Agency, Washington, DC. Accessed March 2014. http://water.epa.gov/type/watersheds/whatis.cfm.

3. Identifying Green Infrastructure Opportunities

This section of the Handbook provides an overview for determining the highest priority sites in a given municipality. The green infrastructure opportunity evaluation and prioritization process will identify specific parcel-based locations within the watershed where green infrastructure or green infrastructure retrofits can be implemented that would provide water quantity and quality benefits in the watershed.

Step 1: **Identification of Target Subwatersheds**

This section builds on the information gathered in Section 2 (Watershed Assessment) to help identify target subwatersheds where green infrastructure implementation will be most effective.

Step 2: **Primary Screening of Potential BMP Locations**

This section outlines primary screening process, emphasizing publicly owned lands (including publically-owned parcels and transportation right-of-ways) as creating the greatest opportunity for green infrastructure.

Step 3: **Secondary Screening and Prioritization**

Opportunities identified in the primary screening process are prioritized based on their suitability and potential to serve as effective green infrastructure sites. The prioritization criteria vary depending on whether the opportunity is located within a public parcel or a transportation right-of-way. This section also provides example scoring tables for ranking potential sites.

Identifying the best potential locations for green infrastructure implementation can be achieved through a site-selection and prioritization process. The site screening and prioritization process is a desktop analysis that systematically evaluates and prioritizes potential sites throughout the watershed. This screening and prioritization process involves GIS-based analyses using the best available data that considers landscape characteristics, jurisdictional attributes, water quality needs, and general site sustainability. The advantage of this prioritization process is the ability to select cost-effective green infrastructure locations that would provide water quantity and quality benefits to the watershed.

This green infrastructure site selection and prioritization process involves three primary steps:

(1) Identify target subwatersheds where green infrastructure implementation would be most effective in addressing known priorities and providing water quantity and quality benefits to the watershed (completed as part of watershed assessment per Section 2).

(2) Perform a primary screening to eliminate sites unsuitable for green infrastructure implementation on the basis of physical and jurisdictional characteristics.

(3) Perform a secondary screening to prioritize potential sites based on suitability. Prioritization identifies candidate sites that are ideal for green infrastructure implementation and most effective in achieving priorities of the watershed.

The green infrastructure opportunity evaluation and prioritization process will identify specific parcel-based locations within the watershed where green infrastructure or green infrastructure retrofits can be implemented that would provide water quantity and quality benefits to the watershed. Parcel-based green infrastructure sites are opportunities for various types or combinations of green infrastructure practices described in Section 5, from vegetated filter strips and planter boxes to bioretention areas and constructed stormwater wetlands. Green infrastructure opportunities in rights-of-way (ROWs) require the use of transportation layers rather than parcel layers. A right-of-way is a type of easement reserved for transportation for the purpose of maintenance or expansion of existing services. ROW green infrastructure opportunities are typically smaller in scale and include bioretention areas, permeable pavement, or a combination thereof.

The following sections discuss the three steps in identifying parcel-based and ROW green infrastructure opportunities sites in coastal Massachusetts.

3.1. Identification of Target Subwatersheds

To prioritize green infrastructure site opportunities, it is important to identify watershed priorities or the watershed goals green infrastructure implementation is intended to achieve. These watershed priorities or goals narrow the focus of green infrastructure implementation to areas where the impacts of green infrastructure would be greatest. Target subwatersheds, where green infrastructure implementation will be the most effective, can be subwatersheds with 303(d)-listed water bodies, with specific amenities or habitats in need of restoration or preservation, with high land-based pollutant loadings, or with known pollutant sources (based on the results of the watershed assessment in Section 2).

Coastal Massachusetts hosts dozens of aquatic habitats from sea grass beds to tidal flats to salt marshes and dunes. These habitats support sensitive species and provide recreational and environmental benefits such as filtering pollutants, serving as spawning habitat, and buffering against storm damage. To protect these coastal resources, special habitat and water quality considerations can be used to identify target subwatersheds. Habitat and water quality priorities specific to the region include bathing beaches, designated shellfish growing areas (DSGAs), salt marsh restoration sites, seagrass beds, diadromous habitats, intertidal habitats, and areas of critical environmental concern (ACECs). Geospatial data that identify water quality, habitat, and coastal priorities that can be used to identify target subwatersheds specific to the region are presented below:

- **Designated Shellfish Growing Areas (DSGAs**). A DSGA is an area of potential shellfish habitat. Compiled by the Department of Fish and Game's Division of Marine Fisheries (DMF), there are 304 DSGAs which have classifications ranging from approved to prohibited areas.
- **Salt Marsh Restoration Sites**. Developed by the Massachusetts Office of Coastal Zone Management (MCZM), these sites are located between Salisbury and Gloucester and were compiled as part of the Parker River/Essex Bay ACEC Project.
- **Areas of Critical Environmental Concern (ACECs).** Designated by the Secretary of Energy and Environmental Affairs (EEA), ACECs are coastal and inland areas that receive special recognition

because of the quality, uniqueness, and significance of their natural and cultural resources. MCZM and the Department of Conservation and Recreation compiled this data layer.

- **Seagrass Beds.** Seagrass beds are critical wetlands components of shallow marine ecosystems along the Massachusetts coastline. MassDEP began a program to map the state's Submerged Aquatic Vegetation (SAV) resources in the early 1990s. Since 1995 the MassDEP Eelgrass Mapping Project has produced multiple surveys of SAV along the Massachusetts coastline.
- **Biodiversity**. The Massachusetts Natural Heritage and Endangered Species Program (NHESP) and The Nature Conservancy's Massachusetts Program developed *BioMap2* in 2010 as a conservation plan to protect the state's biodiversity. *BioMap2* is designed to guide strategic biodiversity conservation in Massachusetts over the next decade by focusing land protection and stewardship on the areas that are most critical for ensuring the long-term persistence of rare and other native species and their habitats, exemplary natural communities, and a diversity of ecosystems.
- **Outstanding Resource Waters (ORWs)**. Designated waters protected under Massachusetts Surface Water Quality Standards (314 CMR 4.00) because of their "outstanding socioeconomic, recreational, ecological, and/or aesthetic values."

3.2. Primary Screening of Potential BMP Locations

Because structural BMPs at any scale involve identifying and setting aside land for stormwater treatment, assessing opportunities on existing, publicly owned lands is especially important. Structural treatment often can be integrated into parks or playing fields and street rights-of-way (ROWs) or medians without compromising function, so opportunities for incorporating BMPs in recreation areas, streets, and other public open spaces are typically prioritized and used as a first step in evaluating available sites.

- ***The primary screening process uses GIS screening techniques to identify candidate locations based on suitability and feasibility for green infrastructure implementation. Primary screening rules out areas where green infrastructure implementation might be infeasible or costly and focuses implementation on public parcels as being most cost-effective.***
- ***The two primary factors considered in the primary screening process for parcel-based green infrastructure opportunities include land ownership and slope. For right-of-way (ROW) green infrastructure opportunities, road type, local topography, and depth to ground water can significantly influence the practicality of designing and constructing these features. Table 3-1 summarizes details on the primary screening criteria for both parcel-based and ROW green infrastructure opportunities.***

The purpose of the primary screening process is to provide a base list of sites potentially suitable for green infrastructure implementation. Prioritization of the remaining candidate sites occurs in the secondary screening process as the next section describes.

Table 3-1. Primary screening criteria for parcel-based and ROW green infrastructure opportunities

Primary Screening Criteria	
Parcel-Based Opportunities	**ROW Opportunities**
▪ **Parcel Ownership and Zoning/Land Use**: Land costs generally are minimized by using existing public lands; therefore, most privately owned parcels are eliminated as potential green infrastructure sites. In some cases, private universities and other private lands may be retained for consideration and should be considered on a case-by-case basis. Depending on the available GIS data, classifications such as zoning, land use, and parcel ownership can be used to distinguish public sites from private sites. ▪ **Slope**: Parcels where the slope exceeds 15 percent should be eliminated in the primary screening process. Slope can be determined on the basis of DEMs or other available topography datasets. In areas where overall slope of the parcel is in question, slope can be verified through review of aerial imagery.	▪ **Road Classification**: High traffic volumes and high speed limits are not favorable road conditions for siting right-of-way (ROW) green infrastructure. Freeways, highways, and major roads should be screened out. Road classification data can be obtained from Census TIGER road data, if local road classification data are not available. ▪ **Slope**: Green infrastructure implementation on streets with grades greater than 10 percent present engineering challenges that substantially reduce the cost-effectiveness of the retrofit opportunity. Road segments with slopes greater than 10 percent should be screened out. ▪ **Depth to Ground Water[1]**: Shallow depths to ground water indicate the potential for ground water inflow, which will diminish the storage capacity of green infrastructure practices. Roads in areas where depth to ground water is less than 10 feet should receive a lower priority.

[1] Coastal areas are commonly characterized by shallow ground water depths. In such cases, the "10 feet" rule of thumb may not apply, and special consideration should be given to green infrastructure BMPs that are favorable for areas with high water tables (see BMP Matrix, Table 5-1).

3.3. Secondary Screening and Prioritization

After primary screening, the remaining sites are prioritized based on their suitability and potential to serve as effective green infrastructure sites with anticipated positive downstream impacts. Positive downstream impacts and overall water quality and quantity benefits vary by watershed. In coastal Massachusetts, for instance, downstream impacts should support the viability of bathing beaches, shellfish beds, sensitive salt marsh, and other coastal habitat.

3.3.1. Prioritization Criteria

The secondary screening and prioritization process involves a GIS-based analysis to rank candidate sites based on various prioritization criteria. Prioritization criteria are different for parcel-based green infrastructure opportunities and ROW green infrastructure opportunities. Parcel-based green infrastructure opportunities can also vary in scale. ***Small-scale parcel-based green infrastructure opportunities typically consider sites for green infrastructure practices ranging from 500 to 2,000 square feet. Large-scale parcel-based green infrastructure opportunities typically consider site for green infrastructure practices of 0.1 acre and greater and require more available space for implementation.*** Prioritization criteria for all parcel-based and ROW green infrastructure opportunities are summarized in Table 3-2 and discussed in detail following the table. The following section describes the prioritization methodology using these criteria.

Table 3-2. Key secondary screening prioritization criteria for parcel-based and ROW green infrastructure

Parcel-based green infrastructure (small- and large-scale)	ROW green infrastructure
▪ Public ownership (except in special cases, per Table 3-1) ▪ Proximity to targeted subwatershed ▪ Proximity to environmentally sensitive or protected areas ▪ Infiltration capacity ▪ Parcel size (large-scale) ▪ Impervious parcel area ▪ Percent impervious ▪ Proximity to storm drainage networks ▪ Proximity to contaminated soils ▪ Proximity to existing BMPs ▪ Proximity to parks and schools ▪ Contributing drainage area (large-scale)[1] ▪ Drainage area percent imperviousness (large-scale) ▪ Known stormwater/MS4 capacity issues	▪ Proximity to targeted subwatershed ▪ Infiltration capacity ▪ Available width

Note:

[1]Drainage areas need to be delineated for each potential green infrastructure opportunity. Identification of large-scale green infrastructure opportunities can still be performed in lieu of drainage area size and percent imperviousness of the drainage area; however, prioritization would significantly benefit from inclusion of these criteria.

Secondary screening criteria for parcel-based green infrastructure opportunities include:

- **Public ownership:** Publicly-owned (e.g., city- or town-owned) parcels are most favorable because they avoid the cost of land acquisition or need for easement establishment and allow for jurisdictions to have direct control over green infrastructure construction, maintenance, and monitoring. These public parcels would be favored over other-owned public parcels such as schools, universities, state facilities, and federal facilities. Certain types of private parcels (e.g., private universities) may be suitable and should be investigated on a case-by-case basis.
- **Proximity to targeted subwatershed:** Parcels within targeted subwatersheds will provide the greatest effect on water quality and habitat enhancement. Parcels that drain to targeted subwatersheds can also be prioritized because these locations will result in positive downstream impacts.
- **Proximity to environmentally sensitive or protected areas:** For parcels located within an environmentally sensitive or protected area, significant restrictions can apply, resulting in construction complexity and elevated costs. Parcels within sensitive or protected areas are considered low-priority sites; however, areas in close proximity to these sensitive or protected areas are prioritized as green infrastructure and can treat the runoff before it drains to these valuable areas.
- **Infiltration capacity**: Mapped hydrologic soil groups (HSGs) provide an initial estimate for the infiltration rate and storage capacity of the soils on-site. Sites where mapped HSGs have high

infiltration rates, and thus are most suitable for infiltration BMPs, receive higher priority. It is important to note that soil maps are initial estimates and that field investigations would be necessary to verify soil conditions.

- **Parcel Size (large-scale)**: Parcel size is a useful indicator to determine if sufficient space is available to implement an appropriately sized green infrastructure. The greater the parcel size, the greater the opportunity for green infrastructure implementation.
- **Impervious parcel area**: Parcels representing a larger total impervious area typically generate more runoff and greater pollutant loads. Green infrastructure implementation on these parcels, therefore, has the greatest potential to result in water quality and habitat benefits.
- **Percent impervious**: Parcels with a higher percentage of impervious area relative to the size of the parcel also typically produce more runoff. These sites are prioritized on the basis of the greater potential to achieve volume reduction and water quality improvements, relative to their overall parcel size.
- **Proximity to the storm drainage network:** Areas in close proximity to the storm drain network are prioritized as they reduce potential construction costs. Green infrastructure on poor draining soils requires underdrain systems that tap into existing infrastructure; therefore, siting green infrastructure opportunities in proximity to the storm drain network can minimize cost and reduce construction complexity.
- **Contaminated sites**: Areas near contaminated sites are of lower priority because of the potential for increased costs and complications during implementation.
- **Proximity to existing BMPs**: To distribute green infrastructure opportunities effectively throughout the watershed, areas in close proximity to existing or planned green infrastructure implementation can be given a lower priority.
- **Proximity to parks and schools**: Areas closest to parks and schools are prioritized because these sites provide a greater opportunity for public outreach and education.
- **Contributing drainage area (large-scale)**: Given the size of the drainage area that could be diverted and treated at each potential large-scale green infrastructure opportunity, sites that capture and effectively treat runoff from the largest drainage areas are given higher priority.
- **Drainage area percent imperviousness (large-scale)**: Contributing drainage areas with a higher percentage of imperviousness produce increased runoff relative to the watershed size during storms. Higher impervious drainage areas are prioritized for greater potential water quality and habitat improvements.
- **Known stormwater/MS4 capacity issues**: Areas with known flooding or other issues related to insufficient storm drain capacity or function should receive a higher priority.
- **Municipality preference:** In many cases, the local municipality may already have a list of one or more potential sites considered favorable for green infrastructure consideration based on local knowledge and any combination of factors listed above.

Secondary screening criteria for ROW green infrastructure opportunities:

- **Proximity to targeted subwatershed:** Parcels within targeted subwatersheds will provide the greatest impact to water quality and habitat enhancement. Parcels that drain to targeted subwatersheds can also be prioritized as these locations will result in positive downstream impacts.
- **Infiltration capacity**: Mapped HSGs provide an initial estimate for the infiltration rate and storage capacity of the soils on-site. Sites where mapped HSGs have high infiltration rates, and thus are most suitable for infiltration BMPs, receive higher priority. It is important to note that soil maps are initial estimates and that field investigations would be necessary to verify soil conditions.
- **Available width**: The width of the area between the curb and the sidewalk, often referred to as the parkway, varies with road type because it accounts for the shoulders, parking lanes, and sidewalks within ROWs. Standard parkway widths per road types vary across state and municipal jurisdictions. Parkway widths can also have distinct zones that allow for parkway edge, furnishings, throughways or walkways, and frontage areas. Green infrastructure implementation in parkway widths can have varying limitations, but generally the greater the parkway width, the more opportunity for sizeable green infrastructure implementation. Parkway width criteria can be adjusted to reflect specific widths in a jurisdiction or county.

3.3.2. Prioritization Methodology (Site Scoring)

Green infrastructure opportunities are prioritized based on the prioritization criteria (Section 3.3.1) using a scoring methodology. Scores range from 1 to 5, where 5 is the highest score assigned to indicate higher priority. To emphasize priority based on potential load reduction and cost-effectiveness, scores of 5 are assigned to municipally owned parcels and sites located within target subwatersheds. A parcel or road segment is assigned a score for each priority criterion and the sum of all scores is the total score. ***Parcels or road segments with the highest total scores are priority green infrastructure opportunities.***

Scoring thresholds for priority criteria vary for small-scale parcel-based green infrastructure opportunities, large-scale parcel-based green infrastructure opportunities, and ROW green infrastructure opportunities. Small-scale parcel-based green infrastructure opportunities have specific parcel size, imperviousness, and impervious parcel area criteria (Table 3-3). Large-scale parcel-based green infrastructure opportunities have specific parcel size, impervious parcel area, contributing drainage area, and drainage area percent imperviousness (Table 3-4). ROW green infrastructure opportunities have specific parkway width criteria (Table 3-5).

The secondary screening and prioritization process ranks candidate green infrastructure opportunities based on their total scores. The highest total score represents sites that are most feasible, cost-effective, and offer the greatest opportunity to provide water quality and habitat benefit. Beyond this desktop prioritization analysis, sites are subject to field investigations to verify site conditions, evaluate potential multi-benefit uses, and determine permitting and construction needs and costs.

Table 3-3. Prioritization criteria for small-scale green infrastructure opportunities

Factor	Score (5 = Highest Priority, 1 = Lowest Priority)				
	5	4	3	2	1
Public ownership	City- or town-owned public parcels and ROWs	Other-owned public parcels (schools and universities, state and federal facilities, utilities, etc.) and certain private parcels.			
Proximity to target subwatershed[1]	Within target subwatershed				Within subwatershed draining to target watershed
Proximity to environmentally sensitive or protected areas (feet)[2]	< 100, but not within a sensitive or protected area				
Infiltration Capacity (HSG soil type)	A, B		C		D
Impervious area (acres)	> 1	> 0.5	> 0.25	> 0.1	
% Imperviousness	60%–80%	80%–90%			< 50%
Proximity to storm drainage network (feet)			< 100	< 300	> 300
Proximity to contaminated soils (feet)			> 100		< 100
Existing/proposed BMP site proximity (miles)	> 5	4–5	3–4	2–3	< 2
Proximity to parks and schools (feet)			< 1,000		> 1,000
MS4 capacity issues	Known flooding areas				No known issues

Notes:

[1] Parcels that do not drain to or are not within a target subwatershed receive a score of zero.

[2] Parcels that are directly within or greater than 100 feet from an environmentally sensitive or protected area receive a score of zero.

Table 3-4. Prioritization criteria for large-scale green infrastructure opportunities

Factor	Score (5 = Highest Priority, 1 = Lowest Priority)				
	5	4	3	2	1
Public ownership	City- or town-owned public parcels and ROWs.	Other-owned public parcels (schools and universities, state and federal facilities, utilities, etc.)			

Factor	Score (5 = Highest Priority, 1 = Lowest Priority)				
	5	4	3	2	1
Proximity to target subwatershed[1]	Within target subwatershed				Within subwatershed draining to target watershed
Proximity to environmentally sensitive or protected areas (feet)[2]	< 100, but not within a sensitive or protected area				
Infiltration Capacity (HSG soil type)	A, B		C		D
Parcel size (acres)	> 200	150–200	100–150	1–100	< 1
% Imperviousness	< 30%	30%–40%			> 40%
Proximity to storm drainage network (feet)			< 100	< 300	> 300
Proximity to contaminated soils (feet)			> 100		< 100
Existing/proposed BMP Site Proximity (miles)	> 5	4–5	3–4	2–3	< 2
Proximity to parks and schools (feet)			< 1,000		> 1,000
Contributing drainage area	> 250	> 150	> 100	> 50	< 50
Drainage area percent imperviousness	> 70%	> 60%	> 50%	> 40%	< 40%
MS4 capacity issues	Known flooding areas				No known issues
Municipal Preference	Score based on municipal evaluation				

Notes:

[1] Parcels that do not drain to or are not within a target subwatershed receive a score of zero.

[2] Parcels that are directly within or greater than 100 feet from an environmentally sensitive or protected area receive a score of zero.

Table 3-5. Prioritization criteria for ROW green infrastructure opportunities

Factor	Score (5 = Highest Priority, 1 = Lowest Priority)				
	5	4	3	2	1
Proximity to target subwatershed[1]	Within target subwatershed				Within subwatershed draining to target watershed
Infiltration Capacity (HSG soil type)	A, B		C		D
Parkway width (feet)	> 10		5–10		< 5

Notes:

[1] Parcels that do not drain to or are not within a target subwatershed receive a score of zero.

4. Site Assessment, Planning, and Design

This section of the Handbook contains green infrastructure planning practices, including land use planning, site assessment, retrofit considerations, and site design examples. It also includes an overview of conceptual design plans. Once the watershed assessment presented in Chapter 2 and potential sites have been identified and prioritized using the guidance in Chapter 3, guidance provided in chapter 4 presents concepts for assessment and planning at the site scale to incorporate green infrastructure concepts and practices into retrofit, redevelopment, and new development projects.

Part 1: **Site Planning and Design Principles**

This section describes the fundamental planning concepts of green infrastructure practices as well as typical constraints and limitations when implementing green infrastructure. It also provides an overview of the site assessment process. An accompanying example conceptual site design is presented in Appendix B.

Part 2: **Preparing Conceptual Design Plans**

This section builds on information presented in Sections 2 and 3. Once sites have been identified, further effectiveness assessment should be performed for the top sites to develop an optimized conceptual design plan. This section provides an overview of preliminary geotechnical investigation, modeling and optimization, and preparing a conceptual design report.

Green infrastructure practices use natural features to slow and filter stormwater runoff. Project characteristics will define which green infrastructure BMPs are applicable. When determining the appropriate green infrastructure requirements, project managers must consider characteristics such as site location, existing topography and soils, and planning elements. These characteristics and their impacts on design are important because green infrastructure BMPs are permanent features that can affect other project elements; therefore, it is critical to conduct thorough site assessments to avoid the need for redesign later. Incorporating green infrastructure early in the site design stage, whether new construction or redevelopment, could reduce the need for and cost of traditional drainage infrastructure by reducing the amount of stormwater to be conveyed off-site.

4.1. Site Planning and Design Principles

The following are the fundamental planning concepts of green infrastructure practices (Prince George's County 1999):

1. ***Using hydrology as the integrating framework***
   Integrating hydrology during site planning begins with identifying sensitive areas, including streams, floodplains, wetlands, steep slopes, highly permeable soils, and woodland conservation zones. For redevelopment or retrofits this could involve evaluating existing soils, the level of disturbance of those soils, and protecting any existing natural features. Through that process, the development envelope—the total site area that affects the hydrology—is defined. This effort must include evaluating both upstream and downstream flow paths and drainage areas that may be affected. For redevelopment or retrofits this process could involve locating the existing storm drainage network.

The functional value of natural wetlands and their value to ecosystems and watersheds where they are located has been well documented. They serve to store rainfall, reduce peak runoff during storms, and provide habitat for a diverse variety of plant and animal species. Wetlands also improve water quality, reduce the effects of erosion by stabilizing soils, dampen the effects of wave action in shoreline areas, and help sustain surrounding aquatic environments (Dennison et al., 1993, Mitsch and Gosselink, 1986). Natural wetlands should be identified and protected within the watershed and at the site scale. The Federal Clean Water Act helps to protect the functions and values of Waters of the U.S. (including many natural wetlands). Section 404 of the Clean Water Act regulates the discharge of dredged or fill material, while Section 402 (National Pollutant Discharge Elimination System) regulates the discharge of pollutants into these resources. CWA Section 402 authority addresses discharges of industrial and construction site stormwater, municipal separate storm sewer systems, and stormwater that contributes to a violation of water quality standards. States can play a role in implementing Clean Water Act programs as well as implement their own wetlands protection programs.

Constructed stormwater wetlands are engineered to mimic the conditions and treatment functions found in natural wetlands. For further information on constructed stormwater wetlands, please refer to Section 5.3.3.

2. ***Use distributed practices***
   Distributed control of stormwater throughout the site can be accomplished by applying small-scale green infrastructure BMPs throughout the site (e.g., bioretention in landscaped areas, permeable pavement parking stalls). This might include preserving areas that are naturally suited to stormwater infiltration and require little or no engineering. Such small-scale, green infrastructure BMPs foster opportunities to maintain the natural hydrology even in highly impervious areas, provide a much greater range of control practices, allow control practices to be integrated into landscape design and natural features of the site, reduce site development and long-term maintenance costs, and provide redundancy if one technique fails.

3. ***Controlling stormwater at the source***
   Undeveloped sites possess natural stormwater mitigation functions such as interception, depression storage, and infiltration. Those hydrologic functions should be restored or designed as close as possible to the disturbed area (e.g., parking lot, building) to minimize and then mitigate the hydrologic effects of site development. Bioretention cells, as shown in Figure 4-1, are an example green infrastructure practice that can serve this function.

Source: Jo Ann Muramoto

Figure 4-1. Bioretention cell (Cape Cod).

4. ***Using simple, non-engineered methods***
   Methods employing existing soils, native vegetation, and natural drainage features can be integrated into green infrastructure designs. These designs integrate natural elements into stormwater management and limit structural material including concrete troughs and vault systems. Examples include bioretention cells, curb pop-outs, and depressed medians, as shown in Figure 4-2.
5. ***Creating a multifunctional landscape***
   Urban landscape features such as streets, sidewalks, parkways, and green spaces can be designed to be multifunctional by incorporating detention, retention, and filtration functions such as curb pop-outs, as shown in Figure 4-2.

Source: Tetra Tech

Figure 4-2. Example of a bioretention curb pop-out (Portland, Oregon).

Siting and selecting appropriate green infrastructure practices is an iterative process that requires comprehensive site planning with careful consideration of all nine steps detailed in Figure 4-3. A site planner, landscape architect, or engineer can follow these steps in developing final site plans. The steps are arranged on the basis of the anticipated design phases of site assessment, preliminary design, and final design (Phases I, II, and III, respectively). Each step is an integral part of developing a site plan that mimics natural conditions; however, some of the steps may not apply in a redevelopment or retrofit situation.

A thorough site assessment is needed initially to identify the development envelope and minimize site alterations. The primary objective of the site assessment process is to identify limitations and development opportunities specific to green infrastructure. For example, development opportunities include available space, use of ROW as appropriate, and maximizing opportunities where properly infiltrating soils exist. Constraints or limitations that need to be factored into site planning when implementing green infrastructure practices include:

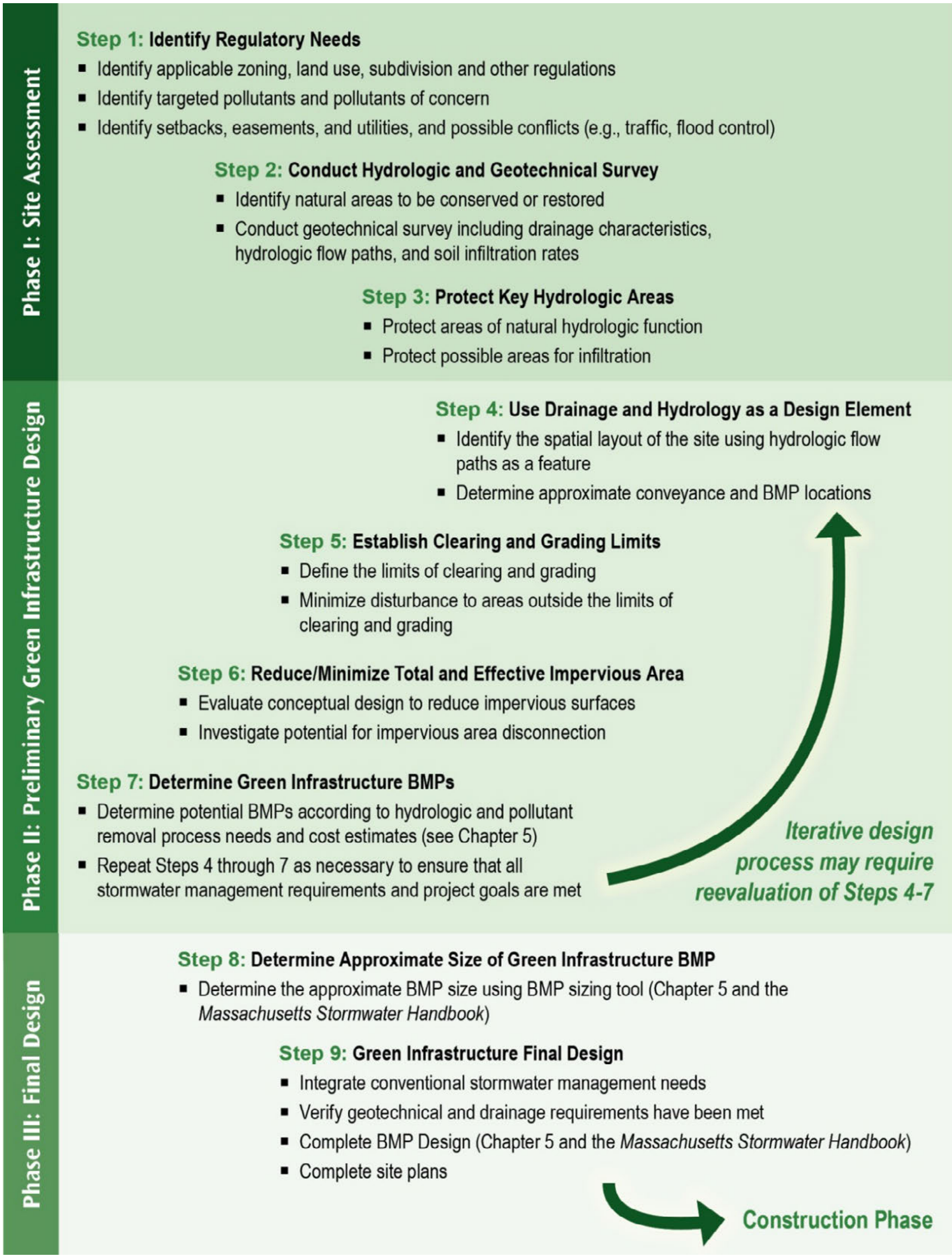
- Slow-infiltrating soils (typically clays)
- Soil contamination
- Steep slopes
- Adjacent foundations of structures
- Wells
- Shallow bedrock
- High seasonal water table
- Coastal flooding and salinity

For both new development and redevelopment, in the preliminary site plan, the development envelope (construction limits) is delineated. Applicable zoning, land use, subdivision, local road design regulations, and other local requirements should be identified to the extent applicable at this stage (Step 1 in Figure 4-3). To make the best and most optimal use of green infrastructure techniques on a site, a comprehensive site assessment must be completed that includes an evaluation of existing site topography, soils, vegetation, and hydrology including surface water and ground water features. High-quality ecological resources (e.g., wildlife habitat, mature trees) should also be identified for conservation or protection. Coastal flooding and salinity can have an impact on the performance of the green infrastructure practice, particularly vegetated practices. StormSmart Coasts (www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/) provides information regarding coastal erosion and flooding that should be considered in the site evaluation including a list of salt tolerant coastal landscaping. With such considerations, the site assessment phase provides the foundation for consideration of and proper planning around existing natural features and to retain or mimic the site's natural hydrologic functions (Steps 2 and 3).

