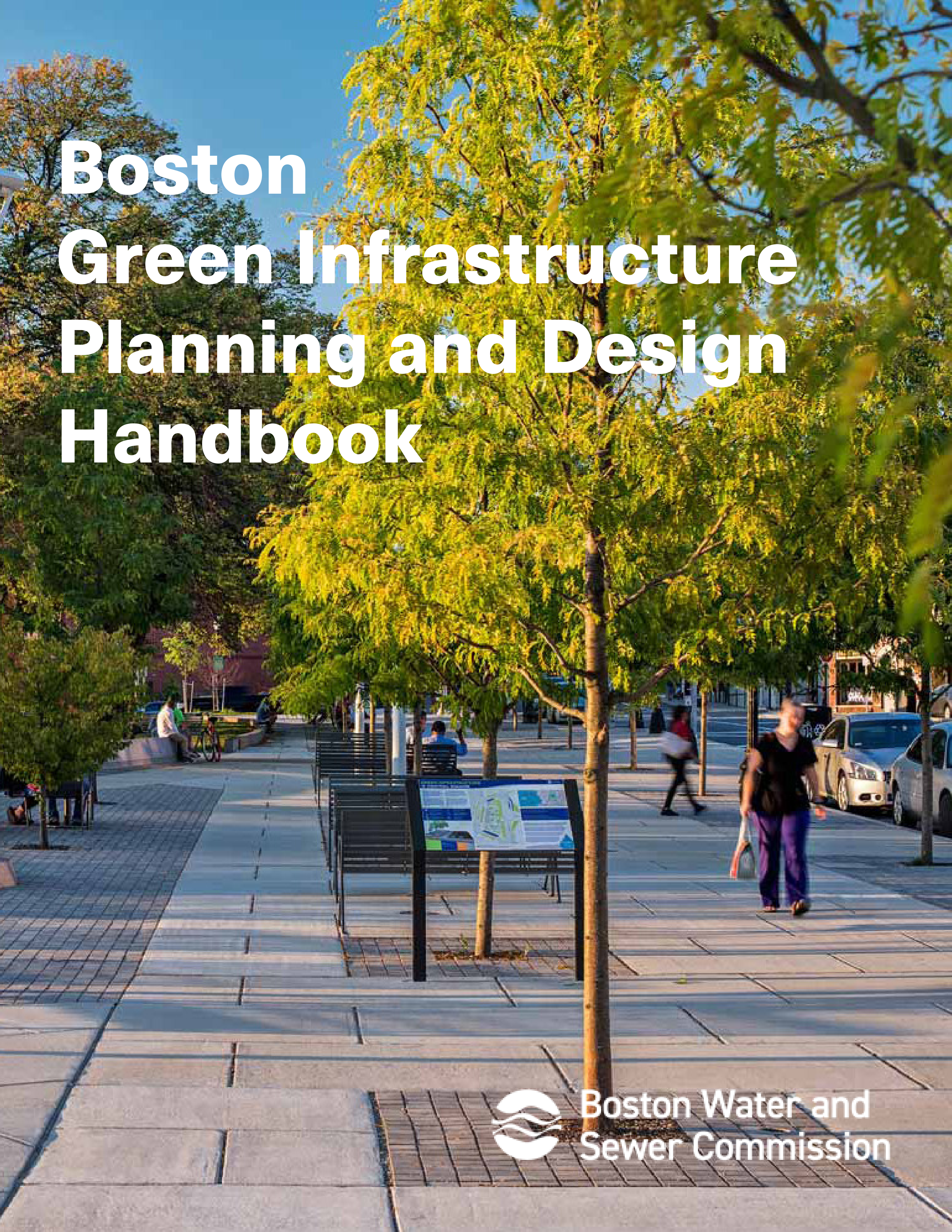
Boston Green Infrastructure Planning and Design Handbook



Boston Water and Sewer Commission

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mad oyster studios somerville, ma (recover green roofs)

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Executive Summary

In the City of Boston and in many other cities around the world, stormwater has historically been treated as a waste product that must be captured at street level with "gray" infrastructure such as catch basins and storm drains and piped to receiving waters with minimal or no treatment. Without treatment, the pollutants picked up by stormwater as it flows across streets, sidewalks, and other impervious surfaces are carried to our receiving water bodies like the Charles River, Neponset River, and Boston Harbor. These contaminants affect our water quality and cause damage to the natural ecosystem. On August 23, 2012, the Boston Water and Sewer Commission (BWSC) entered a Consent Decree with the Conservation Law Foundation and the U.S. Environmental Protection Agency (EPA) to reduce phosphorus loads in the Lower Charles River Basin. The Consent Decree identified Green Infrastructure (GI) and Low Impact Development (LID) techniques as tools for achieving this goal. This Green Infrastructure Planning and Design Handbook (the Handbook) will serve as a guide for both public and private property owners to implement GI techniques to manage stormwater throughout the City of Boston.

Chapter 1: Introduction

Introduction provides a broad overview of GI: a series of strategies that mimic nature and use natural hydrologic processes to capture, retain, detain, and remove pollutants from stormwater. GI techniques use landscape-integrated approaches to store stormwater so it can be infiltrated to the ground, evaporated to the atmosphere, or repurposed to supplement non-potable water demands. GI techniques are well suited to address the three key components of stormwater management: peak rate mitigation, volume reduction, and water quality treatment. Chapter 1 also highlights the co-benefits of GI, which include improved air quality, community involvement, job creation, reduced energy costs, urban heat island mitigation, carbon sequestration, habitat improvement, and increased property values. As a result, GI can dramatically improve the quality of life in the City of Boston through the addition of new green space and amenities. While every city can benefit from GI, the City of Boston faces specific challenges because of historic development patterns and the impacts of climate change.

Chapter 2: The Boston Context

Chapter 2 highlights six key drivers of GI implementation in the City of Boston, including water quality, inland flooding, sea level rise, groundwater levels, urban heat island effect, and habitat corridors and connectivity. Each section describes the driver's associated challenges, how GI can help, and current examples of relevant GI implementation. Chapter 2 also showcases some of the unique pilot projects that the BWSC has been implementing across the City of Boston to address these challenges in partnership with other city agencies.

Chapter 3: Design Guidelines

Design Guidelines provides developers and design professionals with technical guidance on implementing GI solutions in their projects. This chapter will walk you through the research and site analysis process, highlight key design considerations, and provide guidance on how to size a GI solution for your site. The Design Guidelines also emphasize the importance of Operations and Maintenance (O&M) to ensure the long-term performance of GI. The design process is highlighted through an example case study the reader can use for reference.

Chapter 4: GI Toolkit

Lastly, the **GI Toolkit** provides an easy-to-use reference guide for the GI techniques highlighted in this Handbook. The GI Toolkit includes design guidance for implementing infiltration techniques, bioretention techniques, permeable pavements, and rooftop strategies in the City of Boston. The GI Toolkit can be used as a standalone reference or in conjunction with the rest of the text.

From a single-parcel development to a large-scale neighborhood redevelopment, the City of Boston has an opportunity to increase its resilience and overcome challenges associated with stormwater management now and into the future. With cooperation from both public and private developments, implementation of GI projects will undoubtedly have a positive impact on the quality of life in the City of Boston and beyond.

rogers environmental magnet school stamford, ct

central square east boston, ma

kennedy street tree filter washington, dc

rogers environmental magnet school stamford, ct

Terms and Definitions

This glossary provides a simplified overview of many critical terms and definitions related to stormwater management and Green Infrastructure (GI) implementation. Terms are adopted from the Environmental Protection Agency (EPA) website, EPA National Pollutant Discharge Elimination System (NPDES) Permit Writer Training Manual, and the Massachusetts Department of Environmental Protection (MassDEP), unless otherwise noted.

Clean Water Act (CWA) An act passed by the U.S. Congress to control water pollution. It was formerly referred to as the Federal Water Pollution Control Act of 1972 or Federal Water Pollution Control Act Amendments of 1972.

Combined Sewer Overflow (CSO) The discharge from combined sewers which collect both sanitary sewage and stormwater runoff for wastewater treatment under normal (dry) weather conditions. During rainstorms, the system becomes overloaded, and the excess is discharged directly into neighboring waterways from CSO outlets.

Green Infrastructure (GI) The range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters. (Section 502 of the Clean Water Act). Green Infrastructure (GI) is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure—conventional piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment, GI reduces and treats stormwater at its source while delivering environmental, social, and economic benefits.

Gray Infrastructure Used to characterize conventional stormwater management that relies on pipes, large above ground (ponds), or below ground storage (tunnels and tanks) for diverting runoff away from buildings and people and discharging at a single outfall location. Also used in reference to underground structures designed to expanding storage capacity of a combined sewer system to help reduce CSOs.

Impermeable / Impervious Surface A surface or an area, which stormwater cannot penetrate through.

Low Impact Development (LID) Refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat.

Municipal Separate Storm Sewer System (MS4) A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains) owned by a State, city, town, or other public body, that is designed or used for collecting or conveying storm water, which is not a combined sewer, and which is not part of a publicly owned treatment works. Commonly referred to as an "MS4" [40 CFR §122.26(b)(8)].

National Pollutant Discharge Elimination System (NPDES) The national program for issuing, modifying, revoking, and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 318, 402, and 405 of CWA.

Non-Structural Best Management Practices (BMPs) Institutional, educational or pollution prevention practices designed to limit the amount of stormwater runoff or pollutants that are generated in the landscape. The use of non-structural BMPs upstream can reduce the amount of runoff being generated, which in-turn reduces the amount of stormwater that will need to be treated by structural BMPs downstream.

Pervious / Porous / Permeable Surface Surfaces that allow water to percolate into the soil to filter out pollutants and recharge the water table. Examples include planting beds, mulched beds, gravel, permeable pavers, pervious asphalt, forested areas, and meadows. Turf and lawns are pervious, but generally much less so than the above-mentioned surfaces. Solid surfaces that do not allow water to penetrate, forcing it to run off, are called impervious or impermeable. Examples include traditional asphalt, concrete, brick or stone, and traditional roofs.

Stormwater Management The practice of managing stormwater runoff using structural and non-structural best-management practices, including Green Infrastructure.

Stormwater Runoff Rain and snowmelt flowing over the land surface. Runoff picks up pollution such as excess fertilizers, bacteria and animal waste, road salt, and excess sediment and soil. This mixture often flows into storm drains, where it eventually flows into a nearby receiving water such as lakes or rivers.

Total Maximum Daily Load (TMDL) The amount of pollutant, or property of a pollutant, from point, nonpoint, and natural background sources, that may be discharged to a water quality-limited receiving water. Any pollutant loading above the TMDL results in violation of applicable water quality standards.

Watershed An area of land that drains to a specific point, such as a river, lake, ocean, storm drain inlet, or outfall. Catchments, subwatersheds, and basins all refer to different watershed scales.

devotion school brookline, ma

Acronyms

ADA	Americans with Disabilities Act
ASTM	American Society for Testing and Materials
BMP/BMPs	Best Management Practice(s)
BPDA	Boston Planning & Development Agency
BPRD	Boston Parks & Recreation Department
BPS	Boston Public Schools
BPWD	Boston Public Works Department
BSL	Boston Street Lighting
BTD	Boston Transportation Department
BWSC	Boston Water and Sewer Commission
CF	Cubic Feet
CSI	(Boston) Complete Streets Initiative
CSO/CSOs	Combined Sewer Overflow(s)
CWA	Clean Water Act
DCR	(Massachusetts) Department of Conservation & Recreation
EEA (or EOEEA)	(Massachusetts) Executive Office of Energy & Environmental Affairs
EEOS	(Boston) Environment, Energy & Open Space Cabinet
EPA	(U.S.) Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GCOD	Groundwater Conservation Overlay District
GI	Green Infrastructure
GIS	Geographic Information System
HSG	Hydrologic Soil Group
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MS4	Municipal Separate Storm Sewer System
MVP	(Massachusetts) Municipal Vulnerability Preparedness program
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
O&M	Operations and Maintenance
PROW	Public Right-of-Way
SF	Square Feet
SWPPP	Stormwater Pollution Prevention Plan
TMDL	Total Maximum Daily Load
USGBC	United States Green Building Council
USGS	United States Geological Survey

CHAPTER 1

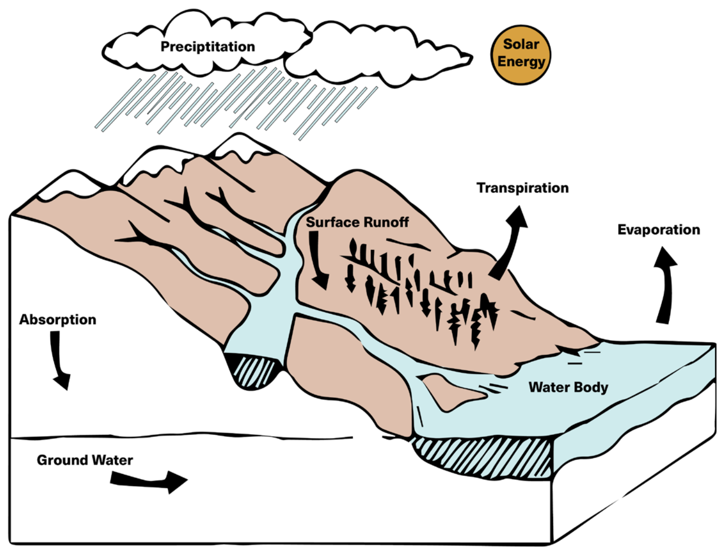
Introduction

Green Infrastructure (GI) features are stormwater management facilities that mimic nature. In the natural world, rainwater soaks, or infiltrates, into the soil. Unfortunately, in most cities and towns rainwater can no longer infiltrate into the ground because of buildings, pavement, sidewalks, and other surfaces that water cannot pass through. These hard surfaces, called "impervious" surfaces, generate stormwater runoff when rainwater falls and "runs off," rather than soaking into the ground. Conventional stormwater management, often referred to as "gray infrastructure," uses catch basins and storm drains to capture stormwater and pipe it, often untreated, to nearby waterbodies. This section reviews the challenges that GI is built to address, how GI works, and the multiple co-benefits it provides to communities.

1.1 The Challenges of Urban Stormwater Runoff

In the natural environment, hydrological processes are heavily influenced by an abundance of trees and vegetative ground cover. Plants absorb and slowly release water back to the atmosphere through evapotranspiration. Healthy soils are permeable, allowing water to infiltrate the ground and provide recharge to streams, wetlands, and aquifers. Vegetation also cleans water: by the time a single droplet of water that travels across a natural landscape reaches the ocean, it has gone through a series of processes which clean it and remove impurities before it flows out to sea.

Unfortunately, this natural process has been significantly and permanently impacted by urbanization and development. As our cities have grown and expanded, development has replaced permeable areas with impervious surfaces such as buildings, roads, and parking lots. When this happens, these areas become impervious, meaning water cannot pass through them. Increased impervious area significantly changes the way that water moves through an ecosystem by creating large quantities of surface runoff and reduced groundwater recharge. This transition has permanently altered the hydrological cycle that keeps our water clean and our natural environment thriving.

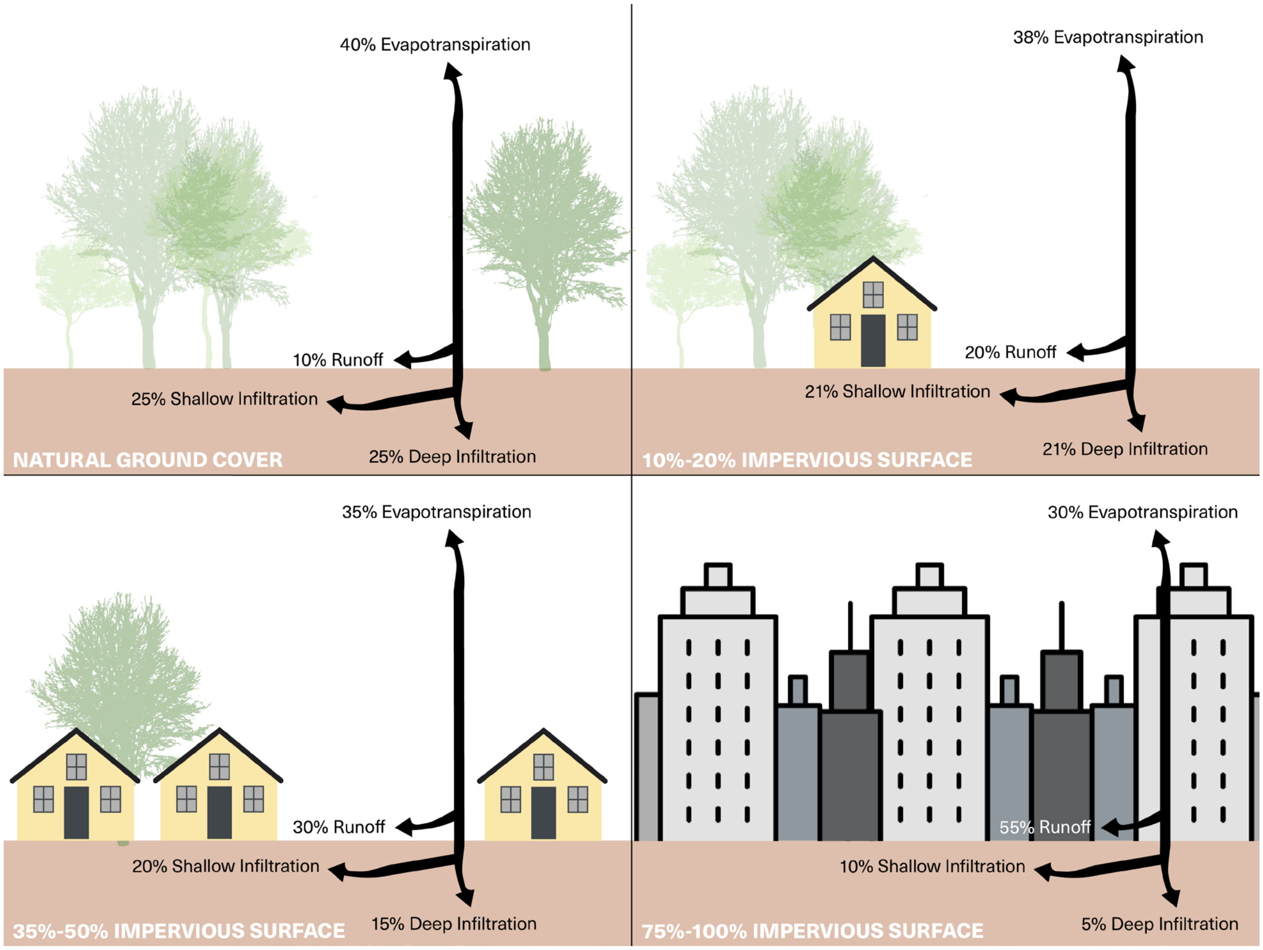


The Hydrological Cycle

Impacts of Stormwater Runoff

Impervious areas are not able to absorb rainwater, resulting in a type of surface runoff generally referred to as stormwater runoff. Stormwater runoff creates major challenges for human and natural environments, including flooding, erosion, and water pollution. For example, during heavy rainfall, stormwater runoff can overwhelm undersized drainage infrastructure and cause localized flooding. As development increases and climate change brings increasingly extreme precipitation events, the risk of overburdening existing infrastructure is increasing. Erosion is another challenge. Stormwater runoff from construction sites and other disturbed areas can pollute water bodies and block stormwater infrastructure, since it may be full of sediment without proper precautions in place. Likewise, increased volumes of stormwater runoff flow faster and carry more sediment at higher flow rates, which can destabilize streambanks. These changes, when unmitigated, can have significant impacts on surrounding land and waterways.

As it travels along impermeable surfaces, runoff collects a variety of pollutants including metals, pathogens, fertilizers, pesticides, trash, oils, nutrients, and bacteria. These pollutants are washed into urban drainage systems and discharged to our rivers and oceans, with the potential to negatively impact wildlife and water quality.



Impacts of Urbanization on Hydrology

Disturbance of the natural hydrological cycle also impacts the plants and trees which grow in our yards, streets, and parks. These green areas provide habitat for wildlife and improve our well-being and the quality of our neighborhoods. However, pavement compacts soil, preventing root air exchange and hindering root growth needed to find essential nutrients. Winter salting and air pollution disturb soil biology and the uptake of nutrients. Runoff reduces the amount of water available to plants that they need to survive before it gets washed away. The urban heat island effect raises local temperatures around trees, which increases their respiration and need for more water. All these conditions result in a harsh urban environment where it is difficult for plants to survive.

A Vicious Cycle

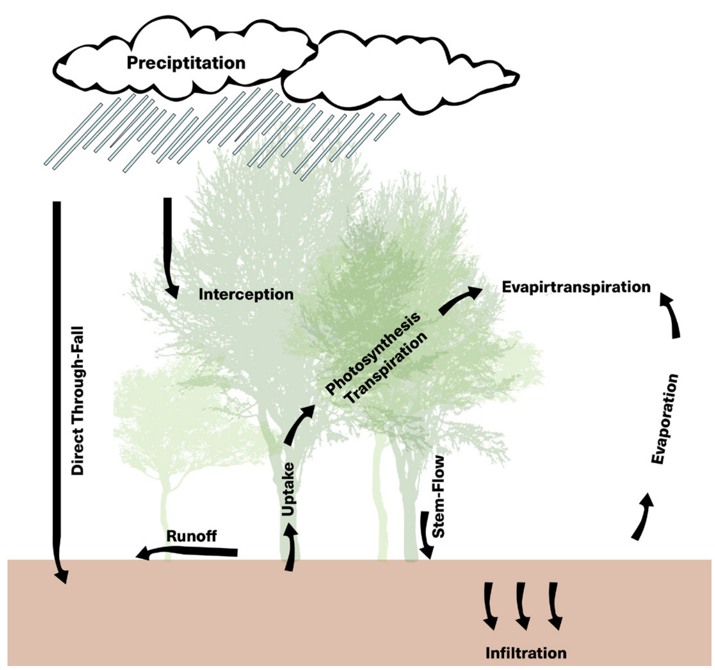
To compensate for these negative impacts, we may use high-intensity landscaping strategies including the introduction of non-native plants, the use of herbicides, pesticides, and fertilizers, and excessive water consumption. All of these result in higher costs for maintenance and exacerbate the challenges associated with contaminated runoff and pollution. Stormwater management in urban areas also poses challenges to our homes, neighborhoods and communities. As described above, without proper drainage, stormwater can create localized flooding and compromise water quality. To transport water through the urban environment, complex infrastructure networks and drainage systems consisting of catch basins and pipes are used to collect and discharge to downstream water bodies. While these systems have provided sufficient stormwater management for decades, much of this infrastructure is old and in need of repair. Expansive urban sprawl coupled with an increase in environmental awareness has drawn attention to the need for a new type of infrastructural investment. Likewise, the impacts of urbanization and climate change, including the urban heat island effect, extreme precipitation, and rising sea levels, have resulted in a push for significant restructuring of resource management. One solution has become increasingly popular for managing stormwater and improving quality of life in urban areas: Green Infrastructure.

1.2 Green Infrastructure Stormwater Management Benefits

Since urbanization has fundamentally altered the natural hydrological cycle, new strategies for replenishing aquifers, reducing runoff, and improving water quality are necessary to improve the health of our watersheds and ecosystems. Green Infrastructure (GI) is a sustainable stormwater management approach that uses distributed small-scale principles and practices to mimic the natural hydrologic cycles of storage, infiltration (groundwater recharge), evapotranspiration, and filtration. Examples of GI solutions include bioretention facilities, infiltration techniques, permeable pavements, and rooftop capture strategies such as green roofs. The GI approach works with nature to manage stormwater as close to its source as possible, reducing reliance on drainage systems while providing essential urban green space. The GI approach also employs landscape-based strategies to minimize the impacts of stormwater runoff from impervious surfaces and treats stormwater as a resource to support vibrant vegetation rather than a waste product to be drained away.

GI systems are intended to function as a sustainable loop: rainwater nourishes plants and soils while landscape systems slow, reduce, and clea nse stormwater runoff to reduce overburdening drainage systems. Widespread GI implementation provides a system of green spaces that improve habitat for flora and fauna, protect our neighborhoods from flooding, filter our air, and clean our water, all through the power of natural processes. As improving water quality is one of the key targets of the 2012 Consent Decree, using GI strategies that specifically include nutrient uptake through vegetation is a key goal of the Boston Water and Sewer Commission (BWSC).

GI also provides an opportunity to make the City of Boston more resilient to the impacts of extreme weather and flooding. Storm events have increased in frequency and intensity worldwide in the last 50 years and are expected to become more frequent and intense as temperatures continue to rise due to global warming. As the risk of flooding is likely to increase dramatically across the United States (including the City of Boston), aging stormwater infrastructure will continue to be overwhelmed, leading to widespread flood risk. GI can mitigate flood risk by slowing and reducing stormwater discharges through volume reduction and peak flow mitigation. The following three sections provide additional details on these three key GI stormwater management benefits.



Impacts of Green Infrastructure on Hydrology

Improved Water Quality

When properly designed and maintained, GI has proven effective at reducing sediments, nutrients, and bacteria in stormwater runoff through infiltration and filtration techniques. GI features mainly use the interaction of the chemical, physical, and biological processes between soils and water to filter out sediment and absorb pollutants from stormwater. Vegetation and their root systems create tiny ecosystems in the soil media. The microorganisms that live in the soil remove pollutants like phosphorus and nitrogen, which can have negative impacts on aquatic life. When infiltration is not feasible, water quality improvements can still be achieved through filtration utilizing sedimentation, straining, and absorption processes as stormwater passes through small pore spaces.

Volume Reduction

GI emulates the functions of natural systems, which retain stormwater in surface depressions and voids created by landscape and soils. GI is highly effective at absorbing stormwater, thereby reducing the volume of stormwater runoff by evaporating it back to the atmosphere and infiltrating it into the ground. As a result, GI reduces the overall volume of stormwater runoff to storm drain systems. The most effective GI strategies use infiltration techniques, which not only treat stormwater and reduce the volume of stormwater discharge but also are able to recharge the groundwater supply. Groundwater recharge is an important part of a healthy watershed because it helps maintain the base flow in nearby streams and wetlands and replenishes drinking water supplies. Landscape-based systems which promote infiltration and evaporation help restore the natural water balance. GI strategies which do not infiltrate stormwater can still reduce the volume of stormwater runoff through evaporation and rainwater reuse.

Peak Flow Mitigation

GI also helps reduce the peak flow of stormwater discharged from a site. The maximum rate of discharge during the period of runoff caused by a storm is called a "peak flow". Peak flow is determined by the size, shape, and characteristics of a watershed (or drainage area) as well as the storm characteristics such as intensity of the storm and its duration. Highly impervious sites rapidly generate and discharge stormwater runoff. A reduction in flood peak flow rates can help to reduce burdens on streams, floodplains, and stormwater infrastructure by slowing down or storing water before gradually releasing it back into the stormwater system. As larger and more extreme rainfall events are predicted as a result of the changing climate, stormwater infrastructure will be especially vulnerable to surcharge conditions, which result in localized inland flooding. By reducing peak flow rates, the total flood volume received by the infrastructure or system can be more efficiently conveyed.

	Peak Rate Mitigation	Volume Reduction	Water Quality
Bioretention (Infiltration)	●	●	●
Bioinfiltration	●	◐	●
Bioretention Planters	◐	◐	●
Tree Filter	◐	◐	●
Sub-Surface Infiltration	●	●	●
Infiltration Trench	●	◐	●
Surface Infiltration Basin	●	●	●
Porous Asphalt	●	●	●
Permeable Pavers	●	◐	●
Green Roofs	●	◐	●
Blue Roofs	●	◐	◐
Cisterns	◐	◐	◐

○ Little to No Benefit ◐ Moderate Benefit ● High Benefit

Green Infrastructure Strategies and Benefits Different GI strategies have different functions. The above matrix shows some of the most successful GI strategies for three key stormwater management demands: peak rate mitigation, volume reduction, and water quality. (Credit: Nitsch Engineering)

1.3 Co-Benefits of Green Infrastructure

Green Infrastructure (GI) strategies serve multiple functions such as cooling and beautifying streets and creating wildlife habitat. GI is also good for people, as a successful project can increase community engagement, create green jobs, and help neighborhoods deal with the impacts of climate change. The following section highlights some of these key co-benefits.

Improved Quality of Life

Studies indicate that green space enhances a sense of well-being. Exposure to nature reduces mental fatigue and has a rejuvenating affect. GI also helps to create a more pedestrian-friendly environment that encourages walking and physical activity, improving overall health.

Reduced Heat Island

GI has been shown to decrease localized and overall urban temperatures, often referred to as the urban heat island effect. Hard surfaces, like pavement and roofs, retain and radiate heat. Natural surfaces, like tree canopy and other types of vegetation, absorb heat and convert it to energy so that plants can grow. Vegetation also creates shade, which reduces overall temperatures.

