Hopedale Pond Storm Drain Mapping, Conceptual Stormwater Designs and Sampling

Hopedale, Massachusetts

PREPARED FOR:
Park Commission
Town of Hopedale
78 Hopedale Street
Hopedale, MA

PREPARED BY:
ESS Group, Inc.
10 Hemingway Drive, 2nd Floor
East Providence, Rhode Island 02915

ESS Project No. H172-000

DRAFT: May 2015

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TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

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1.0 PURPOSE AND BACKGROUND

The purpose of the study described in this report is to confirm sources of pathogens, develop a management strategy, and begin the process of reopening Hopedale Pond to direct-contact recreation.

Hopedale Beach has been out of active use for several years and does not currently support swimming due high levels of pathogens. The primary source of bacteria to Hopedale Pond was identified as part of the Diagnostic and Feasibility Study for Hopedale Pond (ESS, 2009) as the Dutcher Street Outfall, which was found to contribute up to 200,000 cfu/100 ml and phosphorus in the range of 0.2 – 0.3 mg/L, in part from wet weather. These levels of pollutants were confirmed in a 2014 sampling study.

The Town of Hopedale (Town) Parks Commission is spearheading an effort to improve water quality and reestablish direct-contact recreation (e.g., swimming) using green infrastructure retrofits, pet waste management, and waterfowl management. Town's project strategy in this study is to conceptually design work and install stormwater infiltration in Hopedale Town Park, bioretention in the Town-owned area across from the park on the other side of Dutcher Street, and replant vegetation on the Town Beach for the purpose of waterfowl deterrence. The Town is also pursuing water quality management actions. Follow-on steps may include completion and implementation of stormwater design work at three or more locations, implementation waterfowl management, illicit discharge identification and elimination, public education and outreach, and coordination with the Town of Milford, which is partially within the Dutcher Street Outfall catchment area.

2.0 DESCRIPTION OF HOPEDALE POND AND CURRENT CONDITIONS

Hopedale Pond (MA51065) in Hopedale, Massachusetts is a warm-water impounded area of the Mill River. The Mill River is a tributary to the Blackstone River. The Hopedale Pond and the Mill River originally provided power to the former Draper Corporation at Draper Mill. South of the Hopedale Pond, Mill River flows under the old Draper Mill building and then down to Route 16 in Hopedale.

Hopedale Pond is a priority habitat for the Nature Heritage and Endangered Species Program. Fish populations reportedly include yellow perch, bluegills, pumpkinseeds, golden shiners, chain pickerel, yellow bullheads, largemouth bass, black crappie, brown bullheads and American eel. White catfish are also known to be present.[1] The American Brook Lamprey, which is a threatened species in Massachusetts, inhabits the Mill River including Hopedale Pond. Mitigation of stormwater discharged to Hopedale Pond is noted as important to sustain the lamprey and other fish populations in the pond (Town of Hopedale, 2004).

Hopedale Pond is a feature of the Parklands. The Parklands is an approximately 273-acre park in the northwest area Hopedale. It stretches from the corner of Dutcher and Freedom Streets north of the Draper plant, encompasses the area around Hopedale Pond. The Parklands include a bathing beach, bathhouse, picnic tables, and a boat ramp. The Parklands was designed by landscape architect Warren Henry Manning and built between 1899 and 1914 (Massachusetts Heritage Landscape Inventory Program, 2007). As noted in the Town's Plan of Conservation and Development, "the Parklands and Hopedale Pond are key resources that provide opportunities for hiking, fishing, swimming, boating, nature study, and passive recreational activities" (Town of Hopedale, 2004, p.64).

There is extensive weed growth in the pond. Hopedale Pond is on the Integrated List of Waters in Category 4c - Impairment Not Caused by a Pollutant, which is the result of infestation by a nonnative aquatic macrophyte, primarily variable-leaf milfoil. In 2001, Massachusetts Department of Environmental Protection *Water Quality Assessment Report* assessed the pond as eutrophic.

[1] http://www.mafishfinder.com/hopedale-pond-25007-location.html

The Hopedale Pond has been the subject of a number of studies in recent years. This section of our report focuses on the diagnostic and feasibility study that ESS conducted in 2009. This study reviewed both dry-weather and wet-weather sources. In general the study found the most significant wet- and dry-weather contributions of *E. coli*, nitrogen, and phosphorus at Site 4, which is the Dutcher Street Outfall. The table below represents mean and peak levels for *E. coli* at Site 4.

Table 2.1
Peak and Mean Concentrations of *E. Coli* at the
Dutcher Street Outfall during Dry and Wet Weather

Parameter	Dry-Weather		Wet-Weather	
	Mean	Peak	Mean	Peak
E. coli	429 cfu/100mL[a]	>20,000 cfu/100mL	379 cfu/100mL	3,000 cfu/100mL

Notes:

a. "cfu" means colony forming units.

E. coli was found at over 20,000 colonies per 100mL during dry weather and over 3,000 colonies per 100mL during wet weather. As a result, the Town is currently pursuing both dry- and wet-weather mitigation programs.

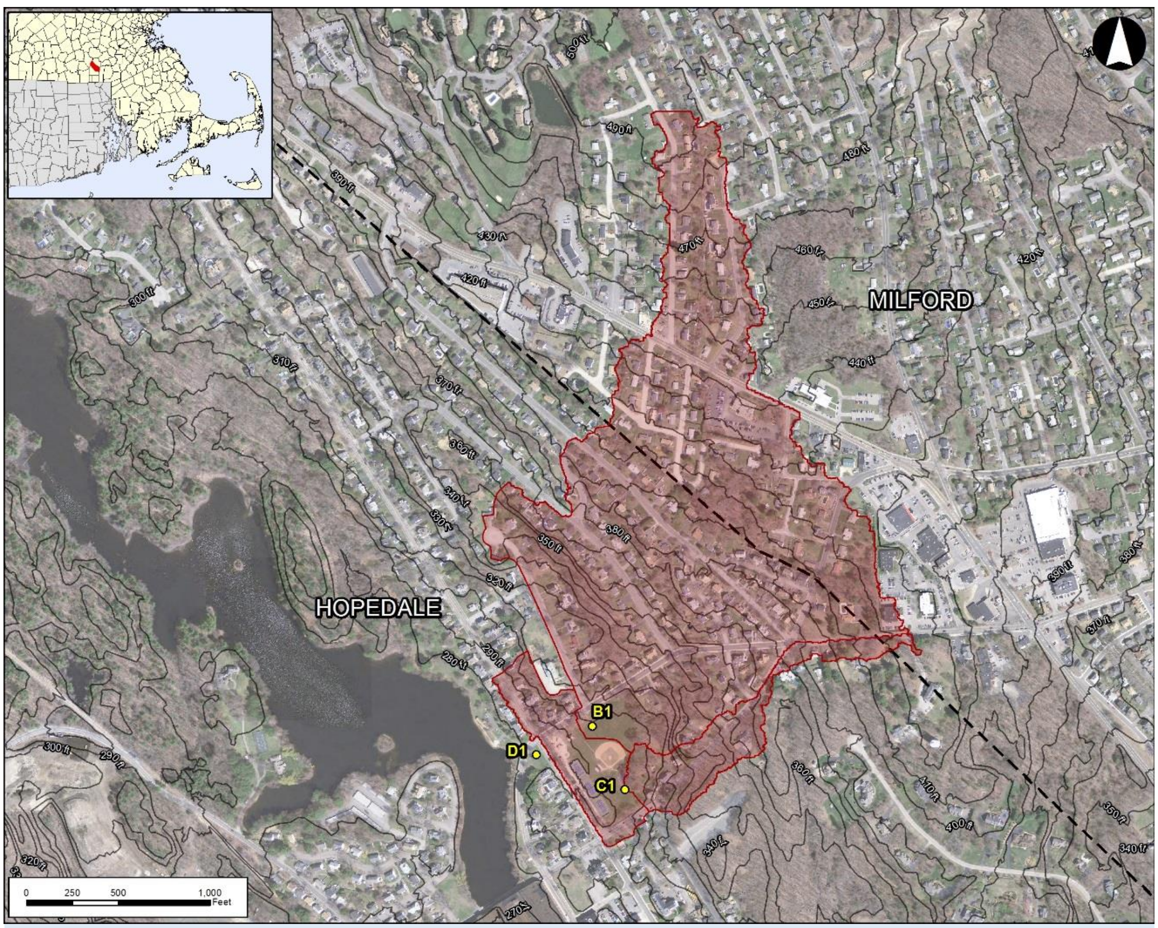

Figure 1—Drainage catchments for the Dutcher Street Subject Outfall in the Hopedale Pond Watershed.

3.0 CURRENT WATERSHED CONDITIONS AND EXISTING STORMWATER INFRASTRUCTURE

Section 3.0 provides a discussion of watershed data including land use, cultural resources and habitat and soils. This section also discusses stormwater infrastructure data that is available from the Town. The purpose of this discussion is to provide information to support the conceptual design of structural BMPs.

3.1 Land Use

Land-use data was obtained from MassGIS. The information is derived from 2005 orthophotographs and covers the entire state at increments ranging from 0.25 to 1 acre. As shown in Table 3.1 below, residential areas make up over 75% of the total watershed area of interest, followed by undeveloped/rural areas which account for just under 20% and a small amount of commercial properties contributing around 4%. For modeling purposes the land use classifications have been grouped from the original designations in the 2005 land use data into slightly broader categories used for the runoff and pollution generation calculations. The land use data was broken down by individual sub basin to refine the model and resulting pollutant loads for specific areas, as seen in Tables 3.1 through 3.4.

Table 3.1
Land Use Breakdown in the Hopedale Watershed Area of Interest (Entire Subject Area – 94.6 acres)

Land Use Classification	Percentage of Watershed by Area
Commercial	4.1%
Residential	77.7%
Undeveloped/Rural	18.2%
Total	**100.0%**

Table 3.2
Land Use Breakdown in Basin B1 (80.2 acres) of The Hopedale Watershed Area of Interest

Land Use Classification	Percentage of Watershed by Area
Commercial	4.8%
Residential	83.5%
Undeveloped/Rural	11.7%
Total	**100.0%**

Table 3.3
Land Use Breakdown in Basin C1 (7.3 acres) of
The Hopedale Watershed Area of Interest

Land Use Classification	Percentage of Watershed by Area
Commercial	0.1%
Residential	51.1%
Undeveloped/Rural	48.8%
Total	**100.0%**

Table 3.4
(Basin D1 – 7.2 acres)
Land Use Breakdown in Basin D1 of
The Hopedale Watershed Area of Interest

Land Use Classification	Percentage of Watershed by Area
Residential	41.0%
Undeveloped/Rural	59.0%
Total	**100.0%**