Phase II, site planning, covers Steps 4–7. Defining preexisting and site-specific drainage patterns is essential for determining potential locations of green infrastructure BMPs (Step 4). For retrofit scenarios, identifying the drainage patterns may include activities such as locating the downspouts from a building, locating existing catch basins, and identifying the direction of flow in a roadway. Once natural and existing hydrologic features are identified and slated to be preserved, areas can be designated for clearing, grading, structures, and infrastructure (Step 5). After the preliminary site configuration has been determined in light of the existing features, impervious area site plans (buildings, roadways, parking lots, and sidewalks) can be evaluated for opportunities to minimize or reduce total impervious area in the site planning phase (Step 6). The specific types of green infrastructure BMPs are determined next (Step 7; e.g., a bioretention cell versus porous pavement for stormwater storage and infiltration).

Green infrastructure concepts and practices can be effectively implemented within the right-of-way to reduce and treat runoff. Street layouts often can be designed to reduce the extent of paved areas, and street widths can be narrowed to decrease the total impervious area as long as applicable street design criteria are satisfied. Specific examples of alternative transportation options include narrow paved travel lanes, consolidated travel lanes, and increased green parking areas. Green infrastructure practices can be incorporated into horizontal deflectors (chicanes), intersection pop-outs, parking lanes, and bike lanes. This approach is often referred to as a green street or complete street (USEPA 2008, City of Boston 2013).

In Phase III, final green infrastructure BMP footprints and sizes are estimated (Step 8). An iterative process working between Steps 4 and 7 can help determine the final site layout for completing the design process (Step 9). These steps are presented in more detail in Appendix B. When Step 6 is complete, detailed determination of stormwater management practice selection and design that considers BMP construction, and operation and maintenance (Section 5) should be made to complete Phase III and the final site design process. Steps 8 and 9 assist in determining BMP sizing and final design. Please refer to Appendix B for a complete example conceptual site design.



Source: Tetra Tech

Figure 4-3. Steps to develop a green infrastructure-based site plan.

4.2. Preparing Conceptual Design Plans

Preparing conceptual designs often begins with a site assessment and identification process similar to that presented in Section 2 and Section 3. Once sites have been identified, further effectiveness assessment should be performed for the top sites to develop an optimized conceptual design plan that includes a site layout to identify the type, size, and location of potential green infrastructure practices and to quantify, where possible, the potential effect of BMP implementation. The following sections present a potential approach to developing conceptual design plans.

4.2.1. Preliminary Geotechnical Investigation

Because mimicking natural conditions is a fundamental concept of green infrastructure, an evaluation of the local subsurface conditions beneath the potential sites should be performed as early in the design process as possible to determine the feasibility and impact of infiltration. This task should involve a review of readily available information, including published geologic literature and maps, topographic maps, aerial photographs, and geotechnical investigations performed at nearby locations. The preliminary investigation should include, at a minimum, an estimate of the feasibility of infiltrating. Where possible, the following parameters should be determined or verified though field investigations:

- Infiltration rate of subgrade soils (ASTM D 3385 Standard Test Method for Infiltration Rate of Field Soils Using Double Ring Infiltrometer, or a comparable method)
- Depth and texture of subsoils
- Depth to the seasonally high ground water table
- Structural capacity of soils
- Presence of expansive clay minerals
- Presence of compacted or restrictive layers
- Underlying geology
- Proximity to steep slopes
- Proximity to structural foundations, roadway subgrades, utilities, and other infrastructure
- Proximity to water supply wells
- Proximity to septic drain fields

Prior to design, further geotechnical investigations should be performed to verify estimates to ensure viability of the project.

4.2.2. Modeling and Optimization of BMP Placement for Green Infrastructure Sites

Developing optimal conceptual designs for green infrastructure projects can be complex, requiring consideration of multiple BMPs with multiple configurations and performance standards. The process can be simplified by using a stormwater model and an optimization algorithm to consider all the design alternatives. Modeling and optimization tools can be used to determine the optimal size and combination of BMPs to maximize water quality and quantity benefits. Such tools allow the ability to evaluate all feasible and economical design options to meet the water quantity and water quality goals

of the project based upon all known design constraints (e.g., infiltration capacity, topography, utilities, and infrastructure). The output from such a tool can be the optimized conceptual site layouts that identify the type, size, and location of potential BMPs at each site. Tools that can be used to optimize the site layout and evaluate impacts to water quality and quantity include EPA's System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN), EPA's Stormwater Management Model (SWMM), i-Tree (USDA Forest Service), EPA's Hydrological Simulation Program – FORTRAN (HSPF), RECARGA (University of Wisconsin-Madison), BMP-DSS (Prince George's County, Maryland), EPA's Stormwater Calculator, and others.

4.2.3. EPA Stormwater Calculator

The National Stormwater Calculator is an example of a simple to use tool for computing small site hydrology for a single site or location. The tool estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover and meteorology. Different types of green infrastructure practices can be employed to help capture and retain rainfall on-site.

The calculator's primary focus is informing site developers and property owners on how well they can meet a desired stormwater retention target. It can be used to answer questions such as the following:

- What is the largest daily rainfall amount that can be captured by a site in either its predevelopment, current, or post-development condition?
- To what degree will storms of different magnitudes be captured on site?
- What mix of LID controls can be deployed to meet a given stormwater retention target?

The calculator seamlessly accesses several national databases to provide local soil and meteorological data for a site. The user supplies land cover information that reflects the state of development they wish to analyze and selects a mix of LID controls to be applied. After this information is provided, the site's hydrologic response to a long-term record of historical hourly precipitation is computed. This allows a full range of meteorological conditions to be analyzed, rather than just a single design storm event. The resulting time series of rainfall and runoff are aggregated into daily amounts that are then used to report various runoff and retention statistics.

The calculator is most appropriate for performing screening level analysis of small footprint sites up to several dozen acres in size with uniform soil conditions. The hydrological processes simulated by the calculator include evaporation of rainfall captured on vegetative surfaces or in surface depressions, infiltration losses into the soil, and overland surface flow. No attempt is made to further account for the fate of infiltrated water that might eventually transpire through vegetation or re-emerge as surface water in drainage channels or streams (USEPA 2013).

4.2.4. Stormwater Management Optimization Tool

An example of an optimization tool is the U.S. Environmental Protection Agency (USEPA) Stormwater Management Optimization Tool (the Opti-Tool) is an Excel-based tool designed for improved stormwater management decision-making. The Opti-Tool BMP simulation and optimization algorithms

are from the U.S. EPA System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model. The Opti-Tool provides a graphic user interface (GUI) for municipal engineers to set up green infrastructure practice site layouts, optimize the size and configuration of green infrastructure practices, review optimization results, and access background information for green infrastructure practice performance simulation, optimization, BMP and operation and maintenance. With retention of all essential SUSTAIN capabilities through an Excel environment, the Opti-Tool offers a user-friendly alternative that does not rely on the ArcGIS platform. The main Opti-Tool window is shown in Figure 4-4

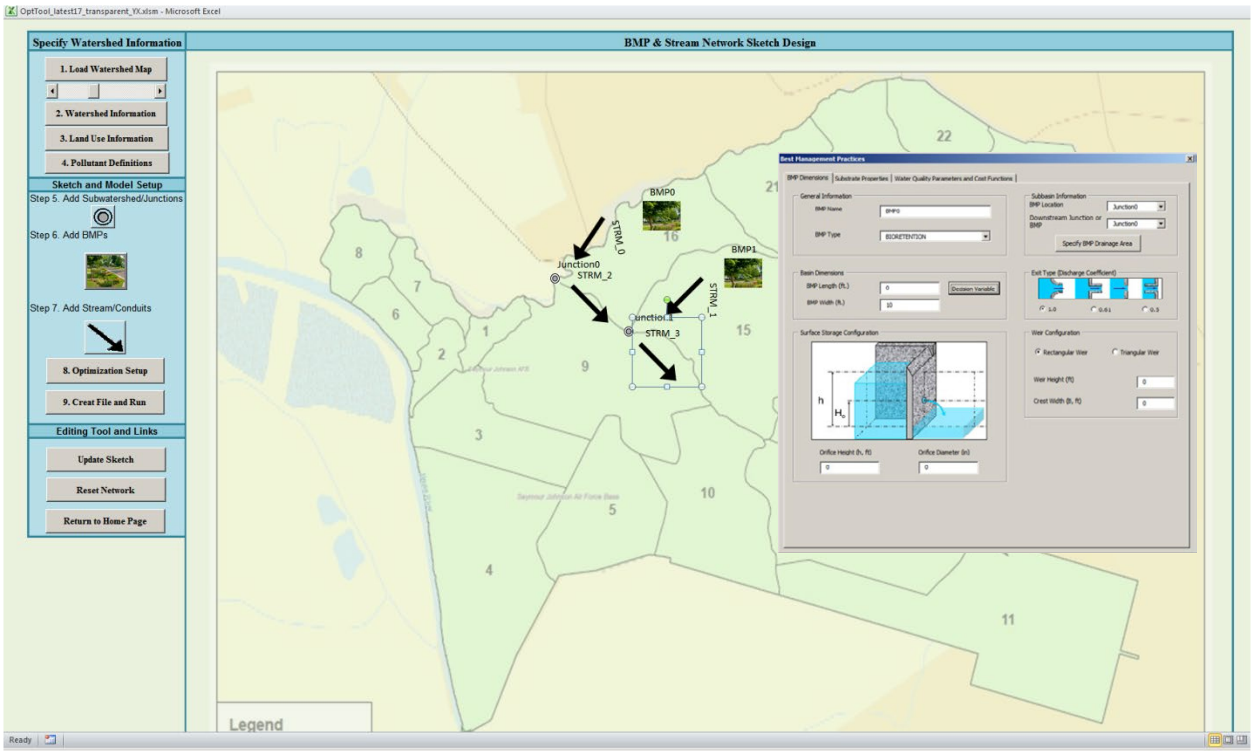


Figure 4-4. Example watershed simulation setup in Opti-Tool with two subbasin and two BMPs.

The Opti-Tool is developed with default parameters specified for USEPA Region I. Long-term runoff time series from various hydrologic response units (HRUs) in the region are provided as default time series. Green infrastructure practice water quality parameters were calibrated using observed data from the University of New Hampshire Stormwater Center (UNHSC). It is expected that with these default parameters the Opti-Tool will help maintain consistency across the region when assessing and reporting the effectiveness of various green infrastructure practices. Green infrastructure practices embedded within the Opti-Tool include biofiltration, dry ponds, grass swale, gravel wetland, infiltration basins, infiltration trenches, and permeable pavement. Green infrastructure representations have been calibrated to report effectiveness for TSS, TP, and Zn removal, all using data from the UNHSC. Efforts are also under way to introduce TN into the water quality representation of the Opti-Tool.

With a flexible and generic structure, the Opti-Tool can be used for many evaluation scenarios. A user may set up a model in the Opti-Tool to represent existing conditions in a watershed, regardless of whether BMPs exist in the watershed or not. Similarly, the Opti-Tool can be used to represent post-development watershed land use conditions without structural practice, in order to quantify the

hydrologic and water quality changes as a result of the development. On the basis of the post-development land use, a user may incorporate green infrastructure practices based on site conditions and then creates an optimization setup for the Opti-Tool to search for the most cost-effective green infrastructure practice configuration for the watershed. Lastly, the user may also use the Opti-Tool to calibrate a certain green infrastructure practice using locally observed data to replace the default water quality parameters provided in the tool. All of these are designed to provide a flexible and yet consistent platform for stormwater practitioners in the region. An example window for checking the Opti-Tool optimization output is shown in Figure 4-5.

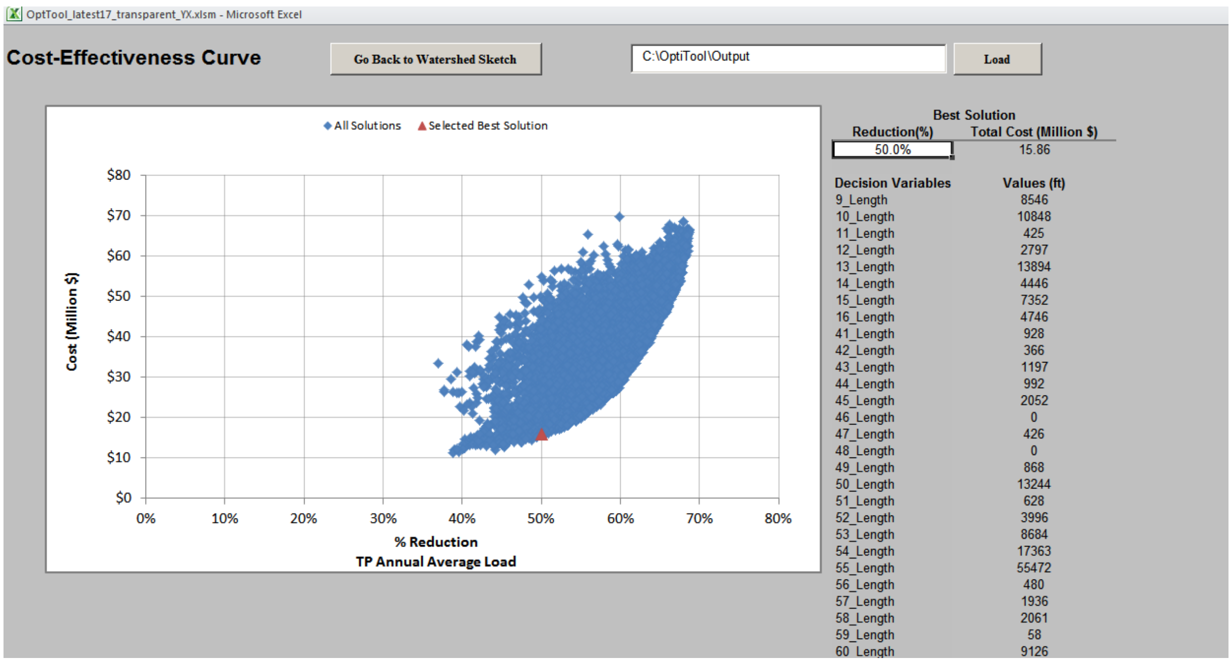


Figure 4-5. Example Opti-Tool output window for checking of optimization results.

All of these are designed to provide a flexible and yet consistent platform for stormwater practitioners in the region.

4.2.5. Conceptual Design Report

All analysis performed in the previous sections should be reviewed and incorporated into a full conceptual design. Conceptual design reports should include, at a minimum, a discussion for each of the following:

Project Description: An overview of the proposed location, recommended BMP types or green infrastructure improvements, and BMP configurations should be included.

Drainage Area Limits: The drainage area for each project should be characterized providing relevant design information including location, size, percent impervious, priority pollutants, watershed impairments, and regulatory requirements.

Screening of Soils and Infiltration Rates: A screening of the local subsurface conditions at each site should be performed to determine the feasibility of stormwater infiltration. Readily available information, including published geologic literature and maps, topographic maps, aerial photographs,

and geotechnical investigations performed at nearby locations should be reviewed and presented. Based on information available, the feasibility of infiltrating stormwater at each site should be considered and reported. However, prior to design, it should be necessary to perform geotechnical investigations to verify estimates to ensure viability of the project.

Performance Specifications: Details required for designing the recommended BMPs or LID improvements should be provided including recommended BMP type, site configuration, BMP configuration, and design recommendations for BMP components to estimate the effectiveness of the proposed green infrastructure design.

Concept Plan/Drawings: Conceptual drawings should include the approximate location and size of the recommended BMP including details of BMP components and configuration.

Architectural Schematic Designs: One rendering per project is recommended to illustrate how the proposed BMPs would be integrated into the site. The illustrations should indicate appropriate landscaping on the surface and show how the BMPs are designed to function below the surface. The renderings can be useful for presentations as part of the public outreach and encouragement activities.

Cost Estimate: A preliminary planning-level cost estimate for the full design and construction of the recommended BMP should be included to assist in planning efforts.

Operation and Maintenance Requirements: Anticipated operation and maintenance requirements based on the type, location, and configuration of the recommended BMP. Any anticipated operation and maintenance concerns should be addressed. (BMP Operation and Maintenance is detailed in Appendix C.)

Calculations: All assumptions and calculations used in developing the conceptual designs should be included in the report.

Management Questions: A discussion of key management questions that could be addressed through implementation of the conceptual design should be included in the report.

Plant Selection: Development of a plant palette with specific planting plans for the potential projects should be included in the conceptual designs where appropriate. Choices for appropriate low water use noninvasive plant material should be included. The impacts of the root depth and required plant spacing of the recommended plant palettes should be considered in the development of the performance standards.

4.2.6. Conceptual Plan

The more detail that is included in the conceptual design report, the more they will serve as effective planning tools for a municipality. Providing details on BMP effectiveness, potential impacts to water quality and quantity, and approximate costs provide greater value in budgeting for future implementation projects to ensure reduction of runoff volumes and pollutant loading through the use of green infrastructure concepts.

4.3. References

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5. Green Infrastructure Practices

This section of the Handbook provides a brief discussion of green infrastructure practices with a BMP Selection Matrix to aid in the selection of the appropriate green infrastructure practice.

Part 1: **Selecting Green Infrastructure BMPs (BMP Selection Matrix)**

This section provides a detailed tool (Table 5-1) to aid project designers in considering and selecting green infrastructure practices according to site characteristics and constraints. Cost estimates are provided for planning purposes.

Part 2: **BMP Sizing**

This section provides an introduction to sizing green infrastructure practices, referring readers to the Massachusetts Stormwater Handbook for BMP sizing standards.

Part 3: **Common Green Infrastructure Practices**

This section gives an overview of the function and treatment mechanisms of green infrastructure, and provides detailed descriptions of many of the most commonly used practices. Each BMP description includes a summary of pollutant removal mechanisms, BMP unit components, BMP-specific site considerations, and more.

Part 4: **BMP Construction and Post-Construction Issues**

This section provides detailed information on considerations for BMP construction oversight and post-construction inspection to ensure successful BMP execution and performance. BMP operation and maintenance requirements are outlined in Appendix C.

Many of the design concepts discussed in Section 4 are useful to establish a foundation and framework for implementing a comprehensive green infrastructure strategy. Thoughtful land use and site-specific planning to minimize runoff can considerably decrease the size (and cost) of structural practices required to meet regulatory requirements or minimize water quality impacts. Once a site's configuration is optimized to reduce stormwater and pollutant sources, runoff from the remaining impervious surfaces should be intercepted and treated by structural BMP practices that use one or more of three basic mechanisms: infiltration, retention/detention, and biofiltration.

Each type of development, and the unique subwatershed in which it is located, present site-specific challenges that make certain green infrastructure practices appropriate for some types of development but not for others. For example, permeable pavement might be an effective and appropriate solution for a low-rise office building; however, in a high-rise residential or office building with underground parking and virtually no undeveloped areas, permeable pavement would not be an effective or appropriate solution. In addition, downstream conditions on neighboring properties, manufactured slopes, the location of structures and utilities, and other design aspects of a project can present unique challenges

for designers and engineers, making what are otherwise effective green infrastructure solutions inappropriate for the specific site.

5.1. Selecting Green Infrastructure BMPs (BMP Selection Matrix)

Table 5-1 is a tool to help project designers consider and select green infrastructure practices according to site characteristics and constraints. Existing or expected site characteristics can be used to determine individual practices or a suite of practices that might be appropriate in site design. In addition, relative cost considerations can help project designers select specific BMPs, particularly between two or more BMPs that achieve the project's goal and meet permit compliance requirements. Therefore, the table lists dollar signs as qualitative costs for a relative comparison between types of BMPs rather than actual values.

Estimated costs in this table cover all components of construction and operation and maintenance for various-sized projects, but do not cover other conveyance needs that might be applicable. Cost estimates are based on the design standards recommended in Volume 2, Chapter 2 of the *Massachusetts Stormwater Handbook* (MassDEP 1997), and can vary widely by the necessary configuration of the BMP and site constraints. These cost numbers are estimates and intended for planning purposes only. The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. Cost estimates, particularly the maintenance costs, do not account for cost savings that result from using integrated practices (e.g., integrating bioretention areas into landscaping where the routine maintenance could be included in the budget for typical landscape maintenance). Including various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were as follows:

- Large BMP system = 4,000 square feet
- Medium BMP system = 2,000 square feet
- Small BMP system = 500 square feet

These categories are based on typically sized BMPs. The BMP system can include the application of multiple BMPs implemented in a treatment train.

- Once individual or groups of BMPs have been selected using this matrix, consult Volume 2, Chapter 2 of the *Massachusetts Stormwater Handbook* (MassDEP 1997) to develop detailed designs.

Table 5-1. BMP selection matrix (Addapted from MassDEP 1997)

Attribute		Pretreatment	Treatment						Conveyance			Other			
		Vegetated Filter Strip	Bioretention[a]		Constructed Stormwater Wetland	Tree Box Filter	Sand filter		Grassed Swale	Water Quality Swale		Cisterns/rain barrels	Vegetated (Green) Roof	Permeable Pavement[b]	
			(no UD)	(UD)			(no UD)	(UD)		(no UD)	(UD)			(no UD)	(UD)
Maximum allowable contributing drainage area (acres)		< 1	< 5		>10[g]	< 1	< 10		< 2	< 2		Rooftop	Rooftop (Self Treating Area)	Self-Treating: No Run-on Self-Retaining: Contributing run-on drainage area to permeable pavement area ratio must be less 2:1.	
Soil infiltration rate (inches/hour)		N/A	> 0.5	< 0.5		N/A	> 0.5	< 0.5	N/A	> 0.5	< 0.5	Rooftop (Self Treating Area)	N/A	> 0.5	< 0.5
Water table separation (feet)		> 2	> 10	≥ 2	At or below permanent pool elevation	N/A	> 10	≥ 2	> 2	> 10	≥ 2	N/A	N/A	> 10	≥ 2
Depth to bedrock (feet)		> 2	> 10	≥ 2	At or below permanent pool elevation	N/A	> 10	N/A	> 2	> 10	≥ 2		N/A	> 10	≥ 2
IMP slope		2-6%	< 0.5%		< 5%	< 0.5%	< 6%		< 4%	< 4%		N/A	< 45°	< 4%	
Pollutant removal	Sediments	High	High		High	High	High		Medium	High		Pollutant removal provided by downstream IMP. Refer to specific IMP for removal efficiency (although stormwater volume reduction can reduce total pollutant loads if rainwater is harvested and reused).	Pollutant removal of green roofs generally occur through stormwater volume reduction.	High	
	Nutrients	Low	Medium		Medium	Medium	Low		Low	Medium				Low	
	Trash	High	High		High	High	High		High	High				High	
	Metals	Medium	High		High	High	High		Medium	High				High	
	Bacteria	Low	High		High	High	High		Low	High				Medium	
	Oil & grease	Medium	High		High	High	High		Medium	High				Medium	
	Organics	Medium	High		High	High	High		Medium	High				Low	
	Pesticides	Medium	High		High	High	High		Medium	High				Medium	
Runoff volume reduction		Low	High	Medium	None	Low	Medium	Low	Low	High	Medium		High	High	Medium
Peak flow control		Low	Medium		High	Low	Low		Low	Medium		Medium	Medium	Medium	
Ground water recharge		Low	High	Low	None	N/A	Medium	Low	Low	High	Low	Medium	N/A	Medium	Low
Setbacks (feet)	Structures		> 10		> 10				> 10	> 10		> 5	N/A	> 10	
	Steep slopes		> 50		> 50				> 50	> 50		> 50	N/A	> 50	
Costs[e]	Construction	$	$ - $$		$	$$	$ - $$		$	$ - $$		$ - $$	$$$	$$ - $$$	
	O & M (small)	$$	$$ - $$$		$ - $$	$$	$$ - $$$		$$	$$ - $$$		$$	$$	$$ - $$$	
	O & M (medium)	$	$ - $$[g]		$ - $$	$ - $$	$$		$ - $$	$ - $$[f]		$ - $$	$$	$$	
	O & M (large)	$	$ - $$[g]		$ - $$	$ - $$	$$		$ - $$	$ - $$[f]		$ - $$	$$	$ - $$	

Notes: UD = Underdrain, IMP = Integrated Management Practice, O&M = Operation and maintenance; [a] If lined, see planter box column; [b] If lined, see sand filter with underdrain column; [c] Separation depth from bottom of IMP to water table; [d] For tank outlet and overflow; [e] Costs are relative, can be variable project to project, and are generalized; [f] Based on necessary regular landscape maintenance already required; [g] Minimum of 25-acre drainage area required for shallow marsh and basin/wetland systems.

5.2. BMP Sizing

Green infrastructure BMPs are typically sized to manage runoff from frequent smaller storm events (most often in the range of 1 to 2 inches of rainfall over 24 hours). The size of a BMP should be established using the characterization of the drainage area and local hydrology. BMPs should be designed by applying either volume- or flow-based design criteria. For further details regarding BMP sizing standards, refer to Volume 1 Chapter 1 and Volume 3 of the *Massachusetts Stormwater Handbook* (MassDEP 1997).

5.3. Common Green Infrastructure Practices

Regardless of their name, all green infrastructure practices are designed to manage stormwater by mimicking natural processes and predevelopment hydrologic patterns. Infiltration, evapotranspiration, filtration, retention/detention, reuse, etc., are one or more of the processes used by green infrastructure practices. By understanding the different functions inherent to each BMP, designers can select practices to target specific pollutant(s) of concern, which is an important consideration within impaired watersheds. Although watershed-specific targets might be defined by local TMDLs and Watershed Protection Plans, site constraints, pollutant fate and transport properties, BMP unit processes and performance, and the stringency of permit requirements must all be evaluated to strategically match green infrastructure practices with targeted pollutant treatment. Typical pollutants targeted for BMP treatment include suspended solids, trash, heavy metals (e.g., copper, lead, zinc), nutrients, pathogens, and organics such as petroleum hydrocarbons and pesticides. Refer to Chapter 2 of the *Massachusetts Stormwater Handbook* (MassDEP 1997) for further details regarding these green infrastructure BMPs, including their benefits and limitations, pollutant removal efficiencies, and required design information.

5.3.1. Vegetated Filter Strips

Vegetated filter strips are bands of dense, perennial vegetation installed on a uniform slope and designed to provide pretreatment of runoff prior to discharging into a BMP. Vegetated filter strips on highly permeable soils can also provide infiltration, improving volume reduction. Increased infiltration can decrease the necessary horizontal length. Such characteristics make it ideal to use vegetated filter strips as a BMP around roadside shoulders, safety zones, or at the edge of small parking lots. Figure 5-1 illustrates a vegetated filter strip installed at the edge of a parking lot.

Source: Massachusetts Stormwater Handbook

Figure 5-1. Vegetated filter strip at the edge of a parking lot.

