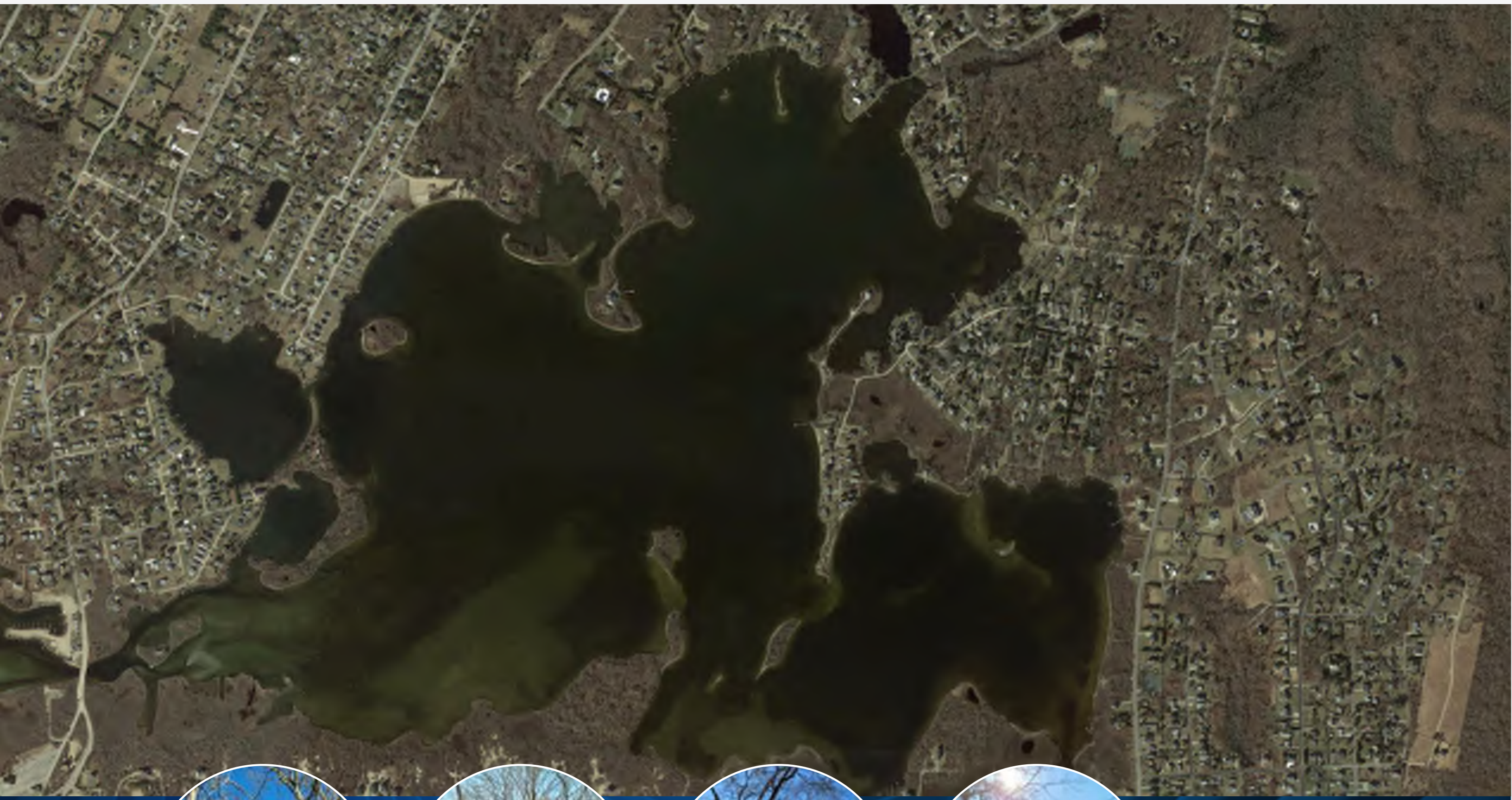
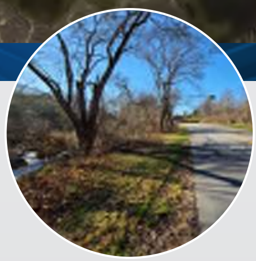
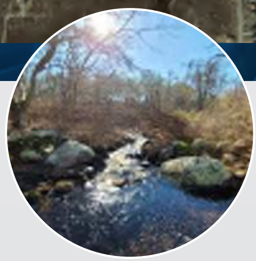
STORMWATER ATTENUATION AND SOURCE REDUCTION STUDY







Town of South Kingstown, Rhode Island
December 2021

WOODARD & CURRAN

TABLE OF CONTENTS

SECTION **PAGE NO.**

1. INTRODUCTION....1-1

2. WATERSHED ANALYSIS....2-1

2.1 Land Cover and Land Use....2-1
2.2 Soils....2-2
2.3 Watershed Hydrography....2-2
2.4 Existing Infrastructure....2-2

3. STORMWATER POLLUTANT SOURCE IDENTIFICATION AND PRIORITIZATION....3-1

4. PRIORITIZED CATCHMENTS....4-1

4.1 Catchment 1: Elm and Balsam Road....4-1
4.2 Catchment 2: Dawley Way....4-1
4.3 Catchment 3: Matunuck School House and Green Hill Beach Road....4-1
4.4 Catchment 4: Twin Peninsula Avenue....4-2

5. POLLUTANT LOAD ESTIMATES....5-1

5.1 Total Nitrogen....5-1
5.2 Bacteria....5-2
5.3 Structural Retrofit Pollutant Removal Efficiencies....5-2

6. STRUCTURAL RETROFIT RECOMMENDATIONS....6-1

6.1 Gravel Wet Vegetated Treatment Systems....6-1
6.2 Catch Basin Retrofit/Infiltration Trench Systems....6-2
6.3 Cost-Benefit Analysis....6-3
6.4 Catch Basin Retrofit Analysis....6-5
6.5 Inspection and Maintenance Considerations....6-5
6.6 Groundwater Recharge....6-5
6.7 Structural Retrofit Summary....6-6

7. NON-STRUCTURAL SOURCE REDUCTION OPPORTUNITIES....7-1

7.1 Non-Structural Controls....7-1
7.2 Additional Pollution Prevention Measures....7-1

8. RECOMMENDATIONS AND NEXT STEPS....8-1

8.1 Structural Retrofit Recommendation....8-1
8.2 Non-Structural Source Reduction Recommendation....8-1
8.3 Next Steps....8-1

TABLES

Table 2-1: Watershed Roadway Summary
Table 2-2: Watershed Summary
Table 3-1: Catchment Analysis
Table 4-1: Catchment 1 Drainage Summary
Table 4-2: Catchment 2 Drainage Summary
Table 4-3: Catchment 3 Drainage Summary
Table 4-4: Catchment 4 Drainage Summary
Table 5-2: Generated TN Loads
Table 5-3: Generated Bacteria Loads
Table 6-1: TN Load Reduction Estimates (lbs/year)
Table 6-2: Bacteria Load Reduction Estimates (billion colonies/year)
Table 6-3: TN Load Reduction Estimates (lbs/year)
Table 6-4: Bacteria Load Reduction Estimates (billion colonies/year)
Table 6-5: Gravel WVTS Cost
Table 6-6: Infiltration Trench Cost
Table 6-7: Catch Basin Retrofit Analysis Summary
Table 6-8: Maintenance Hours Summary
Table 6-9: Groundwater Recharge Summary
Table 6-10: Infiltration Trench Groundwater Recharge
Table 6-11: Structural Control Summary
Table 6-12: Structural Control Summary
Table 7-1: Non-Structural Control Credit Calculation

FIGURES

Figure 2-1: Impervious Area
Figure 2-2: Road Ownership and Road Type
Figure 2-3: Land Use
Figure 2-4: Soils
Figure 2-5: Stream Hydrography and Road Centerline Intersections
Figure 2-6: Stormwater and Water Systems Infrastructure
Figure 3-1: Stormwater Catchments and Pipe Network
Figure 4-1: Overall Watershed with Catchment Areas
Figure 4-2: Catchment 1 Delineation
Figure 4-3 Catchments 2 & 3 Delineations
Figure 4-4: Catchment 4 Delineation
Figure 6-1: Catchment 1 10% Concept Design
Figure 6-2: Catchment 2 10% Concept Design
Figure 6-3: Catchment 3 10% Concept Design
Figure 6-4: Catchment 4 10% Concept Design

APPENDICES

Appendix A: Figures
Appendix B: Total Nitrogen Load Calculations
Appendix C: Bacteria Load Calculations
Appendix D: Cost-Benefit Calculations
Appendix E: Catch Basin Retrofit Calculations
Appendix F: Groundwater Recharge Volume Calculations
Appendix G: Non-Structural Calculations
Appendix H: Reference

1. INTRODUCTION

Green Hill Pond and its 3,400-acre watershed is located primarily in the Town of South Kingstown, Rhode Island and partially within the Town of Charlestown, Rhode Island. The Pond is located south of Commodore Perry Highway (Route 1) between Ninigret Pond to the west and Trustom Pond to the east. The watershed is primarily comprised of private residential properties, paved and gravel public and private roadways, agricultural land, forest, and wetlands, and it is a popular recreation area with Green Hill Park northeast of the pond.