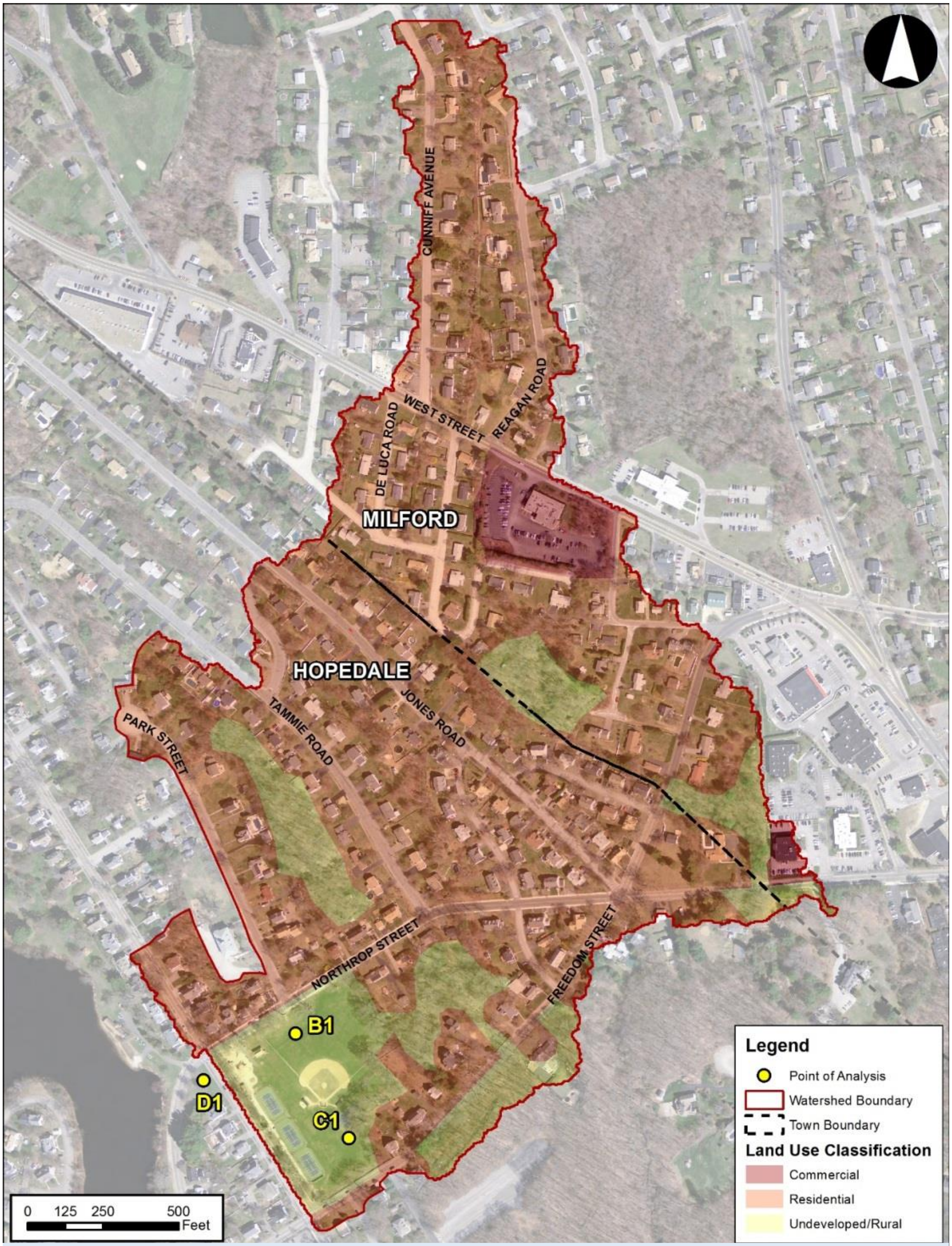

Figure 2—Land Use in the Dutcher Street Subject Outfall Watershed to Hopedale Pond.

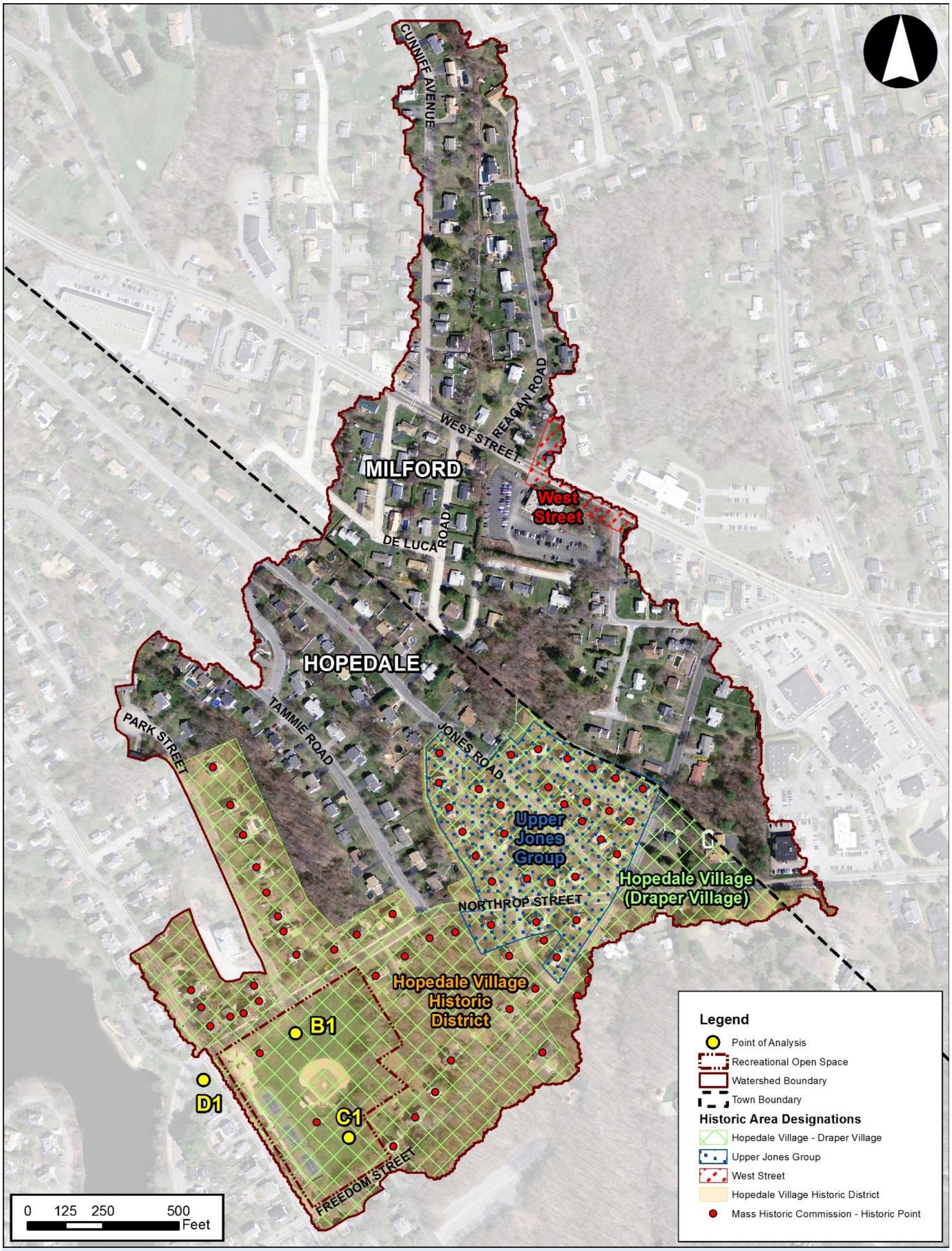

Figure 3—Cultural Resources in the Dutcher Street Subject Outfall Watershed to Hopedale Pond.

3.2 Habitat and Cultural Resources

To determine the existence of cultural resources within the watershed the following sources were consulted:

- The National Register of Historic Places database.
- Massachusetts Historic Commission Inventory (MACRIS database).

3.3 Soils

To determine soil types within the watershed area, a SSURGO-certified data layer published by MassGIS originally from the U.S. Department of Agriculture, Natural Resources Conservation Service, was consulted. With regard to stormwater design, hydrologic soil types are of particular interest within the watershed. The following table breaks down the distribution of hydrologic soil types.

Table 3.5
Hydrologic Soil Groups in the Hopedale Section of the Hopedale Pond Watershed

Hydrologic Group	Percentage	General Distribution in Watershed
A	4.2%	Locate close to pond near outfall location
B	20.4%	Park and strip of residential land running NW to SE through basin
C	75.4%	Majority of the Northern portion of the watershed
D	NA	None found in subject watershed

The main soil types found within the watershed of interest are the Paxton-Urban Land Complex (71.5%), the Chatfield-Hollis-Rock Outcrop Complex (16.0%), Udorthents, smoothed (4.3%), and the Hinckley-Urban Land Complex (4.2%). Table 3.6 below describes the general soil types and Figure 4 shows their distribution within the watershed. Hydrologic Soils Groups A and B are ideal candidates for infiltration BMP practices, which are especially effective at pollutant removal. Although only 24.6% of the subject watershed contains A and B soils, the proximity of those soils to the outfall and to publicly owned parcels enables the consideration of infiltration BMPs. Table 3.6 below describes the general soil types and Figure 4 shows their distribution within the watershed.

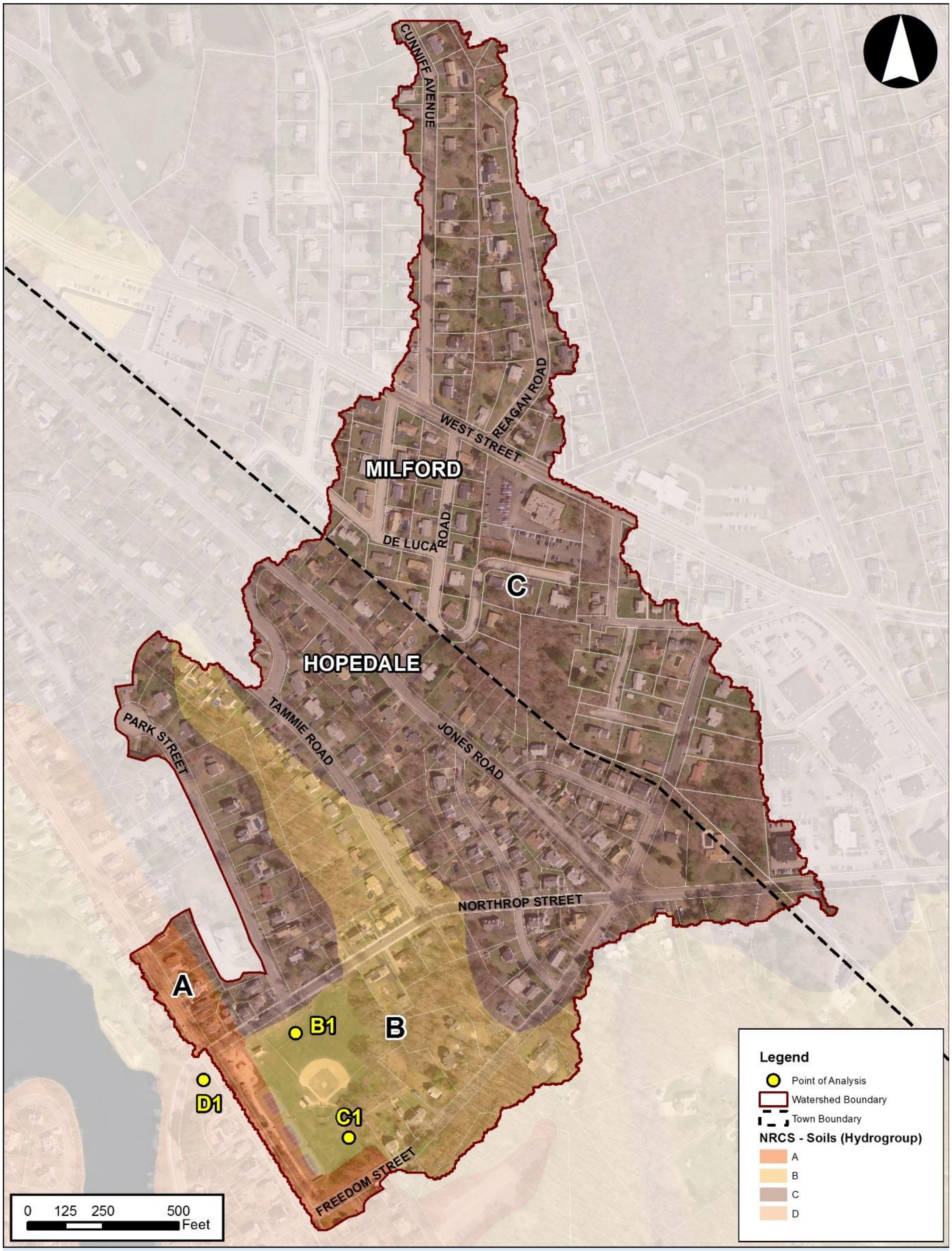

Figure 4—Hydrologic Soils Types

Table 3.6
Soil Types in the Subject Area of the Hopedale Watershed

Soil Symbol	Soil Type	Hydric	HSG	Percentage of Watershed by Area
622C	Paxton-Upland Land Complex	N	C	71.5%
102E	Chatfield-Hollis-Rock Outcrop Complex	N	B	16.0%
651	Udorthents, smoothed	N	B	4.3%
625C	Hinckley-Urban Land Complex	N	A	4.2%
315B	Scituate fine sandy loam	N	C	3.1%
300B	Montauk fine sandy loam	N	C	0.7%
102C	Chatfield-Hollis-Rock Outcrop Complex	N	B	0.04%
71A	Ridgebury fine sandy loam	Y	C	0.01%

4.0 STORM DRAIN MAPPING

Stormwater system infrastructure mapping was conducted in order to enhance the ability to generate accurate watershed areas for several points of analysis. (A PDF of the mapping is provided on the CD as part of Appendix A.) This also supports the development of appropriate stormwater BMPs. Pipe connections exist that tie together areas that would not be hydrologically connected if only a surface runoff analysis was considered. It is also possible, using this infrastructure data, to propose rerouting of pipes to gather a greater amount of stormwater at a specific BMP location. This then allows for more reliable treatment of the water quality volume. Mapping the stormwater conveyance system also provides a report on the condition of the structures. Determining locations of clogged or deteriorating pipes and catch basins is an important factor in limiting potential future flooding issues.