Improved Air Quality

Vegetated GI features reduce smog by lowering air temperatures and the need for air conditioning. Vegetation can also reduce particulate pollution by absorbing and filtering the tiny bits of dust, chemicals, and metals suspended in the air.

Community Involvement

Successful GI implementation requires a multi-disciplinary and inclusive planning and design process that includes residents, neighborhoods, businesses, and institutions such as schools and churches. Involving the community through volunteer workshops, tree plantings, and even GI construction are fun and educational efforts that help build community connections.

Job Creation

GI implementation creates green jobs in design, construction, and maintenance, especially programs that include a Green Jobs Training Program to train workers to build and maintain features. Underserved groups in urban areas benefit immensely from these programs, as the green jobs field continues to grow.

Reduced Energy Costs

Trees and vegetative cover can lower ambient air temperatures in urban areas through shading, windbreak, and evapotranspiration, lowering demand for the energy needed to provide air conditioning. Green roofs also insulate against extensive heat loss in the winter and heat absorption in the summer.

Carbon Sequestration

While studies are still being conducted to quantify the amount of carbon that GI sequesters, healthy soils and vegetation have the potential to pull carbon dioxide from the atmosphere, helping to offset greenhouse gas emissions.

Habitat Improvement

Even small patches of vegetation provide habitat for birds, mammals, amphibians, reptiles, and insects. By reducing erosion and sedimentation, GI also improves habitat in small streams. Large-scale GI such as parks, vegetated wetlands, and urban forests help to facilitate wildlife movement between habitats.

Increased Property Value

Many aspects of GI features can increase property values by improving aesthetics, drainage, and recreation opportunities that can help restore, revitalize, and encourage growth in economically distressed areas. Ensuring that GI strategies do not result in the displacement of low-income residents is critical to ensuring equitable access to GI benefits.

	Improved Quality of Life	Reduced Heat Island	Improved Air Quality	Comunity Involvement	Job Creation	Reduced Energy Costs	Carbon Sequestration	Habitat Improvement	Increased Property Value
Bioretention (Infiltration)	●	●	●	●	●	◐	●	●	●
Biofiltration	●	●	●	●	●	◐	●	●	●
Bioretention Planters	●	●	●	●	●	◐	●	●	●
Tree Filter	●	●	●	●	●	◐	●	●	●
Sub-Surface Infiltration	○	○	○	○	◐	○	○	○	○
Infiltration Trench	○	◐	◐	○	◐	○	◐	◐	○
Surface Infiltration Basin	●	●	●	●	●	◐	●	●	●
Porous Asphalt	○	○	○	○	●	○	○	○	○
Permeable Pavers	◐	○	○	○	●	○	○	○	◐
Green Roofs	●	●	●	●	●	●	●	●	●
Blue Roofs	○	◐	○	○	◐	◐	○	○	○
Cisterns	◐	○	○	○	●	○	○	○	◐

○ Little to No Benefit ◐ Moderate Benefit ● High Benefit

Green Infrastructure Co-Benefits: Co-benefits of different GI strategies. This matrix highlights the key co-benefits of different GI BMPs. Understanding how to maximize the benefits of your GI requirements can lead to a more successful project and create buy-in from multiple stakeholders.

CHAPTER 2
The Boston Context

Green Infrastructure (GI) should always be designed with the local context in mind to optimize benefits. While GI may be easier to implement in less developed areas with more permeable surfaces, cities such as Boston also must find creative ways to install GI into densely developed and impervious areas. The next section of this Handbook explains some of the unique challenges the City of Boston faces regarding stormwater management and introduces the role of the Boston Water and Sewer Commission (BWSC). The chapter highlights six key drivers of GI implementation in the Boston, including water quality, lowered groundwater levels, habitat corridors and connectivity, urban heat island effect, sea level rise in Boston Harbor, and inland flooding.

Left: The Government Center MBTA Station improvements included many GI features in the heart of downtown Boston.

2.1 The Boston Water and Sewer Commission (BWSC)

History of Boston's Sewer System

The City of Boston is home to New England's oldest and largest water, sewer, and stormwater systems. In 1877, the original sewer system was built to address growing public health concerns. Today, the population of the City of Boston has grown to over 692,000, and the city has expanded from a peninsula of 1.2 square miles to approximately 48 square miles through a combination of annexation and land reclamation projects. The City of Boston's aging infrastructure has to manage not only an increase in development and population, but also an increase in flood risk caused by climate change. Significant investment is required to ensure that the existing system can cope with extreme weather while meeting increasingly stringent environmental regulations. The Boston Water and Sewer Commission (BWSC), in conjunction with the City of Boston Environment Department, is the leader for addressing these challenges throughout the city.

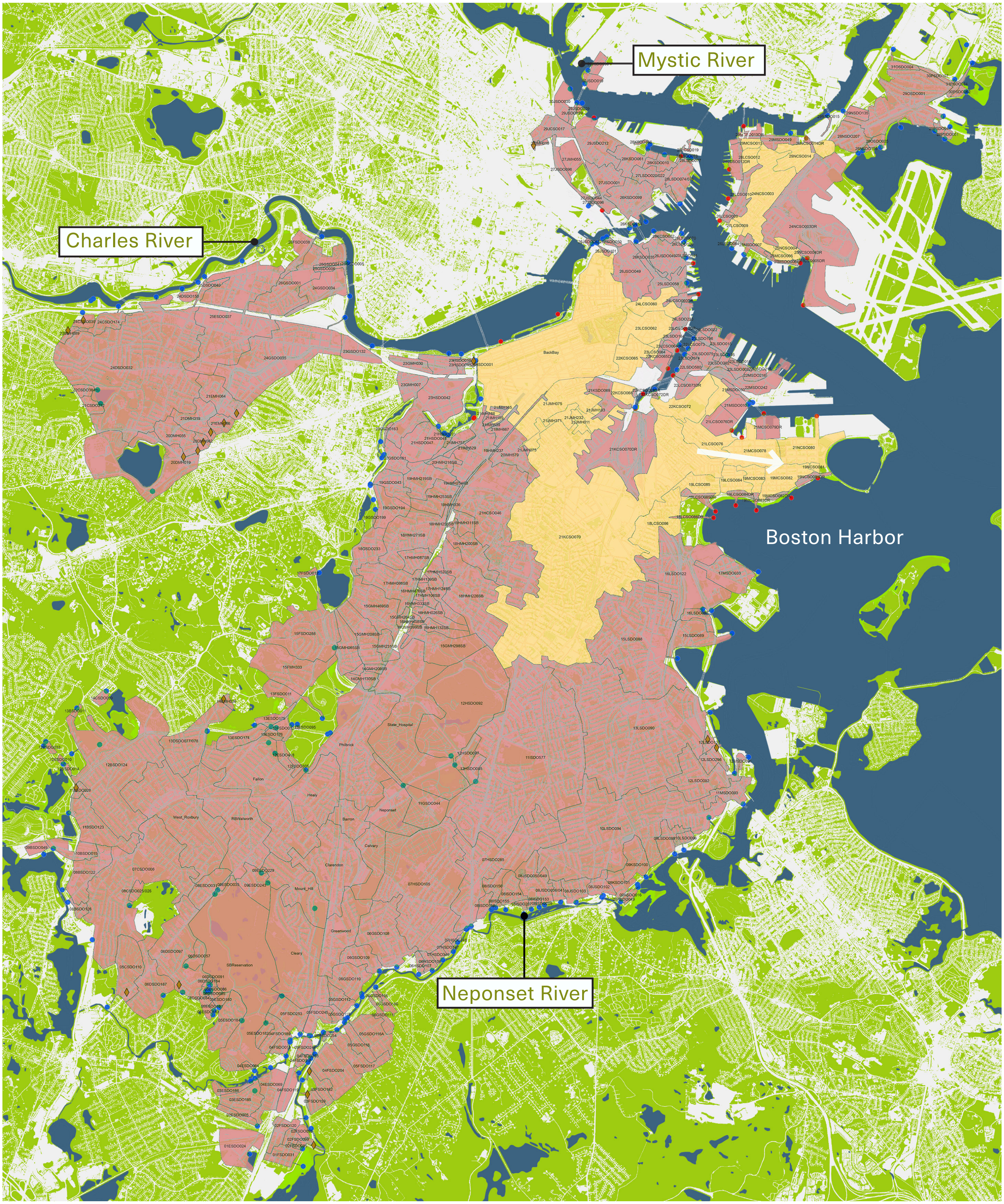
The BWSC's MS4 Area

The BWSC serves the water and sewer needs of approximately 20,500 acres, or 70% of the total land area of the City of Boston. The drinking water distribution system serves approximately 88,800 accounts, including residents, schools and universities, hospitals, businesses, industries, and private and public institutions. In addition to providing drinking water supply, the BWSC is responsible for the maintenance and operation of most of the City of Boston's Municipal Separate Storm Sewer System (MS4), a series of storm drains, pipes, and ditches designed or used to collect or convey stormwater out of the city's neighborhoods and into larger bodies of water like the Charles River, Neponset River, and Boston Harbor. The BWSC's MS4 system consists of both combined and separate stormwater systems that manage drainage for the entire city. Combined systems mean that storm water and sewage share the same drainage systems. When these systems get backed up and create flooding, it creates serious public health concerns. The BWSC is continuing to work on separating other sections within the city to avoid this issue.

The BWSC's NPDES Permit

The BWSC was issued National Pollutant Discharge Elimination System (NPDES) Permit MAS010001, which became effective on October 29, 1999, authorizing stormwater and allowable non-stormwater discharges from its MS4. The permit expired five years later, on October 30, 2004; however, the U.S. Environmental Protection Agency (EPA) administratively continued the permit as allowed by regulation. In order to continue to discharge from the MS4, the BWSC is required to reduce the amount of pollution into its receiving waters, including by reducing phosphorous loads in the Charles River and pathogens in the Neponset river. Best Management Practices (BMPs) including GI are regulatorily supported measures to reduce pollution to the maximum extent practicable and can help BWSC to achieve the required water quality standards.

As part of a holistic stormwater management strategy, BWSC regulations require large development projects to meet performance-based requirements prior to connection and discharge to the MS4 system. For example, the BWSC's standards require the use of GI systems to infiltrate the first 1 inch or 1.25 inches of stormwater over the total impervious area on a site, depending on the project's size. Meeting these requirements may require technical expertise in hydrology, engineering, and landscaping to design successful GI systems. These strategies are provided in greater detail in the Design and Toolkit sections of this Handbook.



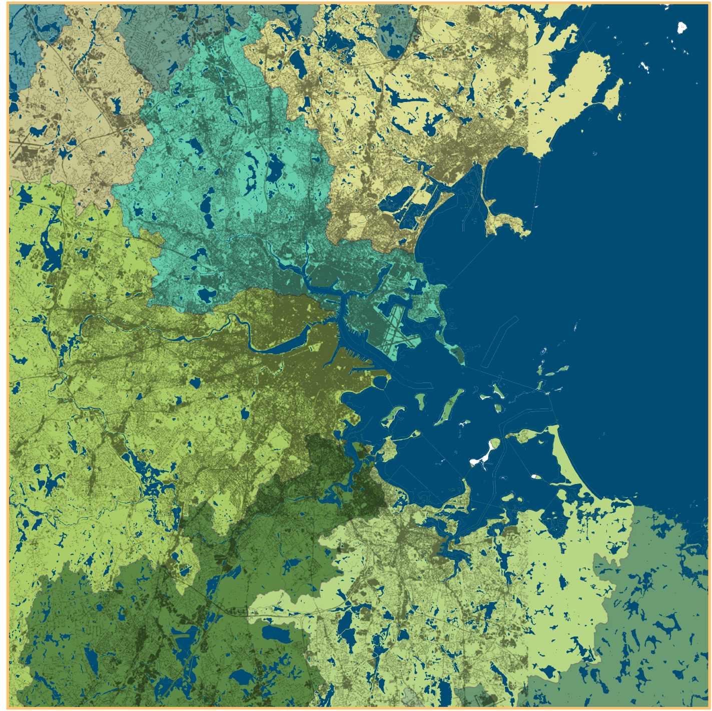
Above: The Boston Water and Sewer Commission (BWSC)'s MS4 area has over 200 storm drain outfalls and interconnections that drain into four receiving waters: the Charles River, the Mystic River, the Neponset River, and Boston Harbor. (Source: BWSC, MassGIS) The city is divided into catchment areas, shown here as the Combined Sewer Area (Pink) and the MS4 Separated Area (Yellow).

2.2 Key Drivers for Green Infrastructure Implementation in Boston

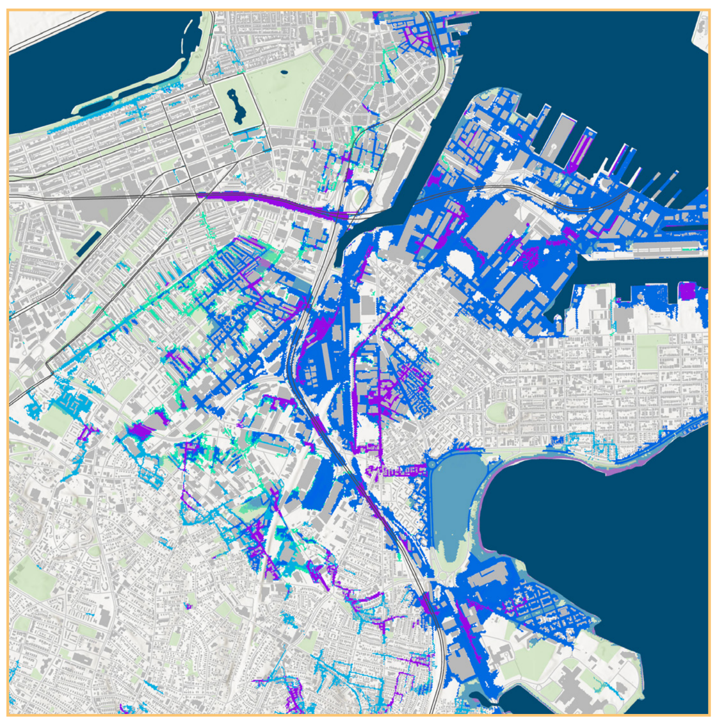
Green Infrastructure's (GI) numerous co-benefits help support the case for widespread implementation to address urban environmental issues beyond stormwater management alone. GI is something advocated for across nearly every city department, including the Boston Public Works Department (BPWD), Boston Transportation Department (BTD), Boston Parks and Recreation Department (BPRD), City of Boston Environment Department, and Boston Planning and Development Agency (BPDA). This cross-sector collaboration enables the Boston Water and Sewer Commission (BWSC) to support the obligations of the Consent Decree and positions the City of Boston as a leader in GI implementation and climate resilience. A few of the multi-department initiatives are highlighted throughout this manual.

GI has also become priority amongst many state and federal agencies, including the Massachusetts Department of Environmental Protection (MassDEP), the Massachusetts Department of Conservation and Recreation (DCR), the Massachusetts Department of Transportation (MassDOT), the Massachusetts Vulnerability and Preparedness (MVP) program, the Environmental Protection Agency (EPA), and even the Federal Emergency Management Agency (FEMA). These agencies provide guidance, financial resources, and technical assistance to implement local GI solutions. This broad base of support for GI only emphasizes the numerous benefits GI provides for our cities, our communities, and our environment.

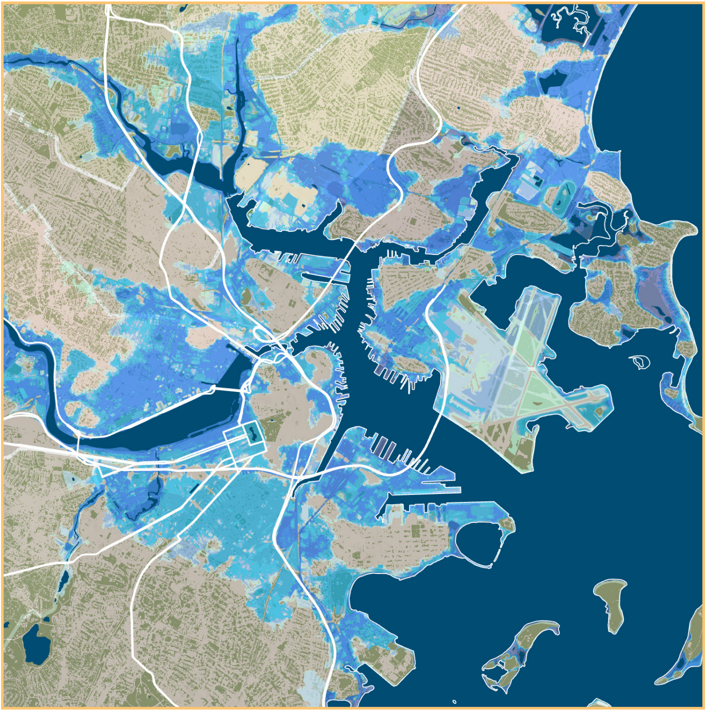
The following section illustrates six key drivers for GI in the City of Boston that are derived specifically from the city's unique character and challenges: improving water quality, replenishing groundwater, protecting from sea level rise, increasing network connectivity, mitigating inland flooding, and reducing urban heat island effect.



Improving Water Quality

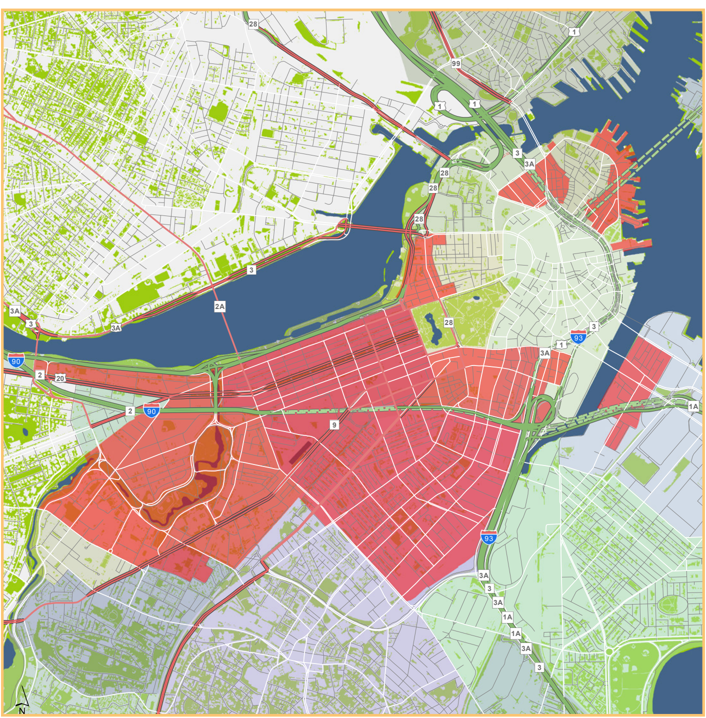


Inland Flooding



Sea Level Rise

Urban Heat Island



Replenishing Groundwater

Habitat and Transportation Connectivity

Improving Water Quality

Water Quality and Regulatory Compliance

As the City of Boston has grown and changed, so too has the Harbor and urban rivers – from their early history as a natural habitat for fish and wildlife, to a dumping ground for sewage and garbage, Boston's waters have been deeply impacted by urbanization. Since the passage of the Clean Water Act in 1972, water quality improvements have been mandated through increasingly strict regulations, monitoring, and enforcement. While the quality of Boston's waters has improved dramatically and serves as a model city comparable to other large cities in the United States, more needs to be done during wet weather conditions. When it rains, urban runoff carries sediments, nutrients, and pathogens into the local water bodies. Stormwater runoff from impervious surfaces remains a threat to the quality of water in Boston.

Green-blue algae blooms caused by excess nutrients dot the surface of the Charles River along the Esplanade in 2020. (Credit: Jesse Costa/WBUR. Source Article)

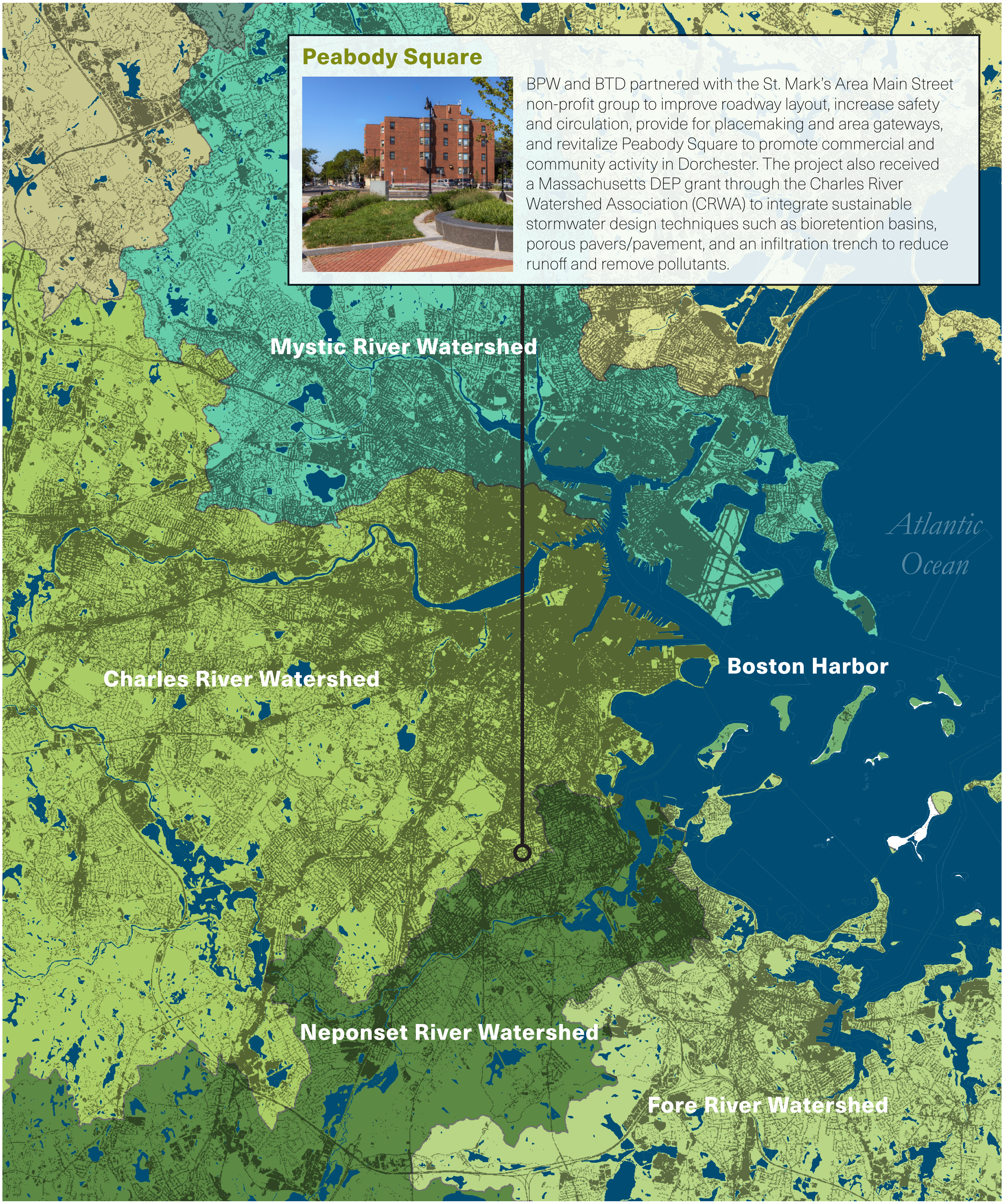
On August 23, 2012, the BWSC filed a Consent Decree settlement with the EPA, the Department of Justice, MassDEP, and the Conservation Law Foundation to enhance its ongoing efforts to comply with the Clean Water Act and to clean and revitalize Boston Harbor and its tributaries, shown on the map to the right. The Consent Decree expands the role of the BWSC as an environmental steward for the City of Boston's waterways. The BWSC has met or exceeded the benchmarks set by the Consent Decree and will continue to fulfill its commitments.

How Green Infrastructure Can Help

Phosphorus is an essential nutrient for all life forms, but too much of it has a significant negative impact on water quality. Increased amounts of phosphorus can stimulate excessive algae growth which causes decreased water clarity, variations in oxygen levels, foul odors, and loss of native flora and fauna. Algal blooms in the Charles River impair the water for fishing and swimming. In urban and suburban areas, phosphorus settles on impervious surfaces such as streets and sidewalks and is picked up by stormwater runoff as it enters the catch basins. Traditional "detention-based" stormwater practices rely on settling to treat stormwater, which helps address solids and constituents adhered to those solids. To effectively remove nutrients, such as phosphorus, green infrastructure stormwater practices that promote infiltration and filtration provide the highest level of effectiveness. GI uses vegetation and soils to absorb sediments, nutrients (like phosphorus), and pathogens from urban runoff.

BWSC Demonstration Projects

GI serves as a critical component of the multi-pronged approach to meet the requirements established by the NPDES Stormwater Permit and the obligations of the Consent Decree. Public and private projects in the City of Boston are integrating green infrastructure strategies to infiltrate and filtrate stormwater runoff from impervious surfaces, which incrementally helps to improve the quality of stormwater discharges to Boston Harbor, the Charles River, the Neponset River, and the Mystic River. Through partnerships with other City agencies, BWSC has implemented a variety of GI demonstration projects at various schools, streetscapes, and public spaces throughout the City. These case studies are presented throughout this Handbook.



Peabody Square

BPW and BTD partnered with the St. Mark's Area Main Street non-profit group to improve roadway layout, increase safety and circulation, provide for placemaking and area gateways, and revitalize Peabody Square to promote commercial and community activity in Dorchester. The project also received a Massachusetts DEP grant through the Charles River Watershed Association (CRWA) to integrate sustainable stormwater design techniques such as bioretention basins, porous pavers/pavement, and an infiltration trench to reduce runoff and remove pollutants.

On August 23, 2012, the BWSC filed a Consent Decree settlement with the EPA, the Department of Justice, MassDEP, and the Conservation Law Foundation to enhance its ongoing efforts to comply with the Clean Water Act and to clean and revitalize Boston Harbor and its tributaries. The map above includes five of the major tributaries and their watersheds that drain into the Boston harbor. Each color highlights the different drainage areas for each watershed including the Charles, Neponset, and Mystic Rivers. The Fore River Watershed is also shown, although it is not covered in the BWSC Consent Decree (Source: MassGIS).

Inland Flooding

Managing Extreme Precipitation

According to the 2018 National Climate Assessment, the Northeast is likely to experience an increase in the frequency and intensity of rainfall events. Boston's stormwater system, which is one of the oldest in the country, was not built to withstand such storms. The 2018 National Climate Assessment found that from 1958 to 2010, there was a 70% increase in the amount of precipitation that fell on days with significant rainfall totals. This increase is greater in the Northeast than any other region of the country and is anticipated to accelerate. During heavy rains, when the stormwater system is at capacity, water stays in the street, and paved roads can quickly become shallow rivers. In addition to the risks of damage to property caused by localized flooding, if water gets into the sanitary or combined sewer systems, it can release untreated sewage back into the street, creating health concerns. The seriousness of this challenge demands public and private solutions to reduce risk city-wide.