Green Hill Pond is a high-quality tidal salt pond designated for shellfish harvesting, recreation, and fish and wildlife habitat. A Total Maximum Daily Load (TMDL) for fecal coliform was developed for Green Hill Pond, Ninigret Pond, Factory Pond Stream and Teal Pond Stream in 2006 by the Rhode Island Department of Environmental Management (RIDEM). TMDL's establish a pollution "budget" for a water body or in other words, establishes the amount of pollutant loading that is permissible in order for the surface water body to meet minimum water quality standards (i.e., "fishable" and "swimmable"). The Ninigret Pond watershed lies entirely within Charlestown. Factory Pond Stream and Teal Pond Stream are important tributary streams within the Green Hill Pond watershed and are considered Class A streams. Sources of fecal coliform bacteria analyzed through a RIDEM study (RIDEM, 2003b) were determined to be primarily related to wildlife (including birds) (69%), unknown (12%), humans (11%), and dogs (8%).

In addition to concerns for fecal coliform in Green Hill Pond, high nitrogen levels have been observed. Although nutrients such as nitrogen and phosphorus aid with plant growth, high concentrations of nutrients can lead to excessive algal and weed growth, reduced dissolved oxygen, and changing pH levels, and can cause depleted oxygen levels, fish kills, and harmful pond conditions. Long-term inputs of nutrients from watersheds can create a nutrient buildup in the ponds sediment that has the potential to release over time and mix back into the water column, creating eutrophic conditions.

Over the past decade several studies have been conducted to evaluate various management options for inputs of primary pollutants of concerns in the Green Hill Pond Watershed.

- In 2007, a Watershed Management Plan for Green Hill and Eastern Ninigret Ponds, was completed by Horsley Witten Group (HWG) and submitted to the RIDEM, Salt Ponds Technical Advisory Committee and Salt Ponds Coalition. The 2007 watershed-based plan made recommendations for stormwater and on-site wastewater management. In 2011, Woodard & Curran was retained by South Kingstown to review the stormwater implementation strategies that had been outlined in this plan and to provide an opinion of the cost and possible benefit of implementation of both structural and non-structural stormwater controls outlined in the HWG Plan.
- In 2011, the South Kingstown Wastewater Facilities Plan Amendment was developed by Woodard & Curran for the Town to identify and address wastewater treatment and nutrient control opportunities in the Green Hill Pond watershed. The study focused on nitrogen sources, largely associated with on-site wastewater systems, and made recommendations for amelioration strategies.

This Stormwater Attenuation and Source Reduction Strategy Report supplements the previous studies with recommendations to address stormwater discharges associated with the developed lands within the Green Hill Pond watershed. Overall, the objective of this report was to comprehensively evaluate likely stormwater inputs into the Green Hill Pond and to identify strategies to reduce the impact of stormwater in the watershed. This report includes the process and rationale used to select stormwater attenuation strategies and types of structural and non-structural stormwater controls to improve water quality by reducing total nitrogen and bacteria concentrations in stormwater runoff within Green Hill Pond and its watershed. This report also provides the Town with specific stormwater management recommendations that will maximize effectiveness per investment in stormwater quality improvements.

2. WATERSHED ANALYSIS

Stormwater inputs that contribute to water quality concerns are primarily derived from the developed portions of a watershed. Stormwater runoff from undeveloped land is not generally considered an excessive source of pollutants. A stormwater attenuation plan will generally include an evaluation of watershed land uses, soil types and existing infrastructure to begin to identify primary areas of concern from a stormwater perspective. This watershed analysis provides the basis for our evaluation of problematic stormwater source areas.

Overall, Green Hill Pond (the Pond) has a surface area of approximately 380 acres which is primarily located in the southwestern corner of the Town of South Kingstown. The pond's watershed is approximately 3,400 acres, of which approximately 2,985 acres (88%) are within South Kingstown and 415 acres (12%) are within Charlestown. This report focuses on the South Kingstown (the Town) portion of the Pond and watershed (the Watershed). For the purposes of this report, "Watershed" shall mean that portion of the Green Hill Pond watershed that lies within the Town of South Kingstown.

2.1 Land Cover and Land Use

Land cover and land use data was collected from The Town of South Kingstown GIS Department and the state's Rhode Island Geographic Information System (RIGIS). These data layers are the basis of the Watershed's stormwater input analysis. Impervious surfaces can contribute to increased stormwater runoff, route surface pollutants quickly to receiving waters and restrict the recharge of groundwater. Pervious areas allow the infiltration of precipitation to recharge shallow and deep groundwater and preserve the hydrologic integrity of a watershed. Most impervious cover in South Kingstown is made up of buildings, parking lots, driveways, and roads.

The percentage of impervious cover in a watershed can indicate the probable health of the watershed and associated waterbody. Extensive literature sources indicate that watersheds with greater than 10% of their land area covered by impervious surfaces exhibit various signs of impairment. The Watershed consists of approximately 87% pervious and 13% impervious area, as illustrated by Figure 2-1 included in Appendix A of this report.

The impervious area within the Watershed includes state owned, town owned, and privately owned paved and gravel roads, and both public and privately-owned buildings, driveways, and parking areas. Figure 2-2 identifies roads within each of these categories, and Table 2-1 demonstrates the mileage of each roadway category in the Watershed.

Table 2-1: Watershed Roadway Summary

Ownership	Roadway Mileage		
	Paved	Gravel	Total
State	5.4	0.0	5.4
Town	12.5	1.4	13.9
Private	4.7	4.9	9.6
Sum =	**22.6**	**6.3**	**28.9**

Land use is also an important factor when understanding the probable health of the watershed and waterbody. Commercial, industrial, residential, and highway land uses generate higher concentrations of pollutants in stormwater runoff than undeveloped or rural areas. Land use distribution within the Watershed based on 2011 data is as follows: undeveloped/rural (65%), residential (33%), commercial (1%), and highway (1%). Table 2-2 summarizes the land use and land cover areas, and Figure 2-3 illustrates the land use distribution within the Watershed.

Table 2-2: Watershed Summary

Land Use	Drainage Area (acres)		
	Pervious	Impervious	Total
Commercial	17.3	16.9	34.3
Residential	708.4	280.9	989.3
Highway (Route 1)	9.8	21.7	31.5
Undeveloped/Rural	1,858.4	71.7	1,930.0
Sum =	**2,593.9**	**391.2**	**2,985.1**

2.2 Soils

Based on data from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), the Watershed consists primarily of hydrologic soil group (HSG) A soils, followed by HSG B, D, and C soils. HSG A generally has the lowest runoff potential and HSG D the greatest. Evaluations of the watershed soils indicate that they are largely conducive to infiltration, which will prove to be beneficial for stormwater attenuation. Figure 2-4 illustrates the locations of each hydrologic soil group.

2.3 Watershed Hydrography

The Watershed contains multiple waterbodies in addition to Green Hill Pond. Bull Head Pond is located north of Route 1. Factory Pond is an important tributary to Green Hill Pond and is hydrologically connected to the pond via Factory Brook. Teal Brook and various other unnamed brooks and wetland systems are located within the Watershed and all ultimately discharge to Green Hill Pond. Figure 2-5 shows the various freshwater rivers and streams within the Watershed in addition to culverts at stream/road intersections.

2.4 Existing Infrastructure

While there are developed areas with concentrated runoff within the watershed, very little of the watershed contains engineered stormwater conveyance infrastructure (pipes, manholes, etc.). This has implications on stormwater attenuation strategies as outlined in Section 3 and 4. Information from the Town, including location of catch basins, manholes, outlets, and drainage pipe, was evaluated in this analysis. The Rhode Island Department of Transportation (RIDOT) owned drainage infrastructure outfalls along Route 1 have also been included based on an existing conditions plan prepared by Louis Berger & Associates, Inc., dated March 1998. Figure 2-6 shows the location of drainage infrastructure, including catch basins, manholes, outlets, and piping in addition to drinking water infrastructure. There is no sanitary sewer collection system within the Green Hill Pond watershed. Drinking water has been included in the analysis to avoid conflicts between recommended stormwater infrastructure and existing drinking water infrastructure. Other utilities of concern for conflicts in a stormwater attenuation report may include subsurface electrical or telecommunications infrastructure. It is our understanding that the only significant subsurface utility infrastructure is under Green Hill Pond Road and consists of three (3) trans-Atlantic telecommunication cables.

3. STORMWATER POLLUTANT SOURCE IDENTIFICATION AND PRIORITIZATION

As discussed in Section 2, the Green Hill Pond watershed is largely comprised of residential developments which are serviced by public and private paved and unpaved roadways. Stormwater runoff is generated from building rooftops, driveways and roadways and conveyed via overland flow paths and/or stormwater drainage infrastructure. The developed areas with stormwater drainage infrastructure and a high likelihood of contributing stormwater runoff directly to the Pond were delineated for further evaluation and prioritization for structural stormwater control retrofits. Figure 3-1 shows developed land catchments evaluated for stormwater management opportunities. Table 3-1 provides a catchment analysis overview that provides the basis for the prioritization process, as described below.