Vegetated filter strips are implemented for improving stormwater quality and reducing runoff flow velocity. As water sheet flows across the vegetated filter strip, the vegetation filters out and settles the particulates and constituents, especially in the initial flow of stormwater. Removal efficiency often depends on the slope, length, gradient, underlying parent soil, and biophysical condition of the vegetation.

Although some assimilation of dissolved constituents can occur, filter strips are generally more effective in trapping sediment and particulate-bound metals, nutrients, and pesticides. Nutrients that bind to sediment include phosphorus and ammonium; soluble nutrients include nitrate. Biological and chemical processes could help break down pesticides, uptake metals, and use nutrients that are trapped in the filter. Vegetated filter strips also exhibit good removal of litter and other debris when the water depth flowing across the strip is below the vegetation height. Maintenance of vegetative cover is important to ensure that filters trips do not export sediment due to erosion of exposed ground (Winston et al. 2012). Table 5-2 reports the water quality performance of vegetated filter strips.

Table 5-2. Pollutant removal characteristics of vegetated filter strips

Pollutant	Relative removal efficiency[1]	Median effluent concentration (mg/L unless otherwise noted)[2]	Removal processes	References
Sediment	High (-195% to 91%)	<u>19.1</u>	Sedimentation and filtration.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Metals	Medium	TAs: 0.94 µg/L, <u>TCd: 0.18 µg/L</u>, <u>TCr: 2.73 µg/L</u>, <u>TCu: 7.30 µg/L</u>, <u>TPb: 1.96 µg/L</u>, <u>TNi: 2.92 µg/L</u>, <u>TZi: 24.3 µg/L</u>	Removal with sediment.	Knight et al. 2013; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-126% to 40%)	*0.18*	Settling with sediment and plant uptake.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Total nitrogen	Low (TN: -17% to 40%, TKN: -18% to 39%, $NO_{2,3}$-N:-18% to 43%)	TN: 1.13, <u>TKN: 1.09</u>, <u>$NO_{2,3}$-N: 0.27</u>	Sedimentation (TKN) and plant uptake.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Bacteria	Low (likely exports pathogens)	N/A	Limited sedimentation, desiccation, predation, and photolysis at surface.	USEPA 2012

[1] This Handbook presents relative removal efficiencies (high, medium, low). Percent removal efficiencies from literature are also included, where available, but can vary dramatically based on site specific conditions.

[2] <u>Underlined</u> effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

5.3.2. Bioretention

Bioretention areas are landscaped, shallow depressions that capture and temporarily store stormwater runoff. Runoff is directed into the bioretention area and then filtered through the soil (often engineered soil) media. Figure 5-2 shows a bioretention area installed on a residential property.

Source: Massachusetts Stormwater Handbook

Figure 5-2. Bioretention area, or rain garden, on a residential property.

Bioretention areas usually consist of a pretreatment system, surface ponding area, mulch layer, and planting soil media. The depressed area is planted with small- to medium-sized vegetation including trees, shrubs, and ground cover that can withstand urban environments and tolerate periodic inundation and dry periods. Plantings also provide habitat for beneficial pollinators and aesthetic benefits for stakeholders. They can also be customized to attract butterflies or particular bird species. Ponding areas can be designed to increase flow retention and flood control capacity.

Bioretention areas provide comprehensive pollutant load reduction at various depths through physical, chemical, and biological mechanisms. Table 5-3 describes the effectiveness of bioretention for targeted management of specific water quality constituents. Infiltration provides the most effective mechanism for pollutant load reduction and should be encouraged where practicable. Treatment performance can also be enhanced (particularly for nitrogen, pathogens, and other pollutants that are removed by sorption) by installing deep media with slow infiltration rates (1 to 2 inches per hour) (Bright et al. 2010; Hathaway et al. 2011; Hunt et al. 2012; Hunt and Lord 2006; Rusciano and Obropta 2007).

Table 5-3. Pollutant removal characteristics of bioretention

Pollutant	Relative removal efficiency[1]	Median effluent concentration (mg/L unless otherwise noted)[2]	Removal processes	Min. rec. media depth for treatment	References
Sediment	High	8.3	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Geosyntec Consultants and Wright Water Engineering 2012; Stander and Borst 2010;
Metals	High	TCd: 0.94 µg/L, TCu: 7.67 µg/L, TPb: 2.53 µg/L, TZn: 18.3 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet	Hsieh and Davis 2005; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012
Hydro-carbons	High	N/A	Removal and degradation in mulch layer.	N/A	Hong et al. 2006; Hunt et al. 2012
Total phosphorus	Medium (-240% to 99%)	0.09	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; ; Li et al. 2010
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.90, TKN: 0.60, $NO_{2,3}$-N: 0.22	Sorption and setting (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009;
Bacteria	High	Enterococcus: 234 MPN/ 100 mL, *E.coli*: 44 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010;
Thermal load	High	68–75 °F	Heat transfer at depth and thermal load reduction by volume reduction (ET and infiltration). IWS enhances thermal load reduction.	4 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012; Jones and Hunt 2009; Jones et al. 2012; Winston et al. 2011; Wardynski et al. 2013

[1] This Handbook presents relative removal efficiencies (high, medium, low). Percent removal efficiencies from literature are also included, where available, but can vary dramatically based on site specific conditions.

[2] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

5.3.3. Constructed Stormwater Wetlands

Constructed stormwater wetlands are engineered, shallow-water ecosystems designed to treat stormwater runoff. Commonly implemented in low-lying areas, stormwater wetlands are well suited to areas along river corridors where water tables are higher. Sediment and nutrients are efficiently reduced by stormwater wetlands by means of sedimentation, chemical and biological conversions, and uptake by wetland plant species. Stormwater wetlands provide flood control benefits by storing water and slowly releasing it over 2 to 5 days. In addition to stormwater management, stormwater wetlands provide excellent plant and wildlife habitat and can often be designed as public amenities. To preserve their effectiveness, MassDEP requires placing a sediment forebay as pretreatment for all constructed stormwater wetlands. An example constructed stormwater wetland is presented in Figure 5-3.

Source: Massachusetts Stormwater Handbook

Figure 5-3. Constructed stormwater wetland with wetland vegetation.

Similar to natural wetlands, water quality improvement is effectively achieved in constructed wetlands through physicochemical and biological processes as water is temporarily stored. Specific unit processes include sedimentation, denitrification, and uptake. Consequently, the flow path through the wetland should be maximized to increase residence time and contact with vegetation, soil, and microbes. Very high sediment removal efficiencies have been reported for properly sized stormwater wetlands (50 to 80 percent reduction), with average effluent concentrations near 9 mg/L (Hathaway and Hunt 2010; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012). Subsequently, particle-bound metals are thought to be reduced as sediment falls out of suspension, and significant reduction of total copper, total cadmium, total lead, and total zinc is expected (although metals can dissociate from sediment and organic matter into solution under anaerobic conditions; Newman and Pietro 2001; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012).

High phosphorus removal rates have been observed in stormwater wetlands, but, similar to metals, phosphorus can desorb from sediments under anaerobic conditions (Hathaway and Hunt 2010). Stormwater wetlands typically perform well for nitrate removal because the anaerobic conditions and organic material in wetland sediment create an ideal environment for denitrification (converting nitrate into nitrogen gas). Significant nitrate reduction is commonly observed in stormwater wetlands, but total nitrogen reduction depends on the species and concentration of incoming nitrogen (Hathaway and Hunt 2010; Moore et al. 2011; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012). Pathogen removal in stormwater wetlands is expected because of predation, solar radiation, and sedimentation (Davies and Bavor 2000; Struck et al. 2008; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc.

2012); furthermore, wetlands tend to reduce bacteria more than do traditional wet detention ponds (Davies and Bavor 2000).

The U.S. EPA recommends the following guidelines to help ensure successful constructed treatment wetland projects:

- Construct treatment wetlands, as a rule, on uplands and outside floodplains in order to avoid damage to natural wetlands and other aquatic resources, unless pretreated effluent can be used to restore degraded systems.
- Consider the role of treatment wetlands within the watershed (e.g., potential water quality impacts, surrounding land uses and relation to local wildlife corridors).
- Closely examine site-specific factors, such as soil suitability, hydrology, vegetation, and presence of endangered species or critical habitat, when determining an appropriate location for the project in order to avoid unintended consequences, such as bioaccumulation or destruction of critical habitat.
- Use water control measures that will allow easy response to changes in water quantity, quality, depth and flow.
- Create and follow a long-term management plan that includes regular inspections, monitoring and maintenance

It is important to note that constructed stormwater wetlands may be subject to the Clean Water Act; determinations are made by EPA and the U.S. Army Corps of Engineers on a case-by-case basis.

5.3.4. Tree Box Filters

A tree box filter is a concrete box containing porous soil media and vegetation that functions similarly to a small bioretention area but is completely lined, must have an underdrain, and has one or more trees. Runoff is directed from surrounding impervious surfaces to the tree box filter where it percolates through the soil media to the underlying ground. If the runoff exceeds the design capacity of the tree box filter, the underdrain directs the excess to a storm drain other device.

Tree box filters have been implemented around paved streets, parking lots, and buildings to provide initial stormwater detention and treatment of runoff. Such applications offer an ideal opportunity to minimize directly connected impervious areas in highly urbanized areas. In addition to stormwater management benefits, tree box filters provide on-site stormwater treatment options, green space, and natural aesthetics in tightly confined urban environments. Tree box filters are ideal for redevelopment or in the ultra-urban setting and may be used as a pretreatment device. Figure 5-4 illustrates a tree box filter shortly after construction.

Tree box filters are capable of consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Current research shows that pollutant removal is possible with underdrains through the function provided at the surface and by the soil media.

Source: Massachusetts Stormwater Handbook

Figure 5-4. Newly constructed tree box filter.

Table 5-4 reports the water quality performance of tree box filters.

Table 5-4. Pollutant removal characteristics of flow-through planters

Pollutant	Relative removal efficiency 1	Median effluent concentration (mg/L unless otherwise noted)2	Removal processes	Minimum recommended media depth for treatment	References
Sediment	High	8.3	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hatt et al. 2008; Hunt et al. 2012Li and Davis 2008; Stander and Borst 2010
Metals	High	TCd: 0.94µg/L, TCu: 7.67µg/L, TPb: 2.53µg/L, TZn: 18.3 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2012
Hydro-carbons	High	N/A	Removal and degradation in mulch layer.	N/A	Hong et al. 2006; Hunt et al. 2012

Pollutant	Relative removal efficiency 1	Median effluent concentration (mg/L unless otherwise noted)2	Removal processes	Minimum recommended media depth for treatment	References
Total phosphorus	Medium (-240% to 99%)	0.09	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; Li et al. 2010
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	<u>TN: 0.90,</u> <u>TKN: 0.60,</u> $NO_{2,3}$-N: 0.22	Sorption and setting (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009;
Bacteria	High	<u>*Enterococcus*: 234 MPN/100 mL,</u> *E.coli*: 44 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010;
Thermal load	High	68–75 °F	Heat transfer at depth and thermal load reduction by volume reduction (ET and infiltration). IWS enhances thermal load reduction.	4 feet	Hunt et al. 2012; Jones and Hunt 2009; Jones et al. 2012; Wardynski et al. 2013; Winston et al. 2011;

[1] This Handbook presents relative removal efficiencies (high, medium, low). Percent removal efficiencies from literature are also included, where available, but can vary dramatically based on site specific conditions.

[2] Concentrations are based on bioretention performance data. <u>Underlined</u> effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

5.3.5. Sand Filters

A sand filter is a treatment system used to remove particulates and solids from stormwater runoff by facilitating physical filtration. It is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sedimentation and filtration chambers. With increased detention time, the sedimentation chamber allows larger particles to settle in the chamber. The filtration chamber removes pollutants and enhances water quality as the stormwater is strained through a layer of sand. The treated effluent is collected by underdrain piping and discharged to the existing stormwater collection system or another BMP. Sand filters can be used in areas with poor soil infiltration rates, where ground water concerns restrict the use of infiltration, or for high pollutant loading areas. Figure 5-5 shows a sand filter that has been installed at the edge of a parking lot.

Source: NCSU BAE

Figure 5-5. Below ground Delaware style sand filter installed in a parking lot.

Sand filters are capable of removing a wide variety of pollutant concentrations in stormwater via settling, filtering, and adsorption processes. Sand filters have been a proven technology for drinking water treatment for many years and now have been demonstrated to be effective in removing urban stormwater pollutants including total suspended solids, particulate-bound nutrients, biochemical oxygen demand (BOD), fecal coliform, and metals (USEPA 1999). Sand filters are volume-based IMPs intended primarily for treating the water quality design volume. In most cases, sand filters are enclosed concrete or block structures with underdrains; therefore, only minimal volume reduction occurs via evaporation as stormwater percolates through the filter to the underdrain. Table 5-5 reports the water quality performance of sand filters.

Table 5-5. Pollutant removal characteristics of sand filters

Pollutant	Relative removal efficiency[1]	Median effluent concentration (mg/L unless otherwise noted)[2]	Removal processes	References
Sediment	High (74% to 95%)	8.7	Settling in pretreatment and surface, filtration and sedimentation in media.	Barrett 2003, 2008, 2010; Bell et al. 1995; Geosyntec Consultants and Wright Water Engineering 2012; Horner and Horner 1995;
Metals	High (14% to 87%)	TAs: 0.87µg/L, TCd: 0.16µg/L, TCr: 1.02µg/L, TCu: 6.01µg/L, TPb: 1.69µg/L, TNi: 2.20µg/L, TZi: 19.9µg/L	Removal with sediment (optional: sorption to organic matter and clay amendments in media).	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-14% to 69%)	0.09	Settling with sediment (optional: sorption to organic matter and clay amendments in media). Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
Total nitrogen	Low (20%)	TN: 0.82, TKN: 0.57, *$NO_{2,3}$-N: 0.51*	Sorption and setting (TKN) and denitrification in IWS (nitrate). Poor removal efficiency can result from media containing high organic matter.	Barrett 2008; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
BOD	High (-27% to 55%)	N/A	Sedimentation, filtration, and biodegradation.	Barrett 2010
Bacteria	High (fecal coliform: -70% to 54%, fecal streptococcus: 11% to 68%)	Fecal coliform: 542 MPN/100mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in surface layer.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012

[1] This Handbook presents relative removal efficiencies (high, medium, low). Percent removal efficiencies from literature are also included, where available, but can vary dramatically based on site specific conditions.

[2] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

5.3.6. Grassed Swales

Grassed swales are shallow, open vegetated channels designed to provide for nonerosive conveyance with a longer hydraulic residence time than traditional curbs and gutters. Grass swales provide limited pollutant removal by sedimentation and gravity separation. Properly designed grass swales are ideal when used adjacent to roadways or parking lots, where runoff from the impervious surfaces can be directed to the swale via sheet flow. Swales are effective for pretreatment of concentrated flows before discharge to a downstream BMP. A grassed swale installed adjacent to a highway is depicted in Figure 5-6.

Source: Massachusetts Stormwater Handbook

Figure 5-6. Grassed swale adjacent to a highway.

5.3.7. Water Quality Swales

Water quality swales are vegetated open channels designed to convey runoff without causing erosion while also improving the water quality of stormwater runoff. Water quality swales incorporate specific features to enhance their stormwater pollutant removal effectiveness. There are both wet and dry water quality swales. Dry swales promote infiltration of the runoff and therefore require porous soils. Wet swales contain standing water and can use soils with poor drainage or high ground water conditions. The slope and cross-sectional area of the swale should sufficiently maintain nonerosive flow velocities. Water quality swales may be used along roadways, at the edge of a parking lot, or as parking lot islands. Figure 5-7 presents a water quality swale installed adjacent to a highway.

Source: Massachusetts Stormwater Handbook

Figure 5-7. Water quality swale adjacent to a highway.

Although high sediment load reductions have been observed in well-constructed swales, performance is highly variable and generally depends on flow rate, particle settling velocity (as determined by particle size distribution), and flow length (Bäckström 2003; Bäckström 2006; Deletic and Fletcher 2006; Yu et al. 2001). The sediment load reductions tend to be primarily associated with coarser sediment particles (sand) that do not pose as great a threat to downstream aquatic life as finer sediment particles (Deletic 1999; Luell 2011; Knight et al. 2013). Because swales offer minimal contact between runoff and sorptive surfaces, dissolved

constituents and metals that tend to be associated with finer sediment particles (such as dissolved copper and zinc) can be harder to remove (Zanders 2005). In some cases, swales have been shown to export heavy metals (Bäckström 2003). USEPA (2012) reports that swales typically export pathogens. To achieve optimal removal of fine sediment particles, minimum swale lengths of 246 feet and 361 feet have been recommended, along with residence times of 5 to10 minutes (Bäckström 2003; Yu et al. 2001; Claytor and Schueler 1996). Additionally, flow depth should not exceed the height of the vegetation. These design parameters can make swales difficult to implement for water quality improvement in areas with limited available footprint. Table 5-6 reports the water quality performance of swales.

Table 5-6. Pollutant removal characteristics of water quality swales

Pollutant	Relative removal efficiency[1]	Median effluent concentration (mg/L unless otherwise noted)[2]	Removal processes	References
Sediment	High (20% to 98%)	13.6	Sedimentation and filtration.	Deletic and Fletcher 2006, Yu et al. 2001, Bäckström 2003, Bäckström 2006, Geosyntec Consultants and Wright Water Engineering 2012
Metals	Medium	TAs: 1.17µg/L, TCd: 0.31µg/L, TCr: 2.32µg/L, TCu: 6.54µg/L, TPb: 2.02µg/L, TNi: 3.16µg/L, TZi: 22.9µg/L	Removal with sediment.	Fassman 2012; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low	*0.19*	Settling with sediment and plant uptake.	Deletic and Fletcher 2006; Geosyntec Consultants and Wright Water Engineering 2012
Total nitrogen	Low	TN: 0.71, TKN: 0.62, $NO_{2,3}$-N: 0.25	Sedimentation (TKN) and plant uptake.	Deletic and Fletcher 2006; Geosyntec Consultants and Wright Water Engineering 2012
Bacteria	Low (typically exports pathogens)	E. coli: 4190 MPN/100 mL, Fecal coliform: 5000 MPN/100 mL	Limited sedimentation, desiccation, predation, and photolysis at surface.	EPA 2012, Geosyntec Consultants and Wright Water Engineering 2012

[1] This Handbook presents relative removal efficiencies (high, medium, low). Percent removal efficiencies from literature are also included, where available, but can vary dramatically based on site specific conditions.

[2] Concentrations are based on vegetated swale performance data. Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations

5.3.8. Cisterns and Rain Barrels

Cisterns and rain barrels are containers that capture rooftop runoff and store it for landscaping and other nonpotable uses. With control of the timing and volume, the captured stormwater can be more effectively released for irrigation or alternative grey water uses between storm events. Rain barrels tend to be smaller systems that direct runoff through a downspout into a barrel that holds less than 100 gallons. As an example, Figure 5-8 shows a 55-gallon residential rain barrel. Cisterns are larger systems that can be self-contained aboveground or belowground systems generally larger than 100 gallons and can direct water from one or more downspouts. Belowground systems often require a pump for water removal.

Source: Massachusetts Stormwater Handbook

Figure 5-8. A 55-gallon rain barrel collecting rainwater from a residential rooftop.

For the Massachusetts Bay and surrounding areas, cisterns and rain barrels primarily provide control of stormwater volume; however, water quality improvements can be achieved when cisterns and rain barrels are used with other BMPs such as bioretention areas. Water in cisterns or rain barrels can be controlled by permanently open outlets or operable valves depending on project specifications. Cisterns and rain barrels can be a useful method of reducing stormwater runoff volumes in urban areas where site constraints limit the use of other BMPs.

Because most rainwater harvesting systems collect rooftop runoff, the water quality of runoff harvested in cisterns is largely determined by surrounding environmental conditions (e.g., overhanging vegetation, bird and wildlife activity, atmospheric deposition,), roof material, and cistern material (Despins et al. 2009; Lee et al. 2012; Thomas and Greene 1993). Rooftop runoff tends to have relatively low levels of physical and chemical pollutants, but elevated microbial counts are typical (Gikas and Tsihrintzis 2012; Lee et al. 2012; Lye 2009; Thomas and Greene 1993). Physicochemical contaminants can be further reduced by implementing a first-flush diverter (discussed later); however, first-flush diverters can have little impact on reducing microbial counts (Lee et al. 2012; Gikas and Tsihrintzis 2012).

The pollutant reduction mechanisms of rain tanks are not yet well understood, but sedimentation and chemical transformations area thought to help improve water quality. Despite limited data describing reduction in stormwater contaminant concentrations in cisterns, rainwater harvesting can greatly reduce pollutant loads to waterways if stored rainwater is infiltrated into surrounding soils using a low-flow drawdown configuration or when it is used for alternative purposes such as toilet flushing or vehicle washing. Rainwater harvesting systems can also be equipped with filters to further improve water quality.

5.3.9. Green Roofs

Green roofs reduce runoff volume and rates by intercepting rainfall in a layer of rooftop growing media.

Source: Massachusetts Stormwater Handbook

Figure 5-9. Vegetated green roof.

Rainwater captured in rooftop media then evaporates or is transpired by plants back into the atmosphere. Rainwater in excess of the media capacity is detained in a drainage layer before flowing to roof drains and downspouts. Green roofs are highly effective at reducing or eliminating rooftop runoff from small to medium storm events. They can be incorporated into new construction or added to existing buildings during renovation or re-roofing.

In addition to stormwater volume reduction, green roofs offer an array of benefits, including extended roof life span (due to additional sealing, liners, and insulation), improved building insulation and energy use, reduction of urban heat island effects, opportunities for recreation and rooftop gardening, noise attenuation, air quality improvement, bird and insect habitat, and aesthetics (Tolderlund 2010; Berndtsson 2010; Getter and Rowe 2006). Green roofs can be designed as extensive, shallow-media systems or intensive, deep-media systems depending on the design goals, roof structural capacity, and available funding. An example green roof is presented in Figure 5-9.

5.3.10. Permeable Pavement

Permeable pavement is a durable, load-bearing paved surface with small voids or aggregate-filled joints that allow water to drain through to an aggregate reservoir. Stormwater stored in the reservoir layer can then infiltrate underlying soils or drain at a controlled rate via underdrains to other downstream stormwater control systems. Permeable pavement allows streets, parking lots, sidewalks, and other impervious covers to retain the infiltration capacity of underlying soils while maintaining the structural and functional features of the materials they replace.

Permeable pavement systems can be designed to operate as underground detention if the native soils do not have sufficient infiltration capacity, or if infiltration is precluded by aquifer protection, hotspots, or adjacent structures. Permeable pavement can be developed using modular paving systems (e.g., permeable interlocking concrete pavers, concrete grid pavers, or plastic grid systems) or poured in place solutions (e.g., pervious concrete or porous asphalt). Some pervious concrete systems can also be precast. In many cases, especially where space is limited, permeable pavement is a cost-effective solution relative to other practices because it doubles as both transportation infrastructure and a BMP. Figure 5-10 illustrates a porous asphalt parking lot.

Source: Massachusetts Stormwater Handbook and Sara P. Grady

Figure 5-10. Porous asphalt parking lot and permeable interlocking concrete pavers in the right-of-way.

Permeable pavement systems, when designed and installed properly, consistently reduce concentrations and loads of several stormwater pollutants, including heavy metals, oil and grease, sediment, and some nutrients. The aggregate sub-base improves water quality through filtering and chemical and biological processes, but the primary pollutant removal mechanism is typically load reduction by infiltration into subsoils. Table 5-7 reports water quality performance of permeable pavement.

Table 5-7. Pollutant removal characteristics of permeable pavement

Pollutant	Relative removal efficiency[1]	Median effluent concentration (mg/L unless otherwise noted)[3]	Removal processes	References
Sediment	High[2] (32% to 96%)	13.2	Settling on surface and in reservoir layer.	Bean et al. 2007; CWP 2007; Fassman and Blackbourn 2011Gilbert and Clausen 2006; MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007;
Metals	High (65% to 84%)	TAs: 2.50µg/L, TCd: 0.25µg/L, TCr: 3.73 µg/L, TCu: 7.83µg/L, TPb: 1.86µg/L, TNi: 1.71 µg/L, TZn: 15.0 µg/L	Removal with sediment and possible sorption to aggregate base course.	Bean et al. 2007; Brattebo and Booth 2003; CWP 2007; Dierkes et al. 2002; Fassman and Blackbourn 2011; Gilbert and Clausen 2006;MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007;
Hydro-carbons	Medium (92% to 99%)	N/A	Removal in surface course and aggregate layer.	Roseen et al. 2009, 2011
Total phosphorus	Low (20% to 78%)	0.09	Settling with sediment, possible sorption to aggregate, and sorption to underlying soils.	Bean et al. 2007; CWP 2007; Gilbert and Clausen 2006; MWCOG 1983; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Yong et al. 2011
Total nitrogen	Low (-40% to 88%)	TKN: 0.80, *$NO_{2,3}$-N: 0.71*	Setting, possible denitrification in IWS, sorption in underlying soils (TKN).	Collins et al. 2010; CWP 2007; MWCOG 1983; Schueler 1987;
Bacteria	Medium	N/A	Sedimentation, filtration, sorption, desiccation, and predation in surface course and reservoir layer.	Myers et al. 2009; Tota-Maharaj and Scholz 2010
Thermal load	Medium	58–73 °F	Heat transfer at depth, thermal buffering through profile, and thermal load reduction by volume reduction (infiltration). IWS enhances thermal load reduction.	Wardynski et al. 2013

[1] This Handbook presents relative removal efficiencies (high, medium, low). Percent removal efficiencies from literature are also included, where available, but can vary dramatically based on site specific conditions.

[2] Run-on from adjacent surfaces with high sediment yield can cause premature clogging of the surface course or subsurface interface. Permeable pavement should not be used to treat runoff from pervious surfaces or other areas with high sediment yield.

[3] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations in *italics* were (statistically) significantly higher than influent concentrations.

5.4. Cold Climate Considerations

Cold climates, such as in Massachusetts, present unique considerations for green infrastructure BMP selection, design, and maintenance. In cold climate locations, freeze/thaw and snow plows are the major concerns for permeable pavement. However, when well-designed, permeable pavement will always drain properly and never freeze solid. Additionally, air voids present in permeable pavement should allow sufficient space for moisture to freeze and expand. When snowfall occurs, municipalities should ensure snow plow blades are raised sufficiently to prevent scraping of permeable pavement surfaces. Sand should never be applied, as it can cause clogging and inhibit BMP function (USEPA, 2008).

Green infrastructure BMPs that incorporate vegetation are also subject so cold weather considerations. Plants selected for these practices should flourish in the regional climate conditions, and salt-tolerant species are most favorable for regions where road salt is applied in the winter (USEPA, 2008).

5.5. BMP Construction and Post-Construction Issues

Successful BMP execution and performance can be hindered when designers lack a complete understanding of BMP requirements, construction is performed by inexperienced contractors, or as a result of inadequate operation and maintenance over the long-term. To help prevent these issues, this section provides considerations for BMP construction oversight and post-construction inspection; both of which supplement the operation and maintenance discussion in Appendix C. It is recommended that project managers include in the construction specifications the considerations presented below. Incorporating important inspection and maintenance activities beginning with the planning and design phase can significantly reduce the long-term operation and maintenance costs for permanent structural stormwater controls. Because post-construction inspections and maintenance are essential to facility function, it is important to ensure that necessary equipment, access, and methods to complete maintenance and BMP evaluation tasks during the operation phase are considered during design.

5.5.1. BMP Construction

Essential functions of permanent BMPs (e.g., bioswales, stormwater wetlands) can be deteriorated by common construction mistakes, such as soil compaction from heavy equipment, erosion and sediment accumulation, or from construction performed in saturated soil conditions. Construction oversight and inspection by a qualified inspector who is familiar with the functions of structural BMPs are highly encouraged for quality control and assurance. Inspectors should verify that the proper temporary erosion control practices are implemented in accordance with federal, state, and local regulations. In addition, construction specifications should include the following practices to protect the permanent green infrastructure BMPs from impairment during construction operations:

- Establish a protective zone around valued natural areas and trees that will be preserved.
- Minimize the use of heavy equipment, especially in areas where infiltration BMPs will be present.
- Minimize soil disturbance and unprotected exposure of disturbed soils.
- Expose only as much area as needed for immediate construction.

- As areas are cleared and graded, apply appropriate erosion controls to minimize soil erosion.
- Protect stormwater infiltration BMPs from unwanted sedimentation during the construction phase.
- Provide a temporary outlet to convey runoff down slope with sediment traps at outlets and inlets.
- Minimize the movement of soil into the drainage system.
- Use sediment and erosion protection practices early in the site clearing and grading process to reduce the sediment-laden runoff reaching soils intended for future infiltration.
- Protect future infiltration facilities from sediment from adjacent properties.