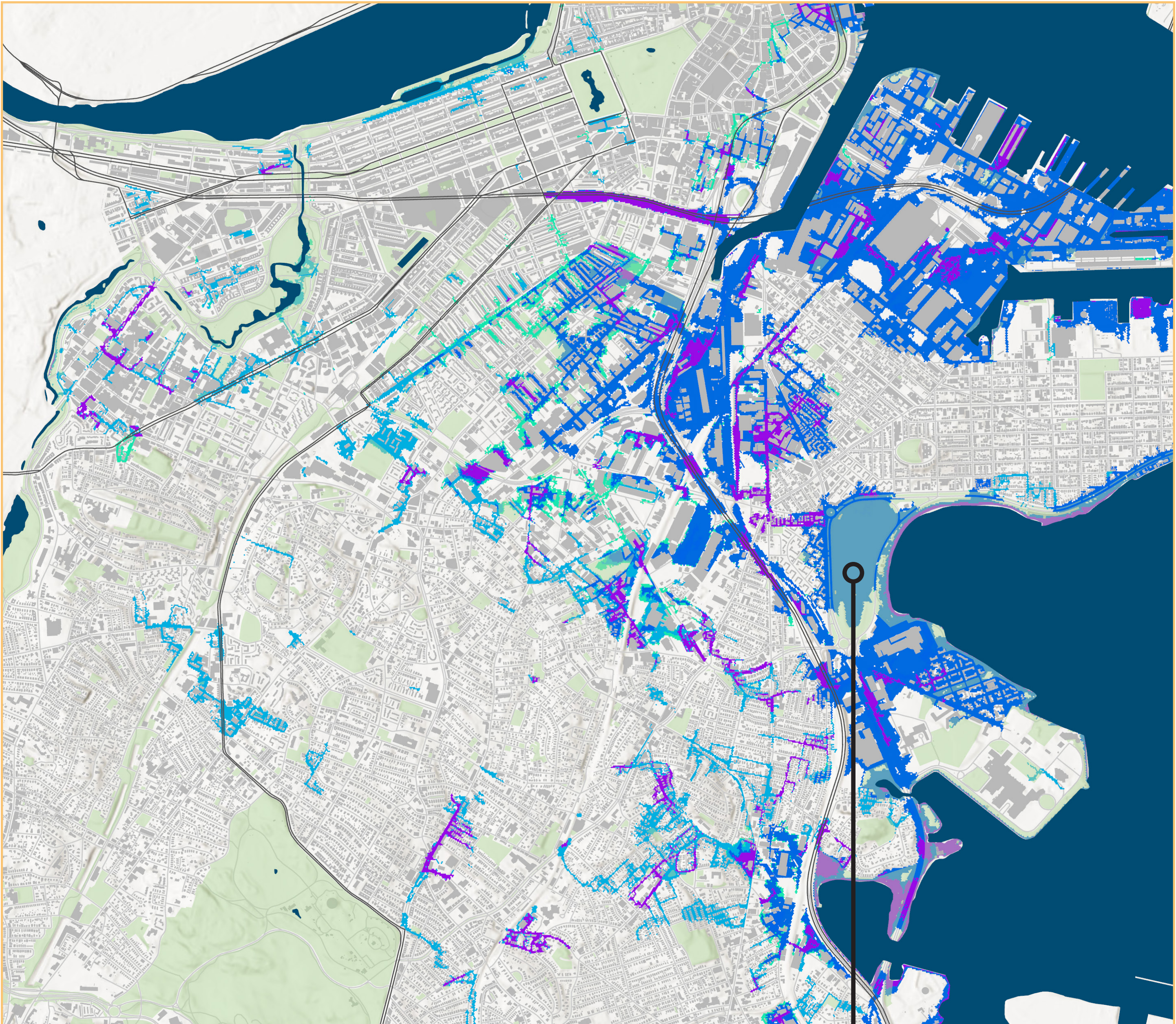
When storm water infrastructure isn't able to drain away, the system can get blocked up and result in overflow. When the stormwater system is combined with sanitary sewers, this water can cause a public health hazard. Source: BWSC

How Green Infrastructure Can Help

Since GI operates on the principle of keeping water as close to where it lands as possible, GI solutions that optimize retention and detention practices are the most effective for helping minimize the occurrence and impacts of inland flooding. Large-scale detention and retention systems are tremendously effective at capturing stormwater during heavy precipitation, storing it, and then either releasing it slowly into the MS4 system, infiltrating the ground, or using soil and plant uptake to release it back into the air through evaporation. Even small-scale GI systems can help reduce flood risk by providing storage and slowly releasing stormwater, especially when implementation of is widespread.

The BWSC Wastewater Facilities Plan

The BWSC Wastewater Facilities Plan (2015) predicts annual and event-based increases resulting from various emissions scenarios. BWSC has adopted the recommendations from the 2015 BWSC Wastewater Facilities Plan to use the 10-year 24-hour design storm volume of 5.20 inches and peak intensity of 1.65 in/hour. The future predicted storm events have also been adopted into the City's Climate Ready Boston reports to support a pro-active approach for development in the City of Boston. The online BWSC Storm Viewer is a public resource that can be used to view coastal and inland flooding predictions for various predicted storm, sea level rise, and coastal events. This information can be used by the City and private developers to identify flood risk and design solutions, such as green infrastructure, large-scale detention systems, and flood barriers to help mitigate coastal and inland flood risk.



Moakley Park Vision Plan

The City of Boston is transforming Moakley Park into a resilient 21st century community amenity through the Moakley Park Vision Plan. While modernizing and enhancing the park's existing athletic facilities and recreational functions, the redesign protects surrounding neighborhoods from sea level rise and storm surge and addresses inland flooding concerns resulting from surcharged storm drains exacerbated by higher tides. The Park's stormwater management approach includes green infrastructure strategies such as stormwater meadows, tree filters, porous pavement, and subsurface storage for large storm holding capacity during coastal flood events.

In 2021, the Boston Water and Sewer Commission launched the online Storm Viewer, an interactive web map application that allows the user to explore different flood inundation models and their impacts on the city. Different types of storms include Airmass, Nor'Easter, Frontal, and Tropical Events, which can be calibrated based on 2030, or 2070 sea level rise projections with storm surge. This map shows the 2030 and 2070 projections for Air Mass storms across different annual probabilities. (Source: BWSC)

Sea Level Rise

Preparing for Higher Tides

Global warming has many consequences for waterfront cities, the most challenging of which may be sea level rise. Although how much sea levels will rise and how quickly is unknown, accelerating rates in the coming decades are likely to increase the frequency and extent of coastal flooding. Extreme weather accompanied by storm surge can also cause significant damage to coastal property and habitats. During coastal flood events, stormwater infrastructure becomes "surcharged", reducing the ability to convey and discharge stormwater from inland areas. As a result, it is critical for the City of Boston to increase its resilience to these impacts.

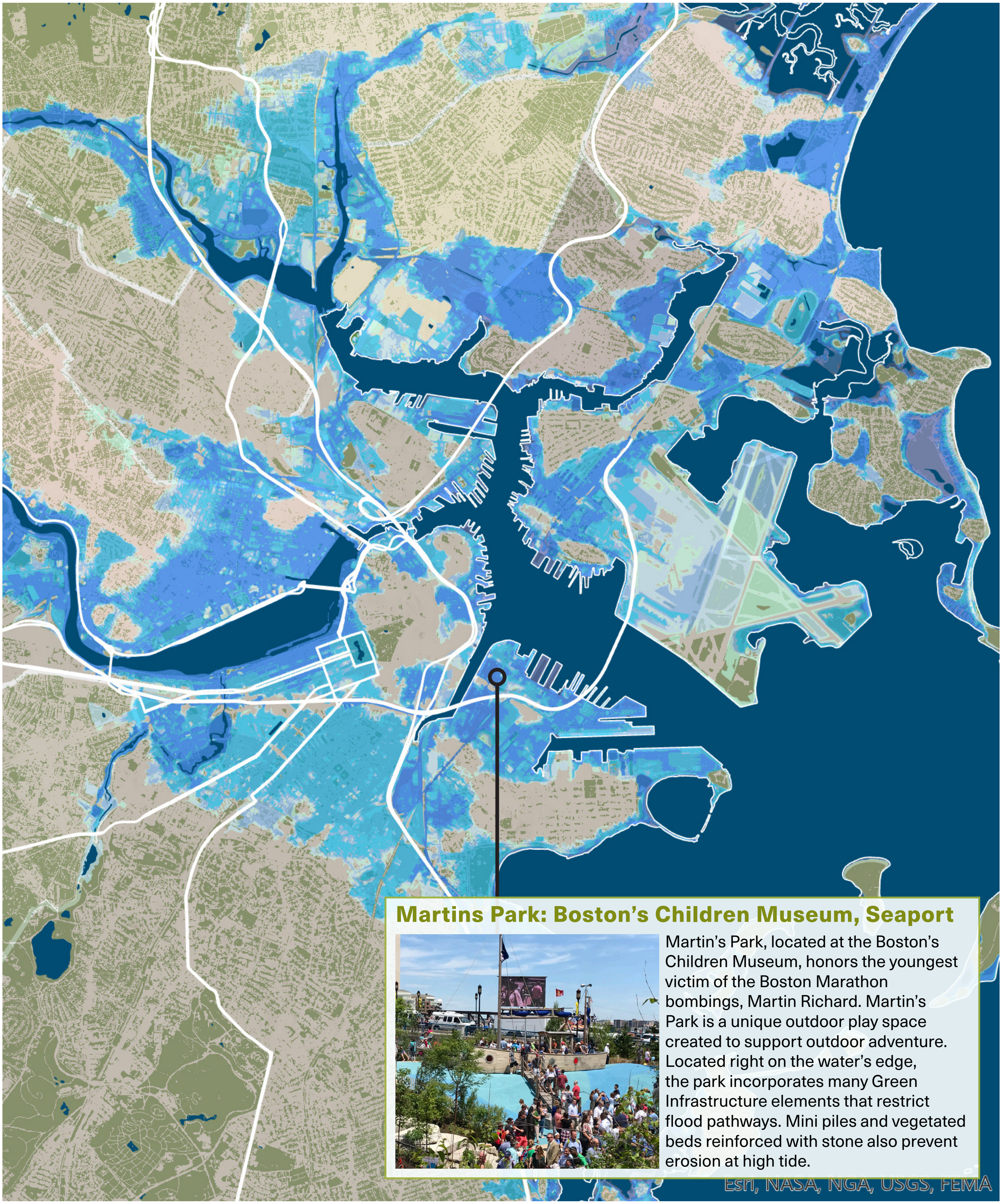
Ryan Playground in Charlestown is an important community asset that faces a host of threats from sea level rise. A proposed redesign would create raised, permeable surfaces like sports fields and wetlands to reduce wave action and protect nearby neighborhoods from rising seas. (Source: Climate Ready Charlestown)

How Green Infrastructure Can Help

"Hard" or "gray" infrastructure systems like seawalls can reduce the impacts of sea level rise and storm surge, but they do not have as many of the co-benefits of GI strategies. Strategies like vegetated berms and wetlands create a protective element, recreational amenity, and habitat for different types of wildlife. Wetlands can also help improve water quality by filtering out pollutants from runoff. Thus, using GI over traditional measures creates both an protective buffer from rising tides and storm surge, while creating a resilient open space along the coastline that keeps the waterfront beautiful and accessible to all.

Coastal Flood Resilience Design Guidelines

Climate Ready Boston is an initiative to help the City of Boston prepare for the impacts of climate change, including sea level rise. In 2019, as a follow-up to extensive research on sea level rise impacts in the city, the BPDA released Coastal Flood Resilience Design Guidelines to help developers and property owners understand their risks and proposed new design guidelines to protect buildings and people. The guidelines provide recommendations for flood protection for all projects within the Coastal Flood Resiliency Overlay District (CFROD), or areas inside the 2070 1% annual chance flood risk zone, which accounts for up to 40 inches of sea level rise. The Design Guidelines highlight landscape strategies like detention features, green stormwater infrastructure, permeable pavements, and green roof systems to ensure that today's investments will last for generations to come.



Martins Park: Boston's Children Museum, Seaport

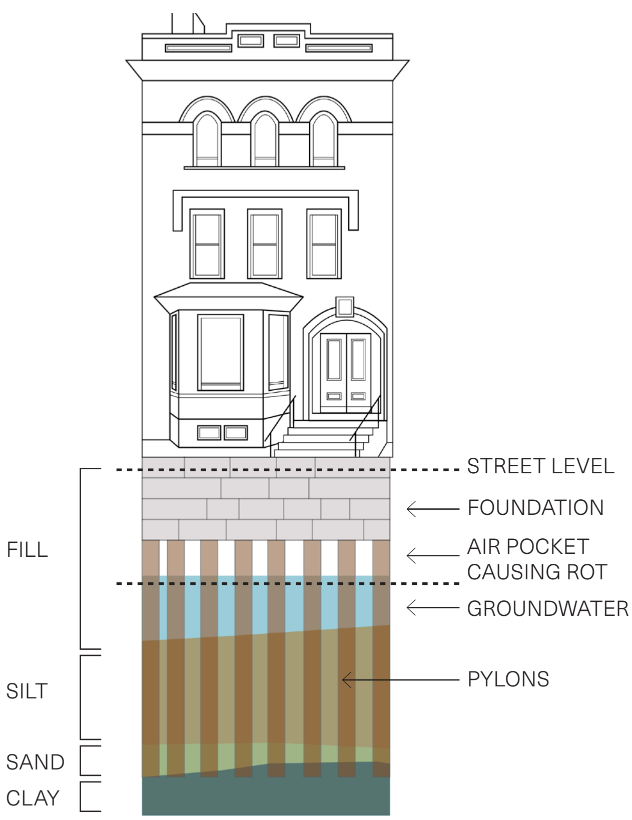
Martin's Park, located at the Boston's Children Museum, honors the youngest victim of the Boston Marathon bombings, Martin Richard. Martin's Park is a unique outdoor play space created to support outdoor adventure. Located right on the water's edge, the park incorporates many Green Infrastructure elements that restrict flood pathways. Mini piles and vegetated beds reinforced with stone also prevent erosion at high tide.

Above: Sea level rise is a regional problem that will affect jurisdictions throughout the Boston area and beyond. This map highlights sea level rise predictions at 1-ft intervals. One foot of sea level rise is highlighted in dark blue, and ten feet of sea level rise is highlighted in the lightest blue color. This does not include flooding impacts exacerbated by storm surge or rainfall. (Source: NOAA Sea Level Rise, MassGIS.)

Replenishing Groundwater

A Historic City Built on Fill

Boston's early settlers constructed the city by dumping tons of gravel, sand, and trash on top of mudflats to 'fill' in the ground. This process was reinforced using wood pylons to support the construction of two-story brick buildings throughout Fenway, Back Bay, South End, Bay Village, Beacon Hill, Chinatown, the Leather District, the Bulfinch Triangle, the North End and Downtown, Fort Point Channel, and East Boston, giving these neighborhoods the character we know and cherish today. For centuries, groundwater levels have preserved the pylons and prevented them from rotting, but over time, groundwater has been depleted. As groundwater is pumped out, oxygen enters the areas where pylons were once preserved, causing rot. As the pylons decompose, the historic buildings start moving, resulting in structural damage.



Section of a historic building affected by drawdown. (Credit: Nitsch Engineering, adapted from Boston Groundwater Trust.)

How Green Infrastructure Can Help:

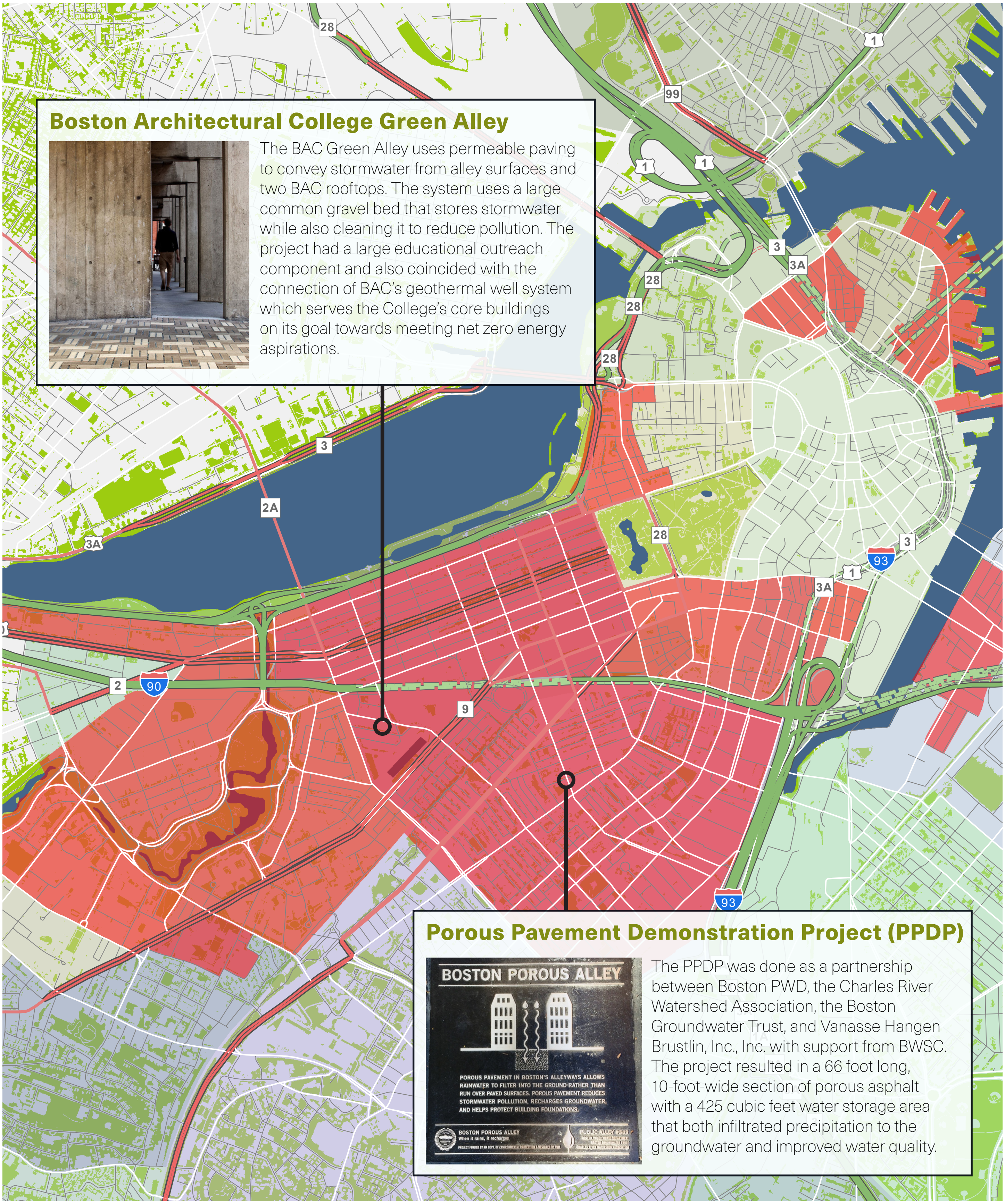
Replenishing groundwater is one way to address this challenge and preserve the City of Boson's historic neighborhoods. One of GI's benefits is groundwater recharge, a process of replenishing shallow aquifer systems. GI features like bioretention and infiltration practices can be designed specifically to divert stormwater from impermeable surfaces and inject it back into the groundwater supply. In the case of Back Bay, this groundwater recharge can help replenish the water level and preserve the wood pylons the historic buildings standing.

The Boston Groundwater Trust and Article 32

Since 1986, the Boston Groundwater Trust has been working to address this issue and protect groundwater levels in the City of Boston. In 2006, the City of Boston adopted a Groundwater Conservation Overlay District (GCOD) to require certain actions to replenish groundwater. The purposes of Article 32 are to:

- Prevent the deterioration of and restoration of groundwater levels in the City of Boston.
- Protect and enhance the City of Boston's historic neighborhoods and structures, and otherwise conserve the value of its land and buildings.
- Reduce surface water runoff and water pollution.
- Maintain public safety.

Projects located in the GCOD are required to retain and infiltrate rainfall on-site.



Boston Architectural College Green Alley

The BAC Green Alley uses permeable paving to convey stormwater from alley surfaces and two BAC rooftops. The system uses a large common gravel bed that stores stormwater while also cleaning it to reduce pollution. The project had a large educational outreach component and also coincided with the connection of BAC's geothermal well system which serves the College's core buildings on its goal towards meeting net zero energy aspirations.

Porous Pavement Demonstration Project (PPDP)

The PPDP was done as a partnership between Boston PWD, the Charles River Watershed Association, the Boston Groundwater Trust, and Vanasse Hangen Brustlin, Inc., Inc. with support from BWSC. The project resulted in a 66 foot long, 10-foot-wide section of porous asphalt with a 425 cubic feet water storage area that both infiltrated precipitation to the groundwater and improved water quality.

Above: The City of Boston adopted the Ground Water Conservation Overlay District (shown highlighted in red) in 2006 to help replenish groundwater in the Fenway, Back Bay, South End, Bay Village, Beacon Hill, Chinatown, Leather District, Bullfinch Triangle, North End, Downtown, Fort Point Channel, and East Boston neighborhoods. (Source: Boston Groundwater Trust, BPDA, MassGIS.)

Urban Heat Island

Keeping Cool in a Warming World

Cities are hotter than rural areas due to urban heat island effect, a phenomenon that describes how buildings, roads, and sidewalks absorb energy from the sun during the day and radiate that heat back out at night. In rural and suburban areas, trees, plants, and waterbodies cool the air through evapotranspiration, but urban neighborhoods tend to be hotter during the day and stay hot at night. Urban heat island effect is exacerbated by climate change as global temperatures continue to rise. Neighborhoods without access to green space or cooling centers are disproportionately vulnerable to negative health impacts, which is why addressing urban heat island is a critical resilience initiative as part of Climate Ready Boston.

How Green Infrastructure Can Help

The types of Green Infrastructure (GI) I best suited for reducing urban heat island effect include landscape-integrated strategies such as bioretention, tree filters, and green roofs. The vegetation in GI can reduce urban heat island effect by lowering the total area of sidewalk and pavement in a city. Trees reflect direct sunlight and provide shade, which is critical relief during hot days. Plants cool the air through evapotranspiration, a critical feature of photosynthesis, which is the process by which plants absorb sunlight and convert it to energy. This amazing process highlights the many benefits that GI can provide simultaneously. Plants can not only reduce flooding and purify our water, as described in previous sections, but they can also shield our neighborhoods from the threats of extreme heat caused by global warming.

Urban Forestry Plan

In September of 2020, Mayor Marty Walsh and the Bostopn Parks and Recreation Department (BPRD) BPRD announced an ambitious goal to develop a 20-year Urban Forestry Plan, with the goal of protecting, restoring, and increasing tree canopy across the City of Boston. The plan also seeks to create economic opportunity for minority-owned businesses and target historically underinvested neighborhoods for tree canopy installation and job training programs. The tree canopy program will not only reduce urban heat island effect, but also improve the quality of the city's ecology, with the goal of planting 2,000 trees per year.

Boston is going to get a lot hotter in the future! In 2016, the City of Boston partnered with the Trust for Public Land's Climate-Smart Cities Initiative to find ways to use GI to prepare the city for increasing Urban Heat Island effect. The report recommended the use of GI such as green roofs and tree plantings in the city's neighborhoods most vulnerable to extreme heat. You can read the Urban Heat Island report here. (Above: Residents cooling off during a heatwave in Boston. Source: Boston Magazine)

City Hall Plaza Renovation

Boston's City Hall Plaza is a seven-acre plaza and one of the City's largest civic spaces. The City Hall Plaza Renovation project will re-invigorate the space to be a more accessible, sustainable, and comfortable shared space for all Bostonians and visitors. The renovation includes an increase in permeable surfaces that will soak up stormwater and 100 new trees that will improve the shade, scale, and air quality of the Plaza. (Source: City of Boston)

Urban heat island effect is caused by the impermeable surfaces such as roads, buildings, and infrastructure that make up our cities. In areas with high degrees of impermeable surfaces, there is usually a lack of vegetation. The map above shows the opposite, featuring the highly permeable surface areas of the Boston area in light green, and formal open space in dark green. The areas of the map that are left white are highly impermeable, and therefore are more vulnerable to higher temperatures. (Source: MassGIS, Analyze Boston)

Habitat and Transportation Connectivity

Creating Connected Networks

In addition to affecting the hydrological system, urbanization fragments critical habitat corridors that native flora and fauna rely on to survive. As cities grow, it also becomes increasingly challenging to design transportation and connectivity networks that allow residents to move freely and easily throughout the city. As attention to reducing greenhouse gases increases, many cities and their residents are seeking ways to promote mobility alternatives such as bike paths and pedestrian corridors, sometimes called greenways or greenlinks. Greenways are linear parks with paths that encourage healthy active transportation. Green links are missing bike and pedestrian connections that, when completed, create a seamless network of greenway paths connected to every neighborhood. These systems often incorporate GI elements to maximize their benefits.

The Rose Kennedy Greenway is an iconic public space in the heart of downtown Boston. In addition to providing a pedestrian friendly way to move through the city, the Greenway includes acres of landscaping maintained completely organically, manages all of its stormwater on site, and provides critical bee and pollinator habitats. (Source: Rose Fitzgerald Kennedy Greenway Conservancy)

How Green Infrastructure Can Help

When GI is designed as part of a larger, interconnected system, it can provide critical habitat for wildlife as well as create more effective hydrological channels to drain water. GI can be integrated into multi-modal transportation networks, especially for bicyclists and pedestrians. When properly designed, narrower, green streets increase safety by decreasing vehicle speeds and make neighborhoods safer for pedestrians and cyclists. GI features can be used to alter curb geometry and traffic patterns, creating shorter, safer pedestrian crossings while reducing ponding and puddling at the base of handicap ramps.

Boston Complete Streets & Green Links

The Boston Complete Streets Initiative (CSI) is a citywide initiative led by BTD in collaboration with various city agencies including BWSC. The CSI developed new street design guidelines that focus on multi-modal transportation, green design, and smart technology to make transportation more accessible to pedestrians, people with disabilities, bicyclists, public transportation users, and drivers. CSI design elements incorporate GI to reduce pollution and promote an environmentally sensitive, sustainable use of the Public Right-of-Way (PROW). Boston Green Links is a city-wide plan to connect people in every neighborhood to the City of Boston's greenway network by installing new paths, new bike facilities, and safer road crossings. It helps to inform where the CSI should be implemented throughout the City of Boston's many neighborhoods.

New England Avenue

The New England Avenue project is a collaboration between several City of Boston departments including the BPWD, BTD, Disabilities Department, BWSC, and BPRD. The improvements were designed in accordance with the City of Boston's Complete Streets Design Guidelines to reduce vehicle speeds through the residential neighborhood, increase safety and mobility for all modes of travel, and incorporate GI elements like bioretention and tree filters to treat stormwater runoff and passively irrigate tree roots.

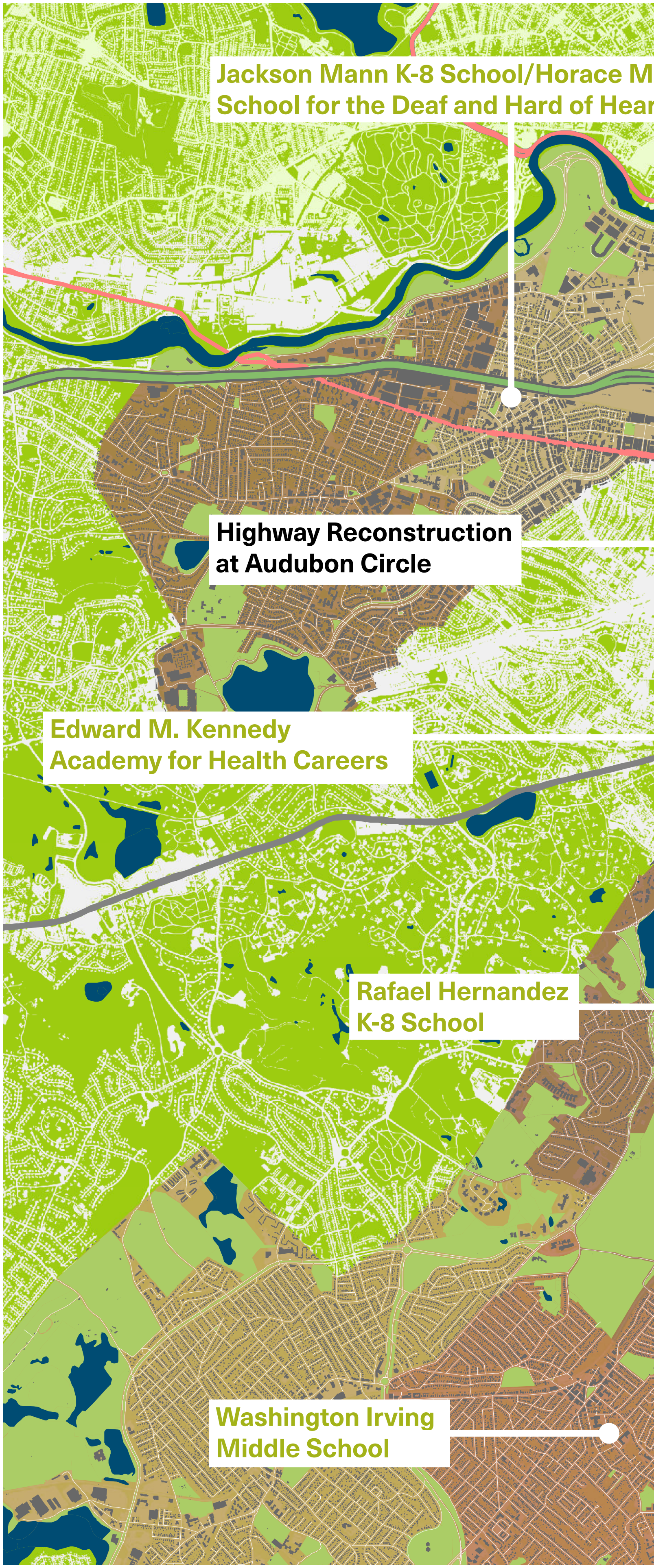
Above: Green Infrastructure elements like trees and bioswales provide critical habitat corridors for species such as birds, butterflies, squirrels, and other insects. These types of habitat corridors also provide critical transportation and recreational amenities for pedestrians and bicyclists. This map shows existing bike routes throughout Boston (yellow) and data points from the Boston Vision Zero survey initiative (red). Boston's open space (light green), tree canopy (dark green), and wetlands are also shown (teal). (Source: MassGIS, Analyze Boston.)

2.3 BWSC Demonstration Projects

The Boston Water and Sewer Commission (BWSC) is required to take swift action to address water quality issues. On May 17, 2013, the BWSC submitted a Phase I Best Management Practice (BMP) Implementation Plan that provided recommendations for implementation of GI and Low Impact Development (LID) measures for stormwater management for demonstration projects located around the City of Boston. Each of the demonstration projects accomplishes the primary goal of capturing and infiltrating the first inch of rainfall.