4.1 Available Data

The Town provided us with hard copy plans showing the known existing stormwater connections and infrastructure, which were georeferenced and digitized to supplement the Dutcher Street Outfall and analysis point watershed delineations.

4.2 Field Data Gathering

Inspection data was collected in cooperation with Highway Department which assisted us in locating and opening catch basins and manholes so that we could conduct inspections of the structures. Our inspections were conducted using a standardized inspection sheet and a Trimble GPS data dictionary with corresponding drop-down menus. A copy of the inspection sheet (Appendix A) is provided in digital form as part of the CD attachment to this memorandum.

Stormwater infrastructure mapping and inspections were conducted during periods of dry weather. The purpose of the dry-weather inspections was to document whether or not the stormwater conveyance system exhibited dry-weather flows. Dry-weather flow is one indicator of potential illicit connections and discharges under the MS4 General Permit. We believe that this data may be helpful in future MS4

General Permit compliance efforts and making this determination was possible as part of our scope of work with minimal additional expenditure of effort.

For the purposes of this study, dry weather is defined as no more than 0.1 inches of precipitation (measured as rainfall) cumulatively over the antecedent 72-hours.

Data from field inspections is included in the GIS mapping data attributes and was also exported into an Excel spreadsheet (Appendix A). The spreadsheet was developed using an Esri standard. We anticipate that this standardized data format will facilitate the Town's use of the data collected for future purposes. Photographs taken of drainage structures are referenced in the compiled excel spreadsheet and are included in Appendix A.

4.3 Field Conditions

Infrastructure investigations and field inspections were conducted on April 24 and May 8, 2015. Temperatures ranged from the low 40s to the low 60s. Due to dry-weather inspection criteria, investigations were limited to days with no more than 0.1 inches in the prior 48 hours. Weather conditions specific to sampling dates and stormwater structures can be located in the compiled Excel spreadsheet.

4.4 Equipment and Data Recording

Table 4.1 below identifies equipment used to conduct the drainage structure mapping field investigation throughout the Town in addition to those parameters or activities for which the equipment was used.

Table 4.1
Field Investigation Equipment

Equipment	Description	Parameter or Activity
GPS Unit	Solid state unit for the purposes of locating points in three dimensions in relation to a coordinate plane.	Used to store the location of each drainage structure hydrologically connected to those outfalls identified in existing data sets and from field mapping exercises
Camera	A variety of digital cameras were used for this survey	Used to photograph drainage structures and/or additional concerns associated with the storm sewer system
Measuring Tape	A standard 25' metal measuring tape	Used to measure the top of sediment, depth of water, height of inverts, diameters of all pipes and the diameter of catch basin and manhole accesses

4.5 Nomenclature of System Features

We used the following conventions to develop names for drainage system features. For the purposes of our work, drainage system features include outfalls, catch basins, manholes, and pipes.

4.5.1 Outfalls

Outfalls have been listed with nomenclature previously used (e.g., SS11). There is no specific naming convention.

4.5.2 Catch Basins and Manholes

Catch basin and manhole names include two terms first 2 or 3 letters of their street name followed by four digits assigned in increments of 10 from north – south and west – east.

For hypothetical example:
"DU0010 represents the northern-most catch basin on Dutcher Street.

4.6 Results

As discussed above, field inspection data was collected on inspection sheets. The completed inspection sheets (Attachment E) are provided as PDF files on the attached CD. Data from the inspection sheets was transposed to an Excel spreadsheet as discussed in Section 4.1. The spreadsheet is provided as an Excel document on the CD attached to this memorandum. Photographs of drainage structures are included in Attachment C.

5.0 STRUCTURAL ALTERNATIVES

A primary objective of this study is to select several suitable sites for conceptual BMP design. Structural stormwater BMP alternatives were considered throughout the Hopedale-owned areas of the Hopedale Pond Watershed.

5.1 Identification of Preferred BMP Locations

BMP locations were selected using the following siting criteria:

- Site BMPs on Town or publically owned property to the extent practicable.
- Maximize potential stormwater capture and treatment based on hydrologic location and existing drainage patterns.
- Avoid disturbance of cultural and historic resources as well as wetlands and other sensitive receptors. (BMPs are all within the Hopedale Historic District Area – also designated on NRHP layer)

We used the MassDEP wetlands layer along with the Massachusetts Historic Commission and National Register of Historic Places cultural resource databases to identify potential BMP locations and selected preferred locations using the process described in sections 5.1.1 - 5.1.3. In the tables below, we identify preferred lots for BMPs with their potential capacity for treating stormwater, which was measured as the water quality volume that we anticipate being able to route to them. The area calculations for Area B1 in Table 5.1 are confined to the portion of the area within the Town of Hopedale. In Table 5.2 this area number has been expanded to include a portion of the drainage area within the Town of Milford.

Table 5.1
Preferred Lots for BMPs and
Potential Capacity for Treating Stormwater in Hopedale

Plat_Lot	Basin	Catchment Area (Ac)	Impervious (Ac)	Water Quality Volume (cu ft)
8-29-0	B1h	43.63	12.59	45,702
8-29-0	C1	7.25	1.78	6,476
8-113-0	D1	7.15	2.55	9,257
8-71-0	D1			

Notes:
a. Water quality volume is defined in Section 5.3 as 1.0 over the impervious surface.

Table 5.2
Preferred Lots for BMPs and
Potential Capacity for Treating Stormwater in Hopedale and Milford

Plat_Lot	Basin	Catchment Area (Ac)	Impervious (Ac)	Water Quality Volume (cu ft)
8-29-0	B1	80.19	24.20	87,846
8-29-0	C1	7.25	1.78	6,476
8-113-0	D1	7.15	2.55	9,257
8-71-0	D1			

Notes:
a. Water quality volume is defined in Section 5.3 as 1.0 over the impervious surface.

Figures 5, 6 and 7 depict the locations and catchments as well as base map data.

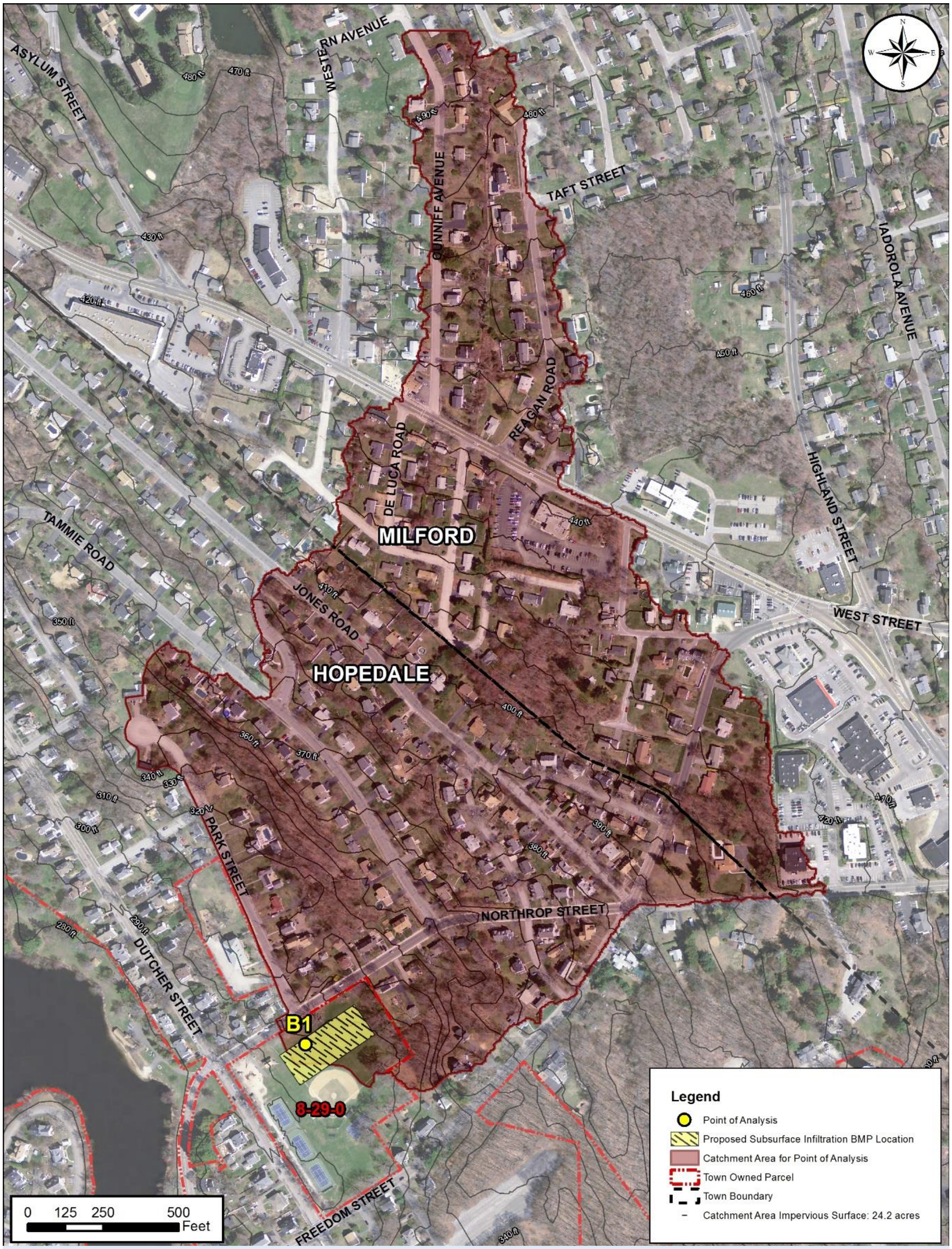

Figure 5— Subsurface Infiltration Chambers for Analysis Point B1

Figure 6—Subsurface Infiltration Chambers for Analysis Point C1

Figure 7—Subsurface Infiltration Chambers and Non-linear Bioretention Area for Analysis Point D1

5.1.1 Selection of Candidate Locations Based on Property Ownership

We used assessor parcel data from MassGIS as well as stormwater infrastructure data supplied by the town and LIDAR generated watersheds to select candidate sites for conceptual BMPs. Our general approach began with identification of the following:

- Town-owned properties in the Hopedale Pond Watershed with green space. We focused on Town-owned properties since they are under Town control and will not require purchase or transfer of development rights. This simplifies the implementation process and eliminates significant potential expense.
- Other publically owned lands near outfalls and privately owned vacant lots contiguous to Town-owned properties with green space. Additional space typically improves the feasibility of BMP implementation. We anticipated that the Town might wish to acquire the properties rights to implement BMPs in locations where hydrologic capacity of Town-owned property is limited, but siting feasibility is otherwise favorable.

The table below presents the properties we identified based on above criteria.