Sensitive areas that require protection should be delineated before grading and clearing starts. It is best to indicate such restrictions on both the grading and erosion control plans. Areas of existing vegetation that are planned for preservation should be clearly marked with a temporary fence. If trees have been designated for preservation, equipment should be prohibited within the drip line to prevent root and trunk damage. Trenching and excavating should not occur within the drip line, and trenches outside but adjacent to the drip line should be filled in quickly to avoid root drying.

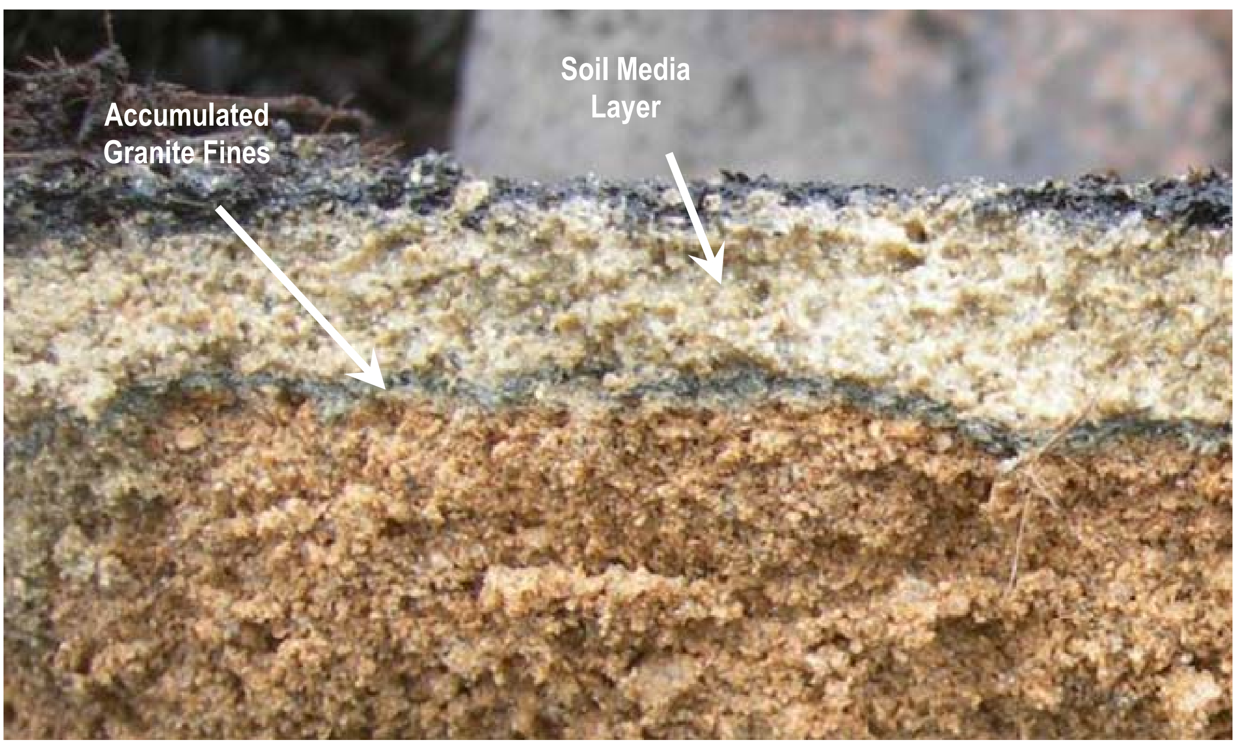
5.5.2. Temporary Erosion and Sediment Control Practices

Soil-disturbing activities at the construction site can increase erosion and sediment risks. Apply an effective combination of temporary soil erosion and sediment controls to minimize the discharge of sediments from the site or into a stormwater drainage system or natural receiving water. MassDEP's *Erosion and Sediment Control Guidelines for Urban and Suburban Areas: A Guide for Planners, Designers, and Municipal Officials,* provides detailed specifications for erosion and sediment control BMPs that are applicable to all construction sites (MassDEP 2003). Properly applying the temporary controls (both on-site and for drainage from off-site parcels with the potential to contribute sediment) is essential and can help preserve the long-term capacity and functions of the permanent stormwater BMPs. Inspection and maintenance of these temporary controls are required to ensure that they remain effective. These controls are in addition to those in the Construction Period Pollution Prevention and Erosion and Sedimentation Control Plan required as part of the Stormwater Report, or the Stormwater Pollution Prevention Plan included as in the NPDES Construction General Permit, if applicable.

Proper construction sequencing can reduce the risk of clogging by excessive accumulation of fine particles in the soil media layers. Designers should specify proper construction sequencing to minimize potential disturbance to green infrastructure BMPs. During construction, the extent of exposed soil should be limited to reduce site erosion by clearly specifying the timing and extent of permanent vegetation establishment. Imported soil media should not be incorporated into BMPs until the drainage area has been stabilized. Where the BMP is treating adjacent roadways or parking areas, soil media should not be installed until at least the first course of pavement has been set to minimize the amount of fines washed from the bedding layers into the BMP. A geotextile liner is not always sufficient to prevent fines from migrating into and clogging the soil media layer; therefore, proper construction sequencing is crucial. Figure 5-11 and Figure 5-12 are examples of the fines that can accumulate and clog the soil media if proper construction sequencing is not followed.

Source: NCSU BAE

Figure 5-11. Example of a bioretention area installed before permanent site stabilization with the inset photo showing the clay layer clogging the mulch surface.



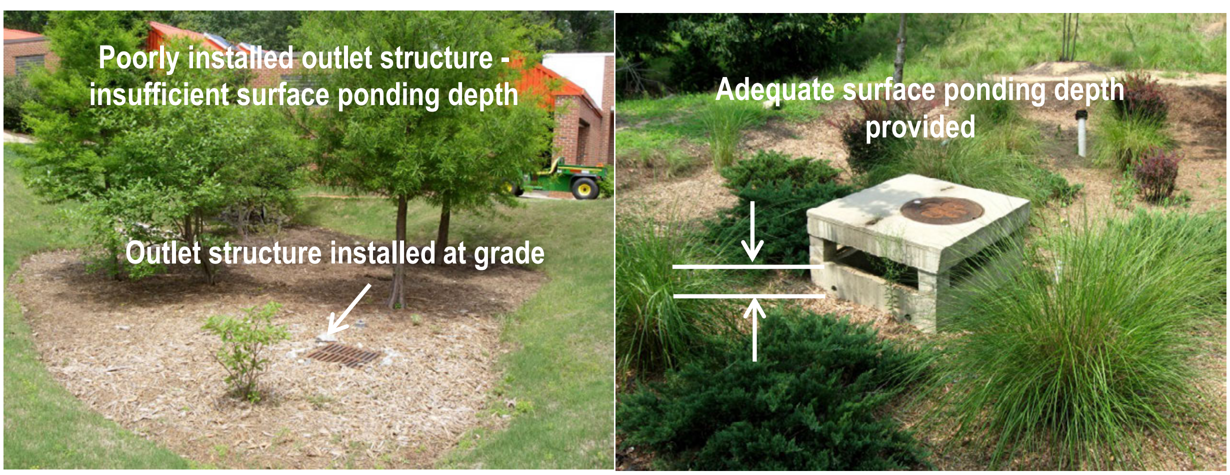
Source: NCSU-BAE

Figure 5-12. Accumulated fines layer as a result of improper construction sequencing.

5.5.3. BMP Construction Inspection

It is essential to inspect all construction phases to ensure that BMPs are properly installed, especially during critical elements such as inverts, inlets, outlets, overflow, and underdrains. Also, designers should stipulate on the plans or specifications which types of materials cannot be substituted (e.g., engineered media). If an element of a structural BMP system was not constructed properly, or the wrong materials were used, the entire system could fail to achieve the desired stormwater benefits. Construction inspection should be performed by the design professional of record or a certified inspector with appropriate training and experience with BMP construction.

Accurate grading of stormwater infrastructure, including structural BMPs and hardscape areas, is critical to ensure proper drainage and BMP function. Research has shown that structural practices with insufficient storage capacity (as a result of inadequate outlet structure details or inaccurate grading) might not perform to meet the targeted hydrologic or hydraulic function (Brown and Hunt 2011; Luell et al. 2011). The designer and contractor should work together to ensure that the project is correctly built to plan. Spot elevations of critical components should be clearly marked on construction plans for verification during construction. If necessary, arrange for appropriate contractor training before starting a BMP construction project, and make training available during construction as needed. It is important to perform field surveys during construction activities to verify that as-built ponding depths have been provided as designed (Figure 5-13); simply measuring the height of the outlet structure relative to the ground surface is inadequate (Wardynski and Hunt 2012).



Source: Tetra Tech

Figure 5-13. Accurate grading and outlet elevations must be provided to achieve intended hydrologic and water quality functions.

Construction activities inherently compact site soils, which can dramatically decrease infiltration rates. Contractors should be properly instructed to minimize compaction by using tracked equipment, excavating the last 12 inches using a toothed excavator bucket, and by minimizing the number of passes over the proposed subgrade while operating the equipment outside of the BMP area where possible (Figure 5-14). To the extent practicable, earth-moving activities should take place during dry conditions to reduce the occurrence of smearing the soil surface, which can also reduce soil permeability.

To mitigate compaction and partly restore infiltration capacity (for practices that are intended to infiltrate), the subgrade should be treated by scarification or ripping to a depth of 9–12 inches (Figure 5-15; Tyner et al. 2009). A soil test might be required after scarifying to verify that infiltration rates have been restored. If the design infiltration rate is not restored after scarifying or ripping, trenches can be installed along the subgrade to enhance infiltration. Trenches should be constructed 1-foot-wide by 1-foot-deep on 6-foot centers and filled with a 0.5-inch layer of washed sand, then topped off with pea gravel (Tyner et al. 2009).

Source: Tetra Tech

Figure 5-14. Heavy equipment (especially wheeled equipment) should be operated outside the excavated area to prevent compaction.

Many urban conditions, especially on retrofit sites, have little or no organic material in the soil structure as a result of compaction, impervious cover, or lack of regeneration during the years prior. Excavation also tends to unearth relatively infertile subsoils. If engineered soil is not specified, a soil test (http://soiltest.umass.edu/services) is recommended to determine the suitability of site soils for plant growth, especially for practices where vegetation will be planted in on-site excavated soils (such as stormwater wetlands). Amendment with 2 to 4 inches of topsoil could be required to improve plant establishment. Consultation with the landscape architect or horticulture designer is recommended to verify rooting depths and establish construction guidance for the landscape contractor. The planting plan should also include guidance on the appropriate time of year to plant trees, shrubs, and grass to reduce plant stress during establishment.

Source: NCSU-BAE

Figure 5-15. For infiltrating practices, mitigate subsoil compaction by ripping grade to a depth of 12 inches.

5.5.4. BMP Inspection and Maintenance

Regular inspection is vital for maintaining the effectiveness of structural BMPs. Generally, BMP inspection and maintenance can be categorized as routine and as-needed. Routine activities, performed regularly (e.g., monthly, biannually) ensure that the BMP is in good working order and continues to be aesthetically pleasing. Routine inspection is an efficient way to prevent potential nuisance situations

from developing and reduce the need for repair or maintenance. Routine inspection also reduces the chance of degrading the quality of the effluent by identifying and correcting potential problems regularly. Property maintenance personnel should be instructed to inspect BMPs during their normal routines.

In addition to routine inspections, as-needed inspection and maintenance of all BMPs should be performed after any event or activity that could damage the BMP, particularly after every large storm event. Post-storm inspections should occur after the expected drawdown period for the BMP, when the inspector can determine if the BMP is draining correctly.

Summary checklists with maintenance requirements are provided below in Section 5.5 for both infiltration and biofiltration and filtration BMPs. Detailed BMP inspection checklists can include minimum performance expectations, design criteria, structural specifications, date of implementation, and expected life span. Recording such information will help the inspector determine whether a BMP's maintenance schedule is adequate or requires revision and will allow comparison between the intended design and the as-built conditions. Checklists also provide a useful way for recording and reporting whether major or minor renovation or routine repair is needed. The effectiveness of a BMP might be a function of the BMP's location, design specifications, maintenance procedures, and performance expectations. Inspectors should be familiar with the characteristics and intended function of the BMP so they can recognize problems and know how they should be resolved.

Green Infrastructure BMP Lifespan

BMP lifespan may vary greatly based on proper design, maintenance, hydraulic and pollutant loading, and other factors. A lifespan of 20 years is generally assumed for stormwater BMPs, as it provides a good horizon for stormwater planning (MDE, 2013).

Routine and as-needed BMP inspections consist of technical and nontechnical activities as summarized below:

- Inspect the general conditions of the BMP and areas directly adjacent.
- Maintain access to the site including the inlets, side slopes (if applicable), forebay (if one exists), BMP area, outlets, emergency spillway, and so on.
- Examine the overall condition of vegetation.
- Eliminate any possibility of public hazards (vector control, unstable public access areas).
- Check the conditions of inflow points, pretreatment areas (if they exist), and outlet structures.
- Inspect and maintain the inlet and outlet regularly and after large storms.
- Ensure that the pretreatment areas meet the original design criteria.
- Check the encroachment of undesirable plants in vegetated areas. This could require more frequent inspections in the growing season.

- Inspect water quality improvement components. Specifically, check the stormwater inflow, conveyance, and outlet conditions.
- Inspect hydrologic functions such as maintaining sheet flow where designed, ensuring functional pretreatment, maintaining adequate design storage capacity, and verifying proper operation of outlet structures.
- Check conditions downstream of the BMP to ensure that flow is properly mitigated below the facility (e.g., excessive erosion, sedimentation).

In every inspection, whether routine or as needed, the inspector should document whether the BMP is performing correctly and whether any damage has occurred to the BMP since the last inspection. Ideally, the inspector will also identify what should be done to repair the BMP if damage has occurred. Documentation is very important in maintaining an efficient inspection and maintenance schedule, providing evidence of ongoing inspection and maintenance, and detecting and reporting any necessary changes in overall management strategies.

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6. Green Infrastructure Review Process

6.1. Local Review Process

Implementing green infrastructure development strategy from design concept to successful construction and long-term operation requires an efficient and well-designed review and approval process. The plan review and approval process helps ensure quality design and construction through the planning, design, construction, and post-construction phases. Most site plan reviews for a specified development are typically performed by a combination of a local planning commission, state or local agency staff (including staff engineers), and governing boards, and are typically conducted to ensure the following:

- The design will comply with local, state, and federal requirements
- Public facilities and infrastructure are adequate to serve future residents
- The development will not adversely impact the environment or adjacent neighborhoods
- Landscaping and screening are appropriate
- Structures and their locations are compatible with surrounding uses

Most municipalities follow a similar plan review process; although larger cities require approvals from several departments, while smaller towns might only have a limited number of people involved. Regardless, an efficient site plan review and approval process should involve continuous interaction between the developer and reviewers from concept planning to final inspection. In a community that has existing stormwater ordinances, site plan review and approval can include the following steps:

(1) Concept plan submittal and meeting between developer and reviewers

(2) Preliminary site plan and stormwater plan submittal, review, and approval

(3) Submittal of operations and maintenance agreements and performance guarantees for stormwater BMPs

(4) Submittal of as-built documentation for stormwater BMPs

(5) Final inspection

(6) Issuance of certificate of occupancy

Designing a site for green infrastructure practices for either new or redevelopment requires a reorganized process from the typical project approach. The site planning process presented in Section 4 is iterative and requires input from a geotechnical engineer, landscape architect, civil engineer, and the building architect. Reviewers and developers (or their engineers) need to have a clear understanding of the stormwater management goals for the community and the optimal green infrastructure practices for a particular site to meet watershed-based targets. Green infrastructure encourages adaptive land use such as minimizing impervious cover; a strategy that often requires interpretation of zoning, paving,

parking, and sidewalk ordinances. Therefore, initiating meetings between developers and regulatory/planning staff early in the planning process is an important strategy for successful and efficient green infrastructure plan review. This early coordination helps determine and document analysis criteria and stormwater management goals that vary by watershed and land use, which reduces interpretation of stormwater management approaches during later stages of plan review. In addition, it could potentially warrant the incentive for communities to offer expedited review to developers that implement green infrastructure design to meet stormwater management goals.

An example project review process is offered in Figure 6-1, with a "traditional" review process on the left, and a green infrastructure alternative review process which provides the incentive of expedited review to encourage developers to use green infrastructure design. This type of flow chart, when tailored to local permitting processes and requirements, can be shared with applicants to inform their decision-making.

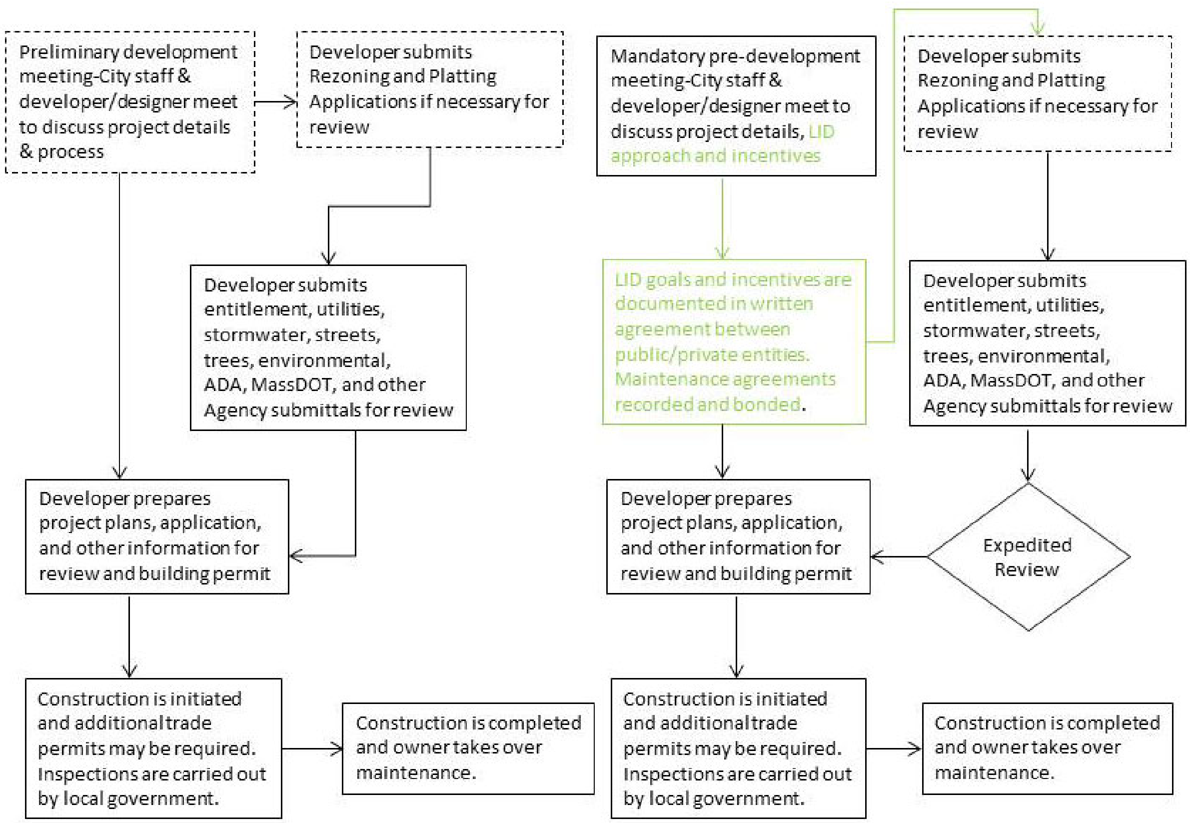

Figure 6-1. Sample planning review process, with (right) and without (left) green infrastructure incentive.

6.2. Massachusetts Plan Review and Permitting Process

As part of the MassDEP's plan review and permitting process, a Stormwater Report must be submitted to document compliance with the state's Stormwater Management Standards (as detailed in Chapter 3, Volume 1 of the *Massachusetts Stormwater Handbook* [2008]). In addition to all plans and supporting information/calculations, the Stormwater Report must also include a brief narrative describing

environmentally sensitive site design and green infrastructure practices used within the development. MassDEP also requires submittal of a checklist to help reviewers and developers ensure the Stormwater Report is complete. Although the checklist includes a section for green infrastructure measures and environmental sensitive design, a more detailed checklist is provided below for further evaluating developments for green infrastructure implementation.

The checklist below (Table 6-1) is intended to assist municipal decision makers in evaluating both public and private development projects that seek to implement green infrastructure design. While this does not incorporate regulatory aspects, it can serve as a convenient tool for evaluating innovative approaches to green infrastructure design and maintenance. **Note that MassDEP has a separate, general checklist to be submitted with its Stormwater Report available at http://www.mass.gov/eea/docs/dep/water/laws/i-thru-z/swcheck.pdf.**

Table 6-1. Planning Review Board supplemental checklist for green infrastructure plan review

Planning Review Board supplemental checklist for green infrastructure plan review				
Site Evaluation	**Provided?**			**Comments:**
Provide vicinity map showing project boundary superimposed on map showing adjacent streets and nearby hydrologic features (streams, reservoirs, etc.) and FEMA floodplain.	☐ Yes	☐ No	☐ N/A	
Identify targeted pollutant and flow attenuation needs.	☐ Yes	☐ No	☐ N/A	
Identify environmentally sensitive areas, areas that provide water quality benefit.	☐ Yes	☐ No	☐ N/A	
Classify and map existing soils, including HSG.	☐ Yes	☐ No	☐ N/A	
Identify areas that are susceptible to erosion or sediment loss.	☐ Yes	☐ No	☐ N/A	
Identify areas of high infiltration potential.	☐ Yes	☐ No	☐ N/A	
Provide total existing impervious area within the site boundary, expressed in acres or square feet and as a percentage of the total project area.	☐ Yes	☐ No	☐ N/A	
Provide total planned impervious area within the site boundary, expressed in acres or square feet and as a percentage of the total project area.	☐ Yes	☐ No	☐ N/A	
Minimize Site Impact	**Provided?**			**Comments:**
Develop previously disturbed land (urban infill, vacant lots).	☐ Yes	☐ No	☐ N/A	
Preserve natural drainage ways.	☐ Yes	☐ No	☐ N/A	
Provide undisturbed buffer for creeks and waterways.	☐ Yes	☐ No	☐ N/A	
Provide details regarding planned slope protection measures to improve geotechnical stability and mitigate potential erosion.	☐ Yes	☐ No	☐ N/A	

Planning Review Board supplemental checklist for green infrastructure plan review				
Minimize grading and filling as much as possible.	☐ Yes	☐ No	☐ N/A	
Plan for phased development and clearing to limit soil disturbance.	☐ Yes	☐ No	☐ N/A	
Incorporate existing drainage infrastructure into the proposed stormwater management plan to extent possible.	☐ Yes	☐ No	☐ N/A	
Minimize Impervious Area	**Provided?**			**Comments:**
Reduce roadway setbacks for buildings.	☐ Yes	☐ No	☐ N/A	
Cluster buildings.	☐ Yes	☐ No	☐ N/A	
Use minimum allowable road widths.	☐ Yes	☐ No	☐ N/A	
Include intersection deflectors (chicanes, pop-outs) in roadway design.	☐ Yes	☐ No	☐ N/A	
Minimize number and dimensions of parking stalls.	☐ Yes	☐ No	☐ N/A	
Use shorter driveways for residences.	☐ Yes	☐ No	☐ N/A	
Limit sidewalks to one side of street where possible.	☐ Yes	☐ No	☐ N/A	
Reduce Effective Impervious Area	**Provided?**			**Comments:**
Downspouts directed to turf or landscaped areas.	☐ Yes	☐ No	☐ N/A	
Driveways graded to pervious areas.	☐ Yes	☐ No	☐ N/A	
Use grassed or landscaped swales instead of curb and gutter.	☐ Yes	☐ No	☐ N/A	
Use pervious alternatives for low-traffic paved areas (e.g., gravel, pavers, porous pavement, grassed parking).	☐ Yes	☐ No	☐ N/A	
Encourage mix-used developments that promote walking versus driving.	☐ Yes	☐ No	☐ N/A	
Encourage Public Open Space	**Provided?**			**Comments:**
Provide high-value undisturbed open space in addition to low-value land (e.g., steep slopes, wetlands).	☐ Yes	☐ No	☐ N/A	
Design compact residential lots with shared common open space.	☐ Yes	☐ No	☐ N/A	
Increase residential unit densities through vertical building or zero lot lines.	☐ Yes	☐ No	☐ N/A	
Maximize Infiltration	**Provided?**			**Comments:**
Locate green infrastructure practices on the relatively lower runoff/higher infiltrating soil types.	☐ Yes	☐ No	☐ N/A	
Incorporate bioretention or infiltration features into landscaping plan.	☐ Yes	☐ No	☐ N/A	
Extend drainage flow paths of swales as long as possible.	☐ Yes	☐ No	☐ N/A	

Planning Review Board supplemental checklist for green infrastructure plan review				
Provide practices and guidelines to minimize soil compaction.	☐ Yes	☐ No	☐ N/A	
Hydrologic Evaluation	**Provided?**			**Comments:**
Provide a detailed description of site design on-site and how the proposed project maximizes use of green infrastructure site design.	☐ Yes	☐ No	☐ N/A	
Provide tabulation of all impacted areas including contributing drainage area, pervious area, slope, soil, surface cover, and runoff coefficient.	☐ Yes	☐ No	☐ N/A	
Provide channel assessment for receiving streams between the project discharge and the domain of analysis.	☐ Yes	☐ No	☐ N/A	
Treatment Control (TC) BMPs	**Provided?**			**Comments:**
Provide details regarding the proposed project site drainage network, including storm drains, concrete channels, swales, detention facilities, stormwater treatment facilities, natural and constructed channels, and the method for conveying off-site flows through or around the proposed project.	☐ Yes	☐ No	☐ N/A	
Provide narrative description of TC BMP selection procedure based on soil infiltration potential, hydromodification management criteria applicability, and required pollutant removal efficiency.	☐ Yes	☐ No	☐ N/A	
Provide sizing calculation for each proposed BMP including water quality design flow, design volume, outlet design, overflow design, drawdown, ponding depth, etc.	☐ Yes	☐ No	☐ N/A	
Provide standard details for bioretention BMP facilities, including underdrain design, soil mix specifications, and overflow design.	☐ Yes	☐ No	☐ N/A	
Identify green roofs, if applicable, along with BMP-specific design details.	☐ Yes	☐ No	☐ N/A	
Identify areas of proposed permeable pavement along with applicable design details including underdrains, if applicable.	☐ Yes	☐ No	☐ N/A	
Identify areas of active landscaping that will require irrigation.	☐ Yes	☐ No	☐ N/A	
Identify rainwater harvesting facilities and standard detail, if applicable.	☐ Yes	☐ No	☐ N/A	
Provide documentation regarding BMP operation and maintenance, access easements, and certification to accept maintenance responsibility.	☐ Yes	☐ No	☐ N/A	
Maintenance	**Provided?**			**Comments:**
Provide details regarding method for maintenance extending into perpetuity (Homeowners Association, Community Facilities District, etc.).	☐ Yes	☐ No	☐ N/A	
Provide details regarding the required BMP maintenance activities and frequency required for each BMP.	☐ Yes	☐ No	☐ N/A	

Planning Review Board supplemental checklist for green infrastructure plan review				
Provide signed documentation providing for BMP maintenance access into perpetuity if access is needed.	☐ Yes	☐ No	☐ N/A	
Sediment and Erosion Controls	**Provided?**			**Comments:**
Protect sensitive environmental features (e.g., streams, ponds, buffers, wetlands, Natural Heritage Inventory sites) from construction impacts.	☐ Yes	☐ No	☐ N/A	
Protect post-construction BMPs and from construction runoff, such as from sediment clogging bioretention areas.	☐ Yes	☐ No	☐ N/A	
Delineate locations and extents all features off-limits to construction traffic, such as drip lines for protected specimen trees and critical habitats.	☐ Yes	☐ No	☐ N/A	

6.3. Incentives

Municipalities can use a variety of incentives to encourage green infrastructure implementation for new and existing developments. Incentives can encourage developers to use green infrastructure practices during the planning and design process for new development projects. For existing development, incentives can help property owners retrofit their sites with new BMPs. In addition to the incentives listed below, section 2.7 of this Handbook lists a number of grant programs available to fund green infrastructure projects. According to EPA, four common incentive mechanisms used at the local level are fee discounts or credits, development incentives, BMP installation subsidies, and awards and recognition programs, as described below (USEPA 2012):

1. *Stormwater fee discount or credit*

Municipalities often charge a stormwater fee based on the amount of impervious surface area on a property. If a property owner decreases a site's imperviousness or adds green infrastructure practices to reduce the amount of stormwater runoff that leaves the property, the municipality will reduce the stormwater fee or provide a credit that helps the landowner meet a water quality performance or design requirement.

2. *Development incentives*

Local governments can offer incentives that are only available to a developer who uses green infrastructure

Definitions

Fee discounts or credits require a stormwater fee that is based on impervious surface area. If property owners can reduce need for service by reducing impervious area, the municipality reduces the fee.