BWSC's first demonstration projects heavily focused on GI streetscapes that emphasized stormwater management in conjunction with safety improvements to help the city accomplish its Vision Zero goals through Complete Street Design Guidelines. Working together with several agencies including the Boston Transportation Department (BTD), Boston Public Works Department (BPWD), Boston Parks and Recreation Department (BPRD), and the Massachusetts Bay Transportation Authority (MBTA), the BWSC and its partners developed GI pilots in three key locations, including the City Hall Plaza/MBTA Government Center Station, Central Square (East Boston), and the Highway Reconstruction at Audubon Circle. Since the early demonstration projects, the BWSC has continued to implement additional streetscape projects across the City of Boston. As of 2021, these GI demonstration streetscapes have grown to include New England Avenue and Codman Square.

While there is a common misconception that GI features are not suitable for an urban environment, the BWSC demonstration projects show the numerous GI features that can be utilized even in dense urban neighborhoods and transit centers. The projects aim to showcase the positive benefits of GI, increase public awareness, and create buy-in to embracing the many opportunities that GI provides.

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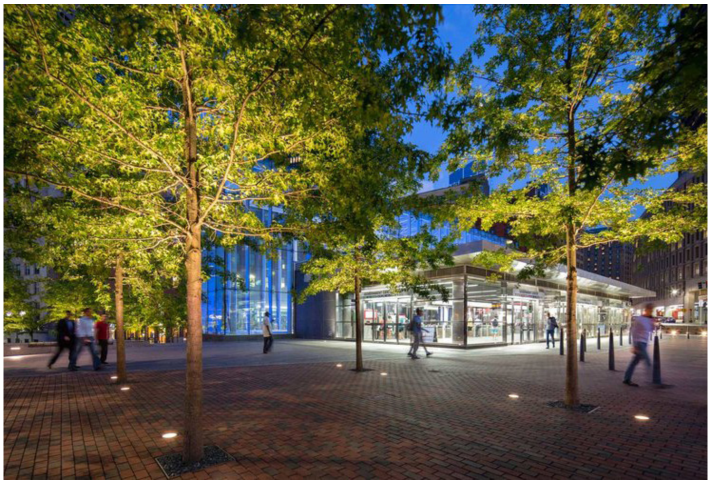
ring
Central Square (East Boston) Complete Streets and Park Improvements
City Hall Plaza/MBTA Government Center Station
David A. Ellis Elementary School
Codman Square
New England Avenue

MBTA Government Center Station Improvements



The MBTA Government Center Station Improvements Project began in 2013 and was completed in Spring 2016. The MBTA project began as a Boston Public Works Department effort to comply with the American Disabilities Act, and BWSC partnered on the project to implement wide ranging permeable surface GI solutions. Other specific features include:

- Tree trenches with porous paver overlay for infiltration of stormwater into sand-based structural soil (to enhance tree health and capture and treat stormwater)
- Passive irrigation system using roof runoff from the station headhouse
- Water quality filter units (before discharge to the Commission's storm drain system)

The eventual designs for the larger City Hall Plaza portion of this project will integrate GI/LID features into Boston City Hall and the surrounding plaza, to highlight first inch rainfall capture requirements.

Partners: Boston Public Works Department

Central Square (East Boston) Complete Streets and Park Improvements

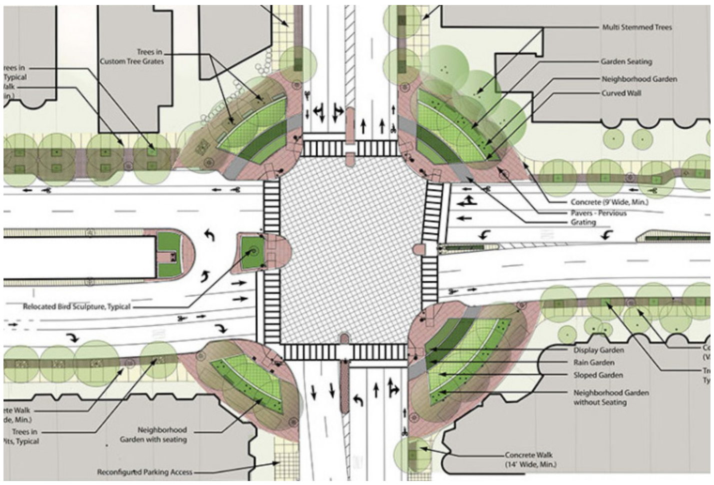
GI features for this project include two different types of subsurface infiltration systems and three different types of permeable surfaces, including:

- Porous concrete slabs over infiltration trench
- Porous asphalt over infiltration trench
- Permeable unit pavers over sand-based structural soil and stormwater infiltration trenches
- Stormwater infiltration trenches/sand-based structural soil under standard sidewalks/roadways
- Passive irrigation system that captures stormwater runoff from roadways and uses it for tree irrigation

The project also includes using modified "control" drainage manholes for routing stormwater into the various stormwater infiltration trenches to achieve the objective of controlling and storing the first 1 inch of rainfall. During periods of high stormwater flow, the control manhole weirs can be overtopped and stormwater is discharged to the Commission's storm drain system. The weirs also have a stop gate, which which can be manually operated to allow stormwater to bypass trenches during winter operations.

Partners: Boston Transportation Department, Boston Public Works Department, and Boston Parks & Recreation Department

Highway Reconstruction at Audubon Circle



Audubon Circle incorporates similar features to those at Central Square. including a combination of subsurface features and permeable surfaces to show how the two can work together, including:

- Rain gardens that infiltrate stormwater runoff
- Permeable unit pavers over sand-based structural soil and stormwater infiltration trenches
- Stormwater infiltration trenches/sand-based structural soils under standard sidewalks/ roadways

Like the Central Square project, the Audubon Circle GI includes control manholes with weirs and stop gates. The inclusion of rain gardens at three of the four corners of Audubon Circle incorporates a landscape design element that provides public open space, surface infiltration features with curb inlets, and passive irrigation for the various landscaped planters.

Partners: Boston Transportation Department, Boston Public Works Department

Build Boston Public Schools (BPS)

In 2017, Boston Public Schools (BPS) announced that they would undertake a 10-year Master Plan, including an assessment of the 133 BPS facilities to determine which facilities need repairs/renovations. BWSC partnered with the Boston Public Schools (BPS) Facilities Management Department to complete GI/ LID pilot projects at five Boston public schools that highlight a variety of GI elements that can be applied to future facility repairs and renovations. The result of the Master Planning process was an initiative called “Build BPS,” which is currently underway.

Schools of varying sizes and development densities were selected for the pilot projects to highlight what is possible in urban school yards. The following five projects were completed in 2018 and a GI curriculum is now being taught in BPS classrooms across the city.

- The David A. Ellis Elementary School
- Jackson Mann K-8 School/Horace Mann School for the Deaf and Hard of Hearing
- Edward M. Kennedy Academy for Health Careers
- Rafael Hernandez K-8 School
- Washington Irving Middle School

Partners: Boston Public Schools

rafael hernandez elementary school roxbury, ma

CHAPTER 3

Design Guidelines

Boston faces specific challenges due to historic development patterns and the impacts of climate change. Chapters 1 & 2 provided a big picture view of why Green Infrastructure (GI) is important to Boston Water and Sewer Commission (BWSC) and how the widespread implementation of GI can help. This chapter provides a developer or design professional with additional information to ensure their project's successful GI implementation. Every project presents an opportunity to strengthen Boston's resilience, have a positive impact on water quality, and address the unique challenges the city faces now and into the future.

3.1 Research & Site Analysis

An essential step to any successful design project is thorough research and site analysis. This process allows the designer and/or developer to identify opportunities and constraints present on their site and in relation to their project goals. A site analysis often informs design decisions such as where to site buildings, roads, and open spaces. In addition, site conditions become factors for the selection of Green Infrastructure solutions. The following sections describe information and resources useful for conducting a site analysis for GI implementation.

Collaboration & Consensus Building

A key element to a successful project is collaboration among various parties, including the owner and design team members such as hydrologists, engineers, landscape architects, and architects. Keeping all team members involved in the process from the beginning ensures different site elements can work in harmony with one another. Often, this collaboration can reveal new design solutions that meet the project goals, as well as prevent conflict and construction problems down the road. It is important to define project goals early in the process and get agreement from all stakeholders. Research and engagement with the following stakeholders can maximize a project's potential:

Feedback from community members and stakeholders is key to the collaboration process and should happen early in the design phase. (Source: Nitsch Engineering)

- Permitting agencies
- Adjacent or nearby businesses
- Community Organizations and Non-Profits
- Educational Institutions and Schools
- Public funding or grant programs
- "Green jobs" and Employment Opportunities

Considering factors beyond the physical site and proposed improvements may lead to unexpected partnerships that make a project more successful.

Desk Research

Conducting a site analysis involves gathering many layers of information – everything from site history, soils, typography, and more. The following is a list of existing site conditions to research as part of the due diligence and site analysis for any project. While not comprehensive, these items should be considered and may lead to additional research depending on specific site conditions:

- Site history, land use, and site context
- Existing vegetation (species, size, condition)
- Topography and hydrologic patterns
- Soils and soil properties obtained from the Natural Resources Conservation Service (NRCS)
- Existing utilities, water lines, and sewer lines
- Existing wetlands or potential endangered species habitats

GIS Analysis

Geographic Information Systems (GIS) tools are very useful for analyzing layers of spatial information. The City of Boston and Commonwealth of Massachusetts, along with other cities, counties, and federal offices, have datasets available for public use. Some useful resources for analyzing your site include:

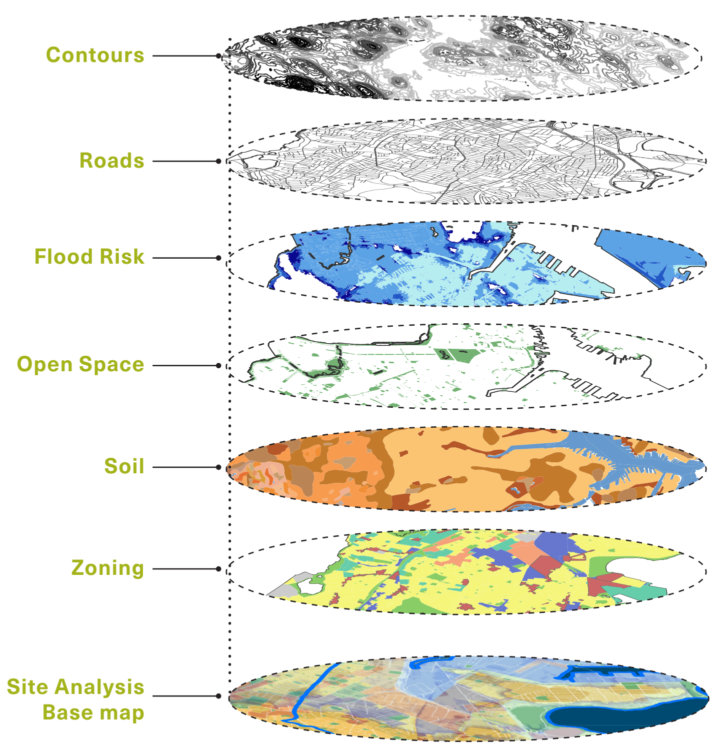
- Boston Open Data
- OLIVER - The MassGIS Online Data Viewer
- BWSC Maproom

Field Research

A site visit and field research are often necessary to produce a successful design. Experiencing the site (at different days and times, if possible) allows the owner and designer to understand how specific elements will impact the design. When designing for GI solutions, visiting the site during wet weather can be very beneficial to the designer and often reveal hydrologic patterns or characteristics of the existing conditions that are not apparent from desk research. Some key elements to examine are:

- Existing tree height, spread, and canopy
- Pervious and impervious surfaces
- Impact of overhead wires/utilities
- Topography and site-scale hydrologic patterns
- Existing stormwater infrastructure
- Pedestrian and vehicular traffic patterns
- Shade and sun exposure

All design teams should strongly consider preparing a topographic survey by a Professional Land Surveyor. This detailed and accurate information becomes invaluable when designing and optimizing GI systems. A topographic and utility survey should be used as a base for design drawings and eventually as-built drawings (a requirement of BWSC Site Plan Approval).



Hydrologic Evaluation

In the analysis stage of the project, it is important for designers to understand the local and regional hydrologic context of the site. Mapping tools, surveys, and site visits are helpful to gather the following data:

- Offsite drainage impacts ("run on" to the site)
- Drainage flow paths and runoff patterns
- Area of impervious surfaces vs. pervious surfaces
- Historic flooding issues on the site
- High and low elevation points on-site
- Location and condition of: existing catch basins, area drains, and trench drains; gutters and swales;
- Elevation, size, capacity, and condition of storm pipes and drains

Designers should aim to maintain or improve the existing hydrology of the site whenever possible. Existing low-lying areas present opportunities for GI as local surface runoff is already directed to these areas via overland flow or storm drain infrastructure. Where Site Plan Submission is required, BWSC requires a pre- and post- construction Drainage Analysis in accordance with the Massachusetts Stormwater Handbook. A registered Professional Civil Engineer will often prepare hydraulic, hydrologic, and water quality calculations to ensure requirements are met.

Site Analysis Conclusions

After gathering research and conditions of the project site, it is important for the assessing team to summarize this research in a site analysis. This could be as simple as written conclusions or could take the form of an illustrative diagram. It can be helpful to visualize opportunities and constraints on a site map. An example of a site analysis for a Case Study is shown in Section 3.3 of this Handbook.

The conclusions from the site analysis form the connection between project design goals and the specific site conditions. The selection of appropriate Green Infrastructure is not a one size fits all solution and requires evaluation of a variety of factors throughout the planning and design process.

At left: Geographic Information Systems (GIS) tools allow design teams to visualize a variety of spatial data in several layers that can help inform Green Infrastructure planning and design. (Source: Nitsch Engineering)

3.2 Green Infrastructure Design

The design process – a project evolving from conceptual ideas to final construction drawings – will look different depending on the project team and project considerations. Successful implementation of Green Infrastructure (GI) solutions requires the project team to collaborate and consider stormwater management throughout the entire design process.

Green Infrastructure & Low Impact Development as Design Goals

The terms Low Impact Development (LID) and GI are often used interchangeably. Both approaches ultimately have the same goals – to preserve natural areas, minimize adverse environmental impacts from stormwater runoff, and manage stormwater at, or close to, its source. Before selecting GI BMPs, consider the following goals for overall site design:

- Stormwater as a resource, not a waste product
- Infiltrate water in the ground where it falls
- Maintain natural drainage systems when possible
- Decentralize stormwater management systems
- Reduce impervious surfaces by reducing building footprint or minimizing at-grade impervious
- Use pervious pavements when possible
- Use GI BMPs to treat, reuse, and infiltrate runoff from pervious surfaces
- Designate separate systems for contaminated and uncontaminated runoff
- Use underground pipes only when necessary

To accomplish these goals, special attention should be given to the hydrology of the site along with the size and scale of site improvements such as buildings or parking areas. Each site is unique and will require a unique plan to manage stormwater. Creative solutions are often born out of collaboration during site design!

Selecting Green Infrastructure Solutions for Suitability & Performance

The design team should select GI solutions based on the site context and the desired performance of different BMPs. Not all GI solutions are suitable for all situations, nor do they provide the same functions depending on site constraints. This Handbook provides a number of tools on the following pages for design teams to understand the functions of different GI solutions:

- Page 47: The Green Infrastructure Overview highlights the GI solutions most suitable for an urban environment. For more details about each GI solution, refer to the Toolkit included in this Handbook.
- Page 48-49: The Suitability Matrix can be used to identify GI solutions that are most appropriate for their unique site conditions based on data gathered in the site analysis phase.
- Page 50-51: The Performance Matrix describes the ability of different GI solutions to perform three primary stormwater management functions: peak rate mitigation, volume mitigation, and water quality treatment.

These tables are not prescriptive nor do they cover the full range of GI options. Many GI solutions can be combined or modified to meet the needs of a specific project. A design team should research the basics of each and understand where flexibility or modification could exist. Creative thinking and collaboration often produce a much better solution than the "out of the box" solution. The GI Toolkit in this Handbook provides more detailed technical information on the selected GI solutions.

Green Infrastructure Overview

INFILTRATION PRACTICES

Subsurface Infiltration typically consist of storage voids within a bed of gravel/aggregate (washed crushed stone), or within storage devices (perforated pipes, plastic arch chambers, etc.) embedded within a bed of gravel used to temporarily store stormwater and exfiltrate to underlying soils.

Infiltration Trenches are shallow excavations filled with washed crushed stone. Voids in the stone temporarily store stormwater for exfiltration into underlying soils. Optional infiltration risers can be used to optimize movement of stormwater into a stone reservoir and are typically designed to overflow at the surface.

Surface Infiltration Basins are depressions or impoundments constructed over permeable soils and provide temporary surface storage for pre-treated stormwater to exfiltrate into underlying soils.

Tree Filters (a.k.a. tree pits or tree trenches) are systems with a tree planted in porous soil and an underlying trench of washed crushed stone and perforated pipe. They often accept sheet flow from paved surfaces. Diverted stormwater from roadway catch basins can also be diverted through a perforated pipe in the crushed stone trench.

BIORETENTION TECHNIQUES

Bioretention (a.k.a. Rain Gardens) are shallow depressions filled with sandy soil and planted with dense, usually native, vegetation. Stormwater runoff is temporarily stored in the surface depression, percolates through soil and a stone reservoir, finally infiltrating into the ground. They are often placed in open spaces adjacent to impervious surfaces.

Biofiltration can be used where poor underlying soil conditions will not allow for infiltration. Biofiltration is similar to Bioretention in that it includes a surface depression filled with sandy soil and plantings. Stormwater percolates through the soil and stone reservoir, where it is drained away by underdrains.

Bioretention Planters are recessed bioretention or biofiltration systems typically contained within a planter or curbing within paved areas such as sidewalks or plazas. Stormwater runoff that drains across paved surfaces often enters through curb cuts.

PERMEABLE PAVEMENTS

Porous Asphalt looks like traditional asphalt but is comprised of larger aggregate and fewer fine particles, creating voids in the pavement, allowing water to infiltrate. It includes several layers of material with specific sizes to absorb, filter, and infiltrate stormwater.

Permeable Pavers are made up of interlocking concrete modules or unit brick pavers. Space between the pavers creates open voids in the surface and allows water to drain into a base of crushed stone.

ROOFTOP STORAGE

Green Roofs are planted rooftops that consist of plants and engineered soil media which intercept and store rainwater. Some rainwater is returned to the atmosphere by evapotranspiration while treated excess water is slowly released to a drainage system.

Blue Roofs are rooftop structures designed to temporarily store and slowly release captured rainwater.

Cisterns are storage tanks used to store captured rainwater and can be surface or subsurface structures. The captured water is usually reused for non-potable water demands such as irrigation or toilet flushing.

Suitability Matrix

EXISTING SITE CONDITION	RANGE	INFILTRATION PRACTICES: Subsurface Infiltration	Infiltration Trench	Surface Infiltration Basin	Tree Filter	Bioret (Infiltr
Development Density	High Density	Most Suitable	Most Suitable	Suitable	Most Suitable	Suit
	Low Density	Suitable	Suitable	Most Suitable	Suitable	Mo Suit
Existing Soil Permeability	Low	Suitable	Suitable	Suitable	Most Suitable	Suit
	High	Most Suitable	Most Suitable	Most Suitable	Suitable	Mo Suit
Microclimate	Full Sun	Suitable	Suitable	Most Suitable	Most Suitable	Mo Suit
	Full Shade	Most Suitable	Most Suitable	Suitable	Suitable	Suit
Slope	Moderate (<6%)	Most Suitable	Most Suitable	Most Suitable	Most Suitable	Mo Suit
	Steep (6-10%)	Suitable	Most Suitable	Suitable	Most Suitable	Suit
Treatment Train Location	Overland Flow	Suitable	Most Suitable	Most Suitable	Suitable	Mo Suit
	Piped Inflow	Most Suitable	Suitable	Suitable	Most Suitable	Suit
OTHER CONSIDERATIONS						
Avg. Annual Maintenance Cost		$$	$$	$$	$$	$$

Suitability: Most Suitable | Suitable

BIORETENTION TECHNIQUES			PERMEABLE PAVEMENTS		ROOFTOP STORAGE		
ention (ration)	Biofiltration	Bioretention Planters	Porous Asphalt	Permeable Pavers	Green Roofs	Blue Roofs	Cisterns
able	Suitable	Most Suitable	Most Suitable	Most Suitable	Most Suitable	Most Suitable	Most Suitable
ost able	Most Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
able	Most Suitable	Most Suitable	Suitable	Suitable	Most Suitable	Most Suitable	Most Suitable
ost able	Suitable	Suitable	Most Suitable	Most Suitable	Suitable	Suitable	Suitable
ost able	Most Suitable	Most Suitable	Suitable	Suitable	Most Suitable	Suitable	Suitable
able	Suitable	Suitable	Most Suitable	Most Suitable	Suitable	Most Suitable	Most Suitable
ost able	Most Suitable	Most Suitable	Most Suitable	Most Suitable	Suitable	Suitable	Suitable
able	Suitable	Most Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
ost able	Most Suitable	Most Suitable	Most Suitable	Most Suitable	Suitable	Suitable	Suitable
able	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
$$	$$$	$$$	$$	$$	$$$	$	$$$

Performance Matrix

		INFILTRATION PRACTICES				BIORET
		Subsurface Infiltration	Infiltration Trench	Surface Infiltration Basin	Tree Filter	Bioretention (Infiltration)
PEAK RATE MITIGATION	Detention Storage & Slow Release	5	5	5	5	4
		Infiltration practices provide temporary storage of runoff through surface or subsurface storage; typically perforated pipe or pre-fab structures embedded in a stone reservoir. Controlled overflow occurs from outlet control structure and/or underdrains, if present.				Bioretenti through bioretenti Controlled ou control dev
VOLUME REDUCTION	Infiltration & Groundwater Recharge	5	5	5	5	4
		Infiltration techniques provide a storage reservoir to retain and infiltrate stormwater using surface storage, subsurface structures, and/or gravel media; used when existing soils are permeable.				Bioretention p and filtration t media. W conditions g
	Evaporation or Reuse	2	2	3	3	3
		Sub-surface applications: stormwater is captured and stored in structures and gravel media, leaving little opportunity for evaporation. Surface infiltration basins may provide some evaporation from temporary surface storage.				Stormwater surface bio planting s evapotra
WATER QUALITY	TSS Removal	5	5	5	5	5
		With adequate pre-treatment, infiltration practices are highly effective at removing sediment and other pollutants through settling and infiltration.				Sediment is devices, s filtration thr infil
	Phosphorus Removal	5	4	5	4	5
		Infiltration practices are highly effective at phosphorus removal through filtration and infiltration processes.				Phosphoru through the s

Low	1	2	3	4	5	High

...ENTION TECHNIQUES		PERMEABLE PAVEMENTS		ROOFTOP STORAGE		
Biofiltration	**Bioretention Planters**	**Porous Asphalt**	**Permeable Pavers**	**Green Roofs**	**Blue Roofs**	**Cisterns**
4	4	5	4	4	4	2
on provides temporary storage surface storage and voids in on media and stone reservoir. utflow occurs at the surface outlet vice and through an underdrain.		Stormwater is filtered and temporarily stored in aggregate voids in stone reservoir; controlled overflow occurs through the underdrain.		Green and Blue Roofs provide temporary storage and controlled release of runoff. Peak rate mitigation for cisterns is variable; when the tank's permanent storage volume is full, the system provides little benefit.		
3	3	5	4	1	1	1
provides temporary storage of runoff through bioretention soil and stone here permeable underlying soil exist, bioretention areas provide groundwater recharge.		Permeable pavements accept runoff and filter it through media. It is temporarily stored in a stone reservoir eventually infiltrating into permeable soil.		Stormwater retained and evaporated from rooftops or stored in cisterns for reuse does not contribute to groundwater recharge.		
3	3	2	2	4	4	4
runoff temporarily stored in the oretention cell and bioretention soils is taken up by plants and anspired to the atmosphere.		Since rainwater is rapidly infiltrated through the permeable surface, little to no evaporation is anticipated.		Green Roofs and Blue Roofs provide temporary storage capacity for rainwater that is evaporated to the atmosphere. Cisterns capture and store roof runoff to be reused for non-potable purposes.		
5	5	5	4	5	5	5
removed through pre-treatment ettling in the surface storage, ough the soil/gravel media, and ltration, when provided.		Sediment is filtered through permeable material and voids in stone media. O&M like vacuum sweeping is critical to remove large particles.		Rooftops are not a source of accumulated sediments; however, if sized to retain the water quality volume and BWSC Retainage Volume, the area can be removed from calculations for these purposes.		
4	4	5	4	3	4	4
us is removed through filtration soil/gravel media and infiltration, when provided.		Phosphorus is filtered through permeable filter material and stone. Additional reduction is achieved with infiltration.		Green and Blue Roofs reduce discharged pollutant load when sized to retain and evaporate the water quality volume and BWSC Retainage Volume.		

Technical Design Considerations

The following technical design considerations focus on the unique site-based considerations that must be factored into the selection, design, construction, and long-term operation and maintenance of GI. Design modifications and specifications are elaborated in the GI Toolkit.

- **Pre-Treatment:** Pre-treatment should be designed to remove trash, debris, and large sediments prior to GI treatment of solids, nutrients, and pathogens. Without proper pre-treatment and regular maintenance, bioretention and infiltration systems risk clogging and failure.
- **Soil Suitability:** The permeability of Boston's urban soils is widely variable. Therefore field or laboratory soil testing (in accordance with the MassDEP Stormwater Handbook) should be performed to determine if soils are suitable for groundwater recharge. Environmental testing may also be necessary in contaminated soils.
- **Separation from Groundwater:** For GI techniques that promote infiltration, separation from seasonal high groundwater should be considered to prevent dewatering. The MassDEP Stormwater Handbook recommends 2 feet of separation between the bottom of the stormwater BMP and the determined seasonal high groundwater elevation.

Utility Clearances

The design of GI techniques must consider the horizontal and vertical location of existing utilities and ensure proper clearances or design modifications are implemented. GI design must consider the following:

- **Overhead wires:** For GI techniques such as tree filters or planted bioretention and infiltration basins, the planting of new trees must be coordinated with the location of overhead electric and telecom wires.
- **Water Infrastructure:** BWSC-owned water mains are typically located with 5 feet of cover; however, this elevation can vary. The recommended clearance between the bottom layer of the GI feature and the top of the water main is 12 inches. No horizontal or vertical clearance is recommended for water service and laterals, assuming they are in good condition.
- **Sanitary Infrastructure:** The design of GI systems should be closely coordinated with the location of BWSC-owned sanitary mains and laterals. The recommended clearance between the bottom later of the GI feature and the top of the sanitary main or lateral is 12 inches. "Open bottom" GI practices that promote infiltration shall not be placed directly over sanitary infrastructure unless a substantial vertical clearance is achieved (5 feet +/-) or unless the sanitary main is lined from manhole to manhole.

Planting Design

Proper plant selection is imperative to a successful nature-based GI solution. Since each site and design solution are different, and although many plants will tolerate different conditions, there is no "one size fits all" application. The following are points to consider when selecting plant material for GI solutions:

- Use plants native to the region as they are best suited to thrive in the region's climate
- Look for plant material with deep roots to improve infiltration
- Specify plants based on their tolerance to wet or dry conditions
- Perform soil tests to measure pH and select plants tolerant to acidic or alkaline soils
- Look for salt tolerant plants if they will be used near parking areas in colder climates
- Consider plants that provide aesthetic characteristics in different seasons.
- Consider basic design principles such as form, texture, color, seasonal interest, and variety.
- Consider Operations and Maintenance burdens

Construction

The project team should consider the construction process when designing GI solutions. Anticipate any issues or conflicts before they arise in the field. The following are topics the owner, contractor, and design team should discuss to ensure GI's long-term success:

- Erosion control – Construction activities disturb soil and, if not controlled, can clog a GI solution and be costly to rectify; specify erosion control measures using a Stormwater Pollution Prevention Plan (SWPPP)
- Site Access – Large construction equipment can compact soils, impacting the ability of some GI solutions to infiltrate; consider the entrance and path of any equipment in relation to the eventual GI solution.

Green Infrastructure solution planting plans should include a mix of color, size, and texture that are visually appealing in all seasons.

- Phasing – When planning construction phases, ensure the activity from one phase will not negatively impact a GI solution already installed in a prior phase.

Operations & Maintenance (O&M)

Adequate Operations and Maintenance (O&M) plans ensure that GI features can achieve their designed storage capacities and predicted pollutant removals over their operational lifespan. It is only through a strong understanding of, and commitment to, long-term O&M that GI features will continue to deliver the many benefits they are designed to provide.