Table 5.3
Candidate Locations for BMPs in Town Ownership

Plat_Lot	Basin	Street	Property Area (Acres)	Type
7-97-0	D1	Freedom Street	9.3	Forested Area
8-113-0	D1	Dutcher Street	0.6	Park or Open Space
8-29-0	B1, C1	Dutcher Street	6.3	Park or Open Space
8-32-0	NA	Park Street	1.6	School
8-71-0	D1	Dutcher Street	353.0	Park or Open Space

5.1.2 Analysis Based on Hydrology and Hydrologic Location

Feasibility of BMP installation at a given site relies significantly on hydrologic location, which can be determined by reviewing topography. We used available LiDAR data to develop topographic mapping. We assumed that both surface and subsurface flow direction generally followed surface topography and applied a version of the Watershed and Trace Flow Analysis tool (available from Blue Marble Geographics), which we customized to develop flow-to analysis, and approximately determined the catchment areas of hydrologic low points on candidate BMP sites. In performing this analysis, we combined two groups of contiguous lots:

We also overlaid the MassGIS 2007 impervious surface coverage data layer to determine the approximate area of impervious surface that would be expected to drain to the candidate sites. Using this approach, we eliminated sites with little or no impervious area in their catchments and sites with catchments that are contained—or nearly contained—within their own property boundaries.

5.1.3 Prioritization of Sites Based on Connectivity to Town-Owned Outfalls

We used area of impervious surface within the drainage catchment of each candidate site as a measure of its potential capacity to treat stormwater. Impervious surface is considered to be a primary source of pollutants in urban runoff. As such, it is commonly used as a unit of measure to determine the capacity of treatment elements in stormwater management practice design.

Sites 8-29-0, 8-113-0, and 8-71-0 were selected for conceptual design. Site 8-32-0 was determined to be outside of the Dutcher Street Outfall Catchment. Site 7-97-0 was found to be located in the upland and determined to be an ineffective location for BMP siting.

Site 8-29-0 is an ideal candidate because it is both publically owned open space, and is hydrologically situated to capture two fairly large drainage areas (B1 and C1). Parcels 8-113-0 and 8-71-0 are also both public open space areas, and although both usable areas are significantly smaller in size they would still be suitable for BMPs to treat runoff from area D1, as well as any additional overflow runoff produced from area B1.

5.1.4 Environmental and General Land-Use Constraints

To be practical, BMPs must be selected to fit in with the conditions of the watershed. Conditions considered should include land use, cultural resources, and environmental constraints such as wetlands, soil type and proximity to groundwater. As described in Section 4.1 above, our candidate BMPs are intended to be appropriate for open spaces and roadways in residential areas. These BMPs include vegetated BMPs (e.g., bioretention) and buried BMPs (e.g., subsurface infiltration). When identifying locations to site BMPs, we used MassGIS data to avoid wetland areas and areas near sensitive historic and cultural resources. We also reviewed hydrologic soil groups (HSG) to determine whether infiltration would be feasible. We assumed HSG soil types A and B would support infiltration and HSG type C soils would require noninfiltrating BMPs (e.g., wet vegetated treatment systems and sand filters).

5.2 Candidate Best Management Practices

For this conceptual design study, we considered BMPs with significant capacity to treat bacteria and based on information available in the *Massachusetts Stormwater Handbook*, which we supplemented with data from the *Rhode Island Stormwater Design and Installation Standards Manual* when data was insufficient. Stormwater treatment mechanisms that work well to remove these pollutants include vegetated treatment, filtration, and infiltration. We considered but generally avoided use of BMPs that treat stormwater primarily by detention and sedimentation since a number of field studies have shown such BMPs to export pollutants such as bacteria and nutrients. Appendix B provides a description of each type of BMP considered for this study as well as a discussion of their general application, advantages, and limitations. Appendix B also provides schematics and photographs of the candidate BMPs. The tables below provide a summary of information in Appendix B.

We selected BMPs primarily for their capacity to remove pathogens and phosphorus and to function appropriately in the subject setting (i.e., Hopedale Pond Watershed, Hopedale area). We used 70 percent removal of pathogens and 30 percent removal of phosphorus as our low-end limits for preferred BMPs. We consider BMPs with vegetative treatment process to be preferred as these processes are generally more reliable for nutrient removal and because vegetated BMPs are more likely to fit in well in residential areas, which are by far the dominant land use in the subject watershed area. We limited our selection of preferred BMPs to those that have the capacity to treat large areas (i.e., five acres or more) or roadways since we are focusing on retrofits to address community areas as opposed to individual private properties.

The following BMPs have been selected as preferred for further consideration. This is not intended to preclude the use of other BMPs, but instead to provide guidance in selecting BMPs for conceptual consideration and further study:

Table 5.4
Candidate BMPs Selected for Further Consideration

Preferred BMPs (Any Setting)	Secondary Consideration (Any Setting)	BMPs (Roadways Only)	Removed from Consideration in this Study
• **Bioretention**	• Water Quality Swale • Gravel Wetland	• **Subsurface Infiltration**	• Dry Wells • Green Roofs et al • Constructed Stormwater Wetland[a] • Wet Retention Pond[a] • Vegetated Filter Strip • Vegetated Drainage Ways • Planter and Tree Box Filters • Porous Pavement • Proprietary Media Filter • Infiltration Trenches • Sand Filters

Notes

a. Removed due to the presence of standing water, which is inappropriate for this application.

Table 5.5
Summary of Candidate Best Management Practices for Selection of Retrofits

BMP Type	Pollutant Removal Capacity		Treatment Process		Application		
	Bacteria (+70%)	TP (+30%)	Infiltration Filtration	Vegetative Treatment	Common Areas	Roads	Drainage Area (+5 acres)
Bioretention	✓	✓	✓	✓	Appropriate	Appropriate	Appropriate
Constructed Stormwater Wetland	✓	✓		✓	Appropriate	Appropriate	Appropriate
Dry Wells	✓		✓				
Grassed Channel (Biofilter Swale)	✓		✓	✓	Appropriate	Appropriate	
Green Roofs	✓			✓			
Wet Retention Pond	✓	✓	✓	✓	Appropriate		Appropriate
Infiltration Basin	✓	✓	✓	✓	Appropriate	Appropriate	Appropriate
Infiltration Trenches	✓	✓	✓			Appropriate	Appropriate
Planter and Tree Box Filters	✓		✓	✓	Appropriate	Appropriate	
Porous Pavement			✓			Appropriate	
Proprietary Media Filter	✓	✓	✓			Appropriate	
Sand Filters	✓		✓		Appropriate	Appropriate	Appropriate
Subsurface Infiltration (Including Leaching Catch Basins)	✓	✓	✓			Appropriate	Appropriate
Vegetated Drainage Ways				✓	Appropriate	Appropriate	Appropriate
Water Quality Swale	✓	✓	✓	✓		Appropriate	Appropriate
Wet Retention Pond	✓	✓	✓	✓	Appropriate		Appropriate
Gravel Wetland	✓	✓	✓	✓	Appropriate		Appropriate

Table 5.6
Preferred Lots and Rationale for Selected BMPs

Point of Analysis	Plat-Lot	General Land Use	HSG Soil Type	Preferred BMP	Rationale for BMP Preference
B1	8-29-0	Undeveloped/Rural (Open Space)	B	Subsurface Infiltration	• Chosen to treat a large percent of the WQV of area B1 and to minimize disturbance of the park and baseball field
C1	8-29-0	Undeveloped/Rural (Open Space)	B & A	Subsurface Infiltration	• Chosen to treat the entire WQV of area C1 and to minimize disturbance of the park
D1	8-113-0	Undeveloped/Rural (Open Space)	A	Subsurface Infiltration	• Chosen to treat a large portion of the WQF for area D1 in combination with additional D1 site (8-71-0) and to minimize impact to open space
D1	8-71-0	Undeveloped/Rural (Open Space)	B & A	Non-linear Bioretention	• Chosen to add treatment capacity and to be aesthetically pleasing and/or for BMP water quality treatment demonstration purposes

5.3 BMP Sizing

BMPs have been conceptually sized based on required water quality volume. We used the *Massachusetts Stormwater Handbook* as a design standard. We determined water quality volume using a standard of one inch depth over the impervious area in each catchment since the purpose this project is to help the Town reopen Town Beach. Area of imperviousness was adapted from the MassGIS impervious area coverage.

We calculated storage volume of stormwater BMPs based on the available area and constraints associated with each BMP type. The following assumptions were made:

- Nonlinear bioretention will have 3:1 side slopes.
- Infiltration basins will have 3:1 side slopes and are four feet deep.
- Surface BMP footprint can occupy up to 80% of open space at a given location.
- Subsurface infiltration provides six cubic feet of water quality storage per linear foot based on three-foot storage depth, six-foot bottom width on a road shoulder or up to 80% of a property footprint and storage bed material porosity of 0.33.

For further analysis, Table 5.8 on the following page summarizes the treatment and treatment capacity that we identified in each of the subject catchments.

5.4 Opinions of Cost

Order-of-magnitude opinions of cost have been developed based on unit treatment values (i.e., cost per cubic foot of treatment capacity) of each of the preferred BMP types. Table 5.9 provides cost on a per catchment basis for the alternatives recommended for each catchment. Unit costs for preferred BMPs in dollars per cubic foot (cu ft) area listed in Table 5.7 below. This table also shows percent pathogens reduction and implied cost-benefit for BMPs by type considering unit costs in conjunction with pollutant removal rate.

Table 5.7
Unit Costs, Percent Reduction and Implied Cost-Benefit for Pathogen for Preferred BMP Types

BMP Type	Unit Cost (Dollars/cu ft)[a]	Pathogen Percent Reduction[b]	Implied Cost-Benefit (Dollar/%Reduction)
Bioretention	$14	70%	$0.20
Subsurface Infiltration	$16	90%	$0.11
Gravel Wetlands	$13	85%	$0.15
Water Quality Swale	$14	70%	$0.20

Notes:
a. Unit cost was determined based on empirical data and observations from previous projects.
b. For consistency, percent reduction is based on the *Rhode Island Stormwater Design and Installation Standards Manual* since many pollutant removal efficiencies were listed as insufficient in the *Massachusetts Stormwater Handbook*.

Table 5.8
Capacity of Selected BMPs

Point of Ananlysis	Treatment Site (Plat_Lot)	WQV[a] (cu ft)	Capacity of BMPs					Treatment Capacity (cu ft)
			Bioretention (cu ft)	Infiltration Basin (cu ft)	Subsurface Infiltration (cu ft)	WVTS (cu ft)	Sand Filter (cu ft)	
B1	8-29-0	87,846			35,640			35,640
C1	8-29-0	6,476			6,494			6,494
D1	8-113-0 8-71-0	9,257	3,411		5,845			9,256

Notes:
a. Water Quality volume of the area draining to the proposed BMP location.

Table 5.9
Cost of Selected BMPs and
Probable Cost Based on Unit Pricing

Point of Analysis	Treatment Site (Plat_Lot)	WQV[a] (cu ft)	Cost of BMPs Based on Unit Price					Cost per Treatment Site Based on Unit Price
			Bioretention ($14/cu ft)	Infiltration Basin ($10/cu ft)	Subsurface Infiltration ($16/cu ft)	WVTS ($13/cu ft)	Sand Filter ($17/cu ft)	
B1	8-29-0	87,846			$570,000			$570,000
C1	8-29-0	6,476			$104,000			$104,000
D1	8-113-0 8-71-0	9,257	$69,000		$69,000			$138,000

Notes:
a. Water Quality volume of the area draining to the proposed BMP location.

Table 5.10
Probable Range of BMP Costs Based on Unit Pricing

Point of Analysis	Treatment Site (Plat_Lot)	Cost per Treatment Site Based on Unit Price	Probable Range of Cost (Rounded to 1000s)	
			Low Range Cost per Treatment Site at -30%	High Range Cost per Treatment Site at +50%
B1	8-29-0	$570,000	$399,000	$855,000
C1	8-29-0	$104,000	$73,000	$156,000
D1	8-113-0 8-71-0	$138,000	$97,000	$207,000

5.5 Anticipated Water Quality Benefits and Cost-Benefit Analysis

Based on desktop analysis, three key discharge points have been identified in the area of interest in the Hopedale watershed. These discharge points and their catchments are mapped and depicted in Figures 5, 6 and 7. A pollutant loading analysis using the Simple Method from the *Rhode Island Stormwater Design and Installation Standards Manual* (December 2010) (RISDISM) was completed for each of the three points of analysis.