Development incentives are offered to developers during the process of applying for development permits. They include zoning upgrades, expedited permitting, reduced stormwater requirements, and other incentives.

Rebates and installation financing give funding, tax credits or reimbursements to property owners who install specific practices. These incentives are often focused on practices needed in certain areas or neighborhoods.

Awards and recognition programs provide marketing opportunities and public outreach for exemplary projects. These programs can include monetary awards.

Source: USEPA 2010

practices. Some economic development corporations will use these incentives to encourage development on targeted sites, such as redevelopment in downtown or underserved areas. For example, cities might offer to waive or reduce permit fees, expedite the permit process, allow higher density developments, or provide exemptions from local stormwater permitting requirements for developers that use green infrastructure practices to meet stormwater management goals.

3. ***Rebates and installation financing***

To offset costs, cities might offer grants, matching funds, low-interest loans, tax credits, or reimbursements to property owners who install specific green infrastructure practices or systems. For example, some communities offer programs that subsidize the cost of rain barrels, plants and other materials that can be used to control stormwater. Similarly, public improvements financed through public and private partnerships can require green infrastructure implementation to meet community goals.

4. ***Awards and recognition programs***

More communities are holding green infrastructure design contests to encourage local participation and innovation. Many communities highlight successful green infrastructure sites by featuring them in newspaper articles, on websites and in utility bill mailings. Some also issue yard signs to recognize property owners who have installed green infrastructure. Recognition programs can help to increase property values, promote property sales and rentals, and generally increase demand for the properties. Businesses receiving green awards can enhance sales materials to generate increase revenue.

6.4. References

MassDEP (Massachusetts Department of Environmental Protection). 2008. *Massachusetts Stormwater Handbook*. http://www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html

USEPA (U.S. Environmental Protection Agency). 2010. *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure*. Accessed March 4, 2013. http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf.

USEPA (U.S. Environmental Protection Agency). 2012. *Encouraging Low Impact Development: Incentives Can Encourage Adoption of LID Practices in Your Community*. Accessed March 4, 2013. http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf.

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Appendix A
Watershed Assessment
Supplemental Information

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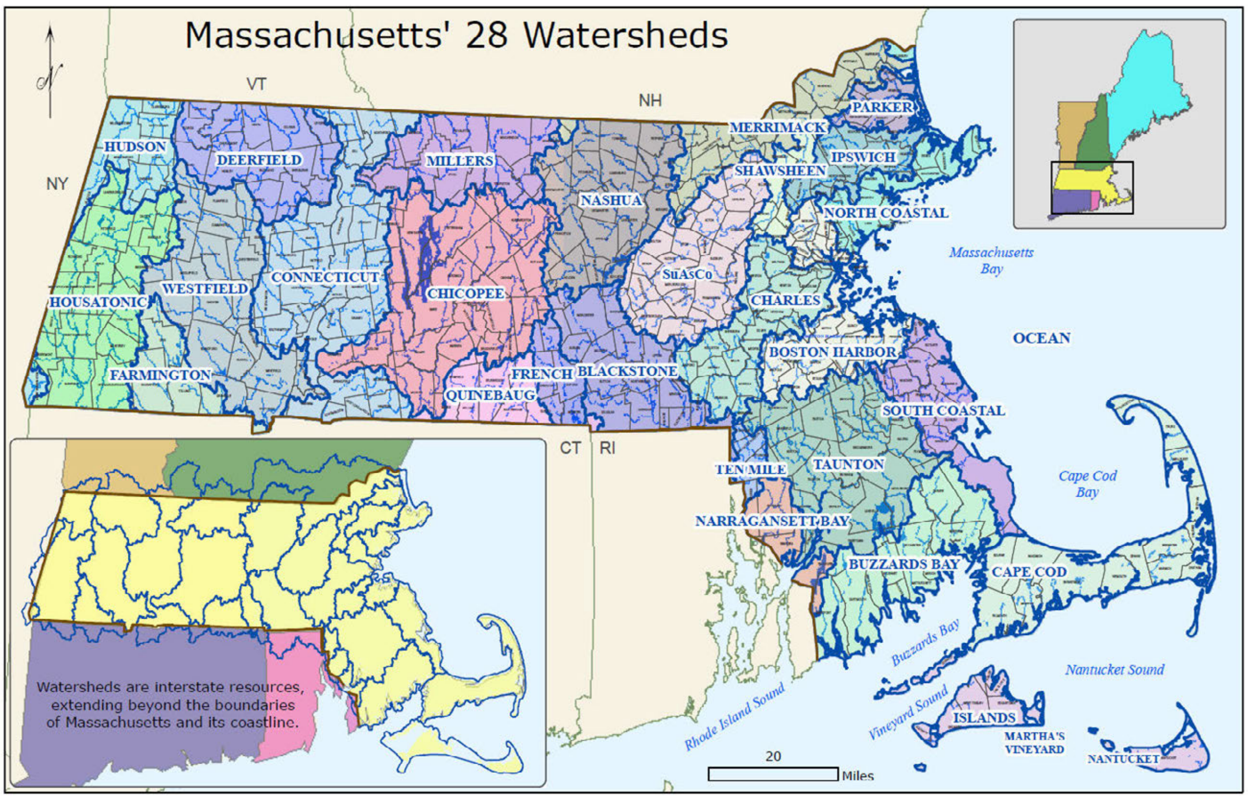
A. Watershed Assessment – Supplemental Information

A.1 Part 1: Identify Study Watershed

A.1.1 Principal Watersheds in Massachusetts

Massachusetts contains eight major drainage areas (*megabasins*)—the Coastal, Connecticut, Housatonic, Hudson, Merrimack, Narragansett, Piscataqua-Salmon Falls, and Thames River basins. These megabasins can be further divided into 27 principal watersheds as shown in Figure A-1.



***Source*: mass.gov**

Figure A-1. Principal watersheds in Massachusetts (8-digit HUCs).

The 27 watersheds in the state can be further subdivided into smaller units depending on the scale and area of interest for the study. Common practice is to use watershed delineations previously developed by the U.S. Geological Survey (USGS) and Natural Resources Conservation Service (NRCS), by which basins, watersheds, and subwatersheds are identified using a Hydrologic Unit Code (HUC) based on scale. Section A.2.1 describes this watershed identification system in more detail.

In the case where HUC subwatersheds still exceed the scale of study, they can be further subdivided into even smaller units at the local scale using other high-resolution datasets (e.g., NHDPlus catchments) or by employing geospatial data such as contour lines, digital elevation models (DEMs), and aerial imagery

to further subdivide watersheds to achieve desired sizes and extents. Using these existing data sources, a geographic information system (GIS) based representation of the study watershed should be developed (or obtained, if it already exists) to define the geographic scope and facilitate assessment.

A.2 Part 2: Identify Existing Hydrologic and Hydraulic Data

A.2.1 Watershed Boundaries

Section 2.1 provided a brief overview of watershed identification. Hydrologic watershed boundaries describe the physical extent of watersheds. USGS and NRCS have developed the national Watershed Boundary Dataset (WBD), which “defines the areal extent of surface water drainage to a point” (USGS 2014). The WBD data, provided by MassGIS, uses the HUC system in which watersheds are identified using 2, 4, 6, 8, 10, or 12 digits depending on scale. For example, hydrologic regions use only a 2-digit HUC while the smallest scale subwatersheds use a 12-digit HUC. The HUC describes where the unit is in the country and the level of the unit, as outlined below (MassGIS 2014b).

- *First 2 digits: region (hydrologic region)*
- *First 4 digits: subregion (megabasin)*
- *First 6 digits: accounting units (basin)*
- *First 8 digits: cataloging units (subbasin)*
- *First 10 digits: watershed units (watershed)*
- *Full 12 digits: subwatershed units (subwatershed)*

The Massachusetts Ocean Resource Information System (MORIS) provides access to the same watershed boundary datasets as MassGIS and is focused on the coastal zone.

It should be noted that additional HUC delineations are possible (for example, some states have developed 14-digit HUCs); however, the HUCs indicated above are those currently developed for Massachusetts. Per MassGIS, USGS developed HUCs up to 8 digits for the U.S. while the NRCS within each state is developing the finer scale delineations (MassGIS 2014b).

The full number of HUC digits used defines the scale of the watershed or subwatershed, which depends on the scale of the project. MassGIS provides access to NRCS 8-digit, 10-digit, and 12-digit HUC data as well as 4-digit HUC data. As an example, Figure A-2 shows a portion of the Cape Cod 8-digit subbasin (purple outline), specifically the *South Shore Tributaries and Islands* HUC-10 watershed, along with other corresponding 10-digit (orange outline) and 12-digit (light grey outline) delineation scales. The thick black outline represents megabasin boundaries (4-digit HUC).

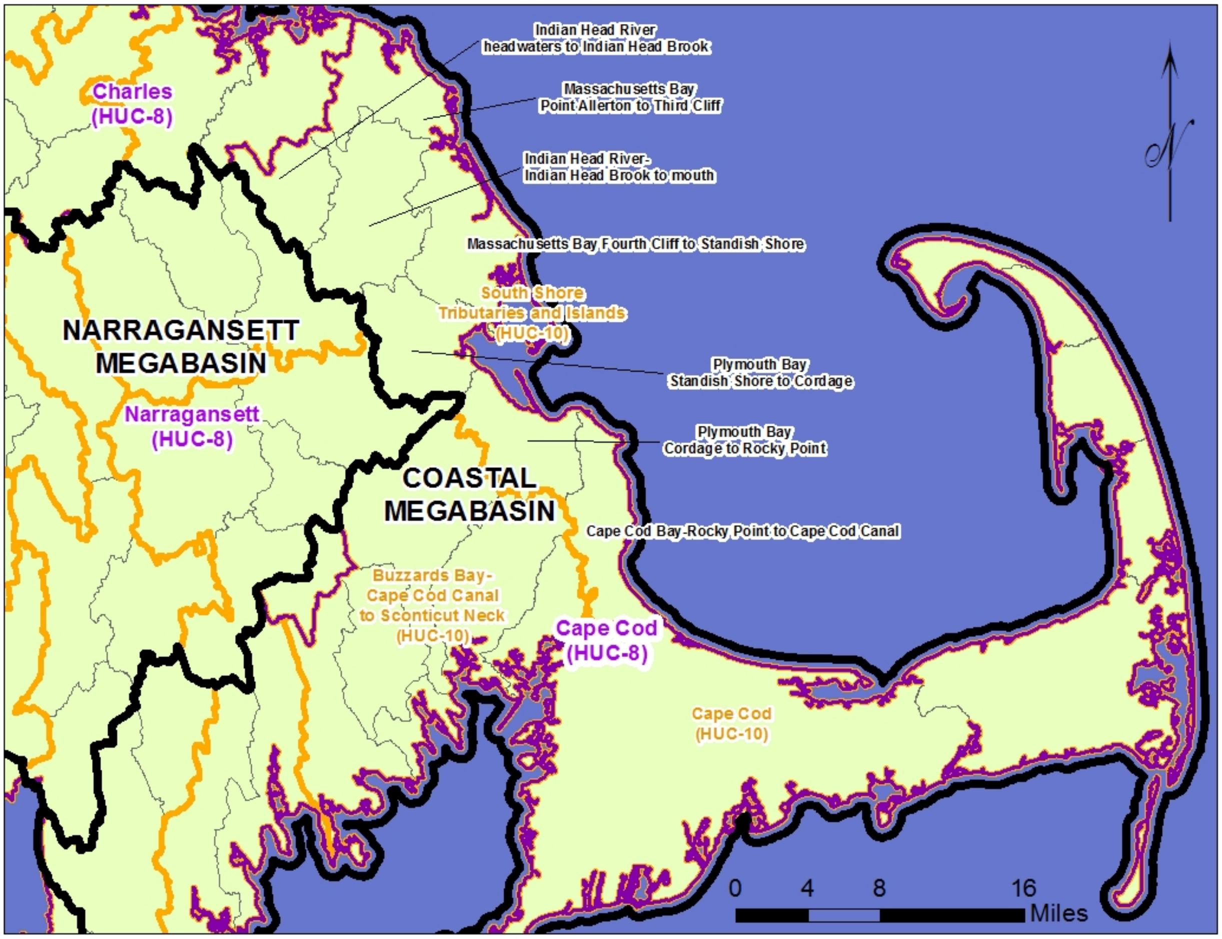


Figure A-2. Cape Cod 8-dight subbasin showing 10- and 12-digit HUCs and megabasin boundaries.

A.2.2 Water Bodies (Hydrography)

Hydrography data represent hydrographic (water-related) features in the watershed, including surface water (lakes, ponds, and reservoirs), wetlands, bogs, flats, rivers, streams, and more (MassGIS 2014a). MassGIS provides access to the Massachusetts Department of Environmental Protection (MassDEP) hydrography dataset, which expands on the existing USGS 1:25,000 scale hydrography layer by adding local stream resolution for enhanced detail, which is ideal for watershed assessment at the local scale.

MORIS is a one-stop shop for spatial hydrography data for coastal Massachusetts. MORIS provides access to DEP rivers, streams, and water bodies (1:25,000), DEP wetlands (1:12,000), and National Wetlands Inventory (NWI) streams and wetlands.

Local-, regional-, or state-level datasets are often the best option for hydrography; however, it is important to know about alternative datasets such as the National Hydrography Data (NHD) and NHDPlus datasets which might be better suited for the particular analysis, or can serve as supplemental data sources. These are available at the following websites, respectively:

- NHD (low-, medium-, or high-resolution):
  http://nhd.usgs.gov/data.html
  Data download available from:
  ftp://nhdftp.usgs.gov/DataSets/Staged/States/
- NHDPlus (medium resolution):
  www.horizon-systems.com/nhdplus/

The existence of streams, lakes, and other water bodies in the watershed with known water quality impairments can be a key factor in determining appropriate locations for green infrastructure. This is discussed in Section A.2.8.5.

A.2.3 Land Use/Land Cover and Impervious Surface

Vegetation, degree of land development, and other features can be observed and quantified in broad terms from aerial photography, but more detailed spatial characterization is facilitated with GIS datasets describing land use and land cover. A popular resource is the National Land Cover Database (NLCD), a national dataset produced by the Multi-Resolution Land Characteristics Consortium (MRLC). The database is updated at approximately 5-year intervals. NLCD 2011 was released in April 2014.

MORIS also provides access to land use and land cover datasets for the coastal zone. Land cover is based on NOAA's Coastal Change Analysis Program (C-CAP). As of mid-2014, the most recent land cover dataset on MORIS was from 2006, and the most recent land use dataset was from 2005. MORIS also provides datasets indicating land use and land cover change over various time periods.

Land use analysis can indicate degree of impervious surface cover, which is often associated with degraded physical and biological stream conditions. Breakdown of existing land use will also indicate percentage of development, including residential, commercial, industrial, and institutional land uses. Expected growth and development can be used to identify spatial distributions of projected land use changes. Increases in development and impervious cover can have significant effects on water quality and quantity, and ***areas with a high degree of development and impervious surface are generally considered high priority for green infrastructure implementation.***

A.2.4 Topography and Elevation

Topography is a description of the surface features of the watershed in terms of shape, aspect, slope, and elevation. Locations with excessive slope might not be suitable for green infrastructure. Section 3 discusses the importance of topography and slope for green infrastructure site prioritization in greater detail.

USGS topographic maps are a visual tool for analyzing the elevation and slope characteristics of a watershed at a larger scale (1:24,000) and are available through MassGIS. For a more detailed description of topography, digital elevation models (DEMs) are typically used for GIS-based analysis. DEMs are spatial data in raster (gridded) format in which each cell (pixel) value represents an elevation above (positive elevation) or below (negative elevation) sea level. MassGIS provides DEM data in

squares with a resolution of 5 meters by 5 meters. USGS also maintains nationwide coverage of DEM data at 30-meter, 10-meter, and 3-meter resolution (http://ned.usgs.gov/), available through the NRCS/USDA Geospatial Data Gateway (GDG, http://datagateway.nrcs.usda.gov/). *Note that 3-meter resolution data are currently not available for all areas of the nation.* DEM data can be used in GIS software such as ArcGIS to calculate slope or render elevation contours.

MORIS also provides access to elevation data, including USGS topographic maps. Also included in MORIS are elevation contours at an interval of 3 meters and an elevation grid at 1:5,000 scale.

A.2.5 Soils

An investigation of soils in the watershed should include descriptions of soil types, textures, and hydrologic properties. For example, soils with higher infiltration capacities are generally better suited for green infrastructure. For green infrastructure assessment purposes, soils are typically rated by hydrologic soil group (HSG), which is a classification system NRCS developed to sort soils into four categories (A, B, C, and D) based on runoff potential, water transmission, texture, hydraulic conductivity, and other physical factors. Group A soils have the lowest runoff potential and Group D soils have the highest runoff potential when thoroughly wet.

Green infrastructure is best suited for native soils with high infiltration capacities, which generally fit into HSGs A, A/B, and B. The existence of clayey/silty soils can prohibit infiltration. As described in Section 3.3, installing green infrastructure on poorly draining soils may require underdrain systems, soil amendments, deep-rooted vegetation, or a combination of these, which increases construction complexity.

MassGIS provides a NRCS SSURGO (Soil Survey Geographic Database)-certified soils data layer, with statewide coverage as of November 2012. Soils data can be downloaded for individual counties or as a single statewide coverage. "SSURGO-certified" indicates that NRCS has reviewed and approved all of the soils data for quality standards. Alternatively, soils data for Massachusetts (and beyond) can be readily downloaded from the NRCS/USDA Web Soil Survey (http://websoilsurvey.nrcs.usda.gov) or through the NRCS/USDA GDG.

Hydrologic Soil Groups (HSG)

HSG	Description	Soil textures
A	Low runoff potential when wet	Sand, loamy sand, or sandy loam
B	Moderately low runoff potential when wet	Silt loam or loam
C	Moderately high runoff potential when wet	Sandy clay loam
D	High runoff potential when wet	Clay loam, silty clay loam, sandy clay, silty clay, or clay

A.2.6 Parcels

Parcel data are essential for identifying ownership when investigating potential green infrastructure opportunities in the watershed. For example, ***vacant and publicly-owned parcels might provide greater probability of successful implementation of green infrastructure*** than those that are currently under private ownership for many reasons. This is discussed further in Section 3. MassGIS provides a recently

completed (October 2013) dataset of property boundaries and information for all but a few communities in the state, based on tax records. Parcel data (“Assessor’s Parcels”) are also available for the coastal zone through MORIS.

A.2.7 Aerial Photography

Even for relatively small watersheds, it is not practical to visually inspect every parcel to match them with the appropriate BMP option. It is recommended that the watershed assessment team employ a systematic screening process based on the best available GIS data coupled with a targeted field assessment. The screening process will incorporate knowledge from BMP experts regarding site suitability to identify which sites are expected to offer the best opportunities for green infrastructure. When combined with the other datasets outlined above, aerial photography can be an effective tool for visually inspecting sites without physically visiting them. Inspection of aerial photos can enable preliminary characterization of land use, vegetation, and impervious cover; identification of utilities such as electric lines and easements; and other important features that can either facilitate or limit green infrastructure. In general, “leaf-off” imagery is most desirable because it enables better visualization of land use and land cover in areas with deciduous trees. ***Aerial photography should be used to screen out locations in the watershed that are not suitable for green infrastructure due to obvious limitations***.

MassGIS is perhaps the best place to start when searching for aerial imagery for Massachusetts. The program currently provides access to USGS color orthoimagery for varying time periods for the entire state. Aerial imagery was completed in April 2013 for three urban areas (metropolitan Boston, Worcester, and Springfield). The 2013 imagery covers a large percentage of the state, and an index map showing the area covered is available on MassGIS. For remaining areas of the state, MassGIS provides color orthoimagery for 2008 or 2009, depending on area. Coverage area for the 2008 and 2009 data can also be viewed on the MassGIS website.

MORIS offers numerous aerial imagery layers for viewing in its interactive mapping feature. However, orthophotos currently cannot be downloaded through MORIS. Alternatively, it is possible that individual counties and municipalities perform their own aerial imagery flyovers.

A.2.8 Additional Data Resources

A.2.8.1 Existing Stormwater Structures and Pipes

Local municipalities typically develop and maintain datasets which identify the locations and specifications of stormwater pipes and features, and if so, these data should be readily available. Some smaller municipalities might not possess spatial data for their stormwater drainage networks. In such cases, it might be necessary to try to obtain engineering drawings (“as-builts”) or rely on site visits to attempt to identify and characterize existing storm features. Section 2.4 describes the process of identifying existing green infrastructure and other stormwater BMPs. At present, MassGIS and MORIS do not provide a statewide GIS dataset that identifies locations of stormwater pipes and features.

A.2.8.2 Streamflow

Long-term continuously recorded stream gage data are most useful for watershed assessment. USGS gauging stations record stream stage at 15-minute intervals then calculate a corresponding discharge from a rating curve. The USGS National Water Information System (NWIS) provides instant access to streamflow data at thousands of sites across the United States, including http://nwis.waterdata.usgs.gov/nwis. In addition, the USGS Instantaneous Data Archive can be used to access continuous streamflow data before October 1, 2007 (http://ida.water.usgs.gov/ida/).

MassGIS provides two datasets relevant to streamflow: one is "Stream-Gaging Stations" and the other is "USGS Data-Collection Stations." However, the most reliable, up-to-date resource for locations of active and discontinued gages is the USGS website. The NWIS Mapper can be used to quickly identify sites in the area of interest, or for the entire state, at: http://maps.waterdata.usgs.gov/mapper/index.html.

Increasing development and impervious coverage in a watershed can significantly impact streamflow by increasing both the magnitude of stormwater runoff (storm "peaks") and the rate at which it reaches the stream. ***Analysis of streamflow data might provide clues on how the hydrology in the watershed has changed over time because of development and help identify locations where green infrastructure can help mitigate those impacts.***

A.2.8.3 Climate and Precipitation

Appropriate characterization of precipitation patterns in the watershed will help determine suitable types of green infrastructure. For example, some practices are better suited for climates with frequent but low-intensity rainfall events, while others are designed for climates with infrequent but high-intensity rainfall events.

Appropriate data should be obtained and analyzed to develop an understanding of the climate of the watershed, particularly with respect to rainfall. Below is a list of several data sources, but note that many others exist. (For example, some municipalities operate and maintain their own rain gauges.)

- National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC), hourly and 15-minute
  www.ncdc.noaa.gov/cdo-web/datasets
- NOAA's Climate Prediction Center (CPC) Hourly U.S. Precipitation (gridded)
  www.esrl.noaa.gov/psd/data/gridded/data.cpc_hour.html
- Massachusetts Hydrometeorological Networks (NCAR Earth Observing Laboratory)
  www.eol.ucar.edu/projects/hydrometnet/massachusetts/
- Community Collaboration Rain, Hail & Snow Network (CoCoRaHS), 1998–present
  www.cocorahs.org/state.aspx?state=ma
- Mass.gov Precipitation Database (Office of Water Resources), monthly data for 176 stations, some dating back to the 1800s
  www.mass.gov/eea/agencies/dcr/water-res-protection/water-data-tracking/rainfall-program.html

A.2.8.4 Water Quality

Analysis of water quality data will enable identification of existing water quality issues in the watershed. Once the baseline water quality conditions and any current water quality concerns are identified, it will be possible to begin to evaluate different green infrastructure practices for their potential to address these water quality issues to restore and maintain water quality in the watershed.

Often, state and local agencies are the best source of water quality data. MassBays Regional Coordinators should serve as primary points of contact for identifying sources of water quality monitoring data, as well as to investigate the potential for partnering to obtain new data.

A source of water quality monitoring data might be local conservation or volunteer groups and organizations with special interests within the watershed.

- Two great examples of volunteer monitoring efforts in the Massachusetts Bays region are the ***North and South Rivers Watershed Association*** (www.nsrwa.org) and ***Salem Sound Coastwatch*** (www.salemsound.org), two of the regional partners of the Massachusetts Bays Program

A.2.8.5 303(d)-Listed Water Bodies (Impaired Waters)

Per 314 CMR 4.00, MassDEP provides a detailed list of waters of the state with water use class, designated use(s), and applicable minimum water quality standards ("Massachusetts Surface Water Quality Standards") (www.mass.gov/eea/agencies/massdep/water/regulations/314-cmr-4-00-mass-surface-water-quality-standards.html).

314 CMR 4.06 lists all waters of the state by major river basin or coastal drainage area and indicates applicable reaches, water use class, and any special considerations (*qualifiers*) that may affect application of the water quality criteria. An excerpt from 314 CMR 4.06 is shown below.

TABLE 24
SOUTH COASTAL DRAINAGE AREA (continued)

BOUNDARY	MILE POINT	CLASS	QUALIFIERS
Jones River			
Source to Wapping Pond	7.0 - 3.4	B	Warm Water High Quality Water
Wapping Road to Elm Street	3.4 - 2.5	B	Warm Water
Cove, Herring, Iron Mine, Second Herring, Stony, and Third Herring Brook and Robinson Creek Portion in North River Corridor			Outstanding Resource Water

Under section 303(d) of the Clean Water Act, states are required to develop lists of waters that are impaired by one or more pollutants. By definition, impaired waters do not meet water quality standards. The 303(d) lists must be developed and updated every 2 years.

An inventory of 303(d)-listed water bodies should be performed to identify streams, reservoirs, lakes, and estuaries that do not fully support their designated uses, and to determine the extent to which the impairment occurs (for example, the length of stream listed as impaired). These areas should be given special attention and consideration. ***Causes of impairment should be reviewed to determine whether green infrastructure could potentially provide a benefit in meeting designated uses***. Knowledge of impaired water bodies in the watershed might aid in prioritization. Designated uses might include habitat for fish, other aquatic life, and wildlife; fish and shellfish consumption; primary (e.g., swimming) and secondary (e.g., boating) contact recreation; and drinking water supply.

It is important to consult the most recently published 303(d) list because outdated listings might include water bodies that have since been delisted, or might not include water bodies that have recently been added. State 303(d) lists are submitted on even years but typically not approved until the following year. The most recent 2012 303(d) list for Massachusetts (Integrated List) was finalized and approved in May 2013, and the 2014 303(d) list is expected to be available in 2015.

An inventory of existing and planned Total Maximum Daily Loads (TMDLs) for 303(d)-listed water bodies should also be completed. The TMDL is the total amount of pollutant that can be assimilated by the receiving water body while achieving applicable water quality standards. Established TMDLs for water bodies in the watershed of interest will include detailed information on planned steps to improve water quality to meet water quality standards and achieve designated uses.

- Information on TMDLs (both draft and completed) and the latest 303(d) list (Integrated List) are made publicly available by MassDEP at www.mass.gov/eea/agencies/massdep/water/watersheds/total-maximum-daily-loads-tmdls.html (“Total Maximum Daily Loads”).
- Mass.gov also provides an interactive mapping utility, which facilitates quick and easy viewing of the statewide 2012 Integrated List of Waters, available at www.mass.gov/eea/agencies/massdep/water/watersheds/2012-integrated-list-of-waters.html (“Interactive Mapping of the 2012 Integrated List of Waters”).

A.2.8.6 Downstream Impairment

Water quality issues in waters downstream of the target watershed should also be considered, and these downstream water bodies should be surveyed for existing impairments and TMDLs. Addressing water quality impairments in upstream water bodies could provide mutual benefit for downstream ones, and this should be considered when selecting sites for green infrastructure.

A.2.8.7 Environmentally Sensitive Areas

As described in Section 3.3.1, significant restrictions can apply for potential green infrastructure sites that are located within an environmentally sensitive or protected area. This can result in construction complexity and elevated costs. Locations within sensitive or protected areas are considered low-priority sites, whereas areas in close proximity to these sensitive or protected areas are prioritized as green infrastructure and can treat the runoff before it drains to these valuable areas.

Environmentally sensitive areas in the watershed might include:

- Shellfish beds
- Sensitive salt marsh and other habitat
- Conserved lands (i.e., public parks, state and federal conservation lands, privately conserved lands, etc.)
- Threatened and endangered species or species of special concern and their habitats
- Outstanding Resource Waters (ORWs)
- National Wetland Inventory (NWI) wetlands
- Recreational lakes and bathing beaches

MassGIS and MORIS provide many datasets that could be relevant and useful for identifying and characterizing environmentally sensitive areas in the watershed.

A.2.8.8 Regulated Floodplains and Floodways

It is important to identify any potential locations in the watershed that are within regulatory floodways and floodplains. The Federal Emergency Management Agency (FEMA) or appropriate local floodplain management agency should be contacted for site-specific information. It is important to consider the increased risk of flooding if green infrastructure is installed in these areas and the impact flooding could have on the function and design of green infrastructure practices.

FEMA publishes National Flood Hazard Layer (NFHL) data, which incorporates Flood Insurance Rate Map (FIRM) data. The FIRM is the basis for floodplain management, mitigation, and insurance activities for the National Flood Insurance Program (NFIP). In recent years, a major effort has been undertaken to update and upgrade all paper FIRMs into digital FIRMs (DFIRMs). The flood data classifies geographic areas by flood risk, which determines whether flood insurance is required and the insurance rate (MassGIS).