- Design for O&M: O&M should not be an afterthought and may influence design decisions.
- Consider O&M access when siting GI solutions.
- Consider cost and frequency of O&M activities
- Consider necessary equipment for maintenance, including storage and resources for operations.
- Training in maintenance techniques or equipment use may be required and should be communicated to the owner during the design process.

The GI Toolkit includes more information and resources for O&M for the GI techniques featured in this Handbook.

Non-Structural Stormwater Management

The Massachusetts Stormwater Handbook defines non-structural approaches to stormwater management that should be considered as part of good housekeeping and ongoing O&M post-construction. These approaches include pollution prevention, street sweeping, erosion control, and snow management, among others. Beyond physical design of the site, the project team should consider how these elements will affect stormwater quality on the site and ensure owners understand the importance of these elements to the success of the GI solution.

3.3 System Sizing

Site Plan Requirements

In accordance with Boston Water and Sewer Commission (BWSC) requirements, projects which trigger Site Plan Submission must meet specific retainage requirements based on the size of the project. A volume of runoff equal to 1 inch of rainfall times the total impervious area on-site must be retained and infiltrated prior to discharge to a storm drain or a combined sewer system for projects less than 100,000 square feet of floor area. For all projects which are at or above 100,000 square feet of floor area, the project must use a volume of runoff equal to 1.25 inches of rainfall times the total impervious area on-site. The BWSC accepts a 30% void ratio for volume within a stone area.

The Site Plan Submission must provide soil borings and/or test pits conducted by a registered Professional Engineer or registered Sanitarian to determine the infiltration rate of the soil on-site. A pre- and post-construction Drainage Analysis must be completed in accordance with the Massachusetts Stormwater Handbook (p. 68). Drainage calculations for the runoff are needed including the storm frequency, time of concentration, peak rate of runoff, and total volume of water for all projects involving over 2,500 square feet of impervious surface. Information, including National Oceanic and Atmospheric Administration (NOAA) Atlas 14 precipitation frequency, can be found on the Precipitation Frequency Data Server website. Infiltration rates will also be used in sizing calculations for Green Infrastructure/Low Impact Development (GI/LID) infiltration practices to treat storm water runoff.

Refer to the BWSC website for more information about the Site Plan Approval Process and Requirements.

Sizing Calculations

To demonstrate compliance with the BWSC's retainage requirements, the civil engineer can utilize hydrologic modeling methodologies prescribed by the Massachusetts Department of Environmental Protection (MassDEP) Stormwater Handbook and other standard practice. A simple spreadsheet methodology can also be used to evaluate stormwater performance and compliance via the following steps:

Step 1:
Determine if the total floor area for the project is less than or greater than 100,000 square feet to confirm required retainage depth is 1 inch or 1.25 inches of rainfall, respectively.

Step 2:
Delineate the drainage area associated with each GI Best Management Practice (BMP) for entire limit of project disturbance.

Step 3:
For each drainage area associated with each GI BMP, determine the Total Impervious Area.

Step 4:
Calculate the Required Retainage Volume based on project size and total contributing impervious area:

At or above 100,000-square feet floor area:
Required Retainage Volume (CF) =
Impervious Area (SF) * 1.25 inches * (1ft/12in)

Less than 100,000-square feet floor area:
Required Retainage Volume (CF) =
Impervious Area (SF) * 1.0 inch * (1ft/12in)

Step 5:
Calculate the Total Provided Storage Volume to retain and infiltrate stormwater for each GI BMP. This will include all storage volume in surface and subsurface basins beneath an outlet elevation. Storage volume provided in soil or stone media should account only for the voids provided in the material, with a maximum assumption of 30%.

Total Provided Storage Volume (CF) =
Surface/Subsurface Storage Volume (CF) + [Stone Storage Volume (CF) * 30% voids]

Step 6:
Confirm Total Provided Storage Volume for all GI/ stormwater management element(s) calculated in Step 5 is greater than the Required Retainage Volume calculated in Step 4.

Confirm:
Total Provided Storage Volume (CF) > Required Retainage Volume (CF)

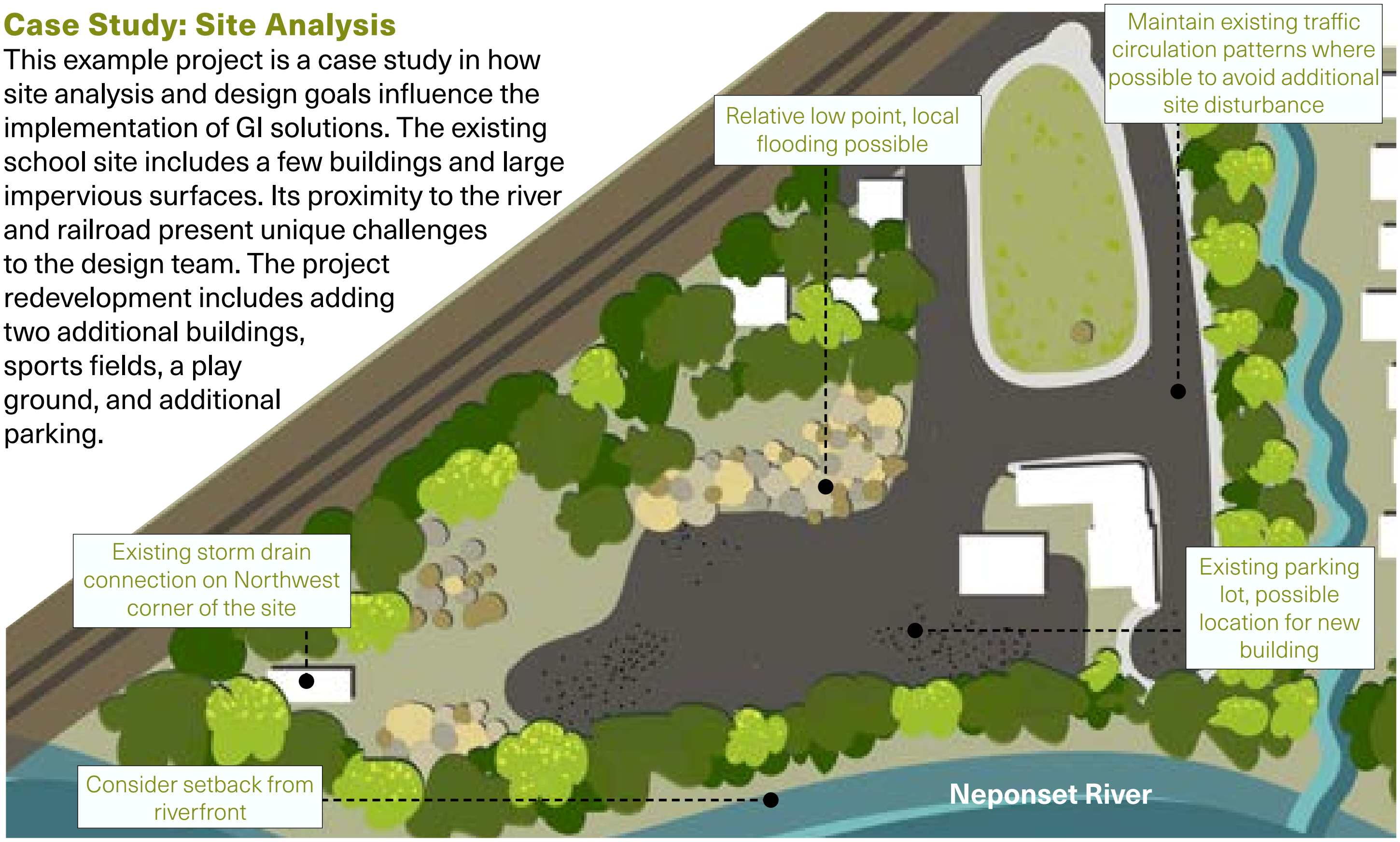
Required vs. Provided Rainfall Retainage Volume Summary:

Project Name/Number:			
Step 1:	Determine total floor area for project:		sq. ft.
	< 100,000 sq ft, retainage requirement is 1.00" rainfall depth		
or	> 100,000 sq ft, retainage requirement is 1.25" rainfall depth		
Step 2:	Delineate drainage area associated with each GI BMP for entire limit of project disturbance.		
Complete the following form for each drainage area associated with a GI BMP:			
Step 3:	Total Impervious Area =		sq. ft.
Step 4:	Calculate Required Retainage Volume		
	Total Impervious Area * rainfall measurement (in.) * (1ft/12in) =		cu. ft.
Step 5:	Calculate each provided storage volume (surface, subsurface, voids in material):		
5a:	Surface/Subsurface Storage Volume		cu. ft.
5b:	Stone Storage Volume (if applicable)		cu. ft.
5c:	Calculate Total Provided Storage Volume		
	Sum of storage volumes =		cu. ft.
Step 6:	Confirm Total Provided Storage is greater than Required Retainage Volume		
	Total Provided Storage Volume (Step 5c):		cu. ft.
	Required Retainage Volume (Step 4):		cu. ft.
	Top number greater?		

All civil engineering plans submitted for Site Plan Submission should include a summary of the Required vs. Provided Retainage Volume, similar to the example shown above. For additional guidance sizing specific GI strategies, reference the GI Toolkit.

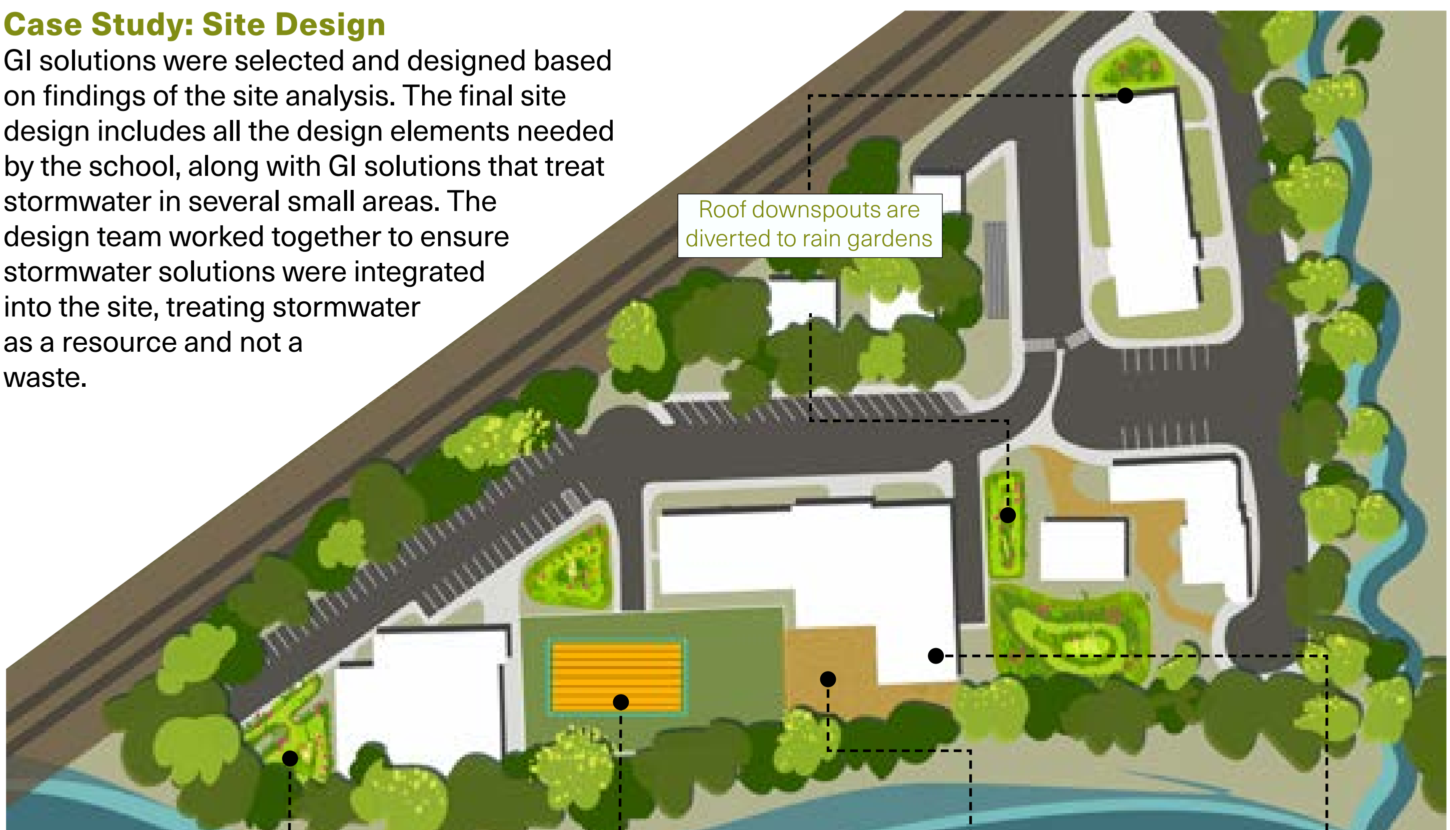
Case Study: Site Analysis

This example project is a case study in how site analysis and design goals influence the implementation of GI solutions. The existing school site includes a few buildings and large impervious surfaces. Its proximity to the river and railroad present unique challenges to the design team. The project redevelopment includes adding two additional buildings, sports fields, a play ground, and additional parking.



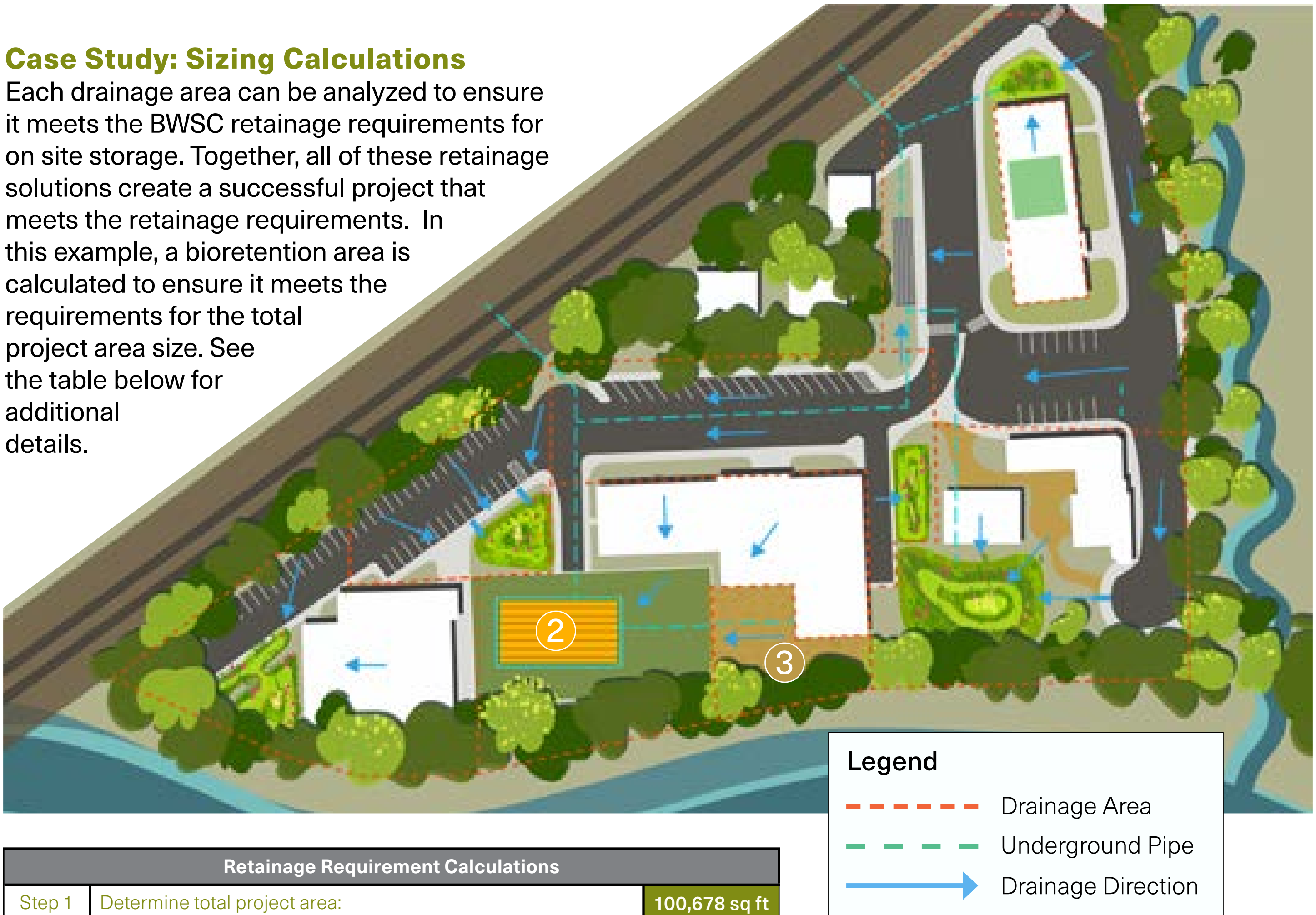
Case Study: Site Design

GI solutions were selected and designed based on findings of the site analysis. The final site design includes all the design elements needed by the school, along with GI solutions that treat stormwater in several small areas. The design team worked together to ensure stormwater solutions were integrated into the site, treating stormwater as a resource and not a waste.



Case Study: Sizing Calculations

Each drainage area can be analyzed to ensure it meets the BWSC retainage requirements for on site storage. Together, all of these retainage solutions create a successful project that meets the retainage requirements. In this example, a bioretention area is calculated to ensure it meets the requirements for the total project area size. See the table below for additional details.



Retainage Requirement Calculations		
Step 1	Determine total project area:	100,678 sq ft
	< 100,000 sq ft, retainage requirement is 1.00" rainfall depth	
	> 100,000 sq ft, retainage requirement is 1.25" rainfall depth	x
Step 2	Delineate drainage areas for each GI BMP for entire limit of project disturbance	
Complete the following calculations for each drainage area		
Example: Bioretention #2 - West Parking Area		
Step 3	Total impervious surface in drainage area =	15,640 sq ft
Step 4	Total impervious area * retainage requirement * (1ft / 12in)	
	15,640 sq ft * 1.25" * (1/12)	1,629 cu ft
Step 5	Calculate each provided storage volume (surface, subsurface, voids in material)	
	System 1: 1,000 sq. ft. bioretention cell with stone reservoir, 50' x 2' x 2'	
5a	Bioretention cell surface storage volume =	
	(Area * 8" ponding depth * (1ft/12in)) = 1,000 sq ft * 8" * (1/12) =	667 cu ft
5b	Soil media storage volume (assume 15% voids, 2' deep)	
	(Area * depth * 0.15) = 1,000 sq ft * 2' * 0.15 =	300 cu ft
5c	Stone storage volume (mass assumption of 30% voids)	
	(Area * depth * 0.3) = 1,000 sq ft * 3ft =	
5d	Calculate total provided storage volume	
	(Surface + media + stone) = 667 + 300 + 900	1,867 cu ft
Step 6	Confirm total provided storage exceeds Required Retainage Volume	
	Total Provided Storage Volume (Step 5d)	1,867 cu ft
	Required Retainage Volume (Step 4)	1,6290 cu ft
	Requirements met (yes/no)	Yes

Additional Sizing Calculations

You may need to calculate multiple retention volumes to meet the BWSC requirements. Below are additional calculation examples of different drainage areas for reference.

1 Cistern

Total Impervious Area = 4,500 sq ft
Required Retainage Volume = 469 cu ft
Total Provided Storage Volume = 481 cu ft
Average 3-day reuse demand = 4,000 gal

2 Subsurface Infiltration Basin

Total Impervious Area = 48,345 sq ft
Required Retainage Volume = 5,036 cu ft
Total Provided Storage Volume = 5,990 cu ft

3 Permeable Pavers

Total Impervious Area = 9,877 sq ft
Required Retainage Volume = 1,029 cu ft
Total Provided Storage Volume = 1,036 cu ft

Consult Chapter 4: Toolkit for additional details on each of the above BMPs.

stata center cambridge, ma

Chapter 4
Green Infrastructure (GI) Toolkit

The Green Infrastructure Toolkit provides more detailed information about designing, constructing, and maintaining typical green infrastructure techniques in Boston. The Toolkit includes guidance for implementing four major categories of green infrastructure including infiltration techniques, bioretention techniques, permeable pavements, and rooftop strategies. Within each of the categories, the Toolkit provides more information about various green infrastructure strategies. For example, bioretention techniques can include bioretention basins in open space or bioretention planters in streetscapes. Although the Toolkit presents the most common green infrastructure approaches applicable to Boston's urban conditions, it should not be considered an exhaustive list as other strategies not included in this Toolkit (such as constructed wetlands) may also be considered.

west of chestnut quincy, ma

4.1 Infiltration Practices

Infiltration practices include a variety of systems that provide temporary storage to filter and exfiltrate stormwater through gravel media and permeable soils. In addition to reducing the volume of stormwater runoff and promoting groundwater recharge, infiltration practices can be designed to provide peak rate mitigation and are highly effective at treating stormwater, especially where permeable underlying soils allow for enhanced infiltration. Infiltration techniques include subsurface infiltration systems, surface infiltration basins, infiltration trenches, and tree filters.

In a dense urban environment where little space is available to manage stormwater using landscape-based techniques, subsurface infiltration systems are a viable option. Subsurface infiltration systems typically consist of storage voids within a bed of gravel (washed crushed stone) or in storage devices (such as perforated pipes, plastic chambers, drywells, or open bottom concrete boxes) embedded within the bed of gravel. Pre-treated stormwater can be introduced to subsurface infiltration systems via pipe distribution.

Surface infiltration basins and infiltration trenches are strategies that collect surface stormwater runoff. Stormwater is exfiltrated through pea gravel, filter sand, or amended planting soils into a crushed stone storage layer. In an ultra-urban environment, street trees can also be adapted to filter and infiltrate stormwater. Tree filters (also referred to as “tree pits” and “tree trenches”) are systems that include a tree with porous soil and an underlying layer of crushed stone with a perforated pipe.

Although infiltration practices can be used as centralized stormwater management systems, they can also be designed as small, decentralized systems that support Low Impact Development (LID) and Green Infrastructure (GI) design goals. Infiltration practices are scalable and adaptable to many sites and conditions. Where soil permeability is poor, infiltration systems can be designed with an underdrain to ensure proper drawdown between storms. Separation from groundwater or an impermeable layer (bedrock) is necessary.

Benefits

- Highly effective at treating pollutants, especially solids and nutrients, through filtration and/or infiltration.
- Reduces stormwater runoff and promotes groundwater recharge.
- Highly adaptable and scalable to a variety of site conditions.

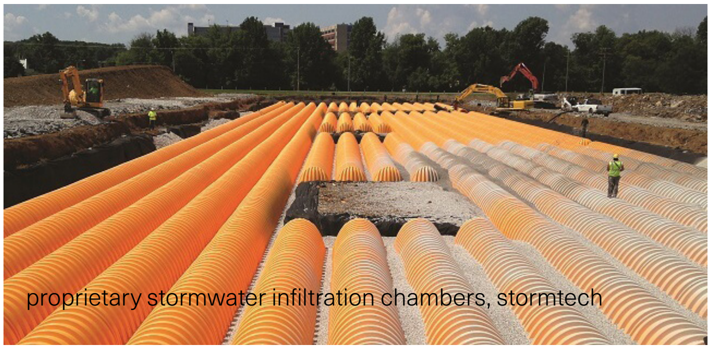
STORMWATER BENEFITS		
	●●●●○	**Peak Rate Mitigation** Slow & Detain
	●●●◐○	**Volume** Infiltrate
	●●●○○	**Volume** Evaporation or Reuse
	●●●●●	**Quality** Solids (TSS)
	●●●●◐	**Quality** Phosphorus

Applicability

Infiltration practices include surface infiltration basins, infiltration trenches, tree filters, and subsurface infiltration systems. All infiltration techniques include temporary storage to exfiltrate stormwater through gravel media and into underlying soils. Although best suited where permeable underlying soils exist, infiltration can be accommodated in a variety of soil conditions assuming separation from seasonal high groundwater (minimum 2 feet) and bedrock can be accomplished.

Subsurface infiltration systems, infiltration trenches, and tree filters are well suited approaches for dense urban sites and streetscapes. However, these systems can also be applied to lower density sites, as well. Although infiltration practices can be used as centralized stormwater management systems, they can also be designed as small, decentralized systems that support GI or LID goals.

Infiltration practices are typically highly economic and effective approaches to manage stormwater. The systems are relatively simple to construct and the materials, such as gravel and perforated pipes, are readily available.



proprietary stormwater infiltration chambers, stormtech

university of virginia charlottesville, va

Constraints

Limitations to infiltration techniques include poor subsoil conditions, high groundwater conditions, presence of bedrock, and contaminated soils. The Massachusetts Department of Environmental Protection (MassDEP) Stormwater Handbook recommends a minimum field permeability rate of 0.17 inches/hour for siting infiltration systems. Infiltration practices should not be located within 10 feet of building foundations where infiltrating water could penetrate below-grade structures. Additional setback requirements from drinking wells, septic systems, steep slopes, and water bodies in accordance with the MassDEP Stormwater Handbook should be adhered to. Special design modifications (such as the use of impermeable liners along the vertical edge of the system) can be used to minimize the horizontal movement of water that could impact roadway sub-base or break out of steep slopes.

Without proper pre-treatment and regular maintenance, infiltration systems risk clogging and failure. And although they are highly effective at addressing stormwater requirements, subsurface infiltration practices do not address other environmental co-benefits (such as heat island mitigation, habitat creation, and improved air quality) when compared to other "greener" approaches to manage stormwater.

Design Considerations

Subsurface Infiltration Systems

Subsurface infiltration systems typically consist of storage voids within a bed of gravel (washed crushed stone) or within storage devices embedded within the bed of gravel that are used to temporarily store stormwater and exfiltrate into the underlying soils. Typical subsurface storage devices used for infiltration systems include perforated pipes, plastic arch chambers, open bottom concrete boxes, drywells, and galleys.

Depending on the type of storage structure utilized, minimum and maximum cover and dead and live loads over the system must be considered as part of the design. The bottom of the subsurface infiltration system should also be 2 feet above the seasonal high groundwater elevation.

Pre-treated stormwater can be introduced to subsurface infiltration systems via pipe distribution. Infiltration systems should be designed to store the required Boston Water and Sewer Commission (BWSC) Retainage Volume for the contributing drainage area. The storage and outlet configuration should be designed to exfiltrate the BWSC Retainage Volume within 72 hours, as recommended by the MassDEP Stormwater Handbook. The system must be designed with an outlet control structure to provide a controlled discharge for large design storms and to provide emergency overflow.

Infiltration Trench

Infiltration trenches are shallow excavations (3 to 7 feet) filled with washed crushed stone. The voids in the stone are used to temporarily store stormwater for exfiltration into the underlying soils. Stormwater runoff enters the trench filters through a layer of pea gravel and into the crushed stone reservoir. The system should be designed to store and exfiltrate the BWSC Retainage Volume within 72 hours, as recommended by the MassDEP Stormwater Handbook. Additional storage can be provided to meet additional stormwater mitigation goals for larger storm events. In ultra-urban settings where surface area is constrained, an infiltration riser can be used to optimize the movement of stormwater into the stone reservoir below.

The infiltration trench is typically designed to overflow at the surface once the capacity of the voids in the crushed stone is exceeded. In urban conditions where surface discharge is not feasible, the design must consider the use of raised area drains or other measures to collect excess overflow when the system capacity is exceeded.

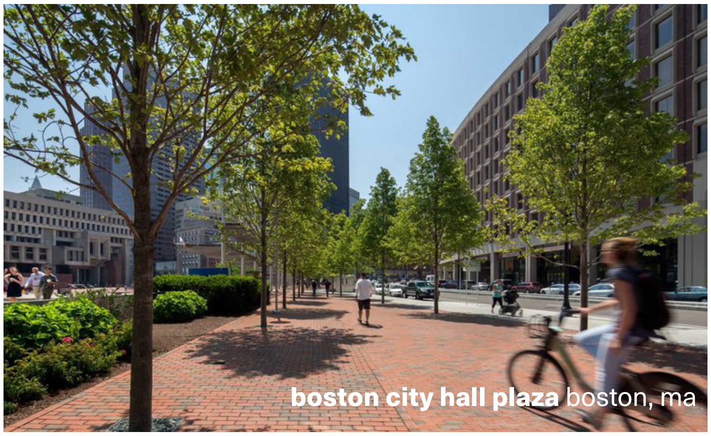
Surface Infiltration Systems

Surface infiltration basins are depressions or impoundments constructed over permeable soils. Surface infiltration basins provide surface storage to temporarily store pre-treated stormwater for exfiltration into the underlying soils. Surface infiltration basins are suitable where field permeability is 0.17 inches/hour or greater. The top 12 inches of soil should be amended or replaced to support the desired planting conditions and drawdown requirements. The system should be designed to store and exfiltrate the BWSC Retainage Volume within 72 hours as recommended by the MassDEP Stormwater Handbook.