Table 3-1: Catchment Analysis

ID #	Area (acres)	Impervious Area (acres)	Total Impervious Area as % of watershed IA*	% of Catchment in Hydrologic A and B Soils	Medium to High Density Developed Land (acres)	Existing Stormwater Drainage System	Municipal Roadways within the Catchment	Direct Piped Discharge Into Mapped Waterways
1	111.32	35.26	9.0	100.0	89.2	Yes	Yes	Yes
2	10.97	3.59	0.9	100.0	10.9	Yes	Yes	Yes
3	5.36	1.87	0.5	100.0	4.3	Yes	Yes	Yes
4	5.89	2.36	0.6	99.8	5.9	No	No	No
5	22.4	6.69	1.7	100.0	18.5	No	Yes	No
6	20.36	7.42	1.9	99.7	17.1	No	Yes	No
7	12.3	4.13	1.1	100.0	12.3	Yes	Yes	No
8	39.78	3.93	1.0	100.0	1.89	Yes	Yes	No
9	26.14	16.72	4.3	100.0	0.00	Yes	No	No
10	20.57	5.37	1.4	71.5	15.2	No	Yes	No
11	3.1	0.74	0.2	92.2	2.7	Yes	Yes	Yes
12	12.56	3.34	0.9	90.0	10.6	Yes	Yes	No
13	20.11	4.44	1.1	56.9	14.6	No	Yes	No
14	5.01	1.44	0.4	99.9	2.8	Yes	Yes	No
15	17.57	5.06	1.3	81.4	15	No	No	No
16	6.39	2.42	0.6	99.5	6.2	No	Yes	No
17	9.85	2.49	0.6	100.0	7.9	Yes	No	No
18	1.31	0.72	0.2	99.9	1.3	Yes	Yes	No
19	15.78	2.99	0.8	95.2	7.9	No	No	No
20	3.6	1.47	0.4	100.0	3.5	No	Yes	No
21	8.04	1.49	0.4	100.0	1.77	No	Yes	No
22	7.4	1.69	0.4	52.4	5.3	No	Yes	No
23	4.83	1.62	0.4	95.4	4.8	No	No	No
24	5.5	2.11	0.5	39.5	4.7	No	Yes	No
25	5.88	1.67	0.4	82.7	5.1	No	No	No
26	7.52	2.16	0.6	60.5	6.9	No	No	No
27	5.03	0.96	0.2	95.6	2.5	No	No	No
28	4.34	1.83	0.5	85.3	4.2	No	No	No
29	4.45	1.1	0.3	22.0	3.7	No	Yes	No
30	4.37	1.41	0.4	74.8	4.4	No	No	No
31	6.05	1.25	0.3	69.3	3.1	No	No	No
32	2.89	0.6	0.2	88.0	2.9	No	No	No

1. Watershed Location and Size: Contributing watershed location and size is an important consideration in the relative impact of stormwater on a receiving waterbody. It is understood that transformation and potential reduction of pollutants occurs when they are transported through natural water systems, such as wetlands, streams, and ponds. Some developed areas in the Green Hill Pond watershed are in remote areas with significant natural wetland buffers from their outfall and the Pond, considering the many waterbodies discussed in Section 2.3 above. Developed drainage areas with proximity to the Pond are much more likely to effectively route pollutants to the Pond. Therefore, developed areas south of Route 1 were prioritized. Additionally, retrofits with larger watersheds have capacity to provide higher pollutant reductions, since the loading to these retrofits is larger. Larger watersheds also tend to have more options for locating structural stormwater controls. Therefore, large, developed drainage areas with stormwater infrastructure closest to the Pond were prioritized over areas distant from the Pond, such as areas north of Route 1 and locations with small contributing drainage areas. Catchment 1 is both the largest single stormwater discharge area in the watershed, contains stormwater drainage infrastructure and contains almost 10% of the entire watershed's impervious area. Retrofitting this catchment was an obvious priority.

2. Development and Land Use: High stormwater pollution concentrations typically correlate with built environments. Watersheds with significant impervious area and with land uses such as commercial, industrial, and high-density residential generate higher concentrations of pollutants in stormwater runoff compared to undeveloped/rural areas. Therefore, when studying the Watershed for stormwater source areas, Woodard & Curran first prioritized areas with the largest impervious area. Since the watershed consists primarily of undeveloped/rural areas such as forest and wetlands, this analysis narrowed the prioritized catchments considerably.

3. Soils: The catchments containing Hydrologic Soil Groups A and B (well-draining soils) are the most attractive for stormwater retrofits, as infiltration is a critical mode of restoring hydrologic conditions and reducing stormwater pollution migration to receiving waters. The catchments with the largest percentages of HSG A and B were prioritized for retrofit potential.

4. Concentrated Flows: The way stormwater is conveyed through a developed landscape will have considerable influence on the design and efficacy of structural, and to some extent non-structural, stormwater control strategies. The existing stormwater conveyance infrastructure (pipes) were evaluated and field-verified to identify where areas of concentrated flow occur within the Watershed. Stormwater retrofits are either not feasible or difficult to design and construct if the contributing stormwater flow is diffused rather than concentrated in pipes or ditches. In some cases, a stormwater conveyance system would need to be designed and constructed to treat stormwater. This is counterproductive as it would further concentrate stormwater flows and is not generally cost-effective. To demonstrate this, the downstream half of Catchment 16 was evaluated for development of conveyance infrastructure to collect stormwater to route it for treatment. The catchment area is about 8 acres with approximately 1.7 acres of impervious area. The retrofit system would require construction of an open channel along a private roadway, culverts at driveways, and a gravel wetland for treatment given less viable soils. The following construction costs includes land acquisition for the treatment system only, not for the conveyance system which would further increase overall cost.

   Total Construction Cost:
$225K (1" treatment depth)
$135K (0.4" treatment depth)

   A cost-benefit analysis was also developed for comparison purposes with the other cost-benefits outlined in Table 6-11. A retrofit developed in Catchment 16, and as described above, would have a cost-benefit of approximately $8,700 per pound of TN removed per year (1" treatment depth) or $7,500 per pound of TN removed per year (0.4" treatment depth). The cost of capturing and treating diffused overland flow is 2-3 times higher compared to other priority retrofits outlined in Section 6. Catchments with existing stormwater drainage systems were prioritized for retrofitting in this plan.

In addition to evaluating developed land catchments, the Factory Pond Stream (also referred to as Factory Brook) watershed was evaluated as it is a direct, channelized flow into Green Hill Pond and therefore presents a unique opportunity within the watershed. Factory Pond Stream flows from Factory Pond through forested wetland, along Matunuck Schoolhouse Road, and outlets into a small cove in the northeastern section of Green Hill Pond. The Factory Pond Stream watershed, shown on Figure 3-1, is approximately 1,350 acres, which represents almost 50% of the watershed within South Kingstown. Per RIDEM's 2006 TMDL analysis, this watershed is a significant contributor of nitrogen and bacteria to Green Hill Pond, and considering it is a channelized flow, it presents an important opportunity for water quality management. An offline stormwater control measure, such as a gravel wetland system, may be viable on Plat 90-1 Lot 129 and/or Plat 90-1 Lot 193, which is town-owned. However, such a system would require diversion of flow from a natural stream and wetland system. While it is highly unusual for a stream diversion and treatment system to be permitted in New England, this parcel has been highlighted with potential, if and when local and state regulatory agencies decide that streamflow treatment systems are necessary in the future to protect downstream resources. Permitting a system like this in Rhode Island would require input from state regulators and is the reason why this retrofit is not evaluated further in subsequent sections of this report.

5. Ownership: Municipal roadways and municipal infrastructure are often easier to retrofit than private property when using public financing. Town-owned roads and infrastructure were prioritized over private roadways for structural retrofits. Figure 2-3 shows the distribution of Town and Private roads within the watershed. Additionally, Route 1 is a heavily travelled roadway within the Watershed and may be a source of pollutants to upstream receiving waters and eventually the Pond. While this roadway may have viable retrofit opportunities, the road and surrounding easements are owned by the State of Rhode Island and are under the Department of Transportation jurisdiction. It is recommended that his drainage area, shown in Figure 4-1 and discussed further in Section 4, be further evaluated for stormwater attenuation potential by RIDOT.
6. Physical Considerations/Conflicts: Based on discussions with the Town, it is understood that Green Hill Beach Road has three (3) underground transatlantic cables (TAC), which if damaged, results in significant financial penalties to the Town. The three (3) TAC lines in addition to the Town's Transite water distribution main make Green Hill Beach Road very problematic for stormwater BMP construction. Therefore, this road was not evaluated for retrofits.

To assist in prioritization of stormwater management opportunities, Woodard & Curran performed field investigations to better understand site specific stormwater attenuation options on June 8, 2021. The purpose of this visit was to confirm the Watershed characteristics described above, with a focus on verification of piped, concentrated and unconcentrated stormwater flow paths. The field investigation identified viable stormwater attenuation (i.e. retrofit) locations and revisited locations identified in previous studies that had been recommended for stormwater retrofits. These investigations confirmed the potential feasibility of priority retrofit locations and located additional opportunities within the Watershed for structural stormwater controls. From the GIS and field-based prioritization described in this section, catchment area 1, 2, 3, and 4 were selected for concept designs.

4. PRIORITIZED CATCHMENTS

Four catchment areas were prioritized for conceptual design of stormwater retrofits based on the evaluation process described in Section 3. These catchments are identified on Figure 4-1 and are best described by their outfall locations. The catchment areas were primarily prioritized based on existing engineered drainage infrastructure, since existing conveyance infrastructure provides for more cost-effective retrofit opportunities compared to capturing and treating diffused overland flow. All catchment areas described below ultimately discharge stormwater runoff to Green Hill Pond.

4.1 Catchment 1: Elm and Balsam Road

Catchment 1 is illustrated in detail in Figure 4-2. Catchment 1 consists primarily of residential land and straddles the South Kingstown/Charlestown town line. Of the four prioritized catchments, Catchment 1 is the largest, has the most extensive drainage infrastructure system, and has the capacity to provide the highest pollutant reduction. Most of the stormwater runoff is captured by a series of roadway catch basins and conveyed to an outlet via a closed conduit drainage system. The outlet consists of a 36-inch RCP pipe and ultimately discharges stormwater flow to an existing wetland near the corner of Elm Road. Catchment 1 drainage area characteristics are summarized in Table 4-1 below.