As of October 2013 final digital flood hazard data are available for a large area of the state, but there are some coverage gaps. Coastal counties without final flood hazard data at this time include Barnstable County and Nantucket County. A DFIRM status map can be viewed on MassGIS (www.mass.gov/anf/docs/itd/services/massgis/nfhl-status.pdf).

Both MORIS and MassGIS provide access to FEMA National Flood Hazard data, which maps the various FEMA flood risk classification zones, the regulatory floodway, and the flooding extent for the 1% and 0.2% annual chance (100-year and 500-year, respectively) probability events.

A.2.8.9 Water Supplies and Dams

It is important to identify any public water sources in the watershed and to consider ways in which water supplies could be affected by green infrastructure, both with respect to water quality and quantity. Green infrastructure could potentially provide water quality benefit by treating stormwater runoff before pollutants are carried into public water supplies. In addition, green infrastructure can infiltrate stormwater, which recharges ground water supplies and any water sources that are fed by ground water.

Accordingly, locations of water supply intakes should be identified as well, if possible. Local municipalities should serve as the first point of contact for identifying the locations of these features.

The MassGIS public water supply dataset identifies the locations of public community surface and ground water supply sources and public non-community supply sources (as defined in 310 CMR 22.00). The data layer is based primarily on information in the DEP's water quality testing system database, the DEP's central database for tracking water supply data (MassGIS). Recharge areas for public water supplies are defined in the Massachusetts Drinking Water Regulations, 310 CMR 22.02 (MassDEP 1997).

The Massachusetts dams dataset from MassGIS contains points derived from a dam safety database maintained by the Massachusetts Office of Dam Safety (ODS). Most of the location information was derived from historic data and has been ground-truthed. It is important to note that there are many non-jurisdictional dams that are not in the ODS database.

A.3 Part 3: Characterize Known Pollutant Loadings

A.3.1 Identify Pollutants of Concern

Pollutants of concern should be identified by first determining which, if any, water bodies in the watershed are listed as impaired, per the most recent 303(d) list, as described in Section A.2.8.5. Further, it is necessary to determine whether any TMDLs have been developed to address specific pollutants. As noted in Section A.2.8.5, a TMDL can provide some insight into proposed methods for attaining water quality standards, which can be helpful for identifying areas in which certain types of green infrastructure practices might provide some benefit.

The 303(d) list of impaired waters (*Integrated List*) generally provides information on known or suspected causes of impairment, as does the TMDL report. However, green infrastructure implementation does not necessarily depend on the existence of 303(d) impairments in the watershed. Green infrastructure can be implemented for benefits not related to specific water quality regulations, such as hydrologic benefits (i.e., residential flooding reduction) and the need to continue to maintain a high standard of water quality in the face of increasing development. Municipalities might look to green infrastructure as a means of achieving many different objectives.

It is important to recognize the many different known and potential sources of stormwater pollution in the watershed to maintain a high standard of water quality, whether or not existing water quality standards are currently being met. Keeping an inventory of activities in the watershed that could potentially contribute to stormwater runoff pollution will facilitate a more efficient process for pollutant control. Potential pollutant sources are discussed below.

A.3.1.1 Wastewater and Stormwater Facilities

Existing permitted water and stormwater facilities should be identified and catalogued. Locations and detailed information on National Pollutant Discharge Elimination System (NPDES) permitted facilities is readily available in online EPA databases, and a search should be conducted for such facilities within the target watershed. EPA's Envirofacts system (www.epa.gov/enviro/) is the umbrella database of

environmental data for a wide number of reporting systems and is an ideal starting point when searching for information on existing facilities.

Some older municipalities operate combined storm and sanitary sewer systems, while others are increasingly separating the two. Municipal separate storm sewer systems (MS4s) are regulated under separate NPDES permits. Per EPA regulations, Phase I MS4s (generally larger cities such as Boston and Worcester) are required to obtain individual permits and Phase II MS4s (generally smaller MS4s in urbanized areas) are required to obtain permit coverage but are typically covered by a general permit.

Many municipalities across the country are developing stormwater utilities whereby residents and commercial developments are charged a fee that funds the treatment and control of runoff before it is discharged to surface waters. In any case, existing stormwater collection systems should be identified and characterized because any proposed green infrastructure improvements in the watershed will become an integral part of these systems. The locations of discharge points for stormwater collection systems are especially important to identify, if possible. These are the locations where local Stormwater Management Standards typically mandate that specific BMPs be implemented to control stormwater quality and volume.

A.3.1.2 Residential Areas

Identify existing and potential sources of stormwater runoff pollution from residential sources. These may include (USEPA 2003):

- Lawn care (fertilizers, pesticides, yard waste, landscaping waste, etc.)
- Septic systems (leaking and poorly maintained systems)
- Auto care (car washing and maintenance, auto fluids, etc.)
- Domestic pets (pet waste)
- Driveways, roads, and sidewalks (litter and debris, road salt, auto fluids, etc.)

A.3.1.3 Commercial Areas

Pollutants in stormwater runoff from commercial areas may include the following sources (USEPA 2003):

- Parking lots, roads, sidewalks, and driveways
- Chemical spills
- Automotive facilities
- Waste management (grease storage, dumpsters and trash containers, etc.)

A.3.1.4 Construction Operations

Ineffective erosion controls and construction vehicles can be sources of stormwater pollution. Erosion on construction sites can cause sediment and debris to enter the stormwater system when erosion controls are not properly installed and maintained. Construction equipment can also be a source of sediment and grease or fluids if not properly maintained (USEPA 2003).

A.3.1.5 Agricultural Operations

The existence of agricultural operations in the watershed can have important implications for stormwater runoff. Therefore, these facilities must be identified and characterized. Principal agricultural operations in the MassBays region include cranberry bogs. Main sources of stormwater runoff pollution include fertilizers, pesticides, and herbicides. Irrigation and drainage may also have water quality impacts.

Efforts should also be made to characterize existing runoff and pollution control practices currently being implemented at agricultural sites.

A.3.1.6 Golf Courses

Golf courses have the potential to contribute stormwater runoff pollution due to the use of fertilizers, pesticides and herbicides, and other maintenance activities including equipment washing, fuel storage, and irrigation.

A.3.1.7 Solid and Hazardous Waste and Toxic Releases

EPA's Envirofacts database can be consulted to identify any existing solid and hazardous waste and toxic release facilities in the watershed. These sites may be classified under the following categories:

- Comprehensive Environmental Response, Compensation and Liability (CERCLA)
- Resource Conservation and Recovery Act (RCRA)
- Toxic Release Inventory (TRI)

The EnviroMapper is a service provided through EPA's Envirofacts website that enables the user to view and select environmental data in a useful map format (www.epa.gov/emefdata/em4ef.home).

A.3.2 Estimate Pollutant Loadings

The watershed assessment process involves estimating relative pollutant loadings from various sources in the watershed. This will facilitate identification of areas with relatively high pollutant loadings, which might be better candidates for green infrastructure compared to areas with relatively low pollutant loadings.

A.3.2.1 Pollutant Loadings based on Existing Monitoring Data

Section A.2.8.4 described identification of sources of existing water quality monitoring data, and Section A.2.8.5 described how to identify impaired waters in the watershed. The data and information gathered in those steps will be used in this section to characterize known pollutant loading in the watershed for pollutants identified for action per Section 2.3.1.

A.3.2.2 Pollutant Loadings based on Land Use

In the absence of monitoring data, wet-weather loading for specific land uses can be estimated based on local hydrology methods and recent local or regional efforts that quantify likely Event Mean Concentration (EMC) ranges for a variety of land uses and sources. If regional literature is lacking, published articles and studies can be referenced for pollutant EMC data. For example, EPA published median EMCs for 10 pollutants and 4 different types of urban land uses (Table A-1) as part of the Nationwide Urban Runoff Program (NURP).

Table A-1. Median EMCs for urban land uses (USEPA 1983)

Pollutant	Units	Residential		Mixed		Commercial		Open/Non-Urban	
		Median	COV	Median	COV	Median	COV	Median	COV
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	--	--
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	µg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/l	33	0.99	27	1.32	29	0.81	--	--
Total Zinc	µg/l	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	µg/l	1900	0.73	1288	0.5	1179	0.43	965	1
Nitrate + Nitrite	µg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	µg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/l	143	0.46	56	0.75	80	0.71	26	2.11

Note: BOD = biochemical oxygen demand; COD = chemical oxygen demand; TSS = total suspended solids; COV= coefficient of variation

Pollutant load is calculated by multiplying the total runoff volume by the EMC. Where water quality treatment is of special concern (i.e., for discharge into environmentally sensitive areas), a simplified method to estimate the runoff volume is to multiply the total impermeable surface area by the appropriate rainfall depth (e.g., 1-inch, depending on local standards). In this case, the rainfall depth and runoff volume are often referred to as the “water quality event” and “water quality volume”, respectively.

Local municipalities commonly publish stormwater manuals or guidance which prescribe specific methods for estimating runoff volume. Local guidance should be consulted to ensure designs comply with any applicable local stormwater codes and standards.

- The ***Massachusetts Stormwater Handbook*** contains specific information related to the Stormwater Management Standards as established by the Stormwater Policy (MassDEP) and can be referenced for specific guidance (www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html).
- The handbook also provides a list of land uses with known higher potential pollutant loads, for which the discharge of stormwater runoff should be eliminated or reduced “to the maximum extent practicable.”

After characterizing the estimated pollutant loading for the sources and areas, it will be possible to prioritize the sources and areas based on their identified contributions to the watershed loading.

A.4 References

MassDEP (Massachusetts Department of Environmental Protection). 1997. Massachusetts Stormwater *Handbook*. Revised February 2008. http://www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html.

MassGIS (Massachusetts Office of Geographic Information). 2014a. MassGIS Data – MassDEP Hydrography. Massachusetts Executive Office for Administration and Finance. Accessed March 2014. http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/hd.html.

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Appendix B
Example Green Infrastructure
Conceptual Site Design

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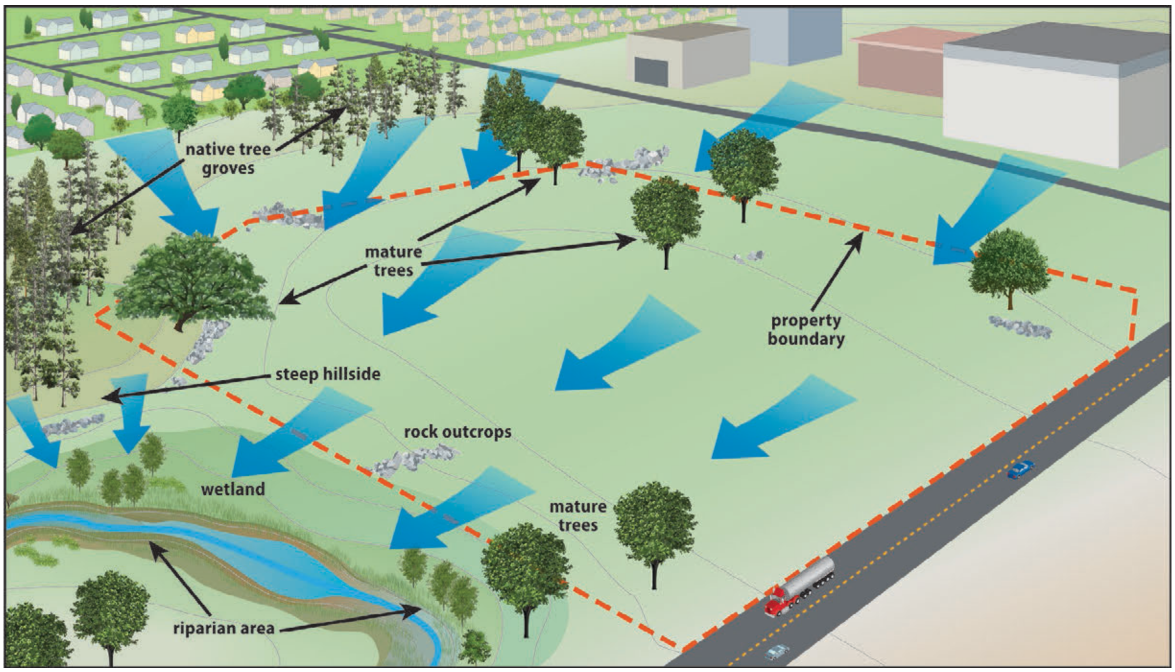
B. Conceptual Site Design Watershed

B.1 Example Green Infrastructure Conceptual Site Design

A series of conceptual site renderings, starting with Figure B-1 below, demonstrate the phases of site assessment, preliminary design, and planning through the final designs and shows how the site changes with each step. Figure B-1 demonstrates a hypothetical site planned to include the construction of a new library, adjoining parking lot, and a surrounding park. This example site will be used to illustrate the steps described in the following sections.



Source: Tetra Tech

Figure B-1. Example capital improvement project conceptual site for green infrastructure.

B.1.1 Phase I – Site Assessment

The first phase of site planning is composed of the site assessment. Steps 1 through 3 below delineate the site assessment process.

B.1.1.1 Step 1: Identify Regulatory Needs

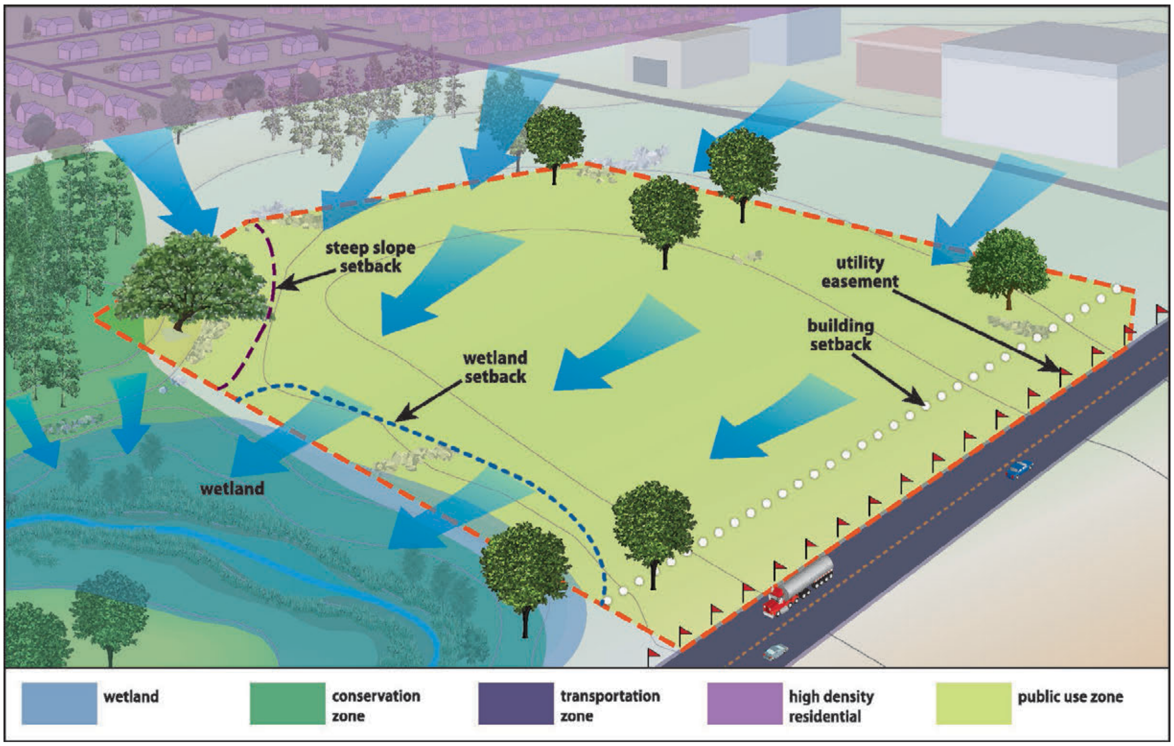
Green infrastructure implementation must be consistent with the applicable federal, state, and local regulations. Under the Wetlands Protection Act (Massachusetts General Laws, Chapter 131, Section 40), and the Massachusetts Clean Waters Act (Massachusetts General Laws, Chapter 21, Sections 26–53), MassDEP uses its authority to apply the Stormwater Management Standards which promote green infrastructure techniques.

To Complete Step 1:

- *Identify applicable zoning, land use, subdivision, and other regulations.*
- *Identify setbacks, easements, and utilities. (Call 811 for utility location.)*
- *Identify targeted pollutants and pollutants of concern.*

Identify applicable zoning land use, subdivision, and other local regulations

Zoning ordinances and comprehensive planning by any local government entity (county, city, and such) provide a framework to establish a functional and visual relationship between growth and urbanization (Prince George's County 1999). The Massachusetts Trial Court Law Libraries contain city and town zoning requirements along with other land use bylaws and ordinances (www.lawlib.state.ma.us/source/mass/bylaws.html). It is recommended that identified land uses also be shown in a visual format similar to Figure B-2.



Source: Tetra Tech

Figure B-2. Identify applicable zoning requirements, utility easements, and site setbacks.

Identify setbacks, easements, and utilities

Defining the boundaries of the site (yellow-dashed line indicating parcel boundaries) also includes identifying the required setbacks and any easements or utilities on the site. Municipal ordinances provide the basic regulations regarding the size and scale of development, such as permitted density, setbacks, and structure height on the basis of the applicable zoning code. Setbacks will restrict the buildable area. Each city and town along the Massachusetts Bay has their own requirements regarding setbacks, easements, and utilities, and local zoning codes should be consulted for this information

Planning and assessment must also include identifying easements on the site. Easements that could be present are a road or sidewalk (ROW) easement; a public utility easement that allows a utility to run gas, water, sewer, or power lines through a private property; or a railway easement. Local utilities departments (e.g., electric, wastewater) should be consulted to determine whether utilities are above or below ground and the required distance that site disturbance should be maintained from any utilities

present. Easements on a site can be determined by consulting as-built drawings and records research; these should be included on site drawings as illustrated in Figure B-2.

Identify targeted pollutant and flow alteration needs

The Stormwater Management Standards state that for-land uses with higher potential pollutant loads, source control, and pollution prevention must be implemented in accordance with the *Massachusetts Stormwater Handbook* (MassDEP 1997) to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable. If through source control or pollution prevention all land uses with higher potential pollutant loads cannot be completely protected from exposure to rain, snow, snowmelt, and stormwater runoff, the proponent shall use the specific structural stormwater BMPs determined by MassDEP to be suitable for such uses as provided in the *Massachusetts Stormwater Handbook* (MassDEP 1997). Stormwater discharges from land uses with higher potential pollutant loads shall also comply with the requirements of the Massachusetts Clean Waters Act (Massachusetts General Laws, Chapter 21, Sections 26–53), and the regulations promulgated thereunder at 314 CMR 3.00, 314 CMR 4.00, and 314 CMR 5.00. Stormwater management systems must be designed so that post-development peak discharge rates do not exceed predevelopment peak discharge rates. The standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

MassDEP identifies impaired water bodies in the state that warrant attention and additional resources. Impaired bodies of water fail to meet water quality objectives and require development of implementation plans targeted at both point source and nonpoint source pollution. Implementation plans for TMDLs often target nonpoint source pollutants by requiring the incorporation of BMPs. Implementing green infrastructure practices offers an effective tool used to enhance water quality to the maximum extent practical. For that reason, site planning should include identifying any impaired water or waters in the region and assessing pollutants of concern to allow planners and designers to consider target pollutant reduction needs in the design phase.

B.1.1.2 Step 2: Define Natural Site Features

Site planners and designers should consider how to use existing natural features of the site in an effort to retain natural hydrologic functions and potentially reduce the cost of drainage infrastructure. Identifying natural or sensitive areas is an integral factor in defining the site area for development and placing site needs and features in the context of the overall watershed.

> ***To Complete Step 2:***
>
> - *Identify natural areas to be conserved or restored.*
> - *Conduct a geotechnical survey including drainage characteristics, hydrologic flow paths, and soil infiltration tests.*

Naturally functioning areas

To enhance a site's ability to support source control and reduce runoff, natural areas that can infiltrate stormwater should be identified in the site design process and conserved or restored. These areas can intercept stormwater without engineered practices, thereby reducing the amount of runoff and the size

and extent of drainage infrastructure. Such natural features can result in cost savings due to decreased infrastructure costs.

The following are fundamental principles encouraging conservation and restoration of natural areas:

- Minimize site grading and the area of disturbance by isolating areas where construction will occur (see Step 5). Doing so will reduce soil compaction from construction activities. In addition, reduced disturbance can be accomplished by increasing building density or height.
- When possible, the site should be planned to conform to natural landforms and to replicate the site's natural drainage pattern. Building roads and sidewalks on the existing contour ensures that natural flow paths and hydrology continue to function.
- An essential factor in optimizing a site layout includes conserving natural soils and vegetation, particularly in sensitive areas such as habitats of sensitive species, wetlands, existing trees, hillsides, conservation areas, karst features, and existing water bodies. Such areas can be used as natural features in site planning to avoid or reduce potential effects of development. Wetlands, for example, provide habitat for several sensitive species, and off-site mitigation does not always provide the same type or quality of habitat. Figure B-3 shows an example of native soils and vegetation protected at a construction site.

Source: Tetra Tech

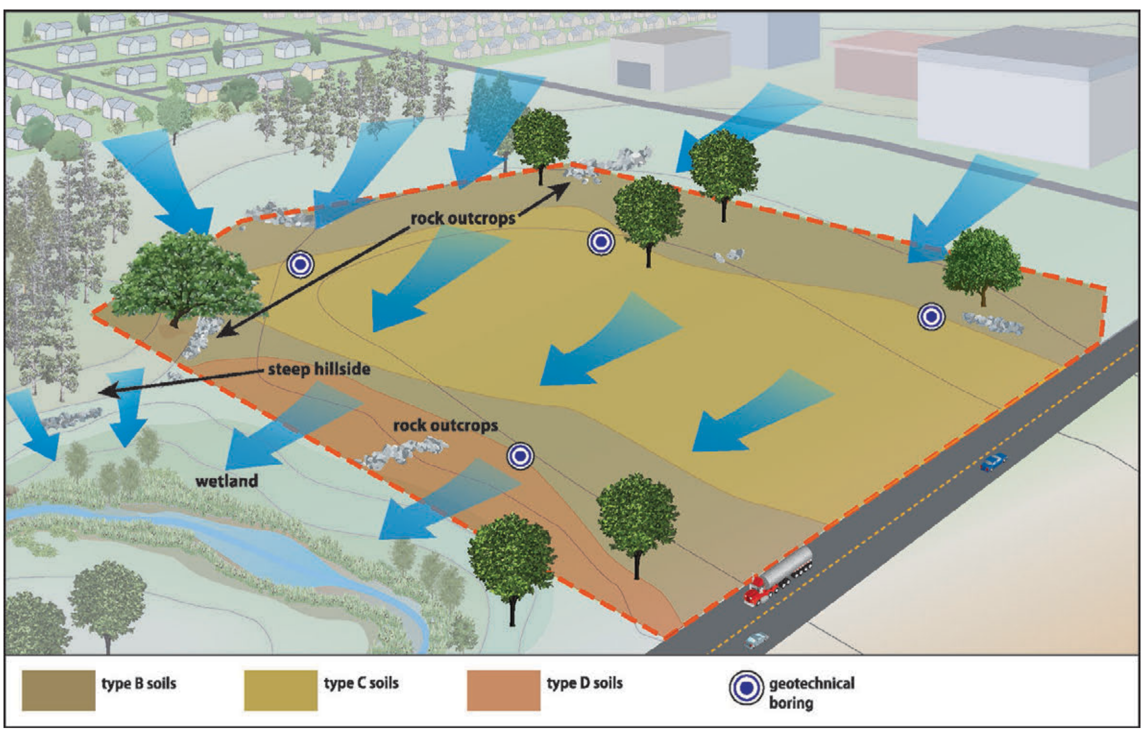
Figure B-3. Preservation of native soils and vegetation.

- In areas of disturbance, topsoil can be removed before construction and replaced after the project is completed. When handled carefully, such an approach limits the disturbance to native soils and reduces the need for additional (purchased) topsoil later.
- Impervious areas (e.g., square footage of parking lots, sidewalks, and roofs) should be minimized by designing compact, taller structures; narrower streets; and using underground or under-building parking.

In the example shown in Figure B-4, the natural and sensitive areas that should be considered for protection during development are identified on the site map, including wetlands, high-quality vegetation, and steep slopes (hillside).

Understand soils through geotechnical surveys

Any project that includes green infrastructure practices should include a soil evaluation or geotechnical investigation. A licensed engineer with geotechnical expertise, a licensed geologist, engineering geologist, hydrogeologist, or other licensed professional acceptable to the local jurisdiction should perform a detailed evaluation of soils, shallow ground water and bedrock conditions. A soil evaluation including soil infiltration testing is intended to identify and protect soils that provide greater infiltration as potential locations for green infrastructure BMPs (Figure B-4). The presence and depth to the seasonal water table or shallow bedrock should also be identified, which will inform BMP design under Phase II. In addition, natural drainage characteristics and hydrologic flow paths should be identified. These features can be used in the design and protected in future steps to maintain the site's natural drainage characteristics.



Source: Tetra Tech

Figure B-4. Protect natural and sensitive areas (wetlands, native tree groves, steep hillside) and conduct geotechnical survey to characterize infiltration capacity of soils.

B.1.1.3 Step 3: Protect Key Hydrologic Areas

Following the green infrastructure site planning concept of using hydrology as the integrating framework, the key hydrologic areas such as hydrologic flow paths and infiltrating soils are protected. To the extent possible, natural hydrologic functions of the site should be preserved. Applying green infrastructure techniques results in a hydrologically functional landscape that can function to slow runoff rates, protect receiving waters, and reduce the total volume of runoff.

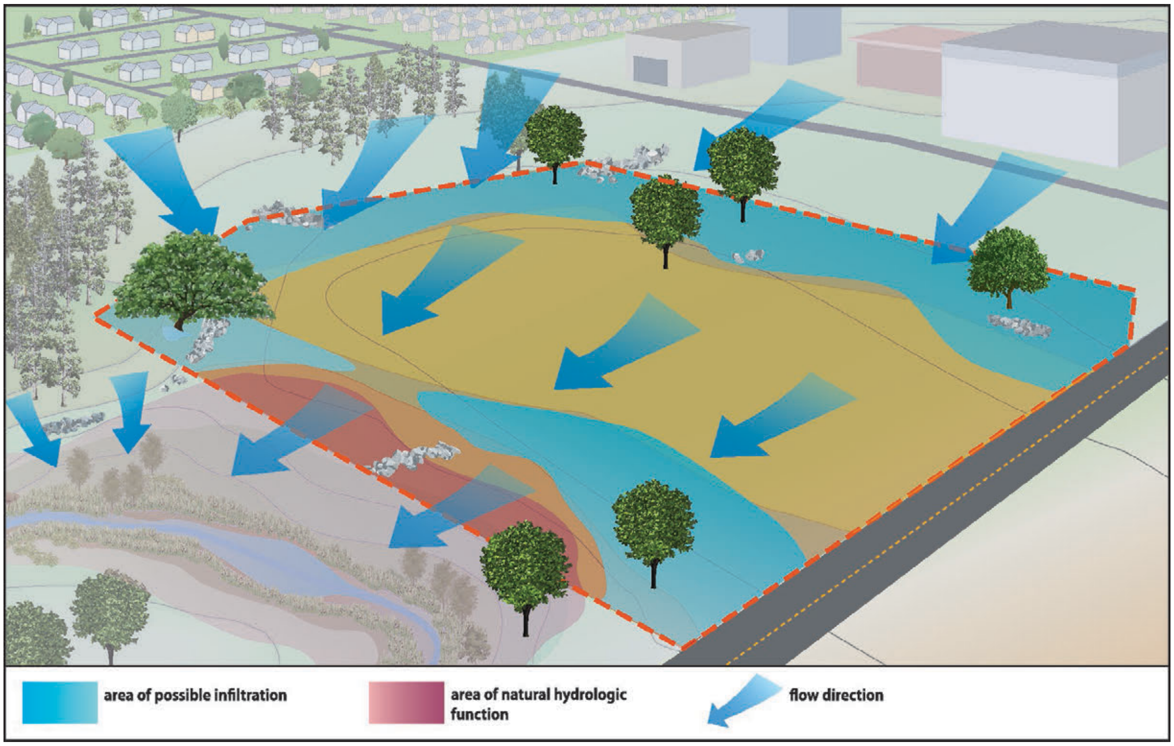
To Complete Step 3:

- *Protect areas of natural hydrologic function.*
- *Protect possible areas for infiltration.*

Second only to flow regimes in ensuring proper hydrology, healthy soils or media often serve as essential elements for achieving green infrastructure functions and providing source control for stormwater treatment. For example, upper soil layers are conducive to slowly filtering and storing stormwater, allowing unit processes such as infiltration, sorption, evapotranspiration, and surface retention to occur.