The system should be designed to retain and infiltrate the required BWSC Retainage Volume with treated excess overflow from larger events conveyed to the downstream storm drain system. Additional surface storage and the outlet/overflow structure configuration should be further adjusted to meet additional stormwater mitigation goals for larger storm events. Surface infiltration basins should be relatively flat to optimize storage and promote exfiltration consistently across the basin bottom. Stepped systems can be designed to accommodate large grade changes in the surrounding topography. An underdrain is recommended in surface infiltration systems to alleviate standing water problems.

Tree Filters

In an ultra-urban environment, street trees can also be adapted to filter and infiltrate stormwater. Tree filters (also referred to as “tree pits” and “tree trenches”) are systems that include a tree with porous soil and an underlying layer of crushed stone with a perforated pipe. Stormwater runoff that sheet flows across sidewalks into the tree pits can drain through porous soils or permeable pavers into the trench of washed crushed stone. Diverted stormwater from roadway catch basins can also be diverted through a perforated pipe in the crushed stone trench. The storage provided by the perforated pipe and crushed stone trench should be designed to store and exfiltrate the BWSC Retainage Volume into the underlying soils. Where poor underlying soil conditions are encountered, an underdrain can be placed within the crushed stone trench to drain excess stormwater away from the tree filter. The depth of the crushed stone reservoir and elevation of the underdrain should be further adjusted based on the exfiltration and drawdown requirements.



boston city hall plaza boston, ma

Design and Sizing Criteria

Infiltration systems should be designed by a registered Professional Civil Engineer using the hydrologic and hydraulic methodologies prescribed by the MassDEP Stormwater Handbook and other standard practice. Designs should be evaluated as part of the site's Pre- vs. Post-Drainage Analysis, as required for BWSC Site Plan Approval.

Contributing Drainage Area

- Calculate the area (impervious and pervious) that will drain to the infiltration system as sheet flow, overland flow, and/or piped flow.

Required Retainage Volume

- Calculate the Required Retainage Volume based on the contributing impervious drainage area and the 1-inch or 1.25-inch rainfall as required (see Chapter 3, section 3.3).

Storage Volume and Depth of Stone Reservoir Sizing

- The storage volume within the surface cell of a surface infiltration basin should be designed to retain and infiltrate the Required Retainage Volume in accordance with BWSC guidelines.
- The storage volume within the stone reservoir and storage structures should be designed to retain and infiltrate the Required Retainage Volume and be further extended to address local/state regulatory peak rate requirements for the project.

Design Underdrains and First Stage Outlets

- The size, configuration, and elevation of underdrains and outlets should be designed to optimize the retainage and infiltration of the Required Retainage Volume to the greatest extent possible into the underlying soils within the recommended 72-hour drawdown time without overflow.

Quantity Control for Storm Events and Overflow Measures

- The engineer may use MassDEP-approved methodologies to model the inflow and outflow characteristics of the system to meet regulatory peak rate reductions for the 2-year through 100-year, 24-hour design storms. Large storms should be modeled to ensure that the outlet structure can accommodate large storms without flooding.

Drain Time Calculations

- All infiltration systems should drawdown within 72 hours, as recommended by the MassDEP Stormwater Handbook.

Contributing Drainage Area

Infiltration practices can be applied to small and large drainage areas. In general, surface and subsurface infiltration systems can be designed to manage contributing drainage areas between 2 and 15 acres. Infiltration trenches are limited to small drainage areas, up to 5 acres. Tree filters are suitable for managing small volumes of stormwater generated from ultra-urban conditions, typically with drainage areas less than 1 acre.

Infiltration systems should be designed to provide storage capacity to retain the required water quality treatment and retainage depth over the contributing drainage area and exfiltrate into the underlying soils. Additional storage capacity will be needed to mitigate larger storm events through the system.

Pre-treatment

Pre-treatment of stormwater prior to infiltration is necessary to remove debris and large sediments that could plug the system. Pre-treatment should be in accordance with the Massachusetts Stormwater Best Management Practice (BMP) Manual and can include deep sump hooded catch basins, manufactured treatment devices, water quality swales, vegetated filter strips, and forebays.

Soils

The MassDEP Stormwater Handbook recommends a minimum site permeability rate of 0.17 inches/hour for siting infiltration systems. The permeability of the underlying soils should be determined by field or lab testing in accordance with the Massachusetts Stormwater BMP Manual. Infiltration systems areas should be designed to draw down within 72 hours based on the permeability of the underlying soils and the capacity of the overflow/underdrain.

Cold Climate

Infiltration practices are applicable in cold climates.

Slopes

Subsurface infiltration systems, infiltration trenches, and tree filters should be designed with a relatively flat bottom (0% to 1% slope max). Subsurface infiltration systems can be installed beneath sloping areas but must consider the minimum and maximum depth across the surface grade change. Infiltration systems should not be placed immediately up-gradient of steep slopes without proper design considerations.

Geotextile

Filter fabric should be used to line the vertical edges of subsurface infiltration systems, infiltration trenches, and tree filters, but is not recommended at the bottom of the system to prevent plugging.

Optional Impermeable Liner

In an urban environment, an impermeable liner may be used along the vertical sides of infiltration systems to prevent the horizontal movement of water towards subsurface basement areas, roadway sub-base, steep slopes, etc.

Streetscape

Infiltration practices within public rights-of-way must be approved by the Boston Public Works Department (BPWD) and/or the Massachusetts Department of Transportation (MassDOT). In addition to the hydrologic considerations presented in this chapter, the design of curbing, pavers, and/or fencing associated with tree pits must also be coordinated with the City of Boston and adhere to applicable local, state, and federal guidelines for structural design and Americans with Disabilities Act (ADA) accessibility. For tree filters, the design and placement of trees and soils within the tree pit (or structural soils extended beneath the sidewalk) must be coordinated with the Boston Public Works Department.

Maintenance

Frequent cleaning and maintenance of the infiltration techniques is critical to prevent clogging. Proper maintenance of the pre-treatment measures is a critical step in preventing clogging and failure of the infiltration practice. Maintenance recommendations for infiltration practices include:

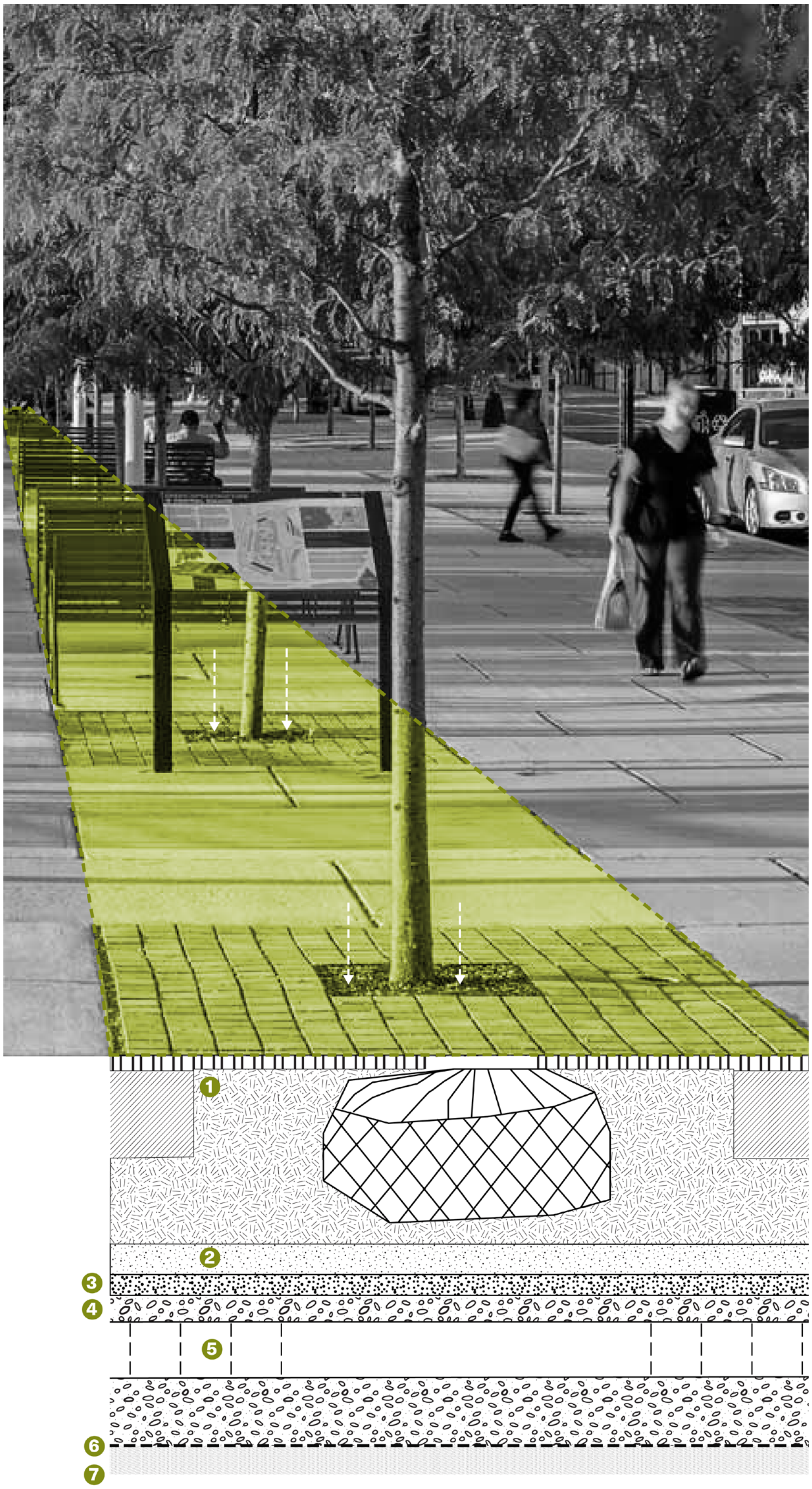
- Inspect infiltration systems at least twice per year and after storm events greater than a 2-year storm.
- Inspect the inlets and observation ports to determine if there is accumulated sediment within the system. Remove all debris and accumulated sediment that may clog the system.
- Inspect and clean pre-treatment devices monthly.

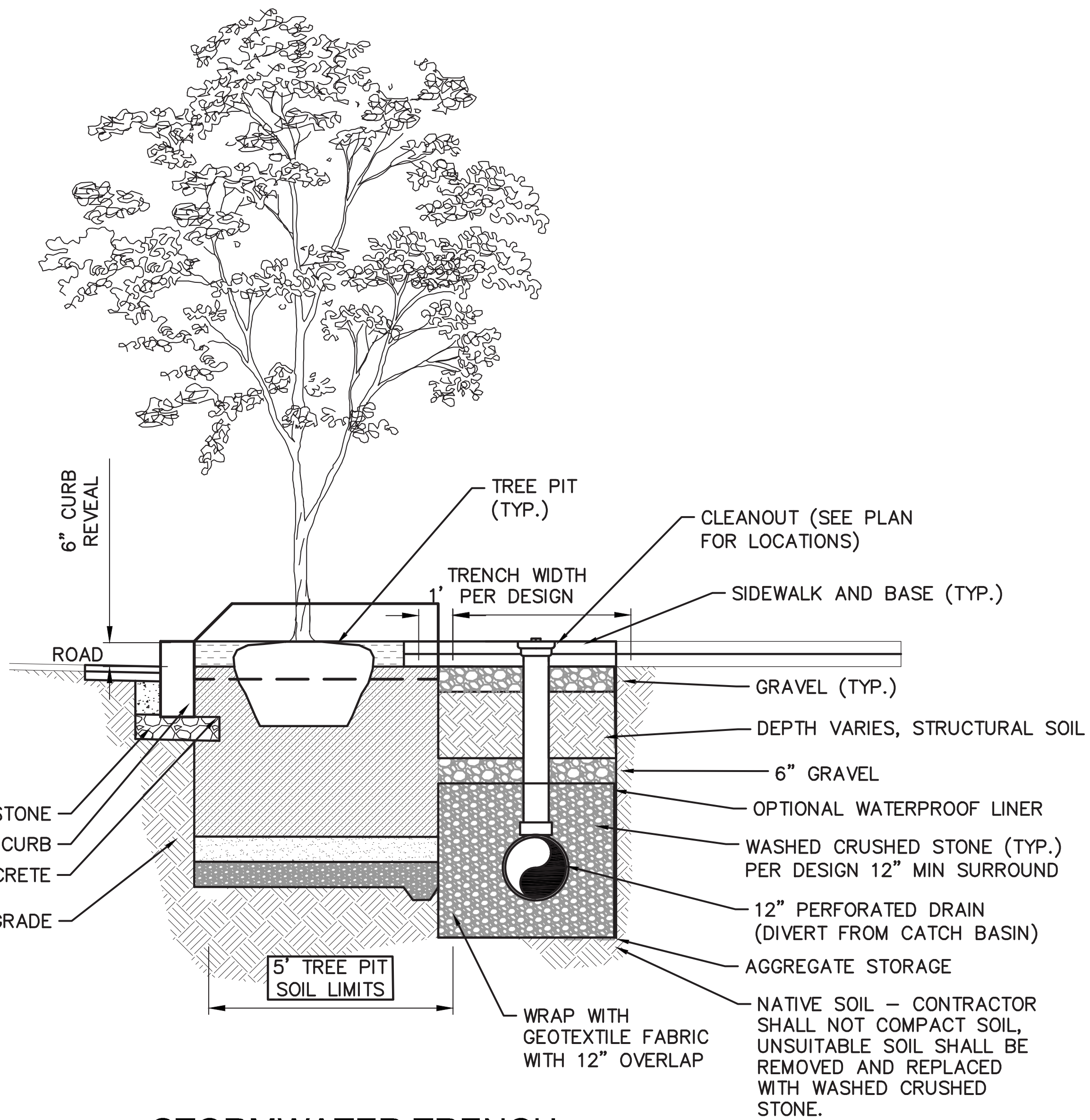
Infiltration Systems Maintenance Schedule

Activity	Frequency
Inspect Infiltration Systems	Bi-Annually
Inspect Inlets & Observation Ports	As Needed
Inspect Pre-treatment Devices	Monthly

Tree Filter

1. **Horticultural Soil**
2. **Structural Soil**
3. **Gravel Filter**
4. **Stone Reservoir**
5. **Perforated Distribution-Pipe/Underdrain**
6. **Geotextile**
7. **Impermeable Liner**





STORMWATER TRENCH

NOT TO SCALE


beth israel hospital boston, ma

4.2 Bioretention Techniques

Bioretention is a Green Infrastructure (GI) technique that uses plants and soil media to filter stormwater pollutants and promote infiltration. Bioretention techniques (sometimes referred to as “rain gardens”) consist of shallow landscape depressions that accept stormwater by sheet flow or piped flow. Bioretention basins and bioswales are typically integrated into open space adjacent to impervious surfaces. In highly urban environments, such as plazas and streetscapes, bioretention techniques can be integrated within planters or curb “bump outs.”

Bioretention is highly effective at treating stormwater, especially sediments and nutrients, through plant uptake, microbial action, filtration, and infiltration. Bioretention is a decentralized approach to treat stormwater and infiltrate small storm events and is not well suited for large drainage areas as an “end-of-pipe” solution.

In addition to providing stormwater benefits, bioretention provides numerous other co-benefits that make it an ideal strategy to help mitigate urban heat island and improve air quality. Bioretention is a landscape-based approach that supports plant diversity and habitat creation and provides opportunities to increase tree canopy and improve open space.

Bioretention is a working stormwater and landscape system that provides several other aesthetic benefits. Bioretention areas must be properly maintained to ensure long-term performance.

Benefits

- Uses a landscape-integrated approach to manage stormwater.
- Highly effective at treating pollutants, especially solids and nutrients, through filtration and/ or infiltration.
- Reduces stormwater runoff and promotes groundwater recharge.
- Addresses other urban environmental issues such as urban heat island mitigation, habitat creation, air quality improvements, and climate change mitigation.

Applicability

Bioretention techniques include bioretention, biofiltration, bioswales, bioretention planters, and bioretention curb extensions ("bump outs"). The typical profile for all bioretention techniques is similar, but the applications vary based on the surrounding context and underlying soil conditions. For example, bioretention, biofiltration, and bioswales are typically located in open space areas adjacent to impervious surfaces, where bioretention planters and curb extensions are integrated within paved surfaces. The adaptability of bioretention techniques make them applicable to ultra-urban areas as well as residential areas.

STORMWATER BENEFITS	Rating	Benefit
	●●●●○	**Peak Rate Mitigation** Slow & Detain
	●●●◐○	**Volume** Infiltrate
	●●●○○	**Volume** Evaporation or Reuse
	●●●●●	**Quality** Solids (TSS)
	●●●●◐	**Quality** Phosphorus

Constraints

Bioretention is not suited for large drainage areas as an "end-of-pipe" solution. Additional limitations to implementing bioretention include poor subsoil conditions, groundwater conditions, available space, and maintenance considerations. For infiltrating bioretention, subsoils should be able to adequate to support infiltration. Bioretention areas are not suitable for areas of greater than 20% slope, but techniques such as terracing or stepped systems can be considered. In urban streetscape conditions, bioretention techniques must be designed to consider access, maintenance, and safety.

Bioretention is most effective where infiltration is possible, but still highly effective when only filtration can be provided (biofiltration). As such, bioretention can be accommodated in a variety of soil conditions, assuming separation from seasonal high groundwater (minimum 2 feet) and bedrock can be accomplished. The design of bioretention systems can be adjusted to help provide additional mitigation for larger storm events using approaches such as increasing the depth of the subsurface reservoir and/or adjusting the height of the underdrain. Bioretention systems can also be lined where concerns of contaminated or unsuitable soils exist.

Design and Sizing Criteria

Bioretention systems should be designed by a registered Professional Civil Engineer using the hydrologic and hydraulic methodologies prescribed by the Massachusetts Department of Environmental Protection (MassDEP) Stormwater Handbook. The bioretention system design should be evaluated as part of the site's Pre- vs. Post-Drainage Analysis, as required for Boston Water and Sewer Commission (BWSC) Site Plan Approval.

Contributing Drainage Area

- Calculate the area (impervious and pervious) that will drain to the bioretention area as sheet flow, overland flow, and/or piped flow.

Required Retainage Volume

- Calculate the Required Retainage Volume based on the contributing impervious drainage area and the 1-inch or 1.25-inch rainfall as required (see Chapter 3, section 3.3).

Bioretention Storage Volume and Depth of Stone Reservoir Sizing

- The storage volume within the surface cell and voids in the bioretention planting soil media should be designed to retain and infiltrate the Required Retainage Volume associated with the contributing drainage area.
- The storage volume within the stone reservoir should be further extended to address local/state regulatory peak rate requirements for the project, as evaluated as part of the Drainage Analysis.
- In ultra-urban settings where an infiltration riser will be used, the surface cell and bioretention planting soil media should be designed to retain a minimum of the 0.5-inch rainfall depth, with the remaining Required Retainage Volume accounted for within the crushed stone reservoir (30% voids) beneath the underdrain.

Design of Underdrain System

- The underdrain should be designed to optimize the retainage and infiltration of the Required Retainage Volume to the greatest extent possible into the underlying soils within the recommended 72-hour drawdown time.

Design of Overflow

- The overflow device(s) should be configured to retain and infiltrate the Required Retainage Volume.
- The engineer may use MassDEP-approved methodologies to model the inflow and outflow characteristics of the system to meet regulatory peak rate reductions for the 2-year through 100-year, 24-hour design storms. Large storms should be modeled to ensure that the outlet structure can accommodate large storms without flooding adjacent structures and/or vehicular or pedestrian spaces.

Drain Time Calculations

- The MassDEP Stormwater Handbook recommends a maximum 72-hour drawdown period for bioretention.
- Drawdown calculations may account for the infiltration rate in the soils as determined by a registered Professional Engineer or Soil Evaluator.

Design Considerations

Separation From Groundwater

The bottom of the stone reservoir for infiltrating bioretention areas should have a minimum separation of 2 feet from the seasonal high groundwater elevation, as recommended by the MassDEP Stormwater Handbook.

Pre-treatment

Pre-treatment of stormwater prior to discharge to the bioretention is necessary to remove trash and debris, and to filter large sediments. Pre-treatment for bioretention techniques in open space can include sediment forebays, vegetated filter strips, grass channels, water quality swales, or pea gravel diaphragm in accordance with the Massachusetts Stormwater Best Management Practice (BMP) Manual. In streetscape conditions, trash grates and forebays should be used to separate trash and sediment and allow for frequent cleaning.

Soils

Bioretention areas can be adapted to areas with variable soil conditions; however, infiltrating bioretention systems should be designed to draw down within 72 hours based on the permeability of the underlying soils and the capacity of the underdrain. The permeability of the underlying soils should be determined by field or lab testing in accordance with the Massachusetts Stormwater BMP Manual.

Slopes

Bioretention systems are suitable where slopes do not exceed 20%. The surface cell of a bioretention basin should be relatively flat; therefore, creating a stepped or terraced system is recommended for moderately sloping areas. The bottom of the bioretention soil media and the bottom of the reservoir layer should not be sloped to optimize the capacity in the stone voids.

Contributing Drainage Area

Bioretention areas are best suited to micro-manage stormwater from adjacent impervious areas where stormwater can be directed via sheet flow or overland flow. Stormwater can also be conveyed to the bioretention via pipe although this is not an optimal solution since it drives down the depth of the system. The size of the bioretention area is typically 5% to 7% of the drainage area if used for treatment, and larger

frick environmental center pittsburg, pa

if also used for recharge. The combination of surface storage and voids in the bioretention soil media should accommodate the required water quality treatment and retainage depth of 1 inch or 1.25 inches over the contributing drainage area, with a target surface ponding depth between 8 and 12 inches.

Plants

The Massachusetts Stormwater BMP Manual includes a robust list of recommended plant species suitable for use in bioretention.

Bioretention Planting Soil

The bioretention planting soil mix is an engineered soil mix consisting of sand, topsoil, and compost. The mix should conform to the “Engineered Soil Mix for Bioretention Systems Designed to Exfiltrate” found in the Massachusetts Stormwater BMP Manual. The depth of the bioretention soil media should be between 2 and 4 feet. This range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil, but thicker soils may be required if deeper rooted plants, shrubs, and trees will be considered. The in-situ permeability rate of bioretention planting soil within the bioretention areas after installation should be between 4 inches/hour and 10 inches/hour. In ultra-urban environments, bioretention planting soil permeability should be designed to accommodate drawdown of standing water within 12 hours to prevent mosquito breeding.

Sand Layer

A sand layer (ASTM D422) serves as a transition between the planting soil bed and the reservoir layer and underdrain pipes. The recommended depth is 6 to 12 inches.

Optional Pea Stone

A 4-inch layer of double washed pea stone can be used between the sand and reservoir layer.

Stone Reservoir and Underdrain

The underdrain should be placed within a layer of washed crushed stone. The sizing of the reservoir and underdrain are variable, based on the stormwater mitigation and drawdown requirements. The depth of the reservoir layer can be increased to further support the project’s stormwater goals for peak rate mitigation and/or groundwater recharge. The minimum recommended depth of the stone reservoir is 8 inches with a 4-inch underdrain.

Overflow Riser

Most bioretention designs will require an overflow riser. Since the bioretention system should be designed to accommodate the water quality and required recharge/retainage volume within the surface cell and bioretention planting soil, treated excess overflow generated from larger storm events will be conveyed to the downstream storm drain system via the overflow riser. The overflow riser is typically a PVC manhole riser with a grate, which will be set at the maximum ponding depth in the surface cell.

Optional Infiltration Riser

In ultra-urban settings where surface area is constrained, an infiltration riser can be used to optimize the use of the stone reservoir to maintain desired ponding depths given a limited surface cell footprint. It is recommended that, at a minimum, the surface depression be sized to store and exfiltrate the volume associated with the 0.5-inch rainfall depth, with the infiltration riser infiltrating the remaining volume generated up to the required rainfall depth into the stone reservoir below. The infiltration riser can also be constructed of a PVC pipe riser with a grate. The PVC pipe should be open bottom and can be perforated once it enters the reservoir.

Geotextile

Filter fabric should be used to line the vertical edges of the bioretention area but is not recommended at the bottom of the system.

Optional Impermeable Liner

An impermeable liner can be used to line biofiltration systems where infiltration is prohibited due to contamination or other concerns. In an urban environment, an impermeable liner may be used along the vertical sides of infiltrating bioretention to prevent the horizontal movement of water towards subsurface basement areas and roadways.

Streetscapes

Bioretention planters and curb extensions within public rights-of-way must be approved by the Boston Public Works Department (BPWD) and/or the Massachusetts Department of Transportation (MassDOT). In addition to the hydrologic considerations presented in this chapter, the design of curb inlet and outlet, planter walls, and/or tree fencing must also be coordinated with the City of Boston and adhere to applicable local, state, and federal guidelines for structural design and Americans with Disabilities Act (ADA) accessibility.


south street & bussey street roslindale, ma

missouri botanical garden st louis, mo

Maintenance

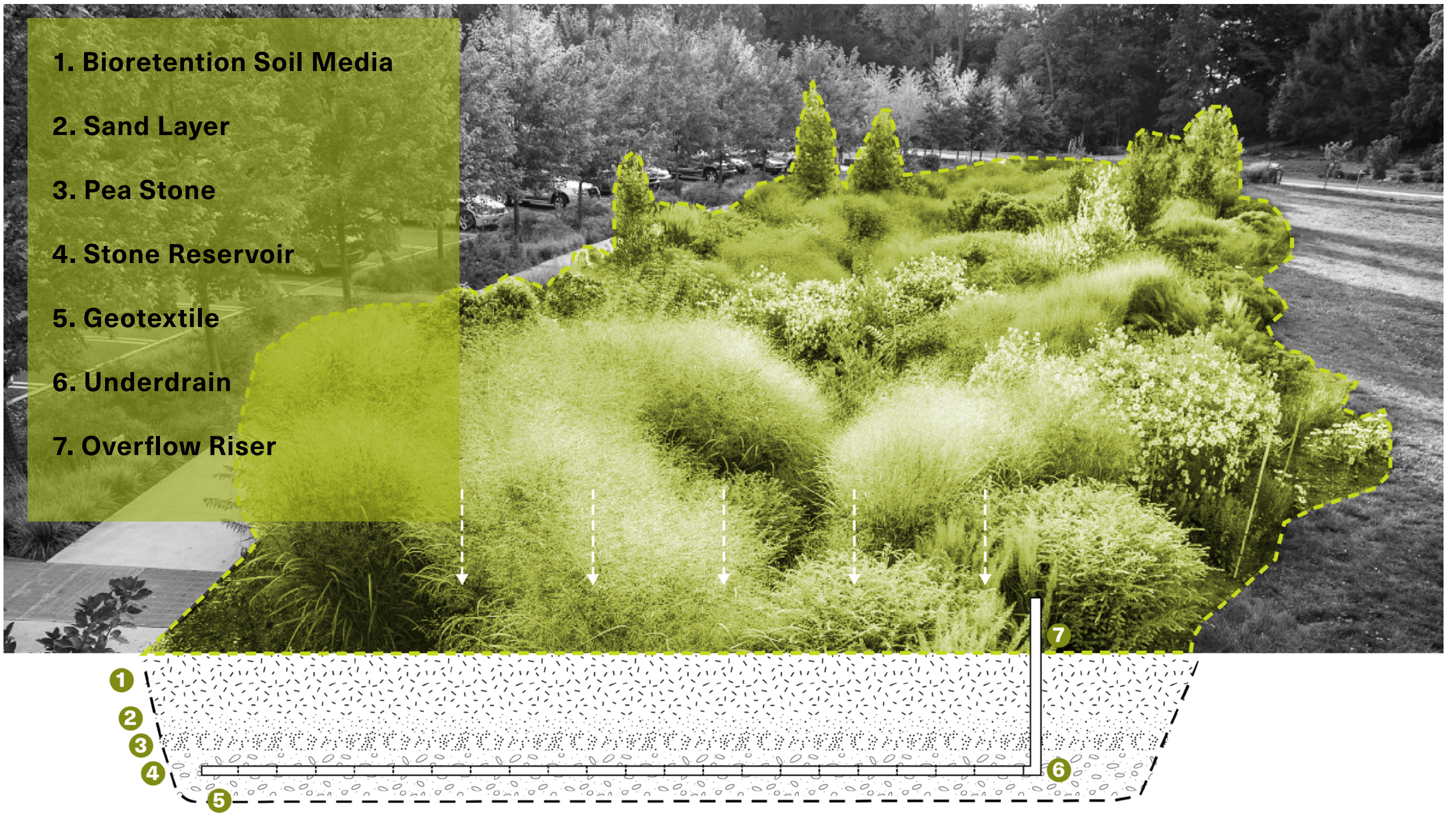
Frequent cleaning and maintenance of the bioretention techniques is critical to prevent clogging. Bioretention maintenance includes trash and sediment removal from the pre-treatment measures and landscape maintenance. For proper maintenance:

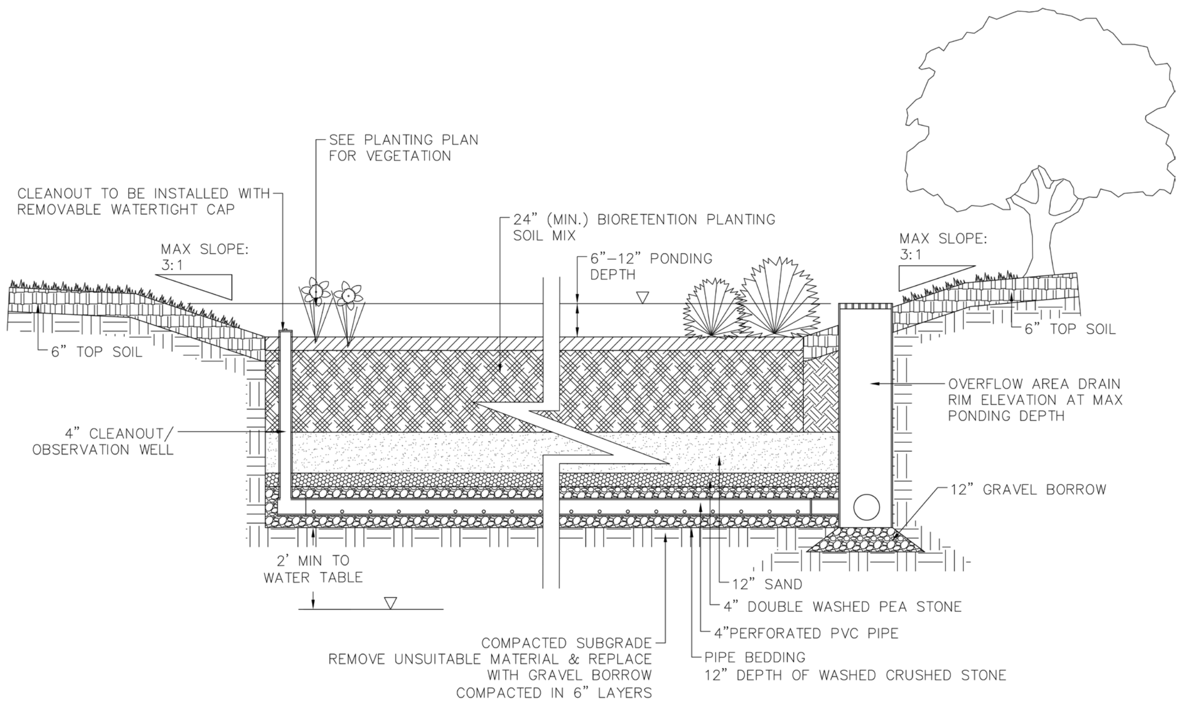
- Inspect the bioretention basin monthly and after large storms.
- Inspect soil and repair eroded areas monthly.
- Remove litter, debris, and accumulated sediment from the pre-treatment areas monthly.
- Treat diseased vegetation as needed. Remove and replace dead vegetation twice per year (spring and fall).
- Inspect the outlet structure frequently for clogging. Clean the outlet structure by removing sediment annually or as needed.
- Minimize the use of concentrated salts on paved surfaces draining to the bioretention basins. Concentrated salts may kill plants, necessitating removal of dead vegetation each spring and replanting.
- Mow grasses and weed as necessary (typically 2 to 12 times per year).
- Perform annual landscape maintenance on trees and shrubs, including pruning and fertilizing if necessary (non-phosphate only).
- Replace the bioretention soil media as needed (recommended once every 10 years).