Table 4-1: Catchment 1 Drainage Summary

Land Use	Drainage Area (acres)		
	Pervious	Impervious	Total
Commercial	1.0	0.7	1.7
Residential	63.6	21.9	85.5
Highway	0.0	0.3	0.3
Undeveloped/Rural	27.7	1.2	28.9
		Sum =	**116.4**

4.2 Catchment 2: Dawley Way

Catchment 2 is illustrated in detail in Figure 4-3 and consists primarily of residential land. Drainage infrastructure within Catchment 2 outfalls at Dawley Way at a parcel that is understood to be privately owned by a homeowners' association. Stormwater runoff is conveyed via overland flow and a series of catch basins to an 18-inch RCP outlet and ultimately discharges to an existing wetland within the privately owned parcel. Catchment 2 drainage area characteristics are summarized in Table 4-2 below.

Table 4-2: Catchment 2 Drainage Summary

Land Use	Drainage Area (acres)		
	Pervious	Impervious	Total
Residential	7.4	2.4	9.8
Undeveloped/Rural	0.1	0.0	0.1
		Sum =	**9.9**

4.3 Catchment 3: Matunuck School House and Green Hill Beach Road

Catchment 3 is illustrated in detail in Figure 4-3 and consists of residential and undeveloped/rural land. Stormwater runoff is conveyed via overland flow and a series of catch basins to an existing 18" outfall at Matunuck School House Road to Factory Brook. Catchment 3 drainage area characteristics are summarized in Table 4-3 below.

Table 4-3: Catchment 3 Drainage Summary

Land Use	Drainage Area (acres)		
	Pervious	Impervious	Total
Residential	3.1	0.1	3.2
Undeveloped/Rural	0.4	0.6	1.0
		Sum =	**4.2**

4.4 Catchment 4: Twin Peninsula Avenue

Catchment 4 is illustrated in detail in Figure 4-4 and consists entirely of residential land. Stormwater runoff is conveyed to a town-owned parcel consisting of natural wetlands via an erosion ditch along the side of Twin Peninsula Avenue. Catchment 4 drainage area characteristics are summarized in Table 4-4 below.

Table 4-4: Catchment 4 Drainage Summary

Land Use	Drainage Area (acres)		
	Pervious	Impervious	Total
Residential	3.6	1.4	5.0
		Sum =	**5.0**

5. POLLUTANT LOAD ESTIMATES

Pollutant loads were estimated using the Simple Method (Schueler, 1987) as recommended and outlined in Section H.3 of RIDEM's Rhode Island Stormwater Design and Installation Standards Manual (RISDISM). This method uses annual rainfall estimates, site percent impervious cover, land use type, and pollutant loading coefficients based on land use to estimate generated pollutant loads. These estimated loads are based on stormwater inputs due to land use and do not specifically consider additional sources such as septic systems, groundwater, wildlife, etc. The RISDISM recommends using the following median event mean concentrations (EMCs) for typical pollutants of concern associated with stormwater runoff.

Table 5-1: RISDISM EMC Values

Table H-2 Median EMC Values for Differing Land Use Categories

Pollutant (mg/l)	Land Use Category				
	Residential	Commercial	Industrial	Highways	Undeveloped/Rural[3]
TSS	100[1]	75[1]	120[1]	150[1]	51
TP	0.3	0.2	0.25	0.25	0.11
TN	2.1	2.1	2.1	2.3	1.74
Cu	.005	.096	.002	.001	-
Pb	.012	.018	.026	.035	-
Zn	.073	.059	.112	.051	-
BOD	9.0	11.0	9.0	8.0	3.0
COD	54.5	58.0	58.6	100.0	27.0
Bacteria*	7000	4600	2400	1700	300

Sources:
1 Caraco (2001); default values from Watershed Treatment Model, from several individual assessments
2 (shaded) Maestre and Pitt (2005); National Stormwater Quality Database, v 1.1
3 CDM (2004) Merrimack River Watershed Assessment Study, Screening Level Model
* Bacteria concentration in #col/100 ml.

Pollutant load estimates for the two pollutants of primary concern within the Pond, nitrogen and bacteria, are summarized in Sections 5.1 and 5.2 below. It should be noted that these estimates represent the wash off pollutant load that is discharged at the drainage infrastructure outfall and do not reflect the transformation, decay, or abatement of nutrients and bacteria in natural systems and therefore do not necessarily represent the load that enters the Pond. Rather, these estimates represent the pollutants discharging from developed areas to provide a valuable way to prioritize structural (and non-structural) stormwater control target areas.

5.1 Total Nitrogen

Total nitrogen loads generated by the Watershed, Route 1, and each prioritized catchment are summarized in Table 5-2 below, and calculations using the Simple Method are presented in Appendix B.

Table 5-2: Generated TN Loads

Drainage Area	TN Load (lbs/year)
Overall Watershed	9,986.8
Route 1	486.2
Catchment 1	569.1
Catchment 2	55.8
Catchment 3	33.6
Catchment 4	30.8

5.2 Bacteria

Bacteria loads generated by the Watershed, Route 1, and each prioritized catchments are summarized in Table 5-3 below, and calculations using the Simple Method are presented in Appendix C.

Table 5-3: Generated Bacteria Loads

Drainage Area	Bacteria Load (billion colonies/year)
Overall Watershed	103,467.7
Route 1	1,633.0
Catchment 1	7,849.3
Catchment 2	844.5
Catchment 3	357.4
Catchment 4	466.9

5.3 Structural Retrofit Pollutant Removal Efficiencies

The ability to reduce pollutant loads was one of the priorities when selecting structural retrofits in each of the four prioritized catchments. Two resources were used to evaluate the pollutant reduction performance of potential structural retrofits: the University of New Hampshire Stormwater Center's BMP Performance Fact Sheets and EPA Region 1's report entitled "Planning Level Green Infrastructure Stormwater Control Measure Performance Curves for Estimating Cumulative Reductions in SW-Related Indicator Bacteria". These documents are provided in Appendix H. They were used to estimate nitrogen and bacteria load reduction performance, respectively. These documents are beneficial to use because they provide pollutant removal efficiencies for various structural controls sized to treat runoff depths from 0.1 to 2.0-inches. Section 6 further describes the structural retrofit selection process and estimated cost-benefit of the selected retrofits at various treated runoff depths.

6. STRUCTURAL RETROFIT RECOMMENDATIONS

Structural stormwater retrofits were evaluated for each of the four catchments based on several criteria, including but not limited to: pollutant reduction performance, physical constraints such as high groundwater, maintenance, constructability, cost, resource area impacts, and groundwater recharge capacity. Based on these considerations, gravel wet vegetated treatment systems (WVTS) and catch basin retrofit infiltration systems are the recommended structural controls for the Watershed.

Gravel WVTS perform well with high groundwater tables since the gravel substrate must be saturated to create anaerobic conditions and enhance nitrogen transformation to gaseous forms. This design consideration is important for the end-of-conveyance systems at the prioritized Catchments 1, 2, and 4 which are near or within existing natural wetland systems which correlates with high groundwater tables. The benefit of these systems is their capacity to treat large volumes of water and in turn reduce significant amounts of pollutants, as discussed further in Section 6.1 below.

Small infiltration-based stormwater control retrofits connected to existing catch basins have the potential to provide pollutant load reduction in a minimal footprint. These systems consist of gravel backfilled trenches with perforated pipes connecting existing catch basins. The perforated pipe and gravel trench provide a means for runoff to infiltrate within the existing conveyance system, in turn providing groundwater recharge and treatment. These systems are discussed further in Section 6.2 below.

Both types of structural stormwater controls will work in almost any area of the Green Hill Pond watershed. Based on the analysis completed as a part of this report, these systems provide the greatest cost-benefit for nutrient and bacteria control and can be used as the primary retrofit treatments in the Green Hill Pond watershed.

6.1 Gravel Wet Vegetated Treatment Systems

Gravel WVTS were evaluated as end-of-conveyance systems at the outfalls in Catchments 1, 2, and 4. Figures representing 10% concept designs of these systems are presented in Appendix A as Figures 6-1, 6-2, and 6-4, respectively. Tables 6-1 and 6-2 below demonstrate the estimated pollutant load reductions for varying treatment depths.

Table 6-1: TN Load Reduction Estimates (lbs/year)

	Treatment Depth (inch) (Reduction Efficiency)	0.1 (22%)	0.2 (33%)	0.4 (48%)	0.6 (57%)	0.8 (64%)	1.0 (68%)
TN Load Reduction (lbs/year)	Catchment 1	125.2	187.8	273.1	324.4	364.2	387.0
	Catchment 2	12.3	18.4	26.8	31.8	35.7	37.9
	Catchment 4	6.8	10.2	14.8	17.6	19.7	21.0

Table 6-2: Bacteria Load Reduction Estimates (billion colonies/year)

	Treatment Depth (inch) (Reduction Efficiency)	0.1 (30%)	0.2 (47%)	0.4 (66%)	0.6 (73%)	0.8 (75%)	1.0 (76%)
Bacteria Load Reduction (billion colonies/year)	Catchment 1	2,377.6	3,705.7	5,142.1	5,701.0	5,871.3	5,971.0
	Catchment 2	255.8	398.7	553.2	613.4	631.7	642.4
	Catchment 4	141.4	220.4	305.8	339.1	349.2	355.1

If these systems are advanced to construction-level design, wetland verification will play an important role in the system design and location. The RISDISM states that WVTS designs shall not be located within jurisdictional waters, including wetlands, but may be allowed in jurisdictional upland buffers in areas already altered under existing conditions. Siting and permitting these systems may be a challenge given the uncertainty of existing wetland extents.

6.2 Catch Basin Retrofit/Infiltration Trench Systems

These systems were evaluated in Catchments 1, 2, and 3, as these catchments have the most extensive drainage systems and largest number of catch basins in the Watershed. A figure representing a 10% concept design of this system within Catchment 3 is presented in Appendix A as Figure 6-3.