The tables below summarize the estimated annual Nitrogen loads and cost-benefit for each discharge point using structural BMPs identified in Section 5.2. The Excel spreadsheet used to calculate pollutant loads can be found in Appendix A. Conceptual design plans showing types and proposed locations of BMPs can be found in Figures 5 - 7.

Table 5.11
Percent Pathogen Reduction in Stormwater Drainage Areas

Point of Analysis	Treatment Site (Plat_Lot)	Percent Pathogen Reduction in Area Draining to Treatment Site					Percent Reduction for BMP Drainage Area
		Bioretention	Infiltration Basin	Subsurface Infiltration	WVTS	Sand Filter	
B1	8-29-0			36.5%			36.5%
C1	8-29-0			90.3%			90.3%
D1	8-113-0 8-71-0	37.3%		42.0%			79.3%

Table 5.12
Percent Pathogen Reduction in the
Hopedale Section of the Hopedale Pond Watershed

Area	Percent Reduction
Watershed	33.1%

Table 5.13
Cost of Reducing Pathogens per Trillion Colonies of Bacteria in Stormwater Drainage Areas

Point of Analysis	Treatment Site (Plat_Lot)	Percent Reduction for BMP Drainage Area	Total Reduction (trillion colonies/year)	Anticipated Cost of BMPs		Cost per Trillion Reduced	
				Low Cost	High Cost	Low Estimate	High Estimate
B1	8-29-0	36.5%	74	$399,000	$855,000	$5,392	$11,554
C1	8-29-0	90.3%	8	$73,000	$156,000	$9,125	$19,500
D1	8-113-0 8-71-0	79.3%	4	$97,000	$207,000	$24,250	$51,750

6.0 RECOMMENDATIONS

The follow discussion provides our recommendations for stormwater management for structural and nonstructural BMPs in the Hopedale Pond Watershed. We also discuss evaluation of effectiveness.

6.1 Summary of Recommendations

We recommend the following management structural and nonstructural approaches.

Nonstructural

The following are recommended nonstructural approaches.

Illicit Discharge Detection and Elimination

The Town has previously conducted illicit discharge detection surveys and found that the most significant concentrations and loadings appear to come from up-gradient of the Milford town line. We recommend coordinating with the Town of Milford and continued investigation of dry-weather sources.

Animal Waste Management

Both domestic and wild animals may be contributing to water quality problems on the Hopedale Pond. There are continued sightings of waterfowl at the Town Beach and laboratory reports of pathogens and nutrients. We recommend the following approaches to addressing animal waste in the Hopedale Pond Watershed:

- **Develop an education program to discourage feeding of geese and to encourage proper pet waste management ($2,000 - $5,000).** It is particularly important to avoid feeding geese that winter over as this encourages them to nest and reproduce.
- **Develop a goose control plan for the Hopedale Pond Watershed ($7,000 - $10,000).** This should include determining population characteristics (e.g., resident vs. transitory), identification of roosting and grazing sites and use of plantings around the beach to discourage congregation.
- **Install pet waste stations ($150 - $300 each) and covered garbage receptacles ($250 - $800 each)** in areas where improper pet waste disposal is observed. Once they are installed, their use should be monitored as part of regular maintenance to make certain that they have been placed effectively.

Figure 9 Example of a dog waste station

Structural

This plan identifies approximately $812,000 in stormwater retrofit alternatives that are recommended for implementation in the watershed of the Hopedale Pond.

We recommend proceeding with design and implementation work at analysis point B1 and C1. These BMPs provide the best cost-benefit.

Table 6.1
Schedule of Structural BMPs with
Probable Costs and Rationale for Selection

Proposed BMP and Probable Cost Range	Recommended Action and Schedule	Rationale
Subsurface Infiltration at Point B1 ($399,000 – $855,000)	• Continue design Year 1 • Submit for permits Year 1 • Implementation Year 2	• Offers best cost-benefit of the BMPs considered in this study. • Offers largest bacterial reduction for all proposed BMPs.
Subsurface Infiltration at Point C1 ($73,000 – $156,000)	• Continue design Year 1 • Submit for permits Year 2 • Implementation Year 2	• Offers second best cost-benefit of the BMPs considered in this study. • It will reduce fecal coliform by 90% in area of contribution. • Offers second largest bacterial reduction for all proposed BMPs.
Subsurface Infiltration and bioretention at point D1 ($97,000 – $207,000)	• Continue design Year 1 • Submit for permits Year 1 • Implementation Year 3	• It will reduce fecal coliform by 79% in area of contribution.

Evaluation
We recommend evaluation using administrative tracking, empirical watershed observations, and sampling at Year 5. Although these BMPs are not a requirement of the MS4 General Permit, we would anticipate conducting an annual evaluation that coincides with development and submission of the annual MS4 report to EPA to demonstrate the Town's willingness to address important stormwater issues. Specifically, we recommend the following:

- Administrative tracking measures:
  - Listing of control and management plans developed.
  - Funding committed and expended.
- Empirical watershed observation measures:
  - Observed use of trash receptacles and dog waste stations.
  - Observed reduction of pet waste.
  - Observation of geese reduction and behavior in the goose management area.
- Year 5 wet-weather sampling:
  - Repeat sampling previously conducted at the Dutcher Street Outfall.

6.2 Overall Schedule for Best Management Practices

Below, we present an overall year-by-year schedule for implementation of stormwater BMPs in the Dutcher Street Catchment of Hopedale Pond. Probable costs for implementation of structural and nonstructural BMPs range from approximately $580 thousand – $1.2 million.

Table 6.2
Schedule of BMP Implementation with
Measures of Success and Probable Costs

Program Year	Nonstructural BMPs	Structural BMPs	Evaluation Measure	Probable Cost Range (total, rounded to 1,000s)
Year 1	• Conduct illicit discharge investigation • Develop education program regarding waterfowl and pets • Develop goose control plan • Install pet waste stations and trash receptacles	• Design and Permit BMPs for points B1 and C1	• Number of illicit discharges identified • Education program developed • Goose control plan developed • Number of pet waste stations installed • Number of trash receptacles installed • Empirical observations of waterfowl and pet waste • Number of BMPs designed • Number of BMPs permitted	$57,000 – $167,000
Year 2	• Removal of illicit discharges	• Design and Permit BMP for Point D1 • Implement BMPs for Point B1	• Number of illicit discharges removed • Empirical observations of waterfowl and pet waste • Number of BMPs installed	$374,000 - $811,000
Year 3		• Implement BMPs for Point C1 • Implement BMPs for Point D1	• Empirical observations of waterfowl and pet waste • Number of BMPs installed	$153,000 – $290,000

7.0 REFERENCES

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Appendix A (Compact Disk)

Inspection Sheet (Example)
Inspection Data Collected
Inspection Photographs
Pollutant Loading Spreadsheet Model

Appendix B

Candidate Best Management Practices

INTRODUCTION

The following text provides a description of best management practices (BMPs) that are used to treat stormwater at end-of-pipe and in the upland areas of drainage catchments. The text provides a general description of each BMP as well as an assessment of pollutant removal capacity, treatment processes provided, and applications, advantages and limitations. The following BMPs are included in alphabetical order:

- Bioretention, Rain Gardens, Stormwater Planters
- Constructed Stormwater Wetland (Including Gravel Wetlands)
- Dry Wells
- Green Roofs, Blue Roofs and Facades
- Infiltration Basin
- Infiltration Trenches
- Planter and Tree Box Filters
- Porous Pavement
- Proprietary Media Filter
- Sand Filters
- Subsurface Infiltration (Including Leaching Catch Basins)
- Vegetated Drainage Ways
- Water Quality Swale
- Wet Vegetated Treatment System (Gravel)

For the most part, BMP types are based on BMPs listed in the Rhode Island Stormwater Design and Installation Standards Manual (RIDEM, 2010). In certain instances (e.g., leaching catch basins), we have adapted BMPs from other standards documents such as the Boston Water and Sewer Commission's Stormwater Best Management Practices: Guidance Document (2013).

Knowledge of pollutant removal capacity in conjunction with BMP treatment mechanisms is important to understanding the capacity of BMPs to improve stormwater quality. Removal capacities have been adapted from the Rhode Island Stormwater Design and Installation Standards Manual and were taken from either Appendix H or the "Key Considerations" text boxes. Treatment processes have been adapted from the Boston Water and Sewer Commission's Stormwater Best Management Practices: Guidance Document. Percent removal data is not available for metals in either of these documents; however, Rhode Island Stormwater Design and Installation Standards Manual qualifies BMPs as to whether they are able to achieve "good" metals removal or not.

A tabular summary of BMP application, advantages and limitations is provided to help ensure that BMPs selected are appropriately suited to the surrounding land use and other watershed conditions. This information was taken from several sources including the Rhode Island Stormwater Design and Installation Standards Manual and the Stormwater Best Management Practices: Guidance Document. We have also included our general knowledge of BMPs.

BIORETENTION, RAIN GARDENS, STORMWATER PLANTERS

Bioretention and rain gardens are shallow landscaped depressions designed to manage and treat stormwater runoff. Bioretention systems are a variation of a surface sand filter, where the sand filtration media is replaced with a planted soil bed designed to remove pollutants through physical and biological processes. The concept of bioretention originated with the Prince George's County, Maryland, Department of Environmental Resources in the early 1990s as an alternative to more traditional management practices. Stormwater flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Treated water is allowed to infiltrate into the surrounding soils or is collected by an underdrain system and discharged to the storm drain system or receiving waters. Small-scale bioretention applications (i.e., residential yards, median strips, parking lot islands) are commonly referred to as rain gardens. Tree box filters are essentially mini bioretention systems installed in concrete vaults. They are most often designed to fit in urban landscapes (e.g., sidewalks as part of street tree systems) where space is at a premium.

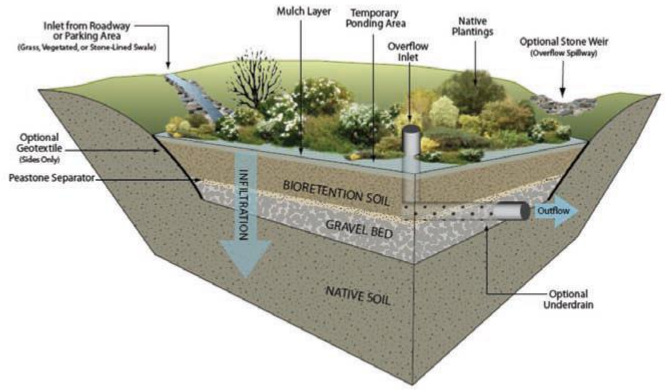


Figure B.1

Table B-1
Pollutant Removal Capacity
Bioretention, Rain Gardens, Stormwater Planters

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	70%
Total Phosphorus	30%
Total Nitrogen	55%
TSS	90%
Metals	Good

Notes:

a. Percent removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs and "Key Considerations" text boxes of the *Rhode Island Stormwater Design and Installation Standards Manual.*

Table B-2
Treatment Processes Provided by
Bioretention, Rain Gardens, Stormwater Planters

Treatment Processes[a]	Process Provided?
Biological Processes	✓
Infiltration	✓ (if designed to infiltrate)
Filtration	✓
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	✓

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-3
Advantages, Disadvantages and Limitations of
Bioretention, Rain Gardens, Stormwater Planters

Applications	Advantages	Limitations
• May be used in a wide variety of settings including residential, commercial, and industrial areas. • May be decentralized (e.g., as rain gardens on individual lots) or centralized in common areas to manage multiple properties. • May be lined and underdrained; or designed to infiltrate and recharge groundwater.	• Highly versatile and adaptable to size of watershed and type of land use. • High solids, metals, and bacteria removal efficiency. • Infiltrating bioretention can provide groundwater recharge. • Helps to mimic predevelopment runoff conditions. • Reduces need for end-of-pipe treatment.	• Bottom of the filter must be at or above the seasonal high groundwater table if infiltration is being used. • Generally requires approximately 3-foot depth for soil bed and ponding area.