Site features that should be protected include riparian areas, floodplains, stream buffers, wetlands, and soils with infiltration potential. Using the information collected in the Step 2 soil evaluation, more specific locations of soils with greater infiltration rates that are near or on hydrologic flow paths should be protected to avoid or limit hydrologic impacts. As an example, Figure B-5 indicates the key hydrologic areas that should be considered for protection. The blue area identified as an area for possible infiltration should be separated from other site features by surrounding it with construction fencing to prevent access and avoid compaction. In addition, the areas having a natural hydrologic function either through storage or conveyance should be protected. (Also see Figure B-5 in setting site clearing and grading limits.)

With the conclusion of Phase I, the initial site assessment has been completed. The decisions made regarding green infrastructure practices during the site assessment process should be documented to ensure that if changes are required in future Phases II and III, the original design ideas are available for reference. That helps ensure that green infrastructure concepts are considered during every component of project site planning. Phase II of site planning, described below, results in a preliminary design plan.



Source: Tetra Tech

Figure B-5. Identify and protect key hydrologic areas, such as infiltrating soils (blue area) and wetlands (orange areas).

B.1.2 Phase II – Preliminary Design

The result of the second phase of site planning is a completed preliminary design done by conducting Steps 4 through 7, below. Working through those steps is an iterative process for designing a preliminary plan that implements green infrastructure concepts as fully as possible.

B.1.2.1 Step 4: Use Drainage and Hydrology as a Design Element

Natural hydrologic functions (e.g., flow paths) should be included as a fundamental component of the preliminary design. Naturally present functions should be retained, or if that is not an option, replicate natural functions with appropriate BMP placement.

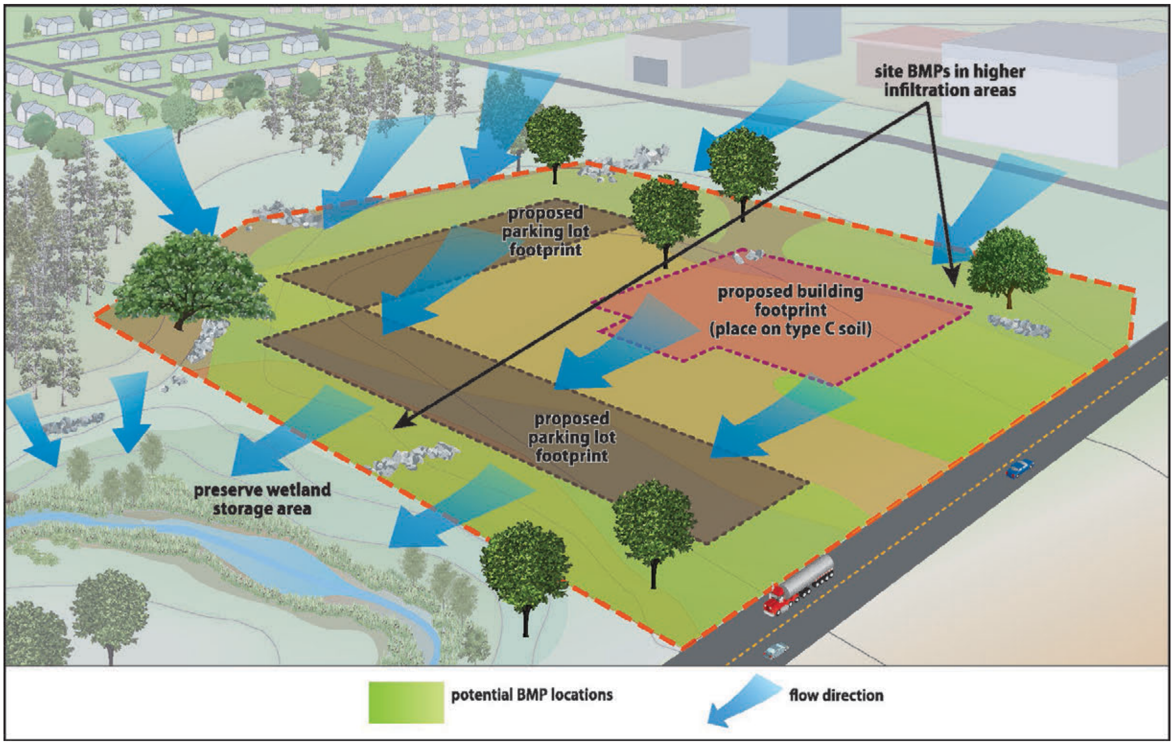
> ***To Complete Step 4:***
>
> - *Identify the spatial layout of the site using hydrologic flow paths and natural drainage as a feature.*
> - *Determine approximate locations for infiltration and conveyance BMPs.*

Spatial site layout options

Natural hydrologic functions, including interception, depression storage, and infiltration, should be distributed throughout the site to the extent possible. In conserving predevelopment and retrofit hydrology, runoff volume, peak runoff rate, flow frequency and duration, and water quality control must be considered. Rainfall abstractions are the physical processes of interception, evaporation, transpiration, infiltration, and storage of precipitation.

Runoff flow frequency and duration should try to mimic predevelopment conditions by implementing practices to minimize runoff volume and rate. Green infrastructure practices also provide pollutant removal processes that enhance water quality treatment for the designed treatment volume.

By setting the development envelope back from natural drainage features, the drainage can retain its hydrologic functions and its water quality benefit to the watershed as shown in the example in Figure B-6, assuming that runoff from the contributing watershed is mitigated to predevelopment conditions.



Source: Tetra Tech

Figure B-6. Identify ideal locations for green infrastructure implementation according to site conditions.

Spatial layout should use the natural landforms and hydrologic flow paths identified in Step 2 as a major design element of the site. Common elements using that premise include designing open drainage systems to function as both treatment and conveyance devices. Impervious elements such as parking lots, roadways, and sidewalks can be designed on the existing contour to minimize effects on the natural hydrologic flow path.

Determine potential BMP locations

Stormwater management practices can be designed to achieve water quality and flood protection goals by applying four basic elements, alone or in combination: infiltration, retention/detention, biofiltration, and evapotranspiration.

Infiltration systems should be designed to match predevelopment hydrology and to infiltrate the majority of runoff from small storm events, when applicable and to the extent possible. Existing site soil

conditions generally determine whether infiltration is feasible without soil amendments or underdrains. Other site conditions that preclude infiltration are high ground water tables, steep slopes, or shallow bedrock. Infiltration systems can also help control peak flow rates by providing retention and volume control.

Retention/detention systems are intended to store runoff for gradual release or reuse. Retention/detention basins also allow for evaporation of runoff and evapotranspiration by plants. They are most appropriate where soil percolation rates are low or where longer retention times are designed into the system. They are also appropriate when designing to control peak flow rates for downstream flood and channel protection.

Biofiltration devices are designed using vegetation to achieve low-velocity flows, to allow settling of particulates and filtering of pollutants by vegetation, rock, or media. Pollutant degradation can also occur through biological activity and sunlight exposure. Biofilters can be designed to be linear features that are especially useful in treating runoff from parking lots and along highways.

Evapotranspiration is inherent in all BMP systems. Evaporation is maximized in systems that retain or detain runoff, and vegetated systems maximize transpiration as plants use the stored water for growth.

Selecting the appropriate structural BMPs for a project area should be on the basis of site-specific conditions (e.g., land availability, slope, soil characteristics, climate condition, and utilities) and stormwater control targets (e.g., peak discharge, runoff volume, or water quality targets).

In the example shown in Figure B-6, areas are identified that will be developed for parking and building footprints. The figure also indicates ideal locations where green infrastructure BMPs can be placed (such as a biofiltration swale and bioretention) and can be incorporated into the natural drainage paths to function as conveyance and treatment green infrastructure BMPs. The infiltration opportunities identified in Figure B-5 suggest that the blue oval near the road, which is on HSG C, would be more suitable for a biofiltration BMP, while much of the rest of the potential BMP area is on HSG B, indicating that this area would be better for infiltration systems (Figure B-6). Note that both biofiltration and infiltration BMPs can also meet landscaping requirements and create features that enhance and beautify the site.

Stormwater management practices can be designed to achieve water quality and flood protection goals by applying four basic elements: infiltration, retention/detention, filtration, and evapotranspiration.

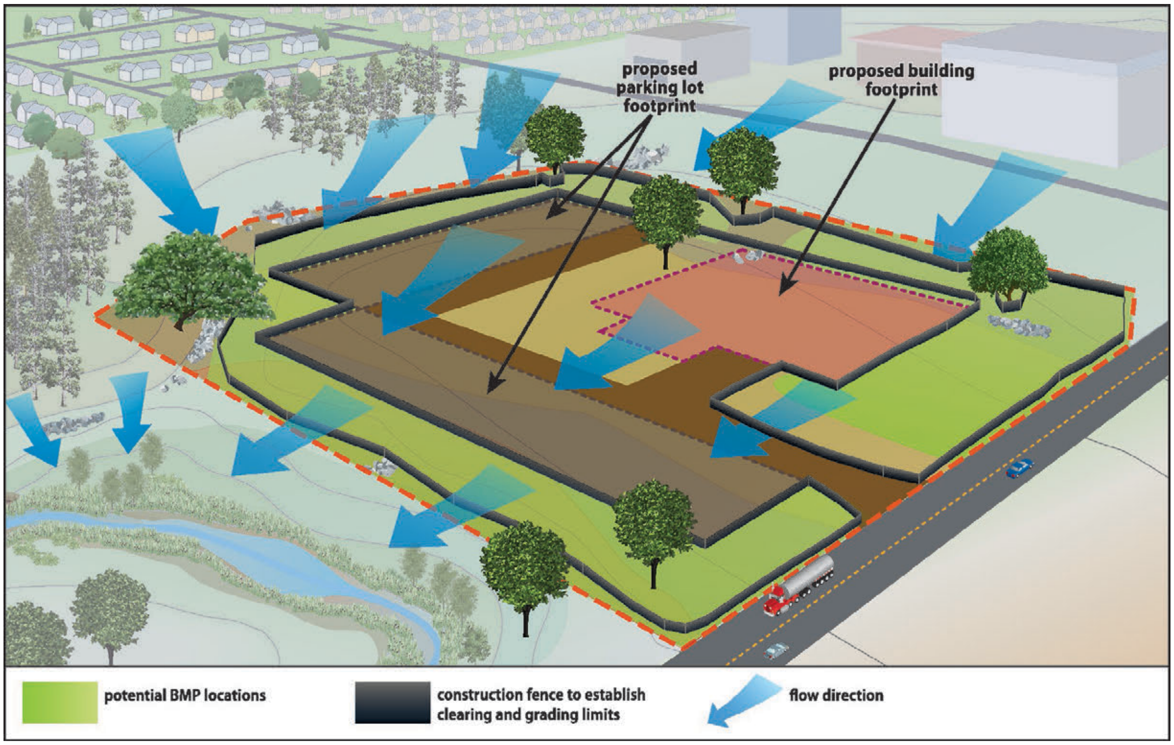
B.1.2.2 Step 5: Establish Clearing and Grading Limits

Limits of clearing and grading refer to the total site area that is to be developed, including all impervious and pervious areas. The area of development ideally should be in less sensitive locations with respect to hydrologic function and should be outside protected areas and areas containing setback regulations, easements, and utilities.

To Complete Step 5:

- *Define the limits of clearing and grading.*
- *Minimize disturbance to areas outside the limits of clearing and grading.*

Site fingerprinting refers to site clearing and development with minimal disturbance of existing vegetation and soils. Such techniques include reducing paving and compaction of highly permeable soils, minimizing the size of construction easements and material storage areas, site clearing and grading to avoid tree removal, delineating and flagging the smallest site disturbance area possible, and maintaining existing topography to the extent possible. Figure B-7 illustrates the use of orange construction fencing to preserve the natural features and drainage pathways, and maintain infiltration on suitable soils at the example site as identified in previous steps.



Source: Tetra Tech

Figure B-7. Establish grading envelope to protect natural areas and infiltrating soils.

B.1.2.3 Step 6: Reduce/Minimize Total and Effective Impervious Area

Rainfall that does not infiltrate or pool where it falls results in runoff. As the imperviousness of the site increases, runoff also increases with each acre of impervious cover producing approximately 27,150 gallons of stormwater for each inch of rainfall. Predevelopment runoff, measured as a runoff coefficient or the ratio of runoff volume to the total amount of rainfall, can be maintained by compensating for increases in impervious areas, soil compaction, and the loss of abstraction through planning and design. Such tools can be used to also manage the peak runoff rate and volume and protect water quality.

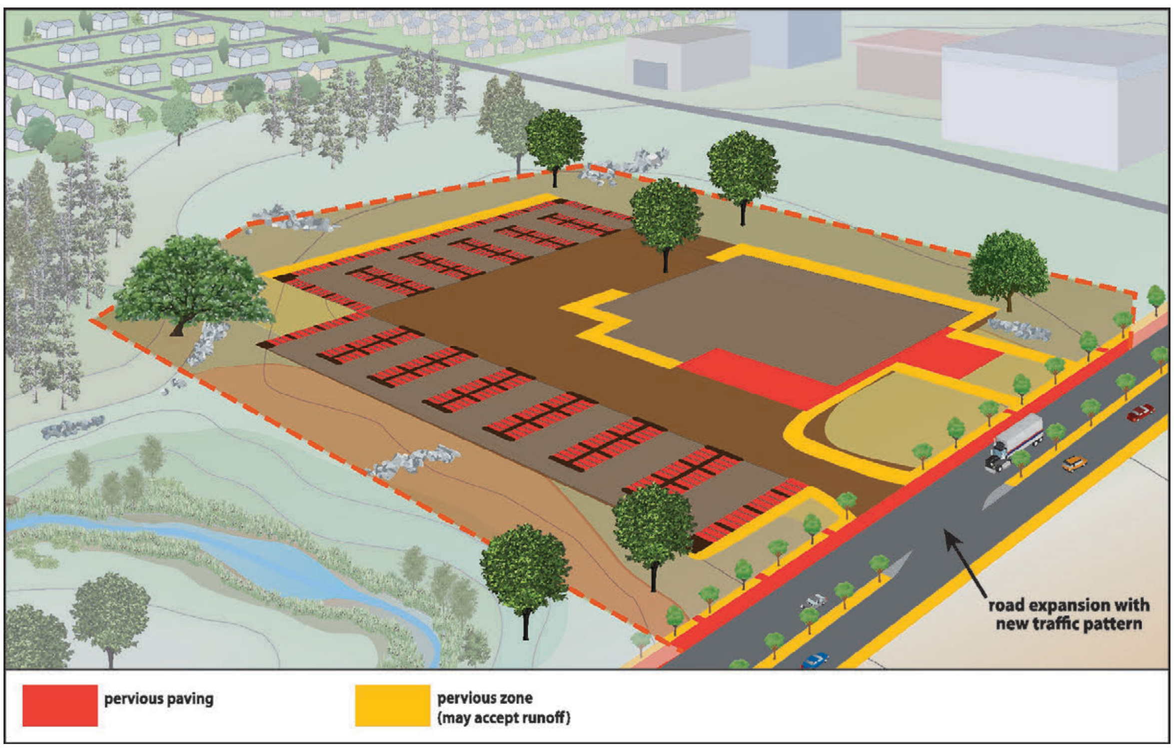
Disconnect impervious area

> ***To Complete Step 6:***
> - *Investigate the potential for impervious area disconnection.*
> - *Evaluate the conceptual design to reduce impervious surfaces.*

Diverting stormwater runoff from impervious areas such as rooftops and pavement to adjacent pervious areas can be used to infiltrate stormwater runoff and to reduce flow rates (shown in Figure B-7). Proper design can align pervious surfaces with building drainage. Such a technique is also referred to as impervious area disconnect.

To reduce the storage and conveyance requirements, the directly connected impervious area of the site should be minimized to the extent practicable. That can be accomplished through increasing the building density by increasing the vertical extent and minimizing the horizontal extent. Impervious area disconnect can also include using permeable features instead of impermeable including permeable pavement for walkways, trails, patios, parking lots, and alleys; and constructing streets, sidewalks, and parking lot aisles to the minimum width necessary.

Possible locations for impervious area disconnect techniques are shown in Figure B-8 below in yellow. As shown in the figure, the medians along either side and in the middle of the roadway provide vegetated pervious areas for minimizing or reducing the impacts associated with the total impervious area and for infiltration and filtration processes to take place. The figure also demonstrates the use of pervious pavement in the parking lot and along the roadway (in red).



Source: Tetra Tech

Figure B-8. Site example demonstrating placement of pervious material (red) and opportunities to minimize connected impervious area (yellow).

Minimize impervious area

Street layouts often can be designed to reduce the extent of paved areas, and street widths can be narrowed to decrease the total impervious area as long as applicable street design criteria are satisfied. Eliminating curbs and gutters along streets and including curb cuts around parking areas, where consistent with city standards and where appropriate, can promote drainage to on-site pervious areas and decrease directly connected area considerably. Other options include replacing curbs and gutters with roadside vegetated swales and directing runoff from the paved street or parking areas to adjacent green infrastructure facilities. Such an approach for alternative design can reduce the overall capital cost of the site development while addressing stormwater quantity and quality issues and improving the site's aesthetic values. Figure B-8 illustrates the inclusion of pervious paving and bioretention systems with curb cuts along the street ROW to demonstrate locations where that can be achieved.

Specific examples of alternative transportation options include narrow paved travel lanes, consolidated travel lanes, increased green parking areas, and horizontal deflectors (chicanes) or intersection pop-outs. Such options can be included for other multi-beneficial purposes such as traffic calming and pedestrian safety (Ewing 1999), increased parking spaces, and improved aesthetics. Four examples of transportation alternatives are described below.

Narrowed travel lanes: Narrow travel lanes can help reduce impervious area and infrastructure costs, calm traffic in pedestrian-oriented areas, and create room for stormwater facilities. Existing roadways can be narrowed to minimum widths in accordance with established roadway standards. Residential street crossings are often combined with traffic-calming measures, which reduce street width and are designed to maintain low vehicle speeds, such as raised crosswalks, chicanes, and gateway narrowing.

Consolidated travel lanes: Consolidating travel lanes or converting unused pavement next to travel lanes into landscape areas can result in reduced imperviousness. The increased landscape space could be used for stormwater facilities and create space for bike lanes, wider sidewalks, and a more balanced and vibrant streetscape. Parking lanes can also be converted to permeable paving that can be used for stormwater management.

Increased green parking: Techniques used to reduce the total impervious coverage and consequential runoff from parking lots are broadly referred to as *green parking*. Green parking techniques include minimizing the number and dimension of parking stalls; using alternative pervious pavers wherever suitable; incorporating stormwater BMPs such as depressed bioretention islands into parking lot designs; and encouraging shared parking and incentivizing structured parking (Figure B-8). When implemented together, green parking alternatives reduce volume and the mass of pollutants generated from parking lots, reduce the urban heat island effect, and enhance a site's aesthetics.

Intersection deflectors (chicane): A *chicane* is a series of deflections involving the narrowing of one side of the street by an amount that requires the through traffic to deflect from its previously straight path (MassHighway 2006). The combination of narrowed street width and the serpentine path of travel slow traffic (Figure B-9). On new streets, chicanes narrow the street by widening the sidewalk or landscaped

areas between the curb and sidewalk. On streets considered for retrofit, raised islands can be installed to narrow the street. Advantages of chicanes include reduced traffic speeds, opportunities for landscaping, and created spaces for stormwater management facilities. Chicanes are inappropriate for use on streets classified as collector or higher, bus routes, emergency response routes, where there is a grade that exceeds 5 percent, or where stopping sight distance is limited such as at the crest of a hill.

Source: Tetra Tech

Figure B-9. Bioretention incorporated into a pop-out (Kansas City, Missouri).

Intersection pop-outs: Intersection pop-outs are curb extensions that narrow the street at intersections by widening the sidewalks at the point of crossing. They are used to make pedestrian crossings shorter and reduce the visual width of long, straight streets (Figure B-10). Where intersection pop-outs are constructed by widening the landscaped planting strip, they can improve the aesthetics of the neighborhood and provide more opportunities for stormwater controls at the site by facilitating interception, storage, and infiltration. Intersection pop-outs should be designed to properly accommodate bicyclists, transit vehicles, and emergency response vehicles. Intersection pop-outs can be installed on local streets; however, pop-outs are inappropriate on major streets and primary arterials.

Reduced width of road sections can also reduce total site imperviousness. Streets, sidewalks, and parking lot aisles should be constructed to the minimum width possible without compromising public safety and access. In addition, sidewalks and parking lanes can be limited to one side of the road.

Source: Tetra Tech

Figure B-10. Example of an intersection pop-out.

Traffic or road layout can significantly influence the total imperviousness of a site plan. Selecting an alternative road layout can result in a sizeable reduction in total site imperviousness. Alternative road layout options that can reduce imperviousness from the traditional layout pattern use queuing lanes, parking on only one side of the street, incorporating islands in cul-de-sacs, and using alternative turn areas that require less pavement (CWP 1998).

Other transportation opportunities for reducing impervious area include using shared driveways, limiting driveway widths to 9 feet, and using driveway and parking area materials that reduce runoff and increase the time of concentration (e.g., grid systems and paver stones).

Several iterations of manipulating site imperviousness can be done to consider natural features, areas of infiltration, and hydrologic pathways to best achieve a balance between necessary imperviousness with disconnected and pervious site features. Once the total area of imperviousness has been minimized, the impervious areas can be incorporated into the site plan or capital improvement roadway project.

In Figure B-8 opportunities for imperviousness reduction and runoff disconnection were identified for both the building site and for alternative transportation options. The sidewalk surrounding the building was disconnected by routing runoff to the pervious landscaped areas surrounding the building (shown in yellow), and pervious paving was identified in the low-traffic areas of the parking lot to reduce site imperviousness. Pervious paving was also identified as an opportunity for reduction in impervious area

for on-street parking (shown in red), and a median bioswale along with ROW bioretention were identified as methods for runoff disconnection (shown in yellow).

B.1.2.4 Step 7: Determine Green Infrastructure BMPs

> ***To Complete Step 7:***
>
> - *Determine potential BMPs according to hydrologic and pollutant removal process needs and cost estimates (see Section 5).*
> - *Repeat Steps 4 through 7 as necessary to ensure that all stormwater management requirements are met.*

Green infrastructure BMPs employ a number of processes, including settling/sedimentation; filtration; sorption; photolysis; biological processes (bioaccumulation and biotransformation/phytoremediation); and chemical processes (for complete descriptions, see Section 5) for pollutant removal. In addition to pollutant removal, green infrastructure BMPs provide hydrologic controls by reducing peak flows and volume through processes of infiltration, evaporation, and storage and reproducing predevelopment hydrologic functions.

During BMP selection, it is important to consider a BMP’s unit processes to ensure that the management practice will provide the necessary benefits and avoid potential complications.

Hydrologic controls dictate how incoming stormwater is partitioned into the various components of the hydrologic budget. Stormwater volume can be detained, infiltrated, evapotranspired, drained, or bypassed depending on the design of hydrologic controls and features such as impermeable liners, underdrains, inlet and outlet structures, soil media permeability, and storage capacity.

Settling/sedimentation is the physical process of particle separation as a result of a difference in density between the solids and water. Most BMPs use settling to some degree, especially through detention or retention practices such as bioretention. Settling is enhanced by slowing down or spreading out runoff to create low-velocity flow conditions.

Filtration is the physical process of separating solids from a liquid media. Particles are filtered from water by the smaller interstitial space the water flows through in the porous medium. Sedimentation and sorption can also occur as water passes through a filtering practice. *Sorption* refers to the processes of *absorption* (an incorporation of a pollutant into a substance of a different state) and *adsorption* (the adherence of a pollutant to the surface of another molecule). Sorption is also referred to under chemical treatment processes. Filtration is a common unit process in a number of BMPs such as bioretention and planter boxes.

Floatation is a treatment unit process where the mechanism for pollutant removal is opposite to that in settling and sedimentation. In floatation, the density of pollutants, such as trash and petroleum, is less than that of water. Oil/water separators and trash guards are the primary BMP practices that use floatation.

Biological treatment processes (bioaccumulation, biotransformation, phytoremediation) are processes that occur in practices that incorporate soils and plants for pollutant removal via biological transformation or mineralization, pollutant uptake and storage, or microbial transformation. It can also include organisms that consume bacteria. BMPs that can be designed to use such unit processes are bioretention, bioswales, and planter boxes.

Chemical treatment processes include sorption, coagulation/flocculation, and disinfection. Chemical characteristics of stormwater such as pH, alkalinity, and reduction-oxidation (redox) potential determine which chemical process is appropriate. Sorptive BMPs generally include engineered media for removing pollutants of concern. Precipitation and disinfection processes require actively adding chemicals to encourage coagulation/flocculation and precipitation or chemicals such as chlorine to mitigate pathogenic microbes in stormwater. Chemical treatment processes are usually employed as end-of-pipe solutions where no other BMP can effectively treat an existing storm drain system. In these cases, low flow might be more effectively treated by pumping into a sanitary sewer.

Using multiple treatment processes either in individual or multiple BMPs is called a *treatment train*. Meeting targeted treatment objectives can usually be achieved using a series of green infrastructure BMPs in a treatment train. Treatment trains can often be designed along ROWs, in parking lots, underground, or incorporated into landscaped areas. Green infrastructure site planning should result in a treatment train of green infrastructure strategies and BMPs to meet treatment and water quality goals.

Using multiple treatment processes either in individual or multiple BMPs is called a treatment train.

A number of factors should be considered for choosing appropriate BMPs for a site. For example, the presence of group C or D soils on a site might preclude the use of an infiltration BMP or require the use of an underdrain into the design of infiltration BMPs. Native vegetation, which is adapted to the local climate and soils, should be used for vegetated BMPs when soils allow. If native soils are replaced with imported soils to improve infiltration, non-native noninvasive but drought-tolerant plants might be a desired choice. Other geotechnical, site-specific considerations include the level of the underlying water table and bedrock, any existing infrastructure in retrofit designs, and the presence of areas of concern that exhibit soil and ground water contamination.

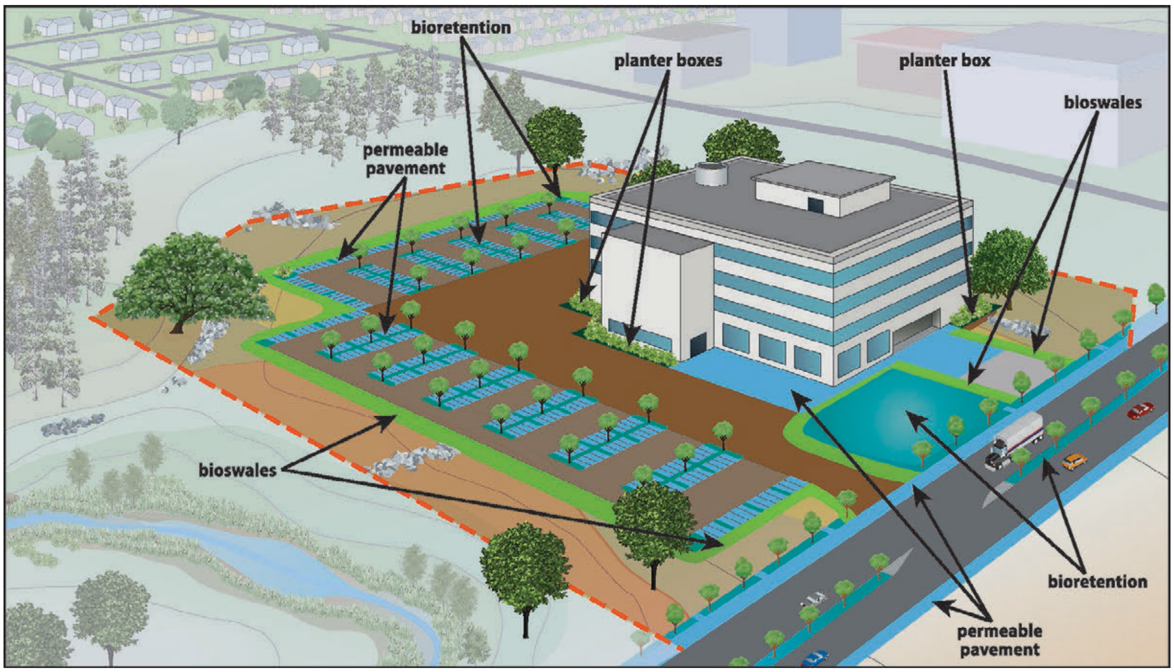
- ***Greenscapes Massachusetts*** is partially funded by MassBays and provides information on low-impact landscaping practices including irrigation and chemical use: http://greenscapes.org/

The information gathered and organized during Steps 1–6 provide the foundation for selecting BMP types that are most appropriate to meet the site's stormwater management needs. Section 5 of this handbook summarizes information about specific green infrastructure BMPs and provides guidance on selecting appropriate green infrastructure BMPs for a site. Table 5-1 (BMP Selection Matrix) summarizes the selection criteria and should be consulted to assist in the process.