The viability of roadway retrofits is based on several factors including underlying soil conditions, seasonal high groundwater table elevations, adjacent properties, utility constraints, roadway slope and others. Field assessment of catch basin and/or other roadway-based retrofits should be conducted by an engineer to refine the anticipated benefit of roadway-related stormwater retrofits if these retrofits are selected and advanced to construction-level design. For this analysis, the following assumptions were made to estimate pollutant load removal:

1. The calculations use load reduction efficiencies for an infiltration rate of 0.52 in/hr, consistent with HSG B soils.

2. These calculations assume the entire impervious area within the catchments drains to a catch basin. However, some of this impervious area may discharge directly to a stream or other waterbody and therefore would not be treated by this infiltration trench system.

3. An average volume per retrofitted catch basin of 150 cubic feet was used. This represents a 40-foot long, 3-foot wide, and 3-foot tall trench with 33% void storage and a perforated 12-inch diameter pipe. As shown in Figure 6-3, some systems may have additional treatment capacity, so this average volume per catch basin is considered conservative and actual treatment volume and runoff depths have the potential to be higher.

Tables 6-3 and 6-4 demonstrate estimated pollutant load reductions for three treatment depths to show the benefit range for various systems sizes. However, due to the limited size of these systems and space within right-of-ways, treatment of 0.4-inches may not be viable in all catchments. Therefore, the treatment depth that is based on the average available volume outlined above is presented in bold. This represents a conservative system size.

Table 6-3: TN Load Reduction Estimates (lbs/year)

	Treatment Depth (inch) (Reduction Efficiency)	0.1 (59%)	0.2 (76%)	0.4 (90%)
TN Load Reduction (lbs/year)	Catchment 1	**335.7**	432.5	512.2
	Catchment 2	32.9	**44.4**	50.2
	Catchment 3	19.8	**26.7**	30.3

Table 6-4: Bacteria Load Reduction Estimates (billion colonies/year)

	Treatment Depth (inch) (Reduction Efficiency)	0.1 (24%)	0.2 (45.5%)	0.4 (61%)
Bacteria Load Reduction (billion colonies/year)	Catchment 1	**1,916.8**	3,130.3	4,763.8
	Catchment 2	206.2	**384.3**	512.5
	Catchment 3	87.3	**162.6**	216.9

6.3 Cost-Benefit Analysis

A cost benefit analysis was completed to compare the selected structural retrofit options based on various treatment depths ranging from 0.1- to 1.0-inch. The benefit was calculated using the reduction performance for the respective retrofits and treatment depth and multiplying the reduction percentage by the overall catchment pollutant load. Cost estimates were taken from the 2011 TMDL Analysis Report and an escalation rate was applied to the cost estimate for inflation. Costs for each structural retrofit based on treatment depth are presented in Tables 6-5 and 6-6 below.

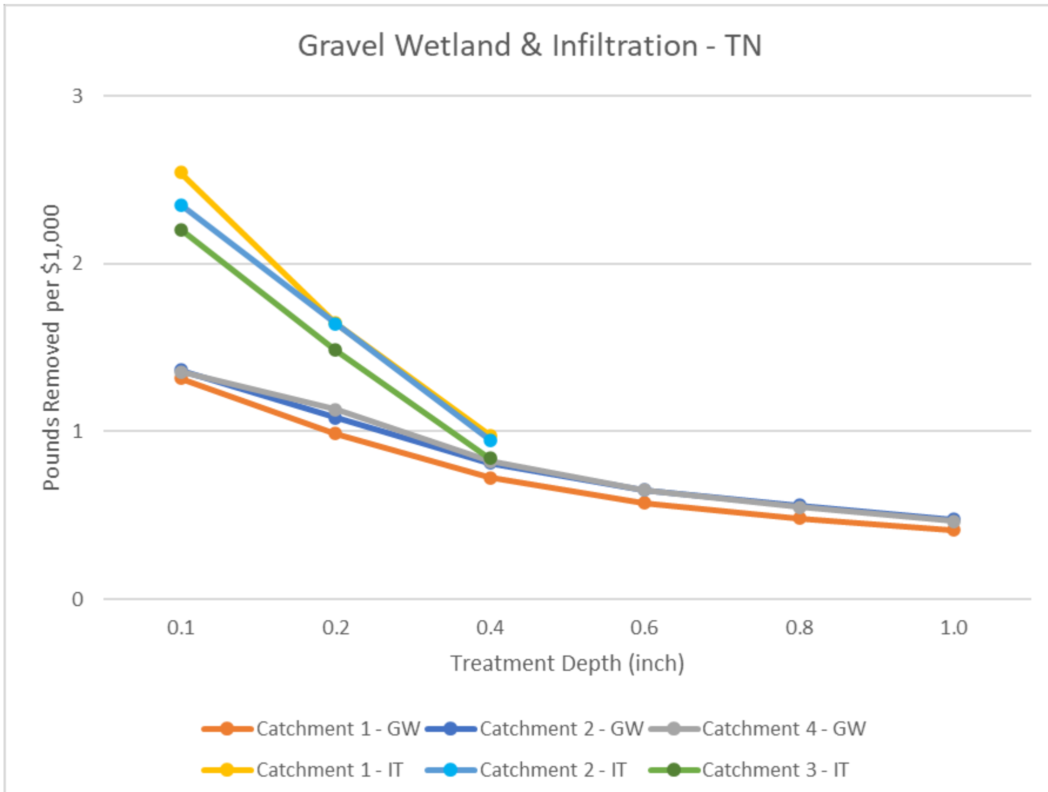
Table 6-5: Gravel WVTS Cost

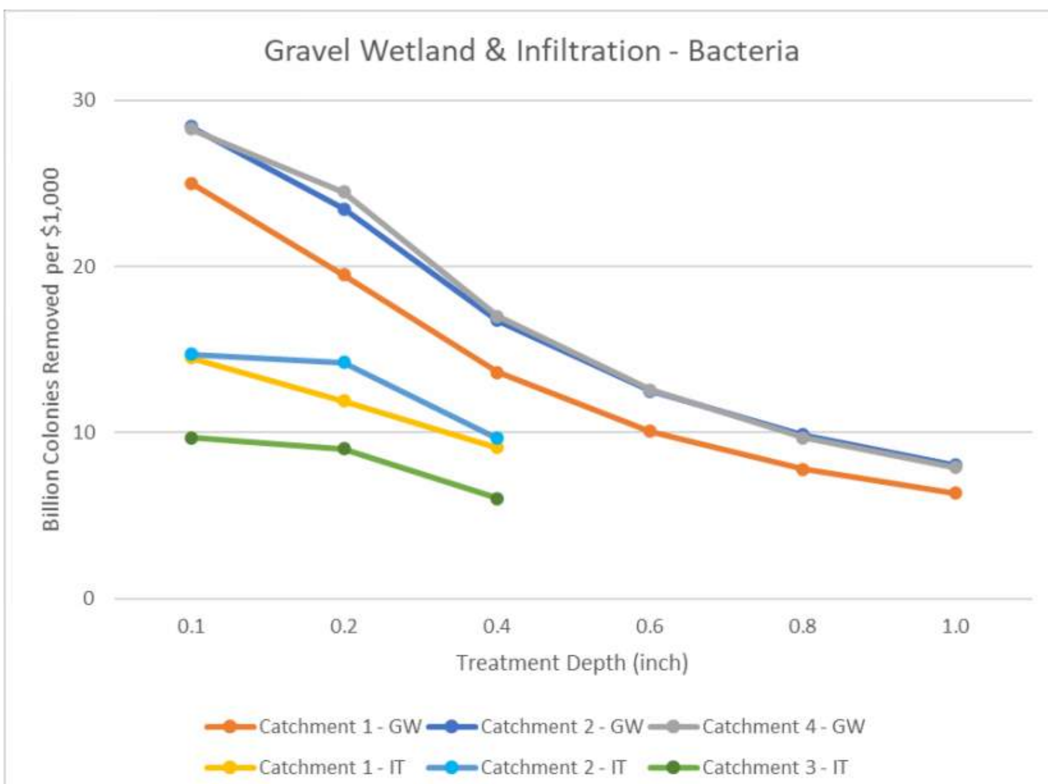
	Treatment Depth (inch)	0.1	0.2	0.4	0.6	0.8	1.0
Total Cost	Catchment 1	$95,000	$190,000	$377,000	$566,000	$753,000	$942,000
	Catchment 2	$9,000	$17,000	$33,000	$49,000	$64,000	$80,000
	Catchment 4	$5,000	$9,000	$18,000	$27,000	$36,000	$45,000

Table 6-6: Infiltration Trench Cost

	Treatment Depth (inch)	0.1	0.2	0.4
Total Cost	Catchment 1	**$132,000**	$263,000	$525,000
	Catchment 2	$14,000	**$27,000**	$53,000
	Catchment 3	$9,000	**$18,000**	$36,000

The analysis demonstrated that the 0.1-inch treatment depth has the most beneficial treatment reduction based on unit cost ($/CF), and a diminishing return is observed for treatment depths greater than this. Additionally, the infiltration trench systems perform better than the proposed end-of-pipe wetland systems for total nitrogen reduction, while the opposite is true for bacteria. Results from this analysis are presented in Appendix D and summarized in the graphics below. The graphics below demonstrate that the infiltration trench systems provide a greater reduction of total nitrogen per one thousand dollars invested, while a gravel WVTS provides a greater bacteria reduction per one thousand dollars invested.