Figure B.2—Photograph of tree box filter.

CONSTRUCTED STORMWATER WETLAND

Figure B.3—Photograph of constructed stormwater wetland.

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

There are several types of Constructed Stormwater Wetlands. Common types of constructed stormwater wetland include shallow marsh, basin/wetland, extended detention, and pocket.

Table B-4
Pollutant Removal Capacity
Constructed Stormwater Wetland

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	60%
Total Phosphorus	48%
Total Nitrogen	30%
TSS	85%
Metals	Fair

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-5
Treatment Processes Provided by
Constructed Stormwater Wetland

Treatment Processes[a]	Process Provided?
Biological Processes	
Infiltration, if designed as such	
Filtration	✓
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-6
Advantages, Disadvantages and Limitations of
Constructed Stormwater Wetland

Applications	Advantages	Limitations
• May be used as regional detention and treatment • May be best for sites without space constraints	• Low maintenance cost • Treatment of large tributary areas • Provides wildlife habitat • Aesthetically pleasing	• High land requirement • High capital cost • Design affected by depth to groundwater and bedrock • Additional restrictions apply in cold-water fishery watershed based on distance from discharge point to streams (and any contiguous wetlands)

DRY WELLS

A dry well is a small, excavated pit, backfilled with stone aggregate. Dry wells function like infiltration systems to control roof runoff and are applicable for most types of buildings.

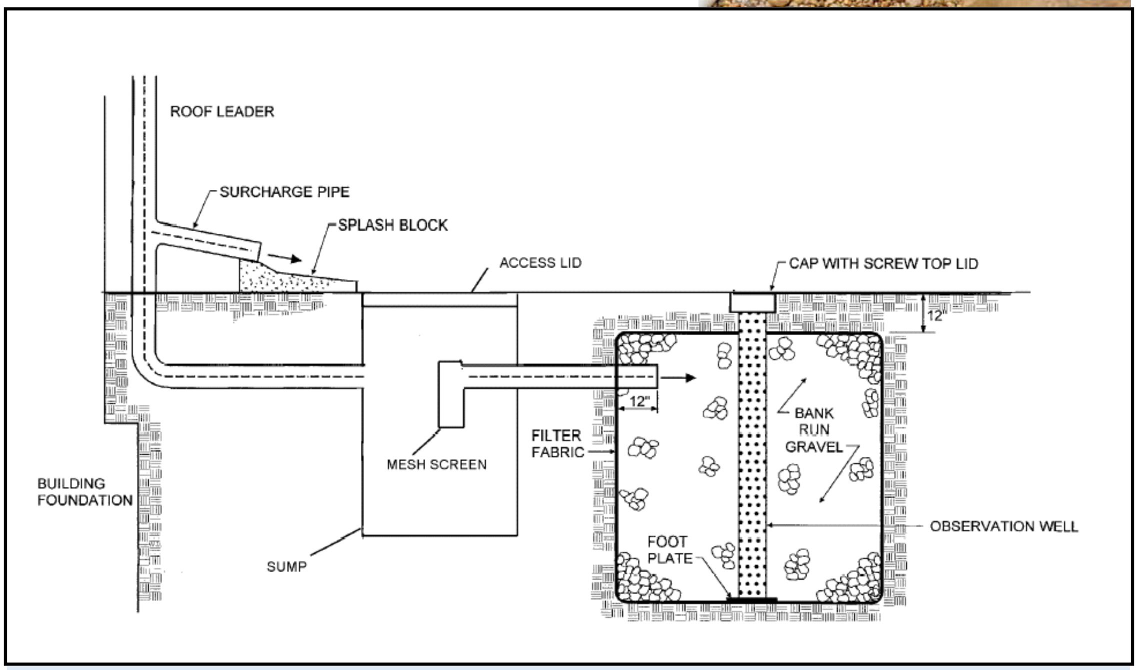


Figure B.4—Photograph and schematic of dry wells.

Table B-7
Pollutant Removal Capacity
Dry Wells

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	90%
Total Phosphorus	55%
Total Nitrogen	40%
TSS	90%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-8
Treatment Processes Provided by
Dry Wells

Treatment Processes[a]	Process Provided?
Biological Processes	
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	✓

Notes:

a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-9
Advantages, Disadvantages and Limitations of
Dry Wells

Applications	Advantages	Limitations
• Can be useful for disposing of roof runoff and reducing the overall runoff volume from a variety of building sites. (e.g., residential, commercial industrial, etc.).	• Low cost. • Provides retention of runoff from roofs. • Recharges groundwater. • Reduces need for end-of-pipe treatment.	• Clogging likely when used for runoff other than from rooftops • Only applicable in small drainage areas • When located near buildings, potential issues with water seeping into cellars or inducing cracking/heaving. • Two-foot minimum separation to groundwater • Minimum soil infiltration rate of 0.5 inches per hour • Infiltration of rooftop runoff from commercial or industrial buildings with pollution control, heating, cooling, or venting equipment may require UIC review and approval.

GREEN ROOFS, BLUE ROOFS AND FACADES

Figure B.5—Photograph of green roofs.

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

Rooftop runoff management structures are modifications to conventional building design that attenuate runoff originating from roofs. The modifications include:

- Vegetated roof covers
- Roof gardens
- Vegetated building facades
- Roof ponding areas (e.g., blue roofs)

Roofs are significant sources of runoff from developed sites. If runoff is controlled at the source, the size of other BMPs throughout the site can be reduced. Rooftop runoff management practices influence the runoff hydrograph in two ways:

- Intercept rainfall during the early part of a storm.
- Limit the maximum release rate.

In addition to achieving specific stormwater runoff management objectives, rooftop runoff management can also be aesthetically and socially beneficial.

Design Variations

- Vegetated roof cover – Vegetated roof covers, also called green roofs and extensive roof gardens, involve blanketing roofs with a veneer of living vegetation. Vegetative roof covers are particularly effective when applied to extensive roofs, such as those that typify commercial and institutional buildings. The filtering effect of vegetated roof covers results in a roof discharge that is free of leaves and roof litter. Therefore, it is recommended where roof runoff will be directed to infiltration devices (see Standards for Infiltration Practices and Dry Wells).
- Because of recent advances in synthetic drainage materials, vegetated covers now are feasible on most conventional flat roofs. An efficient drainage layer is placed between the growth media and the roof surface. This layer rapidly conveys water off of the roof surface and prevents water

from "lying" on the roof. In fact, vegetated roof covers can be expected to protect roof materials and prolong their life.

- If materials are selected carefully to reduce the weight of the system, vegetated roof covers generally can be created on existing flat roofs without additional structural support. Drainage nets or sheet drains constructed from lightweight synthetic materials can be used as underlayments to carry away water and prevent ponding. The total load of a fully vegetated and saturated roof cover system can be less than the design load computed for gravel ballast on conventional tar roofs.
- Although vegetative roof covers are most effective during the growing season, they also are beneficial during the winter months as additional insulation if the vegetative matter from the dead or dormant plants is left in place and intact.
- Roof Gardens – Vegetated roof covers blanket an entire roof area and, although presenting an attractive vista, generally are not intended to accommodate routine traffic by people. Roof gardens, on the other hand, are landscaped environments, which may include planters and potted shrubs and trees. Roof gardens can be tailor-made natural areas, designed for outdoor recreation, and perched above congested city streets. Because of the special requirements for access, structural support, and drainage, roof gardens are found most frequently in new construction.
- Roof gardens generally are designed to achieve specific architectural objectives. The load and hydraulic requirements for roof gardens will vary according to the intended use of the space.
- Intensive roof gardens typically include design elements such as planters filled with topsoil, decorative gravel or stone, and containers for trees and shrubs. Complete designs also may detain runoff ponding in the form of water gardens or storage in gravel beds. A wide range of hydrologic principles may be exploited to achieve stormwater management objectives, including runoff peak attenuation and runoff volume control.
- Vegetated Building Facades – Vegetated facades provide many of the same benefits as vegetated roof covers and roof gardens, including the interception of precipitation and the retardation of runoff. However, their effectiveness is limited to small rainfall events.
- Vertical facades and walls of houses can be covered with the foliage of self-climbing plants that are rooted in the ground and reach heights in excess of 80 feet. Vines can be evergreen or prolific deciduous flowering plants. As for roof gardens, the designer must be judicial in selecting plant species that will prosper in the constructed environment. Planters and trellises can be installed so that vegetation can be placed strategically.
- Roof Ponding – Roof ponding, also known as blue roofs, is applicable where the increased load of impounded water on a roof will not increase the building costs significantly or require extensive reinforcement. Roof ponding generally is not viable for large-area commercial buildings where clear spans are required. Special consideration must be given to ensuring that the roof will remain watertight under a range of adverse weather conditions. Low-cost plastic membranes can be used to construct an impermeable lining for the containment area.

Tables A-10 and A-14 address green roofs only because currently available literature provides only limited pollutant removal and design standards information on blue roofs and vegetated facades.

Table B-10
Pollutant Removal Capacity
Extensive and Intensive Green Roofs

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	70%
Total Phosphorus	30%
Total Nitrogen	55%
TSS	90%
Metals	Good

Notes:
a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

There is no available data on pollutant removal capacity on blue roofs or facades.

Table B-11
Treatment Processes Provided by
Extensive and Intensive Green Roofs

Treatment Processes[a]	Process Provided?
Biological Processes	
Infiltration	
Filtration	
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	✓

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-12
Treatment Processes Provided by
Blue Roofs

Treatment Processes	Process Provided?
Biological Processes	
Infiltration	
Filtration	
Peak Flow Reduction	✓
Plant Uptake	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	✓

Notes:

a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-13
Treatment Processes Provided by Facades

Treatment Processes	Process Provided?
Biological Processes	✓
Infiltration	
Filtration	
Sedimentation	
Vegetated Treatment	✓
Volume Reduction	

Notes:

a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-14
Advantages, Disadvantages and Limitations of Extensive and Intensive Green Roofs

Applications	Advantages	Limitations
• Can use vegetative roofs on residential, commercial and light industrial buildings. • Vegetative roof systems are most appropriate on roofs with slopes of 12:1 to 4:1. • Vegetative roofs may be used on flatter slopes if an underdrain is installed.	• Rooftop runoff management techniques can be retrofitted to most conventionally constructed buildings. • Reduces energy consumption for heating and cooling. • Conserves space. • Reduces wear on roofs caused by UV damage, wind, and extremes of temperature. Vegetative roof covers can reduce bare roof temperatures in summer by as much as 40 percent. • Roof gardens, vegetated roof covers, and vegetated facades add aesthetic value to residential and commercial property that attract songbirds, bees, and butterflies. • Benefit water quality by reducing the acidity of runoff and trapping airborne particulates. • May reduce the size of onsite runoff attenuation BMPs.	• Maximum 20% roof slope, unless specific measures are provided to retain the system on steeper slopes. • Needs to be designed in accordance with weight loads and aesthetics and consideration of thermal performance.