BIORETENTION Maintenance Schedule

Activity	Frequency
Inspect Bioretention Systems	Monthly and/or After Large Storm Events
Inspect Soil & Repair Eroded Areas	Monthly
Remove Litter, Debris, and Accumulated Sediment	Monthly
Treat Vegetation & Remove/ Replace Dead Vegetation	Bi-Annually
Inspect Outlet Structure for Clogging	Annually
Minimize Use of Salts on Adjacent Paved Surfaces	As Needed
Landscape Maintenance	As Needed
Replace Bioretention Soil Media	As Needed (at least every 10 years)

BIORETENTION Basin

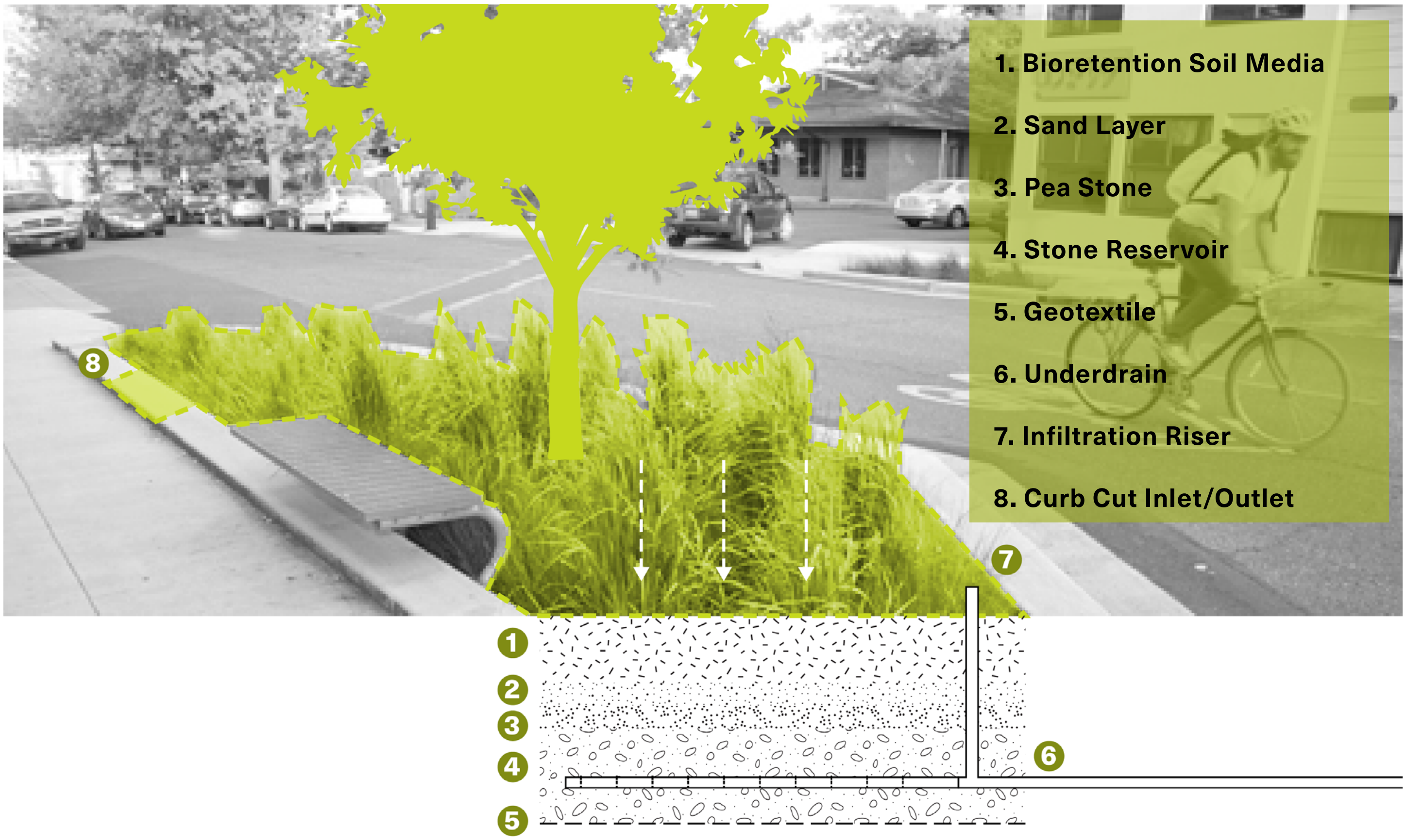


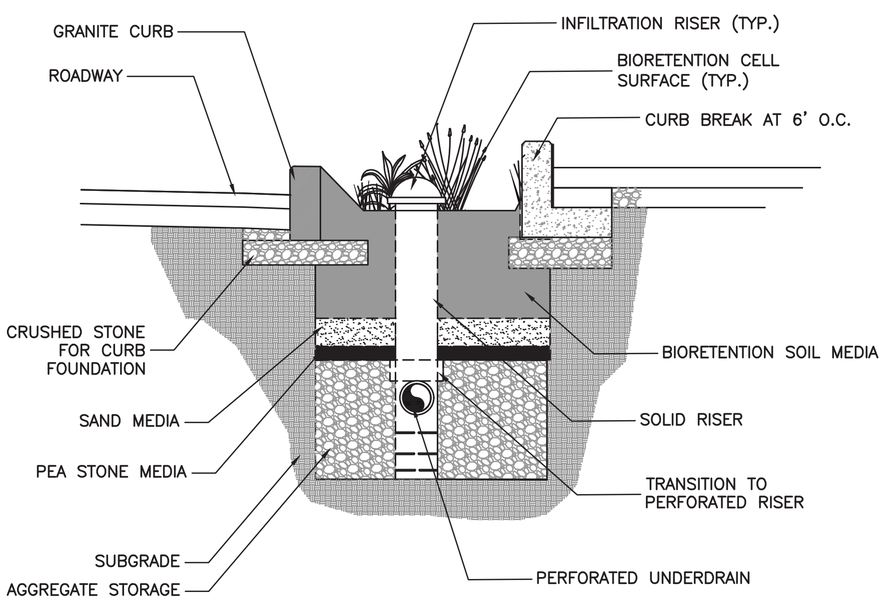


BIORETENTION BASIN

NOT TO SCALE

BIORETENTION Planter





BIORETENTION PLANTER

NOT TO SCALE

peabody square boston, ma

4.3 Permeable Pavements

Permeable paving is a broad term that consists of hardscape surfaces made up of materials or configurations that allow for water to permeate through the surface. All permeable paver systems are comprised of a load-bearing permeable surface with an underlying stone reservoir below. By allowing water to infiltrate through the surface and recharge groundwater, the amount of stormwater runoff is reduced as compared with standard paving materials. Permeable paving is a highly effective water quality treatment technique. As water passes vertically through the underlying media, pollutants are filtered through the aggregate media, stored, and infiltrated into the underlying soil.

Permeable paving is a highly effective low-impact, Green Infrastructure (GI) design technique. Permeable paving provides all stormwater management (treatment and mitigation) in a single footprint and reduces or eliminates the need for a traditional closed drainage systems and additional land for stormwater management. Although the cost of the system (including the paving and aggregate medias) is higher than traditional paving systems, the comparative cost to a traditional paving with a traditional stormwater approach including closed drainage systems and stormwater management practices must be considered. Permeable paving systems must be maintained as part of the Owner's/Operator's ongoing operations and maintenance (O&M).

There are many variations of permeable paving which will be addressed in this section including:

- Permeable Pavers
- Porous Asphalt
- Pervious Concrete
- Grass Pavers
- Rubber Paving
- Porous Bound Aggregate

Porous asphalt and pervious concrete looks like conventional pavements but are formulated with larger aggregate and less fine particles which allows for water to infiltrate within the void spaces. Permeable pavers include interlocking concrete modules and unit (brick) pavers. Configurations of permeable pavers allow for water to penetrate between the modules rather than through the hardscape surface itself.

Permeable Pavers

Porous Asphalt

Pervious Concrete

Grass Pavers

Porous Rubber Paving

Porous Bound Aggregate

Benefits

Incorporating permeable paving provides a stable paved surface that also manages stormwater without utilizing other usable space for stormwater management. Permeable paving also reduces stormwater runoff and promotes groundwater recharge while treating pollutants such as solids, metals, nutrients, and hydrocarbons. Additionally, this strategy provides aesthetic enhancements to urban surfaces (when use of interlocking permeable pavers over traditional asphalt or concrete).

STORMWATER BENEFITS		
	●●●●◐	**Peak Rate Mitigation** Slow & Detain
	●●●●◐	**Volume** Infiltrate
	●●○○○	**Volume** Evaporation or Reuse
	●●●●◐	**Quality** Solids (TSS)
	●●●●◐	**Quality** Phosphorus

Applicability

Selection of the most appropriate permeable paving must consider the type and frequency of the use, durability, and long-term O&M. Surfaces with heavy traffic loads (parking lots, driveways, roadways, and parking lanes) will require highly durable surface materials compared to surfaces with light duty or limited vehicular use. Pedestrian only surfaces should consider Americans with Disabilities Act (ADA) accessibility and safety considerations. The following matrix provides general recommendations for the selection of permeable paving materials depending on the location and use.

Constraints

Major limitations to implementing permeable paving include suitability of site grades, subsoils, and groundwater conditions. In addition, this strategy may be reconsidered if there is a lack of resources to ensure proper annual maintenance. Sites that have a high amount of sediment-laden runoff and high traffic volumes (especially large trucks and heavy axle loads) may cause system failures. Parking areas with high volumes, high dust areas, and areas that have heavy equipment traffic are not recommended for this GI strategy. Underlying subsoils should be able to adequately support infiltration. Design modifications, including underdrains, must be considered where underlying subsoils are not highly permeable.

central square east boston, ma

Recommended Uses for Permeable Paving in Boston

	Porous Asphalt	Pervious Concrete	Permeable Interlocking Pavers	Permeable Unit Pavers	Rubber Paving	Grass Pavers	Porous Bound Aggregate
Roadway driving lane							
Roadway parking lane	●						
Alley	●		●				
Sidewalk pedestrian zone	●						
Sidewalk furnishing zone	●	●	●	●	●		
Parking Lot private	●	●	●			●	
Driveway private	●	●	●	●		●	
Trails	●	●	●	●	●	●	●
Playgrounds	●	●	●	●	●	●	●
Courtyards & Plazas private	●	●	●	●	●	●	●
Walkways private	●	●	●	●	●	●	●

Design and Sizing Criteria

Permeable paving systems should be designed by a registered Professional Civil Engineer using the hydrologic and hydraulic methodologies prescribed by the Massachusetts Department of Environmental Protection (MassDEP) Stormwater Handbook and other standard practice. Designs should be evaluated as part of the site's Pre- vs. Post-Drainage Analysis, as required for Boston Water and Sewer Commission (BWSC) Site Plan Approval.

Contributing Drainage Area

- Calculate the area of permeable paving and additional "run-on" areas.
- Confirm that the specifications for the permeable paving will allow for infiltration of all storm events up to the 100-year, 24-hour storm. If stormwater is anticipated to run off the pervious paving surface, additional drainage, conveyance, and stormwater management techniques may be required.

Required Retainage Volume and Depth of Stone Reservoir Sizing

- The storage volume for the stone reservoir should be designed to retain and infiltrate the 90th percentile rainfall depth for the contributing drainage area, in accordance with BWSC guidelines. The storage volume for the stone reservoir should be further extended to address local/state regulatory peak rate requirements for the project.

Design of Underdrain System

- For poorly draining soils, an optional underdrain may be considered. The underdrain shall be set at an elevation above the static or modeled Required Retainage Volume.

Quantity Control for Storm Events and Overflow Measures

- The engineer may use MassDEP-approved methodologies to model the inflow and outflow characteristics of the stone reservoir to meet regulatory peak rate reductions for the 2-year through 100-year, 24-hour design storms.

Drain Time Calculations

- All pervious paving systems should drawdown within 72 hours, as recommended by the MassDEP Stormwater Handbook.


peabody square boston, ma


rose kennedy greenway boston, ma (mvva)


grass paving system


porous rubber paving

central square east boston, ma

Design Considerations

Permeable paving systems to be designed within public rights-of-way must be approved by the Boston Public Works Department (BPWD) and/or the Massachusetts Department of Transportation (MassDOT). In addition to the hydrologic considerations presented in this chapter, the structural design of permeable paving systems must also be evaluated by a Professional Engineer and conform to applicable local, state, and federal guidelines for structural design and ADA accessibility.

Soils

Permeable paving systems should be considered only where the underlying soils have a permeability of at least 0.17 inches/ hour. Permeable paving systems are intended to infiltrate stormwater and therefore should not be placed on compacted fill.

Cold Climate

Permeable paving systems can be highly effective, even in cold climate. Permeable paving surfaces can reduce meltwater runoff and ponding on roadway surfaces, which turns to ice on standard impervious surfaces. The University of New Hampshire Stormwater Center has conducted significant research and developed specifications for porous asphalt and storage bed design that addresses the concern for frost heaves.

Slopes

Permeable paving should not be used where surface slopes exceed 5%. It is important that the bottom of the stone reservoir remain at a consistent slope. The use of check dams or "stepping" the stone reservoir may be necessary for large areas of pervious paving, depending on the slope.

Contributing Drainage Area

Permeable paving is most effective for managing stormwater that lands upon the surface itself. Stormwater run-on from other impervious drainage areas across the permeable pavement surface should be minimized to the greatest extent possible, as this increases the risk of introducing additional sediment that causes clogging of the system. Unstabilized pervious areas should also not be directed across permeable paving surfaces. The maximum contributing drainage area to permeable pavement surface area ratio is 4:1. The Storage Reservoir must be sized for the entire contributing drainage area to the permeable paving surface.

Setbacks

Pervious paving promotes infiltration and therefore warrants consideration for setbacks from septic systems, surface waters, drinking wells, and foundations. Refer to the MassDEP Stormwater Handbook for specific setback recommendations. Pervious paving should also be coordinated with existing utility infrastructure. Refer to the Design Chapter of this Handbook for more information about offset with existing utilities.

Permeable Paving Surface

Porous asphalt and pervious concrete allow water to permeate through the voids in the pavement. These surfaces are typically mixed with a very low content of fine sand so that it has from 10% to 25% void space. Porous asphalt is a poured-in-place application and requires a specialized specification for batching and installing. A widely accepted specification for use in cold climates was prepared by the University of New Hampshire Stormwater Center. Poured-in-place pervious concrete is not as widely used in cold climates; however, certain prefabricated products (such as Stormcrete) are designed to be easier to install and maintain. Permeable pavers, grass pavers, and rubberized paving surfaces are widely available in the market. The manufacturer's specifications should be reviewed to confirm that the system provides the stormwater function and durability required for the intended use.

Filter and Storage

The University of New Hampshire Stormwater Center has developed specifications for storage beds used in connection with porous asphalt or pervious concrete. According to the University of New Hampshire, the storage bed should be constructed with the following components from top to bottom: 1) a 4-inch choker course comprised of uniformly, graded crushed stone; 2) a filter course, at least 12 inches thick, of poorly-graded sand or bankrun gravel to provide enhanced filtration and delayed infiltration; 3) a filter blanket, at least 3 inches thick, of peastone gravel to prevent material from entering the reservoir course; and 4) a stone reservoir course of uniformly graded crushed stone with a high void content to maximize the storage of infiltrated water and to create a capillary barrier to winter freeze thaw. The bottom of the stone reservoir must be completely flat so that runoff can infiltrate through the entire surface.

If paving stones or grass pavers are used, a top course of sand that is 1 inch thick should be placed above the choker course. Additionally, refer to the manufacturer's guidelines and specifications.

The depth of the stone reservoir can be designed to include underdrains and/or perforated pipes to optimize the storage volume footprint and to provide additional access for inspection and maintenance.

Optional Overflow Riser

For large areas of pervious pavement where system failure could cause erosion or flooding concerns, an optional overflow riser could be considered. This could be configured as an area drain or catch basin structure set with a domed structure to collect water only in the event of permeable pavement failure or a significant storm event. The catch basin or area drain could be connected to the stone reservoir and/or perforated piping below and could also be configured with an emergency overflow to connect to the drain system. The catch basin or area drain could also serve as a cleanout.

Optional Underdrain

Where underlying soil conditions will not allow for adequate drawdown per MassDEP requirements, an underdrain should be placed within the stone reservoir layer. The underdrain should be placed as high as possible in the reservoir to optimize retainage of the BWSC Retainage Volume.

downtown crossing boston, ma (höweler + yoon architecture)

bentley university waltham, ma (unilock)

Maintenance

Frequent cleaning and maintenance of the porous pavement surface is critical to prevent clogging. Frequent vacuum sweeping along with jet washing of porous pavement is required. No winter sanding shall be conducted on the porous surface. For proper maintenance:

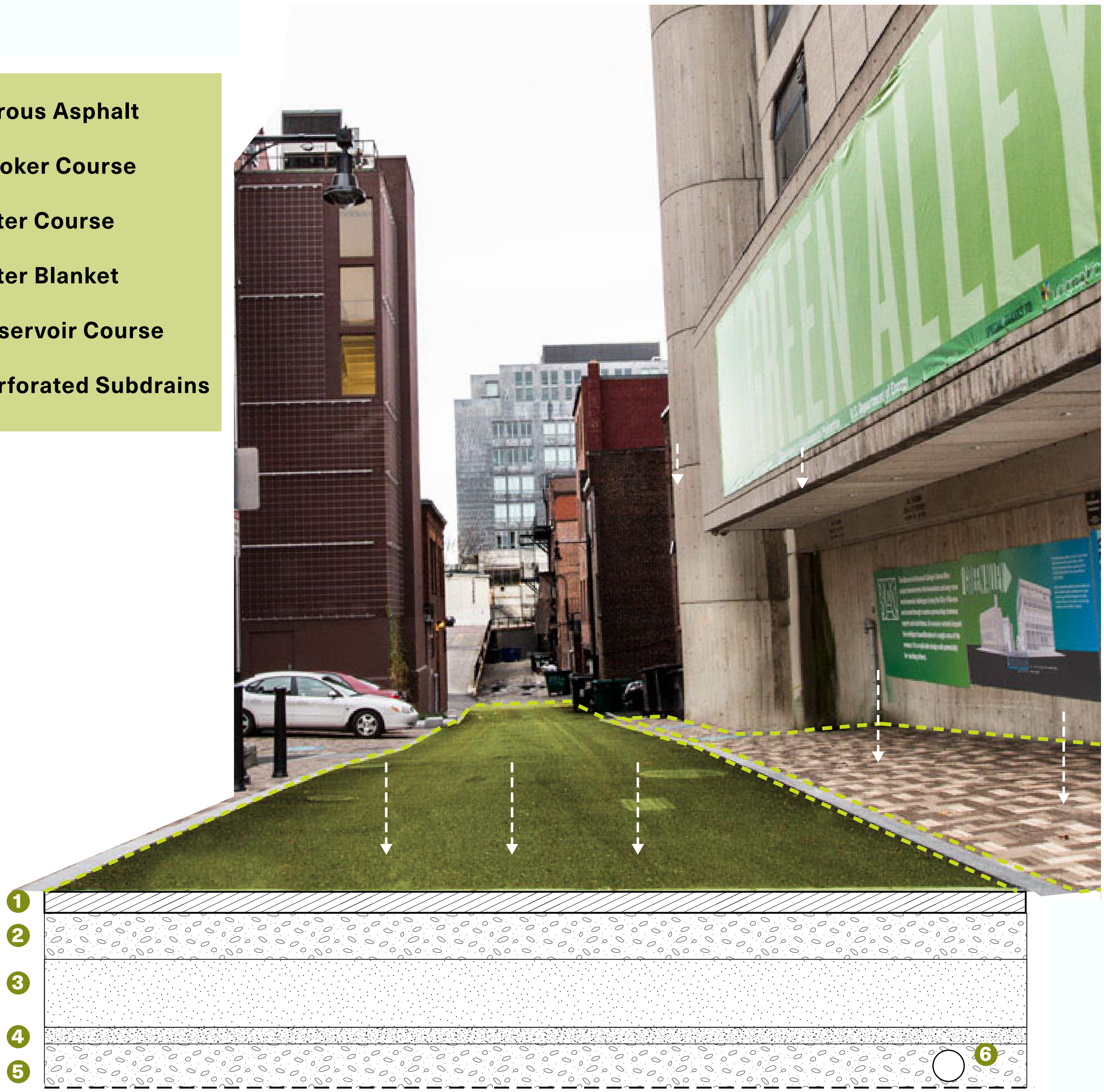
- Minimize salt use during winter months.
- No winter sanding is allowed.
- Keep landscaped areas well maintained to prevent soil from being transported onto the pavement.
- Regularly monitor the porous pavement surface to check for deterioration and make sure that it drains properly after storm events.
- Clean the surface of each porous pavement area using vacuum sweeping as required to keep the pavement functioning as designed. At a minimum, the porous pavement shall be cleaned after the winter season and every three months thereafter. This requirement may be adjusted as needed, based on regular visual inspections of the porous pavement surface.
- Never reseal or repave with impermeable materials.
- Once per year, the infiltrative capacity of the porous pavement should be tested by running a hose over each porous pavement area for 30 minutes.
- Sections of damaged porous asphalt (rutting, etc.) can be repaired by heating and re-rolling the asphalt.
- When infiltrative capacity of porous pavement is reduced to less than the design rate, the porous pavement shall be replaced by milling to the choker course.