Gravel Wetland & Infiltration - TN
Pounds Removed per $1,000
0
1
2
3
0.1
0.2
0.4
0.6
0.8
1.0
Treatment Depth (inch)
Catchment 1 - GW
Catchment 2 - GW
Catchment 4 - GW
Catchment 1 - IT
Catchment 2 - IT
Catchment 3 - IT


Gravel Wetland & Infiltration - Bacteria
Billion Colonies Removed per $1,000
0
10
20
30
0.1
0.2
0.4
0.6
0.8
1.0
Treatment Depth (inch)
Catchment 1 - GW
Catchment 2 - GW
Catchment 4 - GW
Catchment 1 - IT
Catchment 2 - IT
Catchment 3 - IT

6.4 Catch Basin Retrofit Analysis

Finally, a preliminary evaluation was performed to understand potential load reduction if every catch basin within the Watershed was retrofitted to be an infiltration trench system. This evaluation used the same criteria and assumptions listed above, excluding the impervious drainage area assumption. A drainage area of 0.07 residential acres (3,000 CF) per retrofitted catch basin was used. Calculations are presented in Appendix E and potential load reductions for the Watershed are summarized in Table 6-7 below.

Table 6-7: Catch Basin Retrofit Analysis Summary

Drainage Area	Number of CBs	Potential TN Reduction (lbs/year)	Potential Bacteria Reduction (billion colonies/year)
Watershed	133	170	2,020

6.5 Inspection and Maintenance Considerations

Inspection and maintenance of these structural retrofits is an important consideration when selecting a structural treatment system, as maintenance impacts annual system costs and pollutant reduction performance. Good housekeeping and effective non-structural controls, as discussed further in Section 7, can reduce the frequency and extensiveness of annual maintenance, and maintain system pollutant removal efficiency. Inspection and maintenance costs are difficult to estimate since they vary depending on geography, system size, loading to the system based on drainage area land cover and use, and accessibility. Estimating annual maintenance hours, or the time needed to maintain a system, is a more accurate way to understand operation and maintenance burdens. These maintenance hours are estimated based on the structural retrofit's drainage area. Table 6-8 below presents estimated annual operation and maintenance hours for each installed gravel WVTS and infiltration trench systems.

Table 6-8: Maintenance Hours Summary

System	Inspections			Maintenance			Total Field Time per System (Hours)
	Duration (Hours)	Frequency/ Year	Crew Size	Duration (Hours)	Frequency/ Year	Crew Size	
Gravel WVTS	0.5	2	1	6	2	2	25
Infiltration Trench	0.5	2	1	2	2	2	9

Additional inspection and maintenance considerations include necessary equipment, supplies, and property trained personnel. For a gravel WVTS, standard inspection equipment such as a subsurface camera, hand tools, and standard camera may be needed; standard maintenance equipment such as truck and trailer, rakes, shovels, and disposal container may be needed. Other considerations include maintaining and replacing wetland vegetation. For an infiltration trench system, a subsurface camera may be needed for inspection, and a jet-vacuum truck and trained operator will be needed for maintenance. Debris and organic material removed during maintenance of these systems is normally disposed of in public landfills. The Town disposes street sweepings and catch basin spoils at the Rhode Island Resource Recovery Corporation (RIRRC) Central Landfill.

Overall, depending on the number of systems installed, anticipated maintenance hours for each system type are equivalent in annual maintenance time/cost. Operation and maintenance measures, including typical frequency and inspection activities needed for infiltration trench systems and gravel WVTS, are included in Appendix D.

6.6 Groundwater Recharge

A groundwater recharge goal was evaluated for each of the four prioritized catchments using the methodology outlined in the RISDISM. This methodology relates groundwater recharge directly to the contributing impervious area within the catchment. Table 6-9 summarizes the groundwater recharge goals for each catchment, and calculations are presented in Appendix F.

Table 6-9: Groundwater Recharge Summary

	Catchment 1	Catchment 2	Catchment 3	Catchment 4
Groundwater Recharge Volume (cf)	50,118	3,882	2,045	2,085

Gravel WVTS do not provide infiltration and would not meet the groundwater recharge goals in Catchments 1, 2, and 4 if these systems are selected. The infiltration trench systems do provide groundwater recharge and can be sized to meet the calculated groundwater recharge volume if desired. Potential groundwater recharge volumes based on various treatment depths are summarized in Table 6-10 below.

Table 6-10: Infiltration Trench Groundwater Recharge

	Treatment Depth (inch)	0.1	0.2	0.4
Groundwater Recharge Volume (CF)	Catchment 1	**8,748**	17,496	34,992
	Catchment 2	874	**1,748**	3,495
	Catchment 3	584	**1,168**	2,337

6.7 Structural Retrofit Summary

Structural retrofits were evaluated at four prioritized catchment areas based on the criteria presented in Section 3. Table 6-11 and 6-12 below summarizes the benefits, maintenance hours, and cost of the selected retrofits based on a treatment depth of 0.1-inches and 0.2-inches, respectively. While the retrofits can be sized to treat larger runoff depths, and a larger system would remove more pollutants, the system cost increases at a rate greater than the amount of pollutants removed as the treatment depth increases. Treatment of the 0.1-inch runoff depth is recommended, since it has the lowest estimated cost-benefit.

Table 6-11: Structural Control Summary

Retrofit Location	Retrofit Type	Estimated Costs and Benefits Based on 0.1-Inch Treatment Depth						
		TN Reduction (lbs/year)	Bacteria Reduction (billion colonies/year)	Groundwater Recharge Volume (cf)	Annual Maintenance (hours)	Total Cost	Cost per Pound TN Removed	Cost per Billion Colonies (bc) Removed
Catchment 1	Gravel WVTS	125.2	2,377.6	0	25	$95,000	$760/lb	$40/bc
	Infiltration Trench	335.7	1,916.8	8,748	9	$132,000	$390lb	$70/bc
Catchment 2	Gravel WVTS	12.3	255.8	0	25	$9,000	$730/lb	$35/bc
	Infiltration Trench	32.9	206.2	847	9	$14,000	$430/lb	$70/bc
Catchment 3	Infiltration Trench	19.8	87.3	584	9	$9,000	$450/lb	$100/bc
Catchment 4	Gravel WVTS	6.8	141.4	0	25	$5,000	$740/lb	$35/bc

Table 6-12: Structural Control Summary

Retrofit Location	Retrofit Type	Estimated Costs and Benefits Based on 0.2-Inch Treatment Depth						
		TN Reduction (lbs/year)	Bacteria Reduction (billion colonies/year)	Groundwater Recharge Volume (cf)	Annual Maintenance (hours)	Total Cost	Cost per Pound TN Removed	Cost per Billion Colonies (bc) Removed
Catchment 1	Gravel WVTS	187.8	3,705.7	0	25	$190,000	$1,010/lb	$50/bc
	Infiltration Trench	432.5	3,130.3	17,496	9	$263,000	$610lb	$80/bc
Catchment 2	Gravel WVTS	18.4	398.7	0	25	$17,000	$920/lb	$40/bc
	Infiltration Trench	44.4	384.3	1,748	9	$27,000	$610/lb	$70/bc
Catchment 3	Infiltration Trench	26.7	162.6	1,168	9	$18,000	$670/lb	$110/bc
Catchment 4	Gravel WVTS	10.2	220.4	0	25	$9,000	$880/lb	$40/bc

As shown in Table 6-11 and 6-12, the analyzed gravel WVTS are more cost effect at removing bacteria than the infiltration trench retrofits. Additionally, infiltration trench retrofits are not viable in Catchment 4, so a gravel WVTS is the recommended structural retrofit for this catchment. For Catchments 1, 2, and 3, the infiltration trench retrofits are more cost effective at removing nitrogen, provide groundwater recharge, have lower anticipated annual maintenance hours, and are anticipated to have fewer permitting and construction considerations. Therefore, infiltration trenches are the recommended structural retrofits for Catchments 1, 2, and 3 and can be implemented throughout the Watershed.

7. NON-STRUCTURAL SOURCE REDUCTION OPPORTUNITIES

Non-structural pollution prevention practices prevent or reduce stormwater related runoff problems by reducing the exposure and generation of pollutants and/or provide a regulatory framework that minimizes creation of polluting impervious surfaces. Non-structural management practices refer to stormwater runoff management techniques that do not require extensive construction efforts and either limit the generation of stormwater runoff or reduce the amount of pollutants contained in the runoff. Non-structural controls can be the most cost-effective stormwater attenuation strategies for any given watershed but require careful planning, organization of labor resources, education, and outreach and in some cases specialized equipment.

7.1 Non-Structural Controls

Non-structural control credit was estimated using EPA Region 1 MS4 credit policy for enhanced street sweeping, catch basin cleaning, and organic waste/debris removal. These non-structural stormwater controls are widely regarded as best practices, are very commonly employed by municipal roadway managers and, as such, have been developed by EPA Region 1 for crediting stormwater management programs. Additionally, non-structural controls are discussed below but do not have an established nutrient or bacteria control benefit/credit.

The nutrient reduction benefit/credit was applied in this analysis to town-owned paved areas within the entire Green Hill Pond watershed within South Kingstown; gravel roads and private or state-owned paved roadways were not included in the analysis. The credit presented in Appendix G and summarized below is based on the following assumptions, which are dictated by EPA:

1. Enhanced sweeping performed weekly with a mechanical broom from March 1st through December 1st.
2. Catch basin cleaning semi-annually while maintaining a minimum sump storage capacity of 50%. Credit assumes each catch basin within the watershed has an average impervious, residential drainage area of 0.07 acres (3,000± SF).
3. Organic waste/leaf litter collection performed weekly between September 1st through December 1st.