INFILTRATION BASIN

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

Table B-15
Pollutant Removal Capacity
Infiltration Basin

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	95%
Total Phosphorus	65%
Total Nitrogen	65%
TSS	90%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-16
Treatment Processes Provided by
Infiltration Basin

Treatment Processes[a]	Process Provided?
Biological Processes	✓
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	✓

Notes:

a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

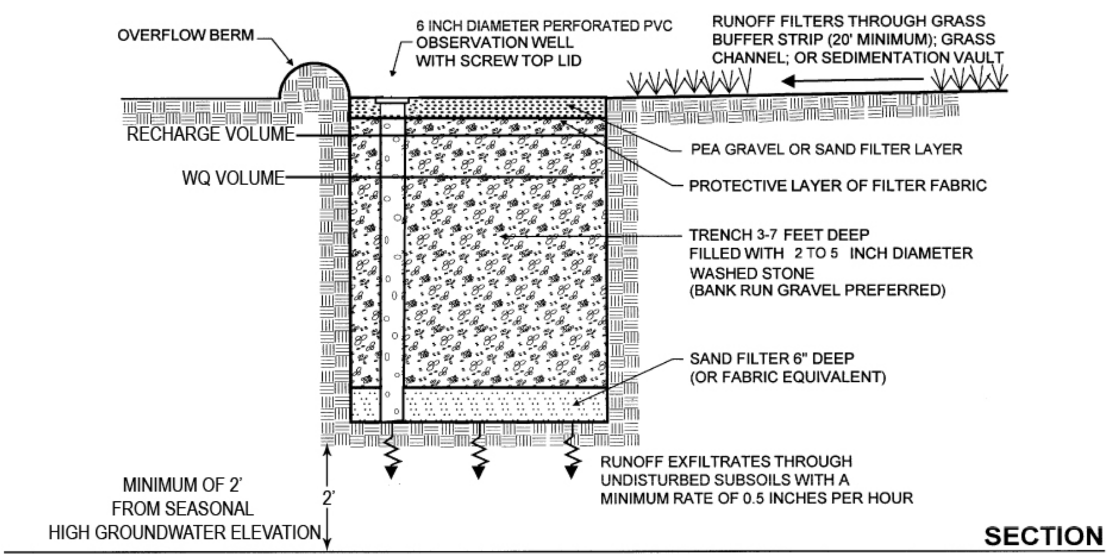
Table B-17
Advantages, Disadvantages and Limitations of
Infiltration Basin

Applications	Advantages	Limitations
• Contributing drainage area should be between 2 and 15 acres • Suitable for sites with gentle slopes, permeable soils, and relatively deep groundwater table	• Reduces local flooding • Can use near cold-water fisheries	• Requires pretreatment • Requires large pervious area • Clogging potential is high so high level of maintenance is necessary • Not suitable for treating high loads of sediment or other pollutants

INFILTRATION TRENCHES

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

Figure B.6—Photograph and schematic of infiltration trench.



Example of Infiltration Trench

Table B-18
Pollutant Removal Capacity
Infiltration Trenches

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	95%
Total Phosphorus	65%
Total Nitrogen	65%
TSS	90%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-19
Treatment Processes Provided by
Infiltration Trenches

Treatment Processes[a]	Process Provided?
Biological Processes	
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	✓

Notes:

a. Treatment processes are assumed to be same as Dry Wells and are identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-20
Advantages, Disadvantages and Limitations of
Infiltration Trenches

Applications	Advantages	Limitations
• Infiltration may be useful for disposing of roof runoff (e.g., dry wells), or runoff from parking lots and roadways. • Infiltration trenches generally have a longer life cycle when hydrologically proceeded by pretreatment such as a vegetated filter strip. • Infiltration generally requires UIC review and approval.	• Appropriate for installation directly adjacent to parking lots or other impervious surfaces • Applicable to small drainage areas, stormwater retrofits and highly developed sites. • High bacteria removal efficiency. • Infiltration provides groundwater recharge. • Helps to mimic predevelopment runoff conditions. • Reduces need for end-of-pipe treatment.	• Susceptible to clogging by sediment • Maintenance required approximately every six months • Minimum soil infiltration rate of 0.5 inches per hour • Natural slope less than 15% • Cannot accept LUHPPL runoff • Separation to high groundwater minimum of 2 feet

LEACHING CATCH BASINS

Leaching catch basins are pre-cast concrete structures with openings within the structure walls and an open bottom. The openings allow water to infiltrate into the surrounding soils. Preferable design of a leaching catch basin involves an offline system with a deep sump catch basin upstream for pretreatment.

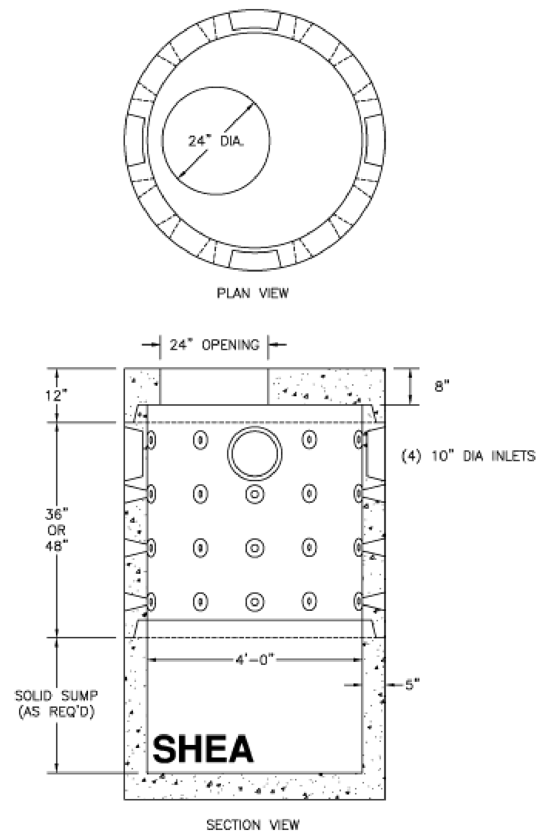


Figure B.7—Schematic of leaching catch basins.

Table B-21
Pollutant Removal Capacity

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	90%
Total Phosphorus	55%
Total Nitrogen	40%
TSS	90%
Metals	Good

Leaching Catch Basins

Notes:
a. Removal rates assumed to be the same as Dry Wells and taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-22
Treatment Processes Provided by
Leaching Catch Basins

Treatment Processes[a]	Process Provided?
Biological Processes	
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	✓

Notes:
a. Treatment processes are assumed to be same as Dry Wells and are identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-23
Advantages, Disadvantages and Limitations of
Leaching Catch Basins

Applications	Advantages	Limitations
• Can be implemented as a retrofit • May be useful in urban areas with land constraints	• Low cost per unit of treatment • Especially suitable retrofit for roads and parking lots • Relatively easy to repair/replace	• Susceptible to clogging by sediment

PLANTER AND TREE BOX FILTERS

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

Figure B.8—Photographs of planter and tree box filters.

Table B-24
Pollutant Removal Capacity
Planter and Tree Box Filters

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	70%
Total Phosphorus	30%
Total Nitrogen	55%
TSS	90%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-25
Treatment Processes Provided by
Planter and Tree Box Filters

Treatment Processes[a]	Process Provided?
Biological Processes	✓
Infiltration	
Filtration	✓
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	✓

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-26
Advantages, Disadvantages and Limitations of
Planter and Tree Box Filters

Applications	Advantages	Limitations
• Commonly used in densely urbanized areas such as along roads, highways, sidewalks and parking lots	• Reduces volume and rate of runoff • Smaller footprint required • May be used as pretreatment device • Provides decentralized stormwater treatment • Ideal for redevelopment or in ultra-urban settings	• Requires vegetative maintenance • Treats small volumes • Treats small tributary areas

PORUS PAVEMENT

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

Figure B.9—Photographs of porous pavement.

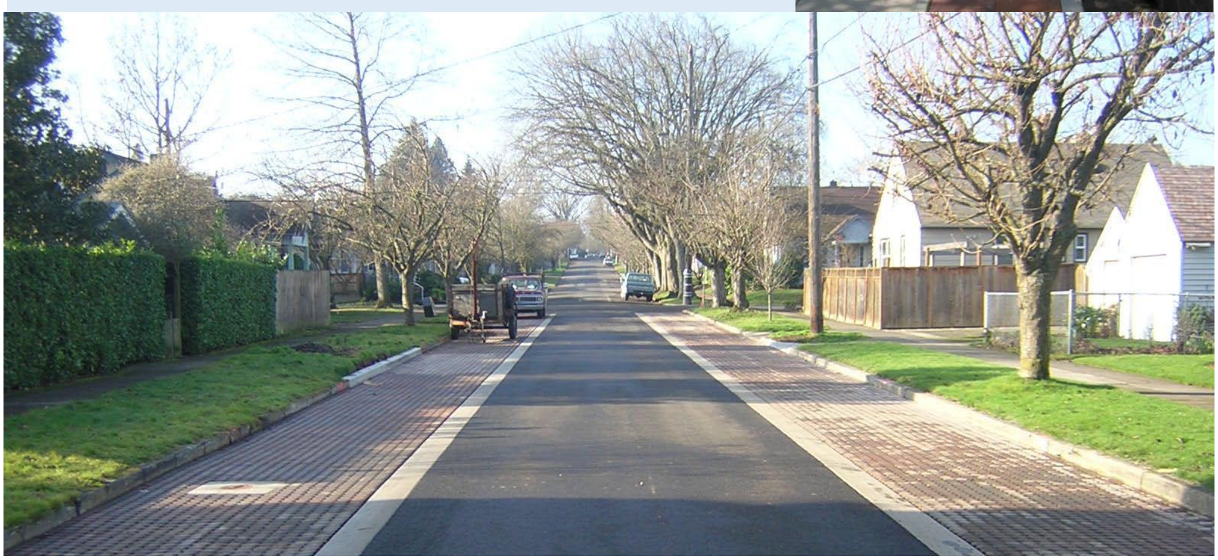


Table B-27
Pollutant Removal Capacity
Porous Pavement

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	95%
Total Phosphorus	40%
Total Nitrogen	40%
TSS	90%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-28
Treatment Processes Provided by
Porous Pavement

Treatment Processes[a]	Process Provided?
Biological Processes	✓
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	✓

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-29
Advantages, Disadvantages and Limitations of
Porous Pavement

Applications	Advantages	Limitations
• Good option for commercial and industrial parking lots • Can be used in urban and residential settings • Can be implemented as a retrofit • Preferable for low-volume, low-speed areas or pedestrian areas • Useful application to sidewalks	• Reduces sediment and particulate-bound pollutants • Reduces amount of impervious area needing water quality treatment	• Frequent clogging if not maintained • No sanding in winter • Compacting of underlying soils is common • Limited removal of dissolved constituents when underdrains are used

PROPRIETARY MEDIA FILTER

Proprietary Media Filters are typically underground structures that first settle out in an upstream structure and then flow through a specific filter media to reduce targeted pollutants.

Removal rates of pollutants vary depending on the filter media. Filtration is the main treatment process that all proprietary media filters provide.