At the completion of Phase II, the site planning for the project is complete. At that point in the site planning process, the development area should be delineated and the approximate type and potential locations for appropriate BMPs should be identified. The preliminary plan should be documented in

addition to the decisions that were made in developing the preliminary plan for future reference and to ensure that the green infrastructure planning concepts are carried through to project construction. After the preliminary design is completed, the final design is achieved through identifying the appropriate green infrastructure facility type and size for meeting stormwater management needs and requirements.

The example shown in Figure B-11 indicates the approximate type and locations of potential stormwater management practices. The type, size, or location could change according to site construction or other site design changes and requirements.



Source: Tetra Tech

Figure B-11. Site plan indicating all possible BMP locations (blue areas) and types (annotated).

Results of Phase II

The analyses in Phase II should produce a preliminary site plan that includes:

- Hydrologic flow paths and natural drainage features (Step 4)
- Locations where infiltration and conveyance features could be located (Step 4)
- Limits of clearing and grading (Step 5)
- Results of an impervious area reduction analysis (e.g., parking area reduction, permeable pavement options) (Step 6)
- Candidate BMPs (see Section 5) and their approximate locations (Step 7)

B.1.3 Phase III – Determine Final Design

B.1.3.1 Step 8: Determine Approximate Size of Green Infrastructure BMPs

To Complete Step 8:

- *Determine the approximate BMP size.*

The level of control that is required for a site to achieve stormwater management goals can be determined through a site-specific hydrologic evaluation. The hydrologic evaluation is performed using hydrologic modeling and analysis techniques. A stepwise process is followed to conduct a hydrologic evaluation:

1. Delineate the watershed and subwatershed areas.
2. Define the design storm (MassDEP 1997).
3. Determine the type of model to be used.
4. Collect data for predevelopment conditions.
5. Using hydrologic models, evaluate predevelopment, baseline conditions.
6. Using hydrologic models, evaluate the hydrologic benefits from decreasing and disconnecting impervious areas, and compare the benefits to baseline conditions.
7. Using hydrologic models, evaluate the hydrologic control from implementation of one or more green infrastructure BMPs.

The Stormwater Management Standards require stormwater management systems to be designed so that the post-development peak discharge rates do not exceed predevelopment peak discharge rates. 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 predevelopment rate from the 2-year and the 10-year 24-hour storms. BMPs that slow runoff rates through storage and gradual release, such as green infrastructure techniques, extended dry detention basins, and wet basins must be provided to meet Standard 2. Where an area is within the 100-year coastal floodplain or land subject to coastal storm flowage, the control of peak discharge rates is usually unnecessary and may be waived.

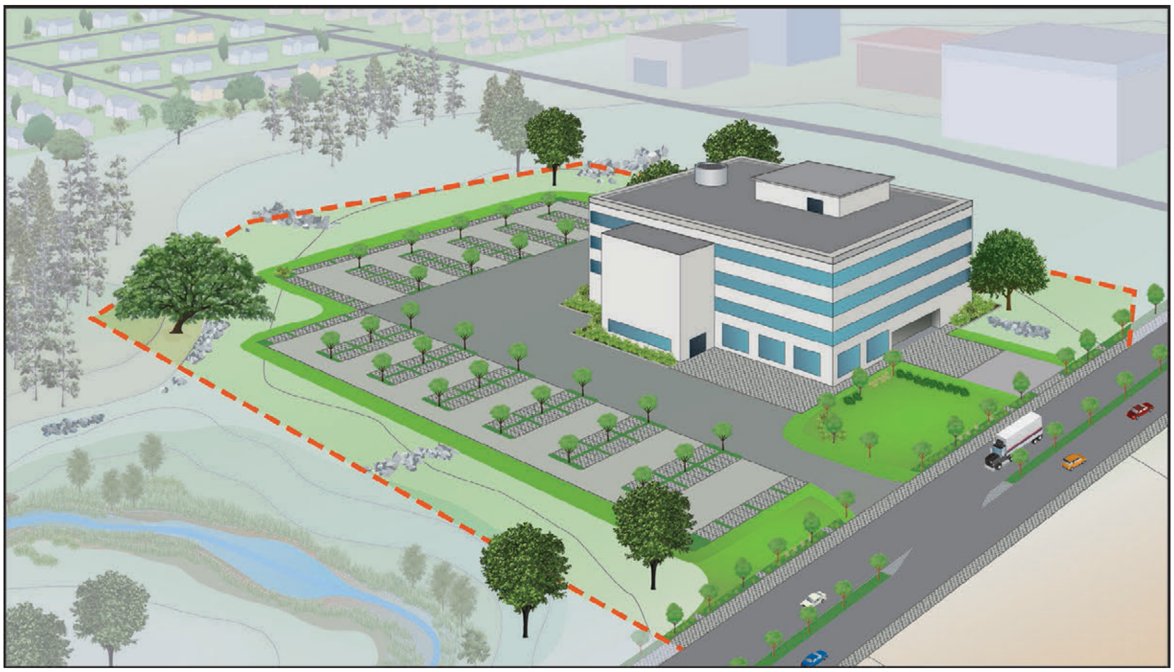
To Complete Step 9:

- *Integrate conventional stormwater management needs.*
- *Verify that geotechnical and drainage requirements have been met.*
- *Complete BMP designs such as finish details and notes.*
- *Complete the site plans.*

The Standards note that an evaluation of the impact of peak discharges from the 100-year 24-hour storm must also be performed. 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. The evaluation might 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 on-site might aggravate downstream impacts, because of the project's location within the watershed and the timing of the release of stormwater.

B.1.3.2 Step 9: Green Infrastructure Final Design

Following iterations of Steps 4–7 and BMP sizing in Step 8, additional conventional stormwater control techniques can be added to the site as necessary to meet site drainage and other requirements (Figure B-12). Review of the earlier documentation of decisions made during planning phases should also be conducted to ensure that the intent of the green infrastructure planning principles were carried through to the final design. The iterative review process can result in more or less area required for stormwater management. Notice that in Figure B-12, the iterative process resulted in the elimination of planter boxes at the base of the building as the other green infrastructure BMPs provided the required volume of capture. The example shown in Figure B-12 illustrates the final site layout, including the properly sited and sized BMP locations.



Source: Tetra Tech

Figure B-12. Completed site plan including iterations of Steps 4–7 and BMP sizing completed.

Completing Step 9 concludes Phase III of the design process. Section 5 provides important considerations for the design, construction, and operation of the chosen BMPs, including BMP construction, inspection, and operation and maintenance.

B.2 References

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Appendix C
Green Infrastructure BMP
Operation, Maintenance, and Monitoring

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C. BMP Maintenance and Monitoring – Supplemental Information

C.1 BMP Operation and Maintenance

The major goal of BMP operation and maintenance is to ensure that the BMP is meeting the specified design criteria for stormwater flow rate, volume, and water quality control functions. If structural green infrastructure systems are not properly maintained, BMP effectiveness can be reduced, resulting in water quality impacts. Routine maintenance and any need-based repairs for a structural BMP must be completed according to schedule or as soon as practical after a problem is discovered. Deferred BMP maintenance could result in detrimental effects on the landscape and increased potential for water pollution and local flooding.

Training should be included in program development to ensure that maintenance staff has the proper knowledge and skills. Most structural BMP maintenance work—such as mowing, removing trash and debris, and removing sediment—is nontechnical and is already performed by property maintenance personnel. More specialized maintenance training might be needed for more sophisticated systems.

Typical BMP maintenance activities include periodic inspection of surface drainage systems to ensure clear flow lines, repair of eroded surfaces, adjustment or repair of drainage structures, soil cultivation or aeration, care of plant materials, replacement of dead plants, replenishment of mulch cover, irrigation, fertilizing, pruning, and mowing. Landscape maintenance can have a significant impact on soil permeability and its ability to support plant growth. Most plants concentrate the majority of their small absorbing roots in the upper 6 inches of the soil surface if the surface is protected by a mulch or forest litter. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches. The common practice of removing all leaf litter and detritus with leaf blowers creates a hard-crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes (Hinman 2005).

In addition to influencing permeability, landscape maintenance practices can adversely affect water quality. Because commonly used fertilizers and herbicides are a source of toxic compounds, use of these substances should be kept to a minimum. Overwatering, which can be a significant contributor to runoff and dry-weather flows, should be prevented. Watering should only occur to accommodate plant health and should be adjusted at least four times a year. Whenever practical, use weather-based irrigation controllers and follow real-time evapotranspiration (plant water use) data using local meteorological information sources. In addition, organic methods for fertilizers and pest control (including Integrated Pest Management) should be used.

General maintenance activities for the two major categories of structural facilities (infiltration and biofiltration/filtration) are as follows:

Infiltration BMPs

- ☐ Mowing and maintaining upland vegetated areas if applicable
- ☐ Cleaning and removing debris after major storm events
- ☐ Cleaning out accumulated sediment
- ☐ Repairing or replacing stone aggregate
- ☐ Maintaining inlets and outlets
- ☐ Removing accumulated sediment from forebays or sediment storage areas when 50 percent of the original volume has been lost

Biofiltration and Filtration BMPs

- ☐ Removing trash and debris from control openings
- ☐ Watering and mowing vegetated areas
- ☐ Removing and replacing all dead and diseased vegetation
- ☐ Stabilizing eroded side slopes and bottom
- ☐ Repairing erosion areas
- ☐ Mulching void areas if needed
- ☐ Maintaining inlets and outlets
- ☐ Repairing leaks from the sedimentation chamber or from deteriorating structural components
- ☐ Removing the top few inches of media and cultivating the surface when the filter bed is clogged
- ☐ Cleaning out accumulated sediment from the filter bed once depth exceeds approximately one-half inch or when the filter layer no longer draws down within 24 hours

Detailed descriptions of operation and maintenance for specific types of green infrastructure BMPs are included in the *Massachusetts Stormwater Handbook* (MassDEP 1997) and general maintenance issues are presented in the following sections.

C.1.1 Bioretention

Maintenance activities for bioretention units should be focused on the major system components, especially landscaped areas. Bioretention landscape components should blend over time through plant and root growth, organic decomposition, and natural soil horizon development. Those biological and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance. Refer to the *Massachusetts Stormwater Handbook* (MassDEP 1997) for design guidance on soil media and plant selection.

Irrigation of vegetated areas might be needed during the plant establishment period but fertilizer and pesticide application should be minimized. In periods of extended drought, temporary supplemental irrigation could be used to maintain plant vitality. Irrigation frequency will depend on the season and type of vegetation. Properly selected vegetation will go dormant during dry periods but will revitalize when rainfall occurs. Native plants generally require less irrigation than non-native plants and should be incorporated into site designs where feasible. Native plants are also less susceptible to disease and require fewer pesticides. Controlled drainage can also be used to manage soil moisture by selectively elevating the underdrain outlet in dry periods; this will result in greater soil moisture retention between rainfall events. The underdrain outlet should always be no less than 18 inches below the soil surface to prevent saturation of the plant rooting zone.

Routine maintenance should include a twice-yearly evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (USEPA 1999). Corrective actions should be taken to remove areas with standing water for more than 24 hours in the BMP to restore proper infiltration rates and prevent mosquito and other vector habitat formation. An Integrated Pest Management Plan should be developed to minimize the use of broad-spectrum pesticides that could kill beneficial insects that feed and pollinate the native vegetation. To maintain the treatment area's appearance, it might be necessary to prune and weed. Replace mulch for aesthetics or when erosion is evident. Depending on pollutant loads, soil media might need to be replaced within 5 to 10 years of construction (USEPA 2000).

Stabilizing the area around the bioretention area can reduce maintenance by reducing the sediment flowing into the BMP. Figure C-1 shows an example of how a bioretention area can clog with sediment if the surrounding area is not properly stabilized. Proper design of inlet systems can also reduce maintenance requirements by removing trash and other gross solids keeping floatables out of the bioretention area and, in some cases, in the street for easy collection and removal by a street sweeper or maintenance crew as shown in Figure C-2.

Source: NCSU-BAE

Figure C-1. Bioretention area clogged with sediment.

Source: Tetra Tech

Figure C-2. Inlet sump to remove gross solids.

C.1.2 Water Quality Swale

The maintenance objectives for water quality swale systems consist of retaining stormwater conveyance capacity, runoff volume control, and pollutant removal efficiency. To meet those objectives, it is important to maintain a consistent ground cover in the water quality swale. Maintenance activities involve replacing or redistributing mulch, mowing (where appropriate), weed control, irrigating during drought conditions, reseeding or sodding bare areas, and clearing debris and blockages.

Manage vegetation on a regular schedule during the growth season to maintain adequate coverage. Accumulated sediment should also be removed manually to avoid concentrated flow. During the plant establishment period, minimize fertilizer and pesticide application. Irrigation might be needed to maintain plant vitality, especially during plant establishment or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Properly selected vegetation will go dormant during dry periods but will revitalize when rainfall occurs. Native plants require less irrigation than non-native plants and should be incorporated into site designs where feasible. Native plants are also less susceptible to disease and require fewer pesticides. An Integrated Pest Management Plan should be developed to minimize the use of broad-spectrum pesticides that could kill beneficial insects that feed and pollinate the native vegetation. Water quality swales should be designed to minimize flow velocity and prevent the type of erosion shown in Figure C-3. If excessive flows are identified as the cause of the problem, they should be diverted to prevent erosion and minimize maintenance.

Source: Tetra Tech

Figure C-3. Erosion caused by excessive flows in a bioswale.

C.1.3 Tree Box Filter

General maintenance requirements for tree box filters are the same as the routine periodic maintenance of other landscaped areas or bioretention BMPs. The primary maintenance requirement for tree box filters is to inspect the vegetation and soil media. Regularly remove any accumulated trash and sediment in the device, especially after large storms, or as needed during periods where overhanging vegetation is dropping leaves. Inspect soils to evaluate root growth and mitigate channel formation or uneven distribution in the soil media.

C.1.4 Sand Filter

The primary maintenance requirement for sand filters is to remove trash, accumulated sediment, and media contaminated with hydrocarbons. If the filter does not drain within 48 hours, or if sediment has accumulated to a depth of 6 inches, the top layer (1–3 inches) of sand (media) must be replaced.

C.1.5 Permeable Pavement

The primary maintenance requirement for permeable pavement consists of regular inspection for clogging (Figure C-4). The main goal of the maintenance program is to prevent clogging by fine sediment

particles, which should be accomplished through a combination of preventative tasks including timely removal of debris (leaf litter, acorns, grass clippings, mulch, and such) and stabilizing surrounding areas. To maintain the infiltrative capacity of permeable pavements, vacuum sweeping should be performed a minimum of twice a year. Frequency of vacuum sweeping should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. Settled paver block systems might require resetting. When modular pavements incorporate turf into their void area, normal turf maintenance practices, including watering, fertilization, and mowing might be required (FHWA 2002).

Source: Tetra Tech

Figure C-4. Plant growth, debris buildup, and puddles indicate that permeable pavement is clogging. Prompt maintenance should be performed to prevent joints from fully sealing.

For proper performance, maintenance staff must ensure that stormwater is infiltrating properly and is not standing or pooling on the surface of the permeable pavement for extend periods of time. Standing water can indicate clogging of the pavement void space and vacuuming is necessary to restore infiltration. If ponding still occurs, inspect and replace the media sublayer, and check the underdrain for blockage.

C.1.6 Cisterns and Rain Barrels

General maintenance activities for cisterns and rain barrels are easily performed by maintenance personnel or homeowners. The Texas A&M Agrilife Extension Service's *Rainwater Harvesting* (2008) guide provides maintenance recommendations to homeowners. The primary maintenance requirement is to inspect the tank and distribution system and test any backflow prevention devices. Rain barrels require minimal maintenance several times a year and after major storms to prevent clogging. Cisterns require inspections for clogging and structural soundness twice a year, including inspection of all debris

and vector control screens. If a first-flush diverter is used, it should be dewatered and cleaned between each storm event that fills the diverted storage pipe. Self-cleaning filters and screens, such as the ones shown in Figure C-5, can help prevent debris from entering the cistern and reduce maintenance. Accumulated sediment in the tank must be removed at least once a year. *The Texas Manual on Rainwater Harvesting* (TWDB 2005) provides additional measures for systems designed for potable water supply or drip irrigation applications.

Source: Tetra Tech

Figure C-5. Self-cleaning inlet filters.

C.1.7 Constructed Stormwater Wetlands

Maintenance activities for wetlands involve removing accumulated sediments and ensuring that plant distribution and flow paths remain as designed. Constructed wetlands built for the purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland regulatory authorities (U.S. Army Corps of Engineers, Region 6) to ensure this is the case (Virginia 2011).

Bedload sediment tends to be concentrated in pretreatment areas and forebays. It is important that this sediment not enter the rest of the wetland, because accumulated coarse sediments can affect the growing conditions of the wetland plants or change flow paths and design depths. Sediment removal should be performed more frequently, or pretreatment and forebay areas should be resized, if excessive sediment is found outside designated areas. Sediment removal in vegetated areas should be performed carefully to prevent damage to plants. Depending on the land use of contributing areas, sediment testing might be necessary to determine if accumulated pollutants require special disposal.

Wetlands should be inspected regularly or as needed after storm events. Inspectors should refer to a map of the wetland as designed to determine if the types and distribution of plants are as intended. Undesirable species should be identified and removed as needed. If plant die-off has occurred, reevaluate growing conditions and select replacement plants adapted to those conditions. Ensure that design depths and flow paths are maintained, and remove trash and debris that has accumulated in or

around the wetland. Outlets should be designed such that the water level in the wetland can be varied for establishment periods and maintenance using a variable outlet control similar to that shown in Figure C-6. A minimum orifice size should be considered and a trash rack, similar to the one shown in Figure C-7, can be used to minimize and limit clogging.

Source: Tetra Tech

Figure C-6. Outlet varied with weir boards.

Source: NCSU-BAE

Figure C-7. Outlet with a trash rack.

C.1.8 Green Roofs

Operation and maintenance of stormwater management (green, blue, brown, biodiverse) roofs primarily involves maintaining drainage structures and vegetation. Roof drains, gutters, and downspouts should be routinely inspected for clogging. If excess material tends to build up around drainage structures, the source of the problem should be remediated. To prevent vegetation from growing too close to roof drains and to identify roof drains for maintenance personnel, a circle of white gravel can be placed around the drain to designate a *no plant zone* as shown in Figure C-8. Vegetation should be inspected periodically, especially during prolonged dry weather, to determine irrigation needs and general health. Properly selected vegetation will go dormant during dry periods, but will revitalize when rainfall occurs. Periodic inspection of growing media and underlying drainage layers might also be necessary for extensive green roofs to ensure that reservoir layers are not filling with sediment deposits or extensive root networks. Intensive green roofs could require pruning and mowing at the end of the growing season, depending on vegetation type.

Roofs require appropriate health and safety protocols for fall protection. Maintenance staff and designers should consult their office safety officer or Occupational Safety and Health Administration guidance for proper equipment and safety plans. Foot traffic should be limited, to the extent practicable, to reduce plant damage and preserve aesthetic design goals. Additional guidance on roof design, maintenance, and leak detection is available from *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* (Tolderlund 2010).

Source: Amy Hathaway

Figure C-8. White gravel indicates a no plant zone for a green roof.

C.2 BMP Monitoring

Performance monitoring of stormwater BMPs is an important component of green infrastructure implementation programs. Monitoring provides the BMP designer and regulator with a mechanism to validate certain design assumptions and to quantify compliance with pollutant-removal performance objectives. Specific monitoring objectives should be considered early in the design process to ensure that green infrastructure practices are adequately configured for monitoring. Detailed monitoring guidance provided by EPA is listed in this section's references list (USEPA 2012). The MassDEP also provides a total suspended solids (TSS) removal calculation worksheet to automatically compute TSS removal efficiency by various BMPs (www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwater-handbook.html). The instrumentation and monitoring configuration will vary from site to site, but the following general principles should be considered.

C.2.1 Monitoring Hydrology

An inlet/outlet sampling setup is suggested as the most effective monitoring approach to quantify flow and volume in stormwater BMPs. The runoff source and type of BMP will dictate the configuration of inflow monitoring. A weir or flume is typically installed at the inlet of BMPs that receive concentrated, open-channel flow (i.e., from a pipe, curb cut, or a swale as shown in Figure C-9, Figure C-10, and Figure C-11). Often a baffle or weir box is used in conjunction with weirs to still flows for more precise readings, as shown in Figure C-12. The height of water flowing over the structure is automatically recorded (typically with a pressure transducer, such as a bubbler), which is used to calculate the inflow rate. By integrating the flow rate over each monitored time step, total runoff volume for each storm event can be calculated.

When runoff enters a BMP via conduit, weirs or weir boxes can still be used for monitoring, but acoustic Doppler velocimeters (ADVs) might be preferred. ADVs measure flow by recording the velocity and depth of water and will provide more accurate results if inflow conduits are expected to flow full (pressure flow), although some models require heavy turbidity to attain accurate readings. Outflow can be monitored using similar techniques as inflow by installing a weir or ADV at the point of overflow/outfall.

Source: Tetra Tech

Figure C-9. Inflow pipe to bioretention area equipped with compound weir and bubbler for flow measurement. Water quality sampling tube and strainer are visible inside pipe.

Source: Tetra Tech

Figure C-10. Inlet curb cut with a v-notch weir.

Source: Tetra Tech

Figure C-11. Outlet of a roadside bioretention pop-out equipped with a V-notch weir for flow monitoring.

Source: Tetra Tech

Figure C-12. Underdrains from permeable pavement equipped with 30-degree V-notch weir boxes and samplers for flow and water quality monitoring.

It is critical during hydrologic monitoring that no downstream tailwater interfere with the monitoring device, or false readings will be generated. To prevent tailwater effects at the inlet, the invert of the inflow pipe should be well above the expected temporary ponding depth of the BMP (Figure C-13). This is typically not possible with offline BMPs because the weir elevation controlling the bypass is at the maximum elevation in the BMP. Additional freeboard between the inlet and the maximum expected water depth should be provided to prevent the inlet monitoring device from being inundated by tailwater from the BMP (Figure C-14). The same considerations should be addressed when monitoring outflow by ensuring that the receiving storm drain network has sufficient capacity to convey high flows such that no tailwater inundates the outflow monitoring device. Figure C-15 shows an example of potential monitoring points.

Source: Tetra Tech

Figure C-13. Example of a bioretention underdrain outlet with sufficient drop to install a flow monitoring weir without encountering tailwater.

Source: Tetra Tech

Figure C-14. Poorly installed H-flume at the inlet to a bioretention area in which the invert of the weir is too low, and tailwater from the bioretention will interfere with measurement.

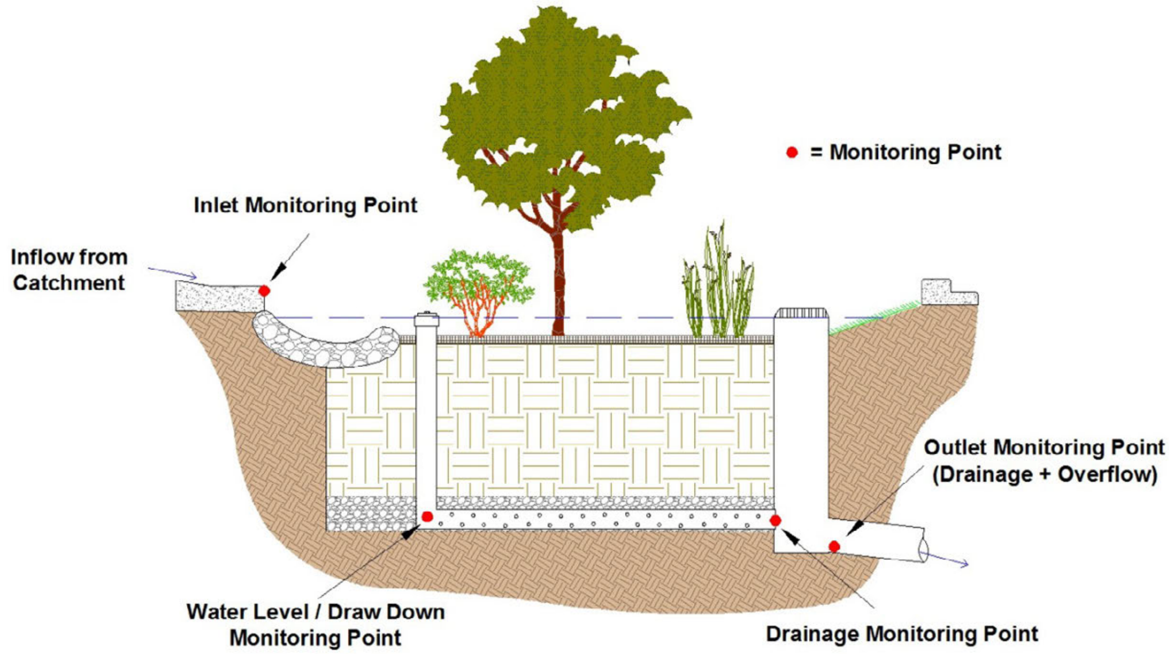

Figure C-15. Monitoring points.

In addition to monitoring inflow and outflow, rainfall should be recorded on-site. Rainfall data can also be used to estimate inflow to BMPs that receive runoff only by sheet flow or direct rainfall (i.e., permeable pavement or green roofs). The type of rain gauge depends on monitoring goals and frequency of site visits (USEPA 2012). An automatic recording rain gauge (i.e., tipping bucket rain gauge), used to measure rainfall intensity and depth, is often paired with a manual rain gauge for data validation (Figure C-16). For more advanced monitoring, weather stations can be installed to simultaneously monitor relative humidity, air temperature, solar radiation, and wind speed. These parameters can be used to estimate evapotranspiration.

Source: Tetra Tech

Figure C-16. Example of manual (left) and tipping bucket (right) rain gauges.

Water level (and drawdown rate) is another useful hydrologic parameter. Depending on project goals, perforated wells or piezometers can be installed to measure infiltration rate and drainage. Care should be taken when installing wells to ensure that runoff cannot enter the well at the surface and short circuit directly to subsurface layers. Short circuiting can result in the discharge of untreated runoff that has bypassed the intended treatment mechanisms. It might be useful to pair soil moisture sensors with water-level loggers in instances where highly detailed monitoring performance data are required (such as for calibration and validation of models).

C.2.2 Monitoring Water Quality

Although hydrologic monitoring can occur as a standalone practice, water quality data must be paired with flow data to calculate meaningful results of constituent loading. Flow-weighted automatic sampling is the recommended method for collecting samples that are representative of the runoff event and can be used to calculate pollutant loads (total mass of pollutants entering and leaving the system). Simply measuring the reduction in constituent concentrations (mass per unit volume of water) from inlet to outlet can provide misleading results because it does not account for load reductions associated with infiltration, evapotranspiration, and storage.

Influent water quality samples are typically collected just upstream of the inlet monitoring device (weir box, flume, and such) just before the runoff enters the BMP. The downstream sampler should be at the outlet control device just before the overflow entering the existing storm drain infrastructure. A strainer is usually installed at collecting end of the sampler tubing to prevent large debris and solids from entering and clogging the sampler. Automatic samplers should be programmed to collect single-event, composite samples according to the expected range of storm flows. Depending on the power requirements, a solar panel or backup power supply might be needed.

In addition to collecting composite samples, some water quality constituents can be monitored in real time. Parameter testing applies to stormwater quality control BMPs. Municipal and construction site parameters are generally the contaminants in runoff studies, such as total dissolved solids, TSS, suspended sediment concentration, or total petroleum hydrocarbons, total Kjeldahl nitrogen, total nitrogen, total phosphorus, chemical oxygen demand, biological oxygen demand, *Escherichia coli*, total coliform, enterococci, pH, conductivity, temperature, and the following metals: lead, copper, zinc, and nickel (TARP 2001).

C.2.3 Sample Collection and Handling

Programmable automatic flow samplers with continuous flow measurements should be used unless it is demonstrated that alternate methods are superior or that automatic sampling is infeasible. Grab samples should only be used for certain constituents, in accordance with accepted standard sampling protocols, unless it is demonstrated that alternate methods are superior. Constituents that typically require grab sampling include pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, total petroleum hydrocarbons, *Escherichia coli*, total coliform, fecal coliform, fecal streptococci, and enterococci. Collection and flow-weighted composite sampling also should follow the NPDES guidance (TARP 2001).

Quality assurance and quality control protocols for sample collection are necessary to ensure that samples are representative and reliable. The entire sample collection and delivery procedure should be well documented in the quality assurance project plan (QAPP), including chain of custody (list of personnel handling water quality samples) and notes regarding site condition, time of sampling, and rainfall depth in the manual rain gauge. Holding times for water quality samples vary by constituent, but all samples should be collected and delivered to the laboratory on ice as soon as possible (typically 6 to 24 hours) after a rainfall event. Some water quality constituents require special treatment upon collection, such as acidification, to preserve the sample for delivery. Appropriate health and safety

protocol should always be followed when on-site, including, for example, using personal protective equipment such as safety vests, nitrile gloves, and goggles.

C.3 References

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