Table 7-1: Non-Structural Control Credit Calculation

TN Load Reduction (lbs/year)			
Enhanced Sweeping	Catch Basin Cleaning	Organic Waste/Leaf Litter Collection	Total Reduction
30.4	7.0	33.8	**71.2**

7.2 Additional Pollution Prevention Measures

Pollution prevention generally consists of a materials management and an alternative product substitution component. Materials management includes the appropriate management and safe handling of common chemicals or substances that may be exposed to stormwater runoff. These materials include fertilizers, pesticides, herbicides, cleaners, automotive products, trash, and waste.

Pollution prevention measures consider material use, material storage, and material disposal controls to prevent discharge into catch basins or direct discharge into the receiving waterbody. The large percentage of private residential properties within the Watershed makes educational outreach an important component of a pollution prevention program. The following are specific actions that can address pollution prevention in the Watershed and have been recommended for implementation by RIDEM in the Green Hill Pond TMDL and in the 2011 TMDL Analysis and Compliance Plan.

1. *Public Education*: Given the extensive private residential land in the watershed, educating residents (permanent or seasonal) and businesses within the Watershed and achieving behavior change has the potential to have a significant impact on pollution reduction to the pond. Various outreach regarding lawn fertilizer, pet waste, waterfowl feeding, and catch basin dumping could be distributed throughout the Watershed to raise awareness about stormwater pollution sources, activities that affect stormwater runoff quality, and pollution reduction. As a basis for outreach efforts, it may be helpful to solicit the support of local stakeholders, such as the Friends of Green Hill Pond (FGHP). Additionally, the RI Nonpoint Education for Municipal Officials (NEMO) provides assistance for Rhode Island communities to help develop program strategies, conduct trainings, and customize outreach materials. A variety of factsheets, checklists, and strategies on pet waste, yard care, wildlife control, dumping into storm drains, and landscape management have been developed through this program and are available online for use. The Town and FGHP may be able to work with NEMO to craft and implement an educational outreach strategy specific to the Green Hill Pond watershed.
2. *Landscape Management:* Landscape related fertilizers, pesticides, and herbicides can pose a significant threat to watershed health. Phosphorus has largely been phased out of most commercial fertilizers but nitrogen in lawn fertilizer is highly mobile and can easily runoff after application. The Town and FGHP could consider an integrated pilot program that would provide a target neighborhood with effective soil management and lawn care outreach activities. The project would demonstrate how to enhance soil structure through overseeding and non-fertilizer turf management, which will in turn improve stormwater retention, will eliminate excessive lawn watering and reduce the need for fertilizer, pesticide, and herbicide use.
3. *Animal Waste:* Wild and domesticated animals can contribute to bacteria pollution as evidenced by the RIDEM TMDL for Green Hill Pond. Pet waste educational programs including posted signage to discourage bird feeding at the beach and Green Hill Park can help reduce bird attraction and associated wastes. Additionally, pet waste stations help improve dog waste pickup by owners. Green Hill Park and high pedestrian traffic roadways are potential beneficial locations.
4. *Rain Barrels and Gardens:* Residential structural stormwater management strategies, such as raingardens and rooftop runoff storage system installation, can be helpful for educational purposes and may help address residential runoff by collecting, storing, and infiltrating residential runoff. These solutions could be most effective if implemented in neighborhoods immediately adjacent, as discussed in previous sections, and that discharge directly to the Pond. Rebate programs or rain barrel giveaway programs have been successful in advancing homeowner education and implementation.
5. *Evaluation of Land Use Planning and Redevelopment Requirements:* Local regulatory requirements provide the mechanism for proper land use development standards and stormwater regulations designed to avoid, reduce, and manage stormwater runoff. Due to the nature of the study area (highly developed residential), Town ordinances and regulations can continue to be refined for the consideration of more stringent redevelopment requirements for stormwater management on residential properties. Specifically, private residential redevelopment requirements could include increased requirements for stormwater retention prior to discharge to the public drainage system. RI NEMO promotes a Low Impact Development Self Assessment that will compare local regulations to national benchmarks for effective stormwater management and may be useful in evaluation of strategies for improving local codes and policies.
6. *Bank Stabilization and Erosion Controls:* Sediment resulting from soil erosion can be rich in nutrients, and soil stabilization and erosion control can prevent nutrient loading through soil transport. Areas adjacent to the Pond that have visible sedimentation and erosion issues, such as degraded shoreline, should be inventoried and stabilized through a variety of controls such as erosion control blankets, riprap, hydroseeding, and turf reinforcement matting. Additionally, with extensive unpaved, private roadways in the watershed, unpaved roadway best management is a very important pollution prevention measure. Programs managed through the

USDA Natural Resources Conservation Services, or their local affiliate organization will often provide tech assistance and grant programs for roadway best management. Programs such as Pennsylvania State University's Center for Dirt and Gravel Road Studies have extensive best management practice literature that can be curated and shared by the FGHP to local roadway contractors.

8. RECOMMENDATIONS AND NEXT STEPS

8.1 Structural Retrofit Recommendation

Based on the results of the cost-benefit analysis, permitting and ownership considerations, and groundwater recharge analysis, catch basin retrofits/infiltration trench systems are recommended for Catchments 1, 2, and 3, while a gravel WVTS is recommended for Catchment 4. A gravel WVTS is more cost-effective at removing bacteria than the infiltration trench system. Additionally, Catchment 4 does not have existing drainage infrastructure, so an infiltration trench system is not viable in this catchment.

Alternatively, the infiltration trench systems provide groundwater recharge while gravel WVTS do not. They are located within Town-owned roadways, so land would not need to be acquired to construct and access these systems. Since they are located outside of natural wetland systems and buffers, permitting the systems is not foreseen to be problematic as it may be with the identified gravel WVTS. Finally, these systems are more cost-effective for reducing total nitrogen loads and are smaller systems that the Town can construct throughout the Watershed as funding becomes available. Therefore, these systems achieve this report's goal of providing the Town with specific stormwater management recommendations that will maximize effectiveness per investment in stormwater quality improvements.

8.2 Non-Structural Source Reduction Recommendation

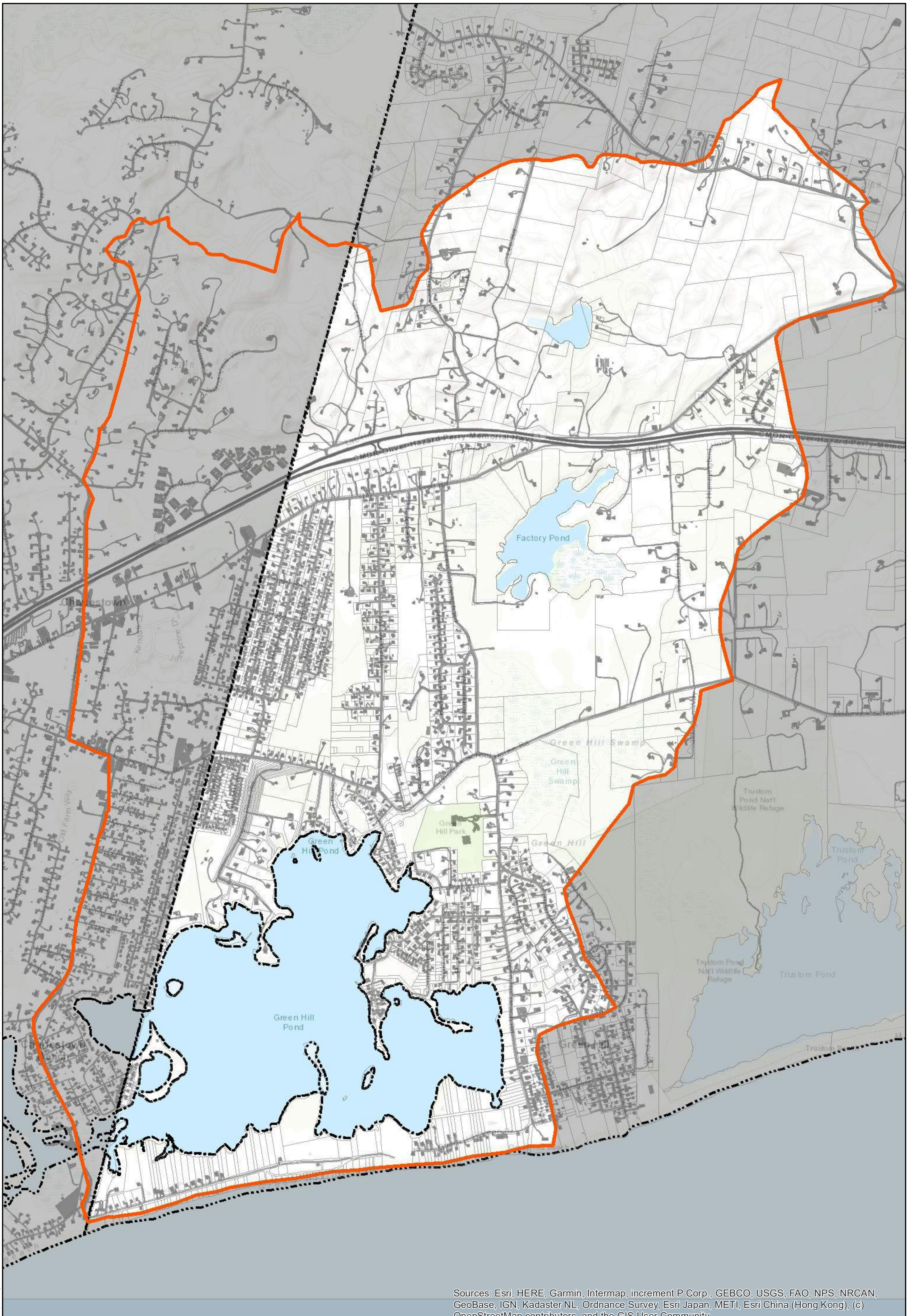
Various non-structural source reduction alternatives are presented in Section 7. Of these, enhanced sweeping, catch basin cleaning, and organic waste/leaf litter collection are recommended to reduce nutrient loading to the Pond and have quantifiable benefits for pollution reduction. Additionally, outreach efforts that focus on homeowner best management, pet waste management, fertilizer control and runoff or sediment reduction techniques should be developed and implemented for long-term watershed health.