Table B-30
Advantages, Disadvantages and Limitations of
Proprietary Media Filter

Applications	Advantages	Limitations
• Sites with space constraints • Ultra-urban areas	• Suitable for specialized applications, such as industrial sites, for specific target pollutants • Preferred for redevelopments or in the ultra-urban setting when LID or larger conventional practices are not practical	• Must be purchased from private sector firm • May require more maintenance • “Wet” systems that are designed to retain water can cause mosquito and vector problems unless access points are sealed

SAND FILTERS

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

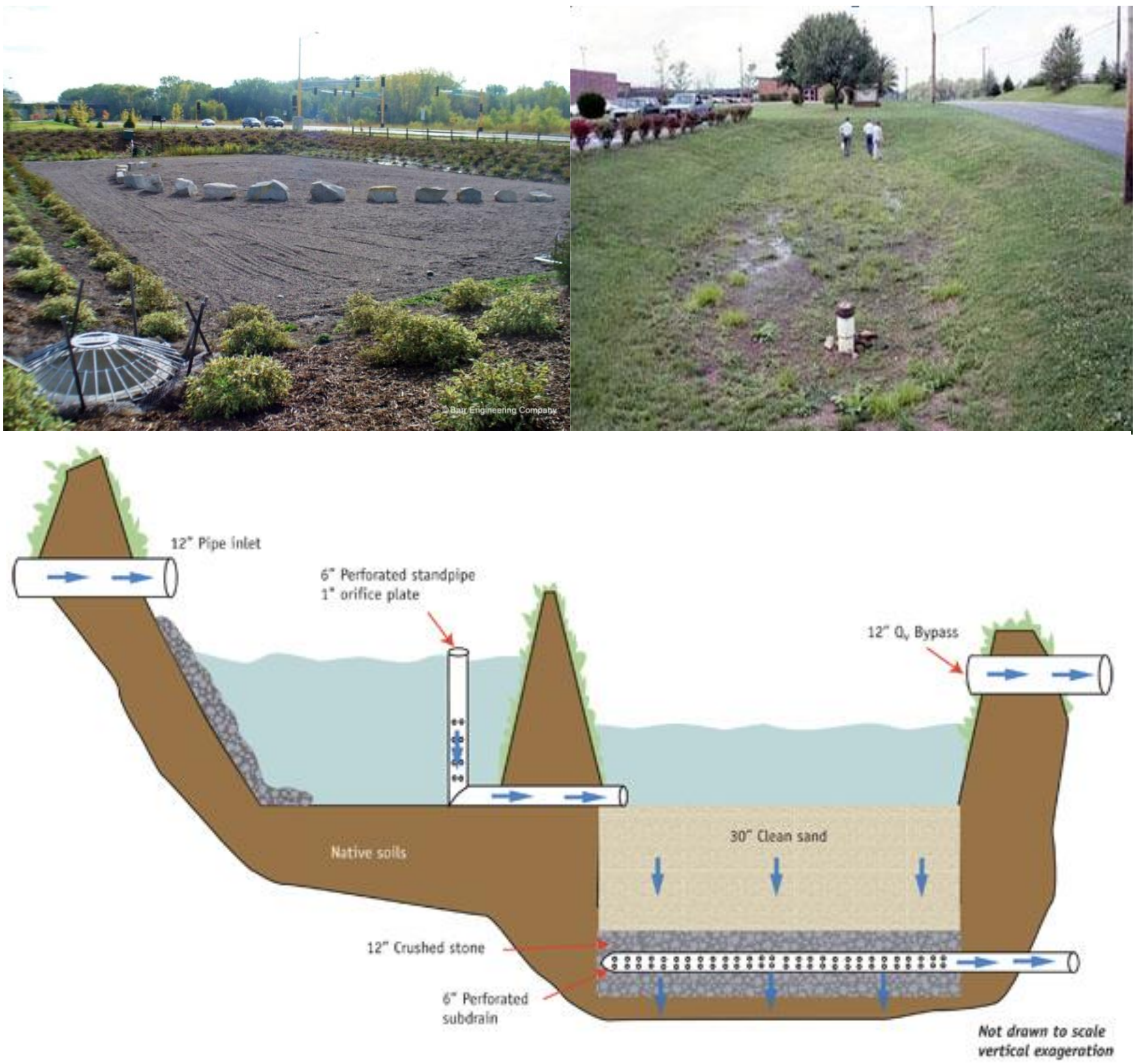


Figure B.10—Photographs and schematic of sand filters.

Table B-31
Pollutant Removal Capacity
Sand Filter

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	70%
Total Phosphorus	59%
Total Nitrogen	32%
TSS	86%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-32
Treatment Processes Provided by
Sand Filter

Treatment Processes[a]	Process Provided?
Biological Processes	✓
Infiltration	
Filtration	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	

Notes:

a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-33
Advantages, Disadvantages and Limitations of
Sand Filter

Applications	Advantages	Limitations
• Can be used in ultra-urban sites with small drainage areas • Drainage area can be 100% impervious like parking lots • May be useful as redevelopment / retrofit projects	• Long design life if properly maintained • Good for densely populated urban areas or parking lots • Relatively small footprint area	• Pretreatment required to prevent clogging • Frequent maintenance required • Costly to build and install • Limited removal of dissolved constituents • May not be effective in winter • Can be unattractive and create odors

SUBSURFACE INFILTRATION

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

Figure B.11—Rendering of subsurface infiltration structure.

Table B-34
Pollutant Removal Capacity
Subsurface Infiltration

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	90%
Total Phosphorus	55%
Total Nitrogen	40%
TSS	90%
Metals	Good

Notes:
a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-35
Treatment Processes Provided by
Subsurface Infiltration

Treatment Processes[a]	Process Provided?
Biological Processes	
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	
Volume Reduction	✓

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-36
Advantages, Disadvantages and Limitations of Subsurface Infiltration

Applications	Advantages	Limitations
• Applicable for private and public projects, commercial and residential • Can be implemented as a retrofit • May be useful in urban areas adjacent to buildings	• Low cost per unit of treatment • Especially suitable retrofit for roads and parking lots	• Susceptible to clogging by sediment • Minimum soil rate of 0.5 inches per hour • Separation from seasonal high groundwater, minimum of 2 feet

VEGETATED DRAINAGE WAYS

Structural drainage systems and storm sewers are designed to be hydraulically efficient for removing stormwater from a site. However, in doing so, these systems tend to increase peak runoff discharges, flow velocities and the delivery of pollutants to downstream waters. An alternative is the use of natural drainage ways such as grass natural drainage systems.

The use of natural open channels allows for more storage of stormwater flows on-site, lower stormwater peak flows, a reduction in erosive runoff velocities, infiltration of a portion of the runoff volume, and the capture and treatment of stormwater pollutants.

Figure B.12—Photograph of vegetated drainage ways.

Table B-37
Pollutant Removal Capacity
Vegetated Drainage Ways

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	No Treatment
Total Phosphorus	No Data
Total Nitrogen	No Data
TSS	No Data
Metals	No Data

Notes:
a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-38
Treatment Processes Provided by
Vegetated Drainage Ways

Treatment Processes	Process Provided?
Biological Processes	
Infiltration	
Filtration	
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	

Notes:
a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-39
Advantages, Disadvantages and Limitations of Vegetated Drainage Ways

Applications	Advantages	Limitations
• Use vegetated open channels in the street right-of-way to convey and treat stormwater runoff from roadways, particularly for low-density development and residential subdivisions where density, topography, soils, slope, and safety issues permit. • Use vegetated open channels in place of curb and gutter to convey and treat stormwater runoff. • Design drainage systems and open channels to: ▪ Increase surface roughness to retard velocity. ▪ Include wide and flat channels to reduce velocity of flow and encourage sheet flow if possible. ▪ Increase channel flow path to increase time of concentration and travel time.	• Reduces or eliminates the cost of constructing storm sewers or other conveyances, and may reduce the need for land disturbance and grading. • Increases travel times and lower peak discharges. • Can be combined with buffer systems to enhance stormwater filtration and infiltration.	• Maximum longitudinal slope of 4%, without checkdams • Can erode during large storms • Treats small tributary areas

WATER QUALITY SWALE

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

Figure B.13—Photograph of water quality swale.

Vegetated open channels designed to treat and attenuate the water quality volume and convey excess stormwater runoff. Dry swales are primarily designed to receive drainage from small impervious areas and rural roads.

Wet swales are primarily used for highway runoff, small parking lots, rooftops, and pervious areas. Vegetated open channels designed to treat and attenuate the water quality volume and convey excess stormwater runoff. Dry swales are primarily designed to receive drainage from small impervious areas and rural roads. Wet swales are primarily used for highway runoff, small parking lots, rooftops, and pervious areas.

Table B-40
Pollutant Removal Capacity
Water Quality Swale

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	70%
Total Phosphorus	30%
Total Nitrogen	55%
TSS	90%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-41
Treatment Processes Provided by
Water Quality Swale

Treatment Processes[a]	Process Provided?
Biological Processes	✓
Infiltration	✓
Filtration	✓
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	✓

Notes:
a. Treatment processes identified from Boston Water and Sewer Commission (BWSC) *Stormwater Best Management Practices: Guidance Document*, January 2013.

Table B-42
Advantages, Disadvantages and Limitations of
Water Quality Swale

Applications	Advantages	Limitations
• Residential settings along roadways.	• Low capital cost • Low maintenance requirements	• Can erode during large storms • Treats small tributary areas • Not for areas with very flat grades, steep topography, or poorly drained soils • Higher degree of maintenance than curb and gutter systems

GRAVEL WETLAND

Gravel WVTS is a wet stormwater basin system designed to provide treatment primarily in a wet gravel bed with emergent vegetation. The SGW is designed as a series of horizontal flow-through treatment cells, preceded by a sedimentation basin (forebay) designs maintain a saturated gravel bed and provide treatment by stormwater movement through the gravel bed and plant/soil treatment processes.

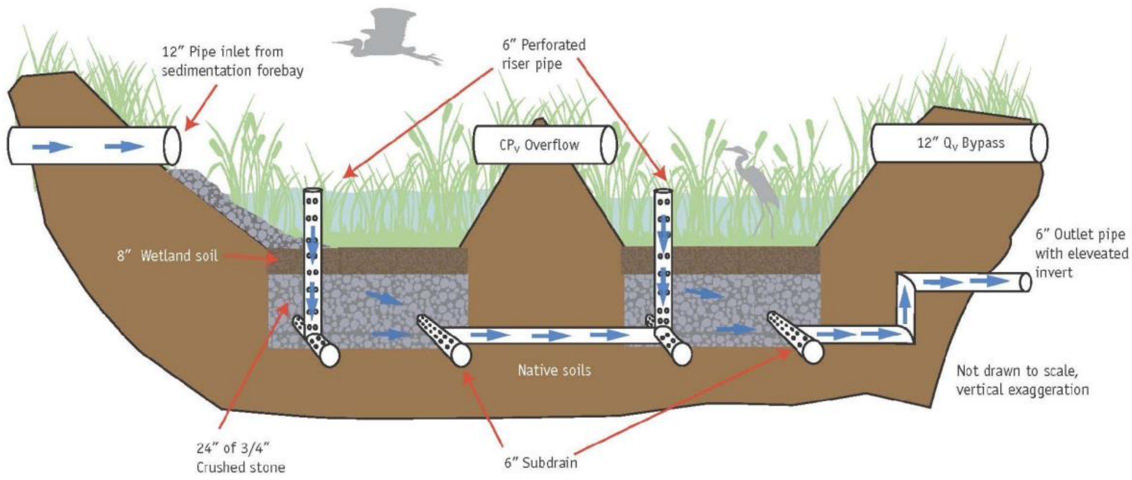


Figure B.14—Schematic of wet vegetated treatment system.

Table B-43
Pollutant Removal Capacity
Wet Vegetated Treatment System (Gravel)

Target Constituents	Removal Rates Based on the *Rhode Island Stormwater Design and Installation Standards Manual*[a]
Bacteria	85%
Total Phosphorus	53%
Total Nitrogen	55%
TSS	86%
Metals	Good

Notes:

a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-44
Treatment Processes Provided by
Wet Vegetated Treatment System (Gravel)

Treatment Processes	Process Provided?
Biological Processes	✓
Infiltration	
Filtration	✓
Sedimentation	✓
Vegetated Treatment	✓
Volume Reduction	

Notes:
a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

Table B-45
Advantages, Disadvantages and Limitations of
Wet Vegetated Treatment System (Gravel)

Applications	Advantages	Limitations
• May be used in a wide variety of settings including residential, commercial, and industrial areas; but are most commonly applied to commercial and industrial settings. • May be decentralized (e.g., bioretention) or centralized in common areas to manage multiple properties. • Must be lined and underdrained to ensure proper function.	• Desirable for small drainage areas, stormwater retrofits and highly developed sites. • High bacteria removal and nutrient removal efficiency. • Reduces need for end-of-pipe treatment. • Well-suited for water quality retrofit of existing storm drainage systems and stormwater ponds.	• High land requirement • High capital cost • Design needs to consider depth to groundwater and bedrock • Additional restrictions apply in cold-water fishery watershed based on distance from discharge point to streams (and any contiguous wetlands)

Notes:
a. Removal rates taken from Table H-3 Pollutant Removal Efficiency Rating Values for Water Quality BMPs of the *Rhode Island Stormwater Design and Installation Standards Manual*

REFERENCES

Boston Water and Sewer Commission. (2013). *Stormwater Best Management Practices: Guidance Document.*

RIDEM. (2010). *Rhode Island Stormwater Design and Installation Standards Manual*.