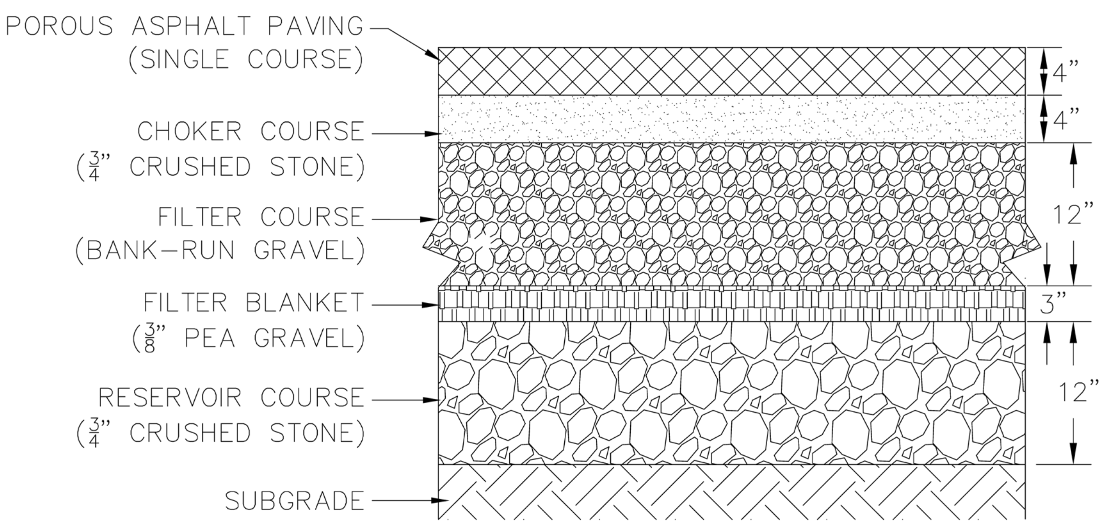
Permeable Paving Maintenance Schedule

Activity	Frequency
Monitor Paving Surface Drainage Efficiency	As Needed
Clear Porous Asphalts/ Concretes Use a power washer followed by vacuum sweep to ensure pores are clear for water to drain	Quarterly
Inspect Surface for deterioration or other flaws Remove plant material that is dead or in poor health	Annually
Assess Exfiltration Capability If found to decline, follow measures identified in the Operation and Maintenance Plan	As needed, at least once per year
Reseed Grass Pavers to Fill Bare Spots	As Needed

Porous Asphalt

1. Porous Asphalt
2. Choker Course
3. Filter Course
4. Filter Blanket
5. Reservoir Course
6. Perforated Subdrains





TYPICAL POROUS ASPHALT SECTION DETAIL

NOT TO SCALE

Permeable Pavers

1. Concrete Pavers

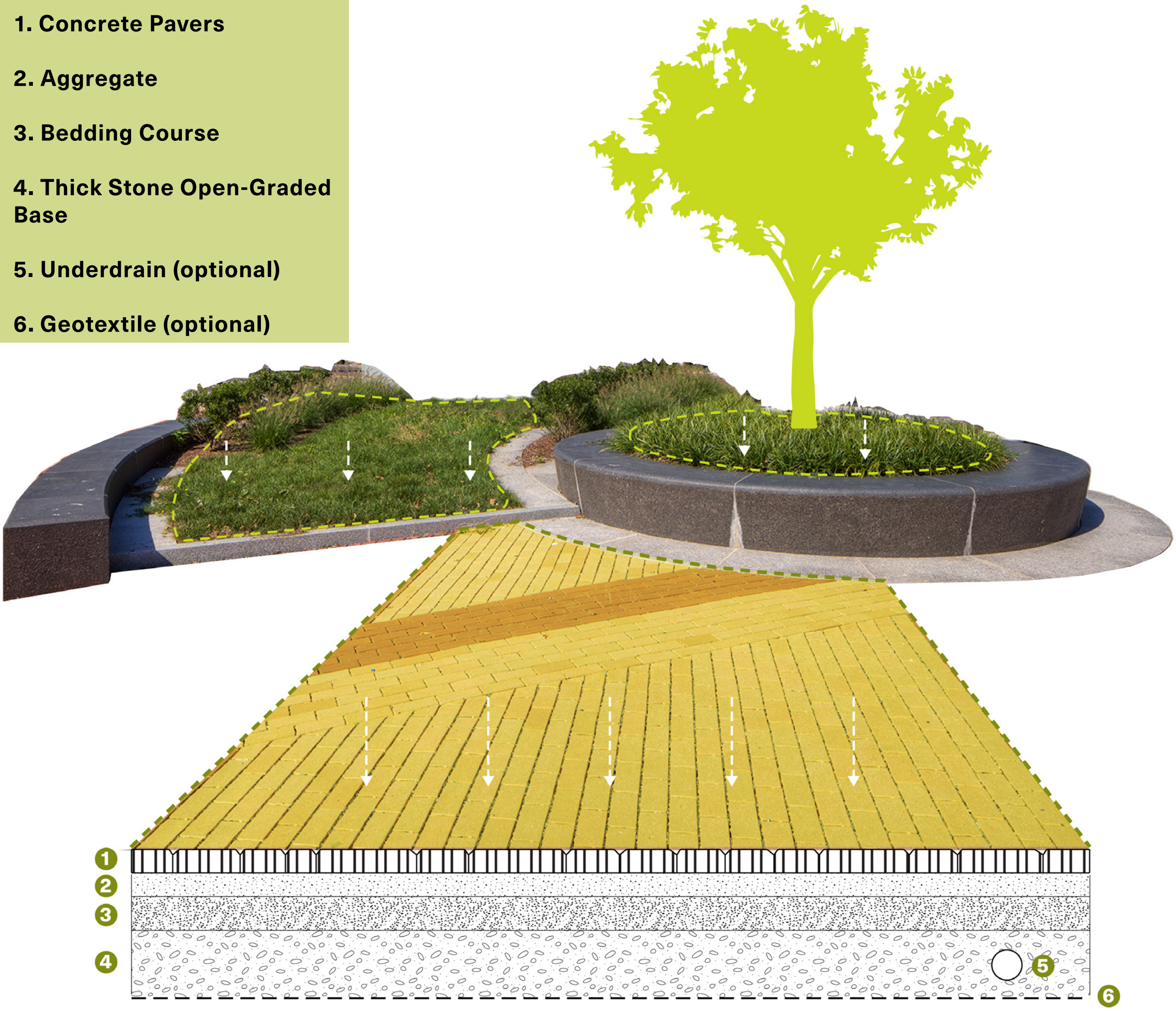
2. Aggregate

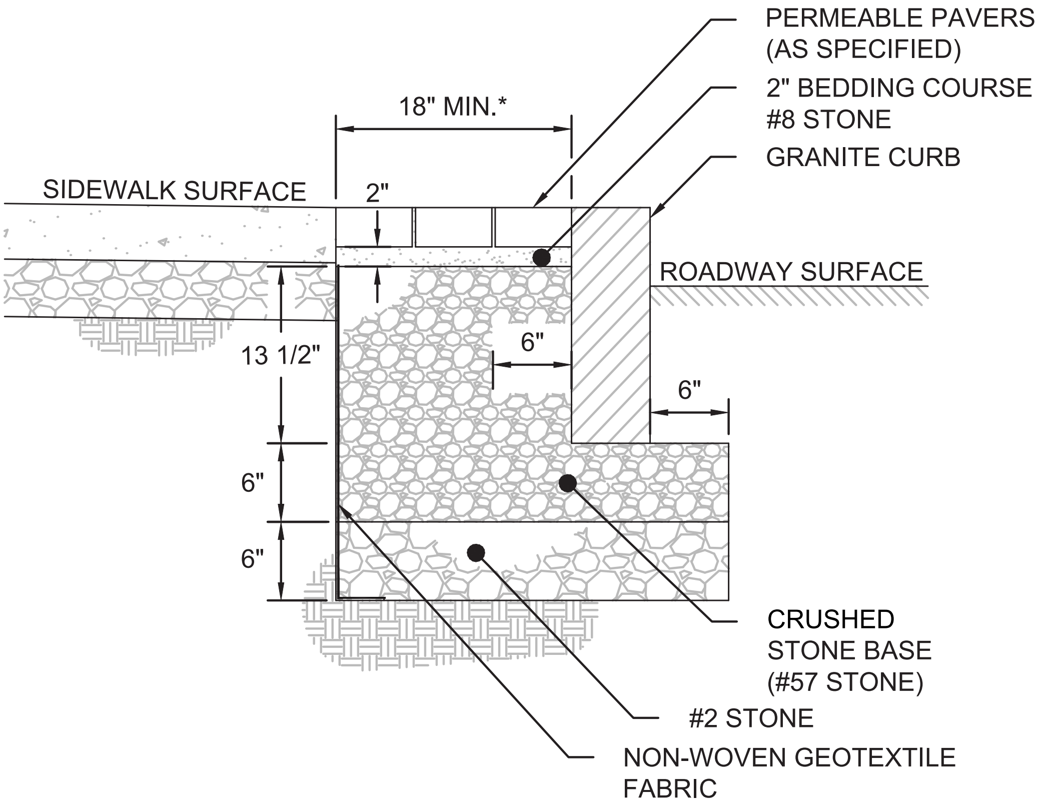
3. Bedding Course

4. Thick Stone Open-Graded Base

5. Underdrain (optional)

6. Geotextile (optional)





NOTE:

1. PERMEABLE PAVERS WITHIN THE PUBLIC RIGHT-OF-WAY MUST COMPLY WITH THE CITY OF BOSTON PUBLIC WORKS DEPARTMENT REQUIREMENTS.
2. PERMEABLE PAVERS SHALL BE INSTALLED WITH A MINIMUM WIDTH OF 18" FOR SIDEWALKS UP TO 7'. FOR SIDEWALKS OVER 7', PERMEABLE PAVER WIDTH SHALL BE 1' PER 5' OF SIDEWALK.
3. DEPENDING ON SOIL CONDITIONS AND GROUNDWATER, IT MAY BE APPROPRIATE TO PROVIDE AN UNDERDRAIN BEHIND THE CURB AND WITHIN THE CRUSHED STONE BASE. UNDERDRAIN MAY BE REQUIRED IN SOILS WITH LOW INFILTRATION RATES. IF USED, THEY MUST BE INSTALLED ABOVE THE GROUNDWATER ELEVATION.
4. ALL PERMEABLE SYSTEMS SHALL BE MAINTAINED AS PER MANUFACTURER RECOMMENDATIONS.

PERMEABLE PAVER AT SIDEWALK

NOT TO SCALE

hancock tower boston, ma (mikyoung kim design)

4.4 ROOFTOP STORAGE

In ultra-urban conditions, rooftops account for a large portion of the impervious surfaces that generate stormwater runoff and contribute to urban flooding issues. Strategies to retain, detain, evaporate, and reuse rainwater that falls on the roof include green roofs, blue roofs, and rainwater harvesting using cisterns. These approaches are used to manage stormwater within the building footprint and do not typically require additional site areas to manage stormwater.

Green roofs are planted rooftops that consist of plants and engineered soil media. Green roofs intercept and store rainwater in the soil media and underlying drainage layers. The rainwater is taken up by plants and returned to the atmosphere by evapotranspiration. Treated excess water is slowly released to the drainage system.

There are two types of green roofs – extensive and intensive green roofs. Extensive green roofs include a relatively shallow depth of soil media that supports the growth of sedums, herbs, and grasses. Extensive green roofs can be sized to retain the required water quality volume and thereby provide volume reduction (through plant uptake and evapotranspiration) and peak flow attenuation for small storms. Intensive green roofs include a deeper and richer soil media used to support the growth of lawns, annual and perennial flowers, shrubs, and trees. Intensive green roofs can provide volume reductions and peak flow attenuation for larger storms.

In addition to managing stormwater, green roofs offer a variety of co-benefits including urban heat island mitigation, habitat creation, sound mitigation, carbon sequestration, increased roof membrane life span, and building energy savings. Green roofs can also provide aesthetic benefits and outdoor gathering space (if designed to be occupiable). Green roofs, especially intensive green roofs, are more maintenance-intensive and typically require irrigation.

Blue roofs are rooftops designed to temporarily store and slowly release rainwater. Blue roofs can be designed to retain the water quality volume and reduce the volume of stormwater discharge through evaporation. Blue roofs are applicable to ultra-urban conditions, but do not offer the many co-benefits offered by green roofs.

Cisterns (or tanks) can also be used to collect rainwater from rooftops. Rainwater harvested cisterns can be reused for non-potable water demands such as toilet flushing and irrigation. Rainwater harvesting is an approach used to conserve potable water and provide some stormwater management benefits. Cisterns can be further designed to provide additional fluctuation storage for peak rate mitigation above the permanent storage volume. The stormwater management performance of cisterns varies greatly based on precipitation and supply vs. demand scenarios. For example, a "full" cistern may not have capacity to retain additional rainwater, whereas an empty cistern would retain rainwater and support a volume reduction through subsequent reuse.

STORMWATER BENEFITS		
	●●●◐○	**Peak Rate Mitigation** Slow & Detain
	●○○○○	**Volume** Infiltrate
	●●●●○	**Volume** Evaporation or Reuse
	●●●●●	**Quality** Solids (TSS)
	●●●◐○	**Quality** Phosphorus

Benefits

Green Roofs
- Reduces the volume and peak rate of stormwater runoff for small, frequent storms
- Highly effective stormwater approach for ultra-urban conditions and constrained sites with poor soil conditions
- Provides several other co-benefits including energy savings, urban heat island mitigation, and habitat creation

Blue Roofs
- Provides peak rate attenuation for all storms and reduces the volume of runoff for storms through evaporation
- Highly effective stormwater approach for ultra-urban conditions and constrained sites with poor soil conditions

Cisterns
- Conserves water by capturing and storing rainwater to supplement non-potable water demands such as toilet flushing and irrigation
- Reduces the volume of stormwater runoff for small, frequent storm events

harvard business school cambridge, ma (recover green roofs)

Applicability

Green & Blue Roofs

Green and blue roofs are highly effective in ultra-urban conditions, especially where CSO or inland and coastal flooding issues exist. Green and blue roofs are applicable to industrial, commercial, institutional, and residential green roofs with flat and low angle pitches. Green and blue roofs are suited for new construction but can be considered for redevelopment with careful consideration of structural impacts and roof membrane protection. Green roofs and blue roofs manage stormwater on the rooftop and are well suited for constrained sites where stormwater infiltration is not feasible due to space limitations or soil conditions.

Cisterns

Cisterns are used to capture, store, and reuse rainwater that falls on rooftops. Captured rainwater is filtered (and in some cases disinfected) prior to reuse for non-potable water uses such as irrigation, toilet flushing, and mechanical makeup water. Rainwater harvesting systems are most applicable to new construction, particularly if the captured rainwater will be reused for building toilet flushing which requires a dual plumbing system (purple pipe). Cisterns are typically constructed in building basements or below-grade outside the building footprint in cold climates. Cisterns can be designed with additional capacity above the reservoir to mitigate the peak rate for large storm events.

Constraints

Green & Blue Roofs

Green roofs, blue roofs, and cisterns are strategies that reduce stormwater runoff, especially for small, frequent rainfall events. Although these systems reduce the volume of stormwater runoff, they do not promote infiltration and do not support groundwater recharge goals. As such, these strategies are not suitable as a stand-alone stormwater management approach where groundwater recharge is a priority. Green roofs and blue roofs can be designed to retain and evaporate the water quality storm event, which thereby provides water quality treatment through volume reduction. Some research indicates that green roofs may generate phosphorus; therefore, special maintenance procedures, including the use of phosphate-free fertilizers, should be applied.

Green roofs and blue roofs must be designed in accordance with State Building Codes and require specific attention to structural supports, waterproofing membranes, and fire safety. Green roofs also require frequent maintenance, and thicker green roofs may require irrigation. Intensive green roofs and blue roofs that store large volumes of rainwater may require additional structural elements that add cost and complexity to projects. The construction cost for green roofs is high when compared to other stormwater management approaches in isolation;

however, green roofs can support cost savings when evaluated as part of a life cycle cost analysis that accounts for long-term heat and energy cost savings and reduced roof membrane replacement costs.

A common concern about green roofs and blue roofs is the potential for leaks. The current materials available for waterproofing, as well as more rigorous design and construction standards for these practices, have addressed these concerns in recent decades. These systems have been widely used in European countries and are more widely acceptable in the United States driven by the green building movement.

Cisterns
Cisterns must be designed to balance supply (rainfall) and demand (non-potable water use). Therefore, the stormwater management benefits of cisterns vary greatly. For example, a "full" cistern may not have capacity to retain additional water, whereas an empty cistern would. Cisterns used for seasonal uses, such as irrigation, would only be anticipated to reduce the stormwater volume during the season of use and would provide little to no additional benefit during the dormant months. Stormwater management volume reductions after rainfall events can be quantified based on the availability of storage at the time of the storm and the subsequent "drawdown" from daily use such as irrigation or toilet flushing. The maximum recommended volume reduction is typically three to four days of reuse following a rainfall event. In many cases, additional stormwater management measures, such as infiltration practices, will be necessary to meet stormwater management goals.

Due to treatment requirements necessary to address public health codes for repurposing rainwater for non-potable water uses, the cost for rainwater harvesting is typically high. A life cycle cost analysis can help determine the long-term return on investment based on purchased water savings. Additional considerations for rainwater harvesting include code compliance and long-term operations and maintenance (O&M) requirements.

Design Considerations

Green Roofs
Green roofs typically include a waterproof membrane, a drainage layer, a soil layer, and plants. The soil layer should be sized to provide the necessary depth for growing the desired plants, as well as to store the required water quality volume within the soil voids for plant uptake and evapotranspiration. The soil media should be lightweight and porous with minimal organic content and compost. The underlying drainage layer typically consists of a geotextile membrane, root barrier, and perforated plastic sheets to store and drain excess water. A waterproofing membrane is placed beneath the drainage layer on top the roof sheathing.

Extensive green roofs typically consist of hardy, low-growing, drought-resistant, spreading perennials or self-sowing annuals that provide dense cover and can withstand heat, cold, and high winds. Vegetation can be planted as mats, plugs, sprigs, or seeds. The Massachusetts Department of Environmental Protection (MassDEP) Stormwater Best Management Practices (BMP) Manual provides a list of recommended plantings including sedum (stonecrop), delospermum (ice plant), sempervivium, creeping thyme, allium, phloxes, anntenaria, ameria, and abretia. Intensive green roofs require deeper soil volumes to grow grasses, shrubs, and trees and may require irrigation.

Green roofs have been widely used in Europe and have become more broadly accepted in the United States. Green roof manufacturers can provide more specific design guidance for installing and maintaining green roofs.

Design and Sizing Criteria

Blue & Green Roofs

Hydrologic calculations for designing a green roof require specific considerations pertaining to the retention capacity, evapotranspiration rates, and rate of release. The New Jersey Stormwater Management Best Practices Manual provides a detailed methodology that can be used to confirm the rainfall retention and discharge parameters for a green roof using an adjusted curve number methodology. Some green roof manufacturers have developed independent models calibrated by actual green roof installations that can be referenced.

Green and blue roofs can be designed to retain and evapotranspire/evaporate the Boston Water and Sewer Commission (BWSC) Retainage Storm (1 inch or 1.25 inches). A registered Professional Engineer should provide calculations that demonstrate the system has the capacity to retain the required volume using industry-accepted methodologies. For a green roof, the calculations must be based on the water capacity of the green roof media. For a blue roof, the calculations must demonstrate the roof storage capacity and the ability to evaporate the BWSC Retainage Storm within 48 hours. Designs should be evaluated as part of the site's Pre- vs. Post-Drainage Analysis, as required for BWSC Site Plan Approval.

Cisterns

For cisterns, the following simple calculations can be used to demonstrate retainage and reuse of the Required Retainage Volume:

Contributing Drainage Area

- Calculate the contributing drainage area. Calculate the impervious roof area that will be directed to the cistern.
- Calculate the Required Retainage Volume based on the contributing impervious drainage area and the 1-inch or 1.25-inch rainfall as required by BWSC.

Determine the Three-Day Tank Drawdown

- Determine the estimated demand for non-potable water daily and multiply by three to calculate the Three-Day Tank Drawdown. For example, if the estimated daily toilet flushing is 1,000 gallons/day, this number would be used to determine the estimated three-day drawdown of 3,000 gallons (1,000 gallons/day * three days).
- The Three-Day Tank Drawdown can be used as the Provided Storage Volume.
- The Total Storage Volume of the tank should be greater than the Three-Day Tank Drawdown. Tanks should be sized to optimize rainfall supply and demand.

Compare the Required Retainage Volume to the Three-Day Tank Drawdown

- Compare the volumes determined above. If the Three-Day Tank Drawdown volume is greater or equal to the Required Retainage Volume, rainwater harvesting can be used to meet the BWSC retainage requirements. If the Three-Day Tank Drawdown volume is not greater than the Required Retainage Volume, additional infiltration practices must be employed on-site to meet the requirement.

harvard business school cambridge, ma

Blue Roofs
Blue roofs require the use of a specially designed and insulated waterproof membrane systems. Blue roofs are typically suited for new construction, as they may require additional structural considerations to support the temporary storage of rainwater on the roof. Some blue roofs include ballast or other materials with void storage. The blue roof technology is also incorporated into green roof technologies. Rainwater stored on the roof is evaporated and slowly released from drains specially designed to slowly release rainwater to the storm drain system. Blue roofs should be designed to draw down within 48 hours in accordance with the International Building Codes and Massachusetts Building Codes.

Cisterns
Cisterns are storage tanks used to store captured rainwater to be reused for non-potable water demands such as toilet flushing and irrigation. Cisterns can be installed within a building structure (typically within the basement) or external to the structure (most commonly on-site below-grade in cold climates). Cisterns must be water-tight and can be cast-in-place or pre-manufactured and are typically made of concrete, steel, and fiberglass.

Determining the most efficient and economical size for a cistern requires evaluation of the availability of rainfall compared to the estimated demand for non-potable water. The New England climate is a humid climate that experiences rainfall year-round; however, periods of summer drought are becoming more common and should be accounted for in the analysis. A water balance analysis can be used to evaluate the supply and demand for various tank sizes to determine the most efficient volume for the project. From a stormwater management perspective, the recommended volume reduction that can be accounted for after a given rainfall event is the equivalent of the anticipated drawdown (or demand) over three to four days following the rainfall event (based on recommendations developed by the U.S. Green Building Council's (USGBC) LEED Rating System). For a large roof with a relatively small daily demand, this volume may not equate to the BWSC Retainage Volume and therefore a secondary volume reduction strategy must be employed for overflow from the tank (such as an infiltration practice).

Another major design consideration for rainwater harvesting relates to water quality. Pre-treatment devices are recommended to prevent particulates and debris from entering the cistern. Additional filtration and disinfection may be necessary on the "demand side" to ensure the quality of the water does not impact the equipment (pumps and plumbing system) and to ensure that water is safe in accordance with relevant public health codes. All components of the rainwater harvesting system that are located within the building must conform to the Massachusetts Building Code.

Contributing Drainage Area
Rooftop capture strategies such as green roofs, blue roofs, and rainwater harvesting addresses the stormwater management for the rooftop area only. If only portions of the roof are green roof, blue roof, or directed to a cistern, then the remainder of the impervious rooftop will require additional stormwater management measures on-site.

Pre-treatment

Green and blue roofs do not typically require pre-treatment since rainwater falling upon the roof is managed where it falls. If the water quality volume is retained and evaporated on a green or blue roof, the rooftop area can be removed from the impervious area used for calculating additional water quality treatment requirements on-site. Excess water would be considered "pre-treated" if it will be further managed using an on-site strategy (such as infiltration).

Rainwater captured from rooftops and directed to cisterns should be pre-treated due to the variety of particulates, debris, nutrients, metals, and organic materials that can accumulate on rooftops from atmospheric deposition, overhanging trees, and birds. Inline filtration devices can remove sediments and particulates prior to entering the cistern. Additional filtration and disinfection may be necessary prior to pumping, treatment, and reuse based on local and state public health codes. Overflow from cisterns can be directed to infiltration practices for additional stormwater management.

Cold Climate

Rooftop strategies such as green roofs and blue roofs are effective year-round. Evaporation and evapotranspiration rates are much greater in the warmer months and therefore the systems are anticipated to be most efficient during the spring, summer, and fall seasons, but are still effective during the winter. During deep freeze events the soil medium on a green roof may become frozen, so an emergency bypass may be necessary. Rainwater harvesting can also be used year-round; however, snowfall will not be converted to liquid that can be stored in cisterns until melting occurs. Also, rainwater harvesting for irrigation only provides stormwater volume reductions during the growing season and is not an effective year-round stormwater management strategy.

Roof Slope

Green and blue roofs are most effective on flat or low roof pitches (<15%). Green roofs can be constructed on larger pitched roof with specific design features to be coordinated with the green roof manufacturer. Rainwater can be harvested from flat to steeply sloping roofs. However, to maximize capture efficiency, special design considerations should be applied to steeply sloping roofs to prevent spillover.

Plumbing Code and Building Codes

Additional considerations for design of cisterns include considerations for structural integrity, buoyancy, access, and maintenance. Although the rainwater drawn to reuse is typically pumped, it is recommended that the system's overflow be designed to drain by gravity. Internal cisterns should be evaluated to ensure life safety impacts in the rare situation the tank fails/ruptures. There are limitations on the reuse of captured rainwater. Consult your local and state public health codes to confirm reuse opportunities.

Maintenance

Green Roofs
Green roofs require frequent maintenance. For modular green roofs or green roof systems, the maintenance recommendations provided by the manufacturer should be followed. In general, maintenance recommendations for green roofs include:

- Perform frequent landscape maintenance during the establishment period including watering, weeding, and mulching.
- Perform bi-annual landscape maintenance after establishment including weeding, mulching, and pruning.
- Remove woody vegetation (if applicable).
- If fertilizers will be applied, develop an Integrated Fertilizer Management Plan to ensure that phosphate-free fertilizer will be used, and the transport of other nutrients will be minimized.

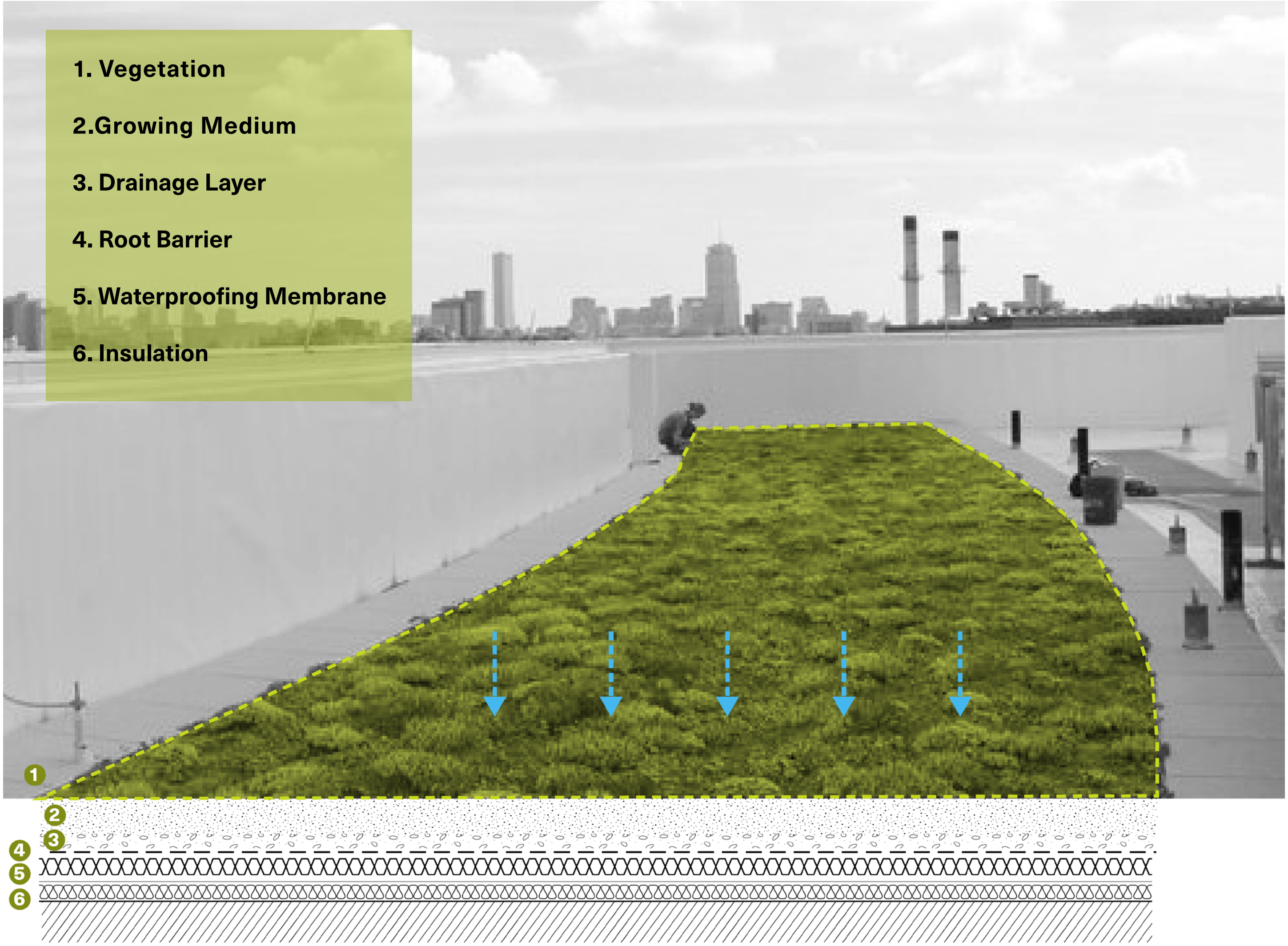
Cisterns
Pre-treatment devices will help prevent the discharge of debris and sediment from entering cisterns; however, inspection and annual maintenance is still anticipated. If sediment and debris accumulate in the tank, it will need to be removed by vacuum. Rainwater harvesting systems require complex O&M requirements to upkeep pumps and treatment units. Many package rainwaters harvesting systems come with specific guidelines for O&M that should be followed.

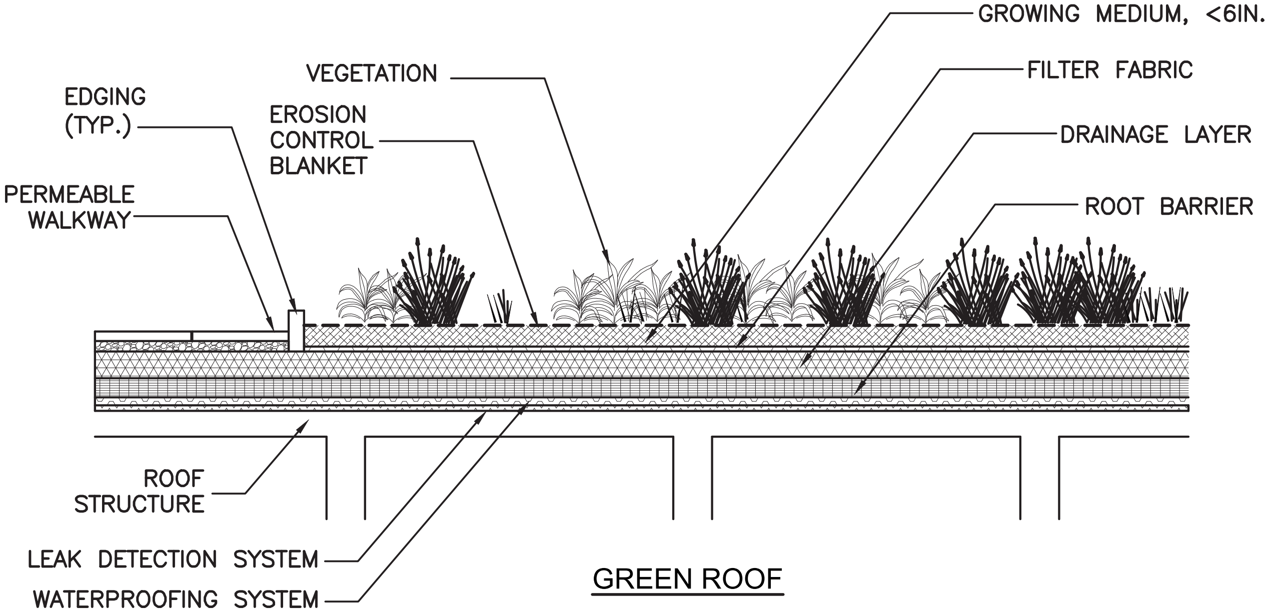
Green Roof Maintenance Schedule

Activity	Frequency
Landscape Maintenance water, weed, & mulch	During Establishment
Landscape Maintenance weed, prune, & mulch	Bi-Annually
Remove Woody Vegetation If applicable	As Needed
Integrated Fertilizer Plan if using fertilizers	During Design

christian science center plaza, boston ma

Green Roof


1. Vegetation
2.Growing Medium
3. Drainage Layer
4. Root Barrier
5. Waterproofing Membrane
6. Insulation
1
2
3
4
5
6



GREEN ROOF

NOT TO SCALE