8.3 Next Steps

Several viable structural and non-structural stormwater controls have been identified for the watershed that would provide long-term nutrient and bacteria reduction benefit. The next step in improving pond water quality is selection and implementation of identified structural controls by advancing the concept level designs to permitting and construction. Stormwater permitting would be through CRMC since their jurisdiction encompasses areas between the coastline and Route 1. As mentioned above, the infiltration trench retrofit option may be constructed with minimal permit requirements by the state since the disturbance associated with the installation is less than the threshold that would trigger a full-blown permit application.

APPENDIX A: FIGURES

Figure 2-1: Impervious Area



Impervious Area

South Kingstown, RI

Greenhill Pond Watershed

Figure 2-1

Legend

- Parcel
- Green Hill Pond Watershed
- Town Boundary

Impervious Area

- Permeable
- Impervious

0 0.125 0.25 0.5 Miles

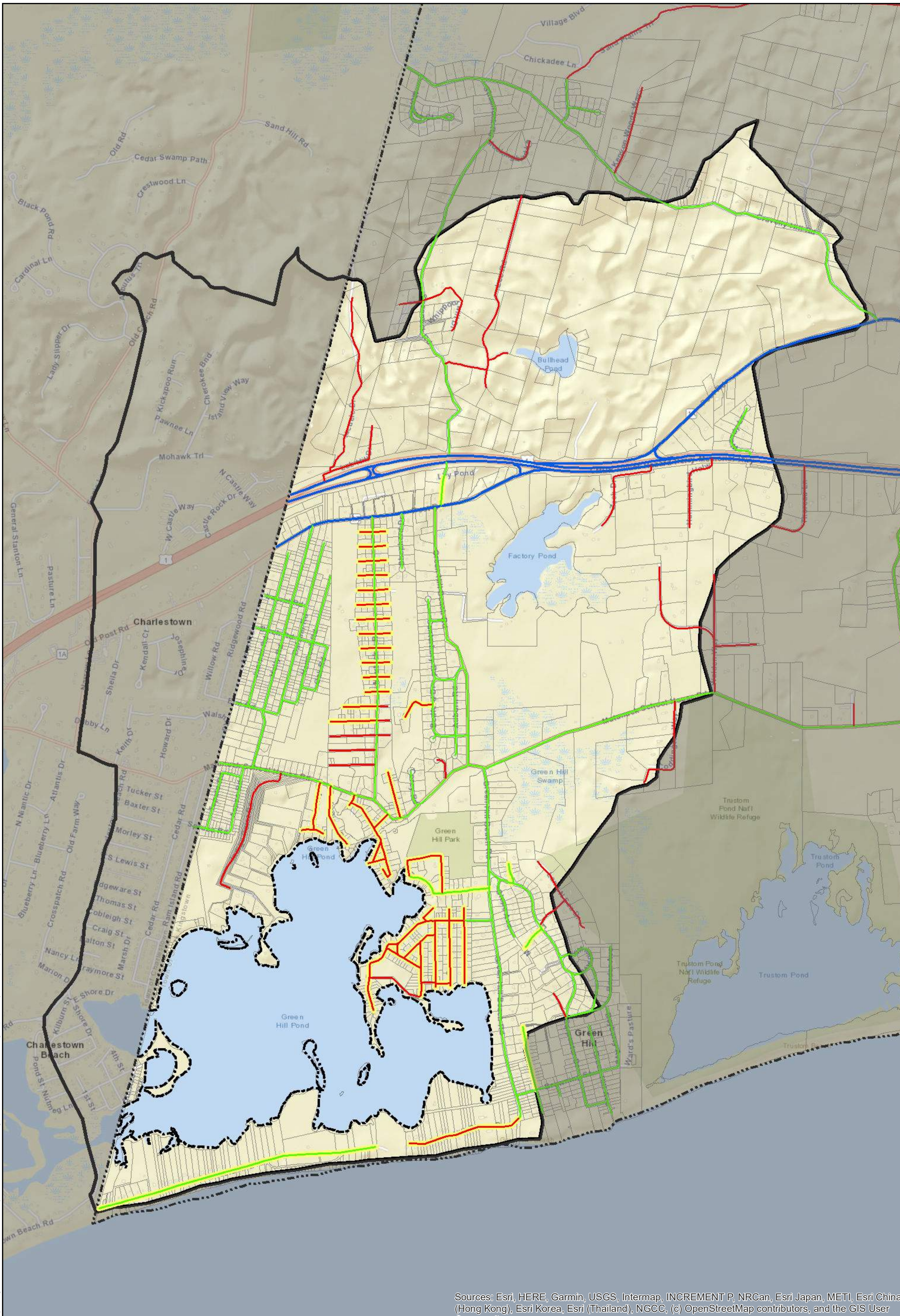
N

WOODARD & CURRAN

Project #: 233191

Map Created: March 2021

Figure 2-2: Road Ownership and Road Type



Road Ownership & Road Type

South Kingstown, RI

Greenhill Pond Watershed

Figure 2-2

Legend

- Green Hill Pond Watershed
- Town Boundary
- Parcel
- Privately Owned Road
- State Owned Road
- Town Owned Road
- Gravel Road

0 0.125 0.25 0.5 Miles

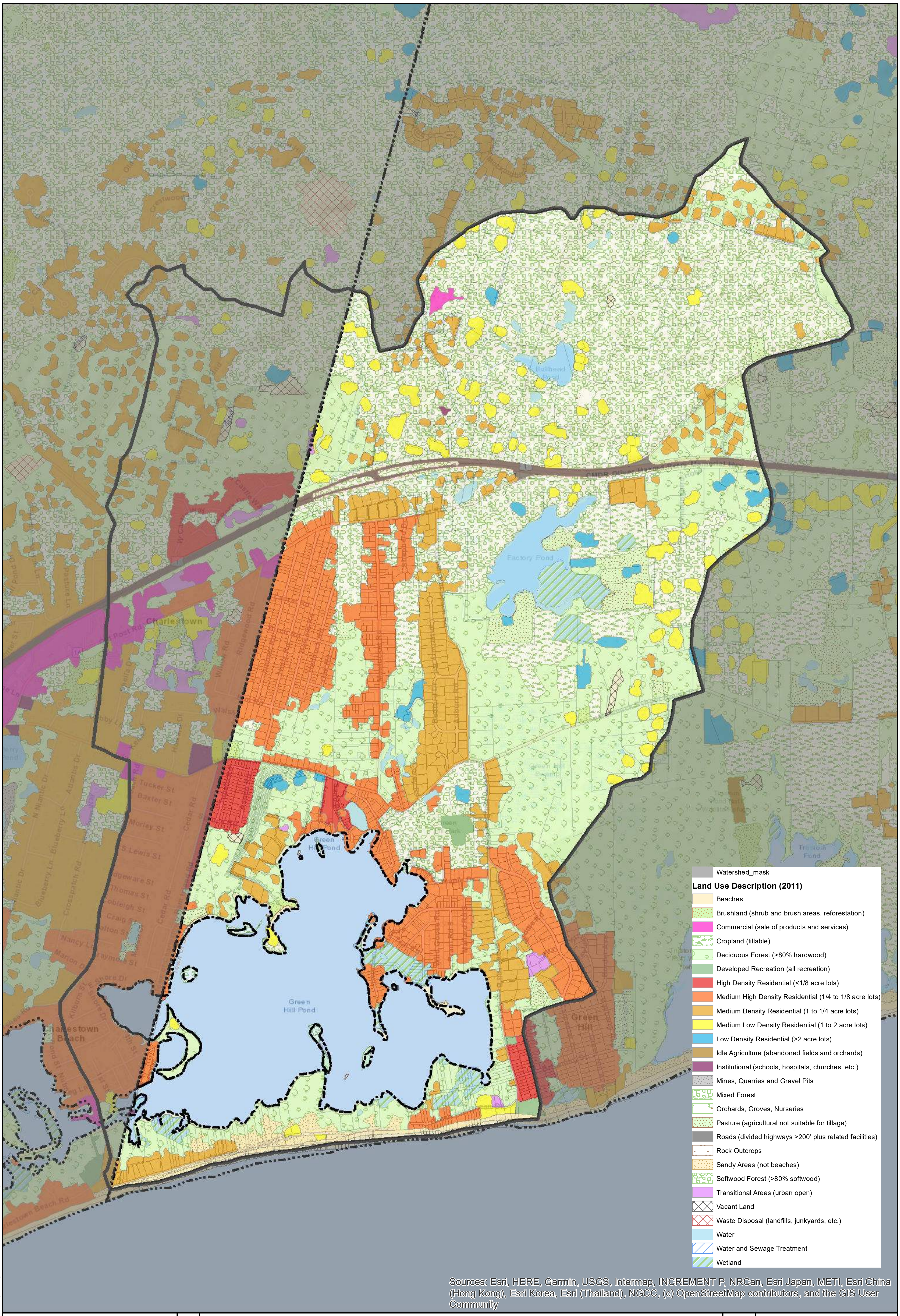
N

WOODARD & CURRAN

Project #: 233191
Map Created: March 2021

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources:**

Figure 2-3: Land Use



Land Use

South Kingstown, RI

Greenhill Pond Watershed

Figure 2-3

Legend

Green Hill Pond Watershed

Town Boundary

Parcel

0 0.125 0.25 0.5 Miles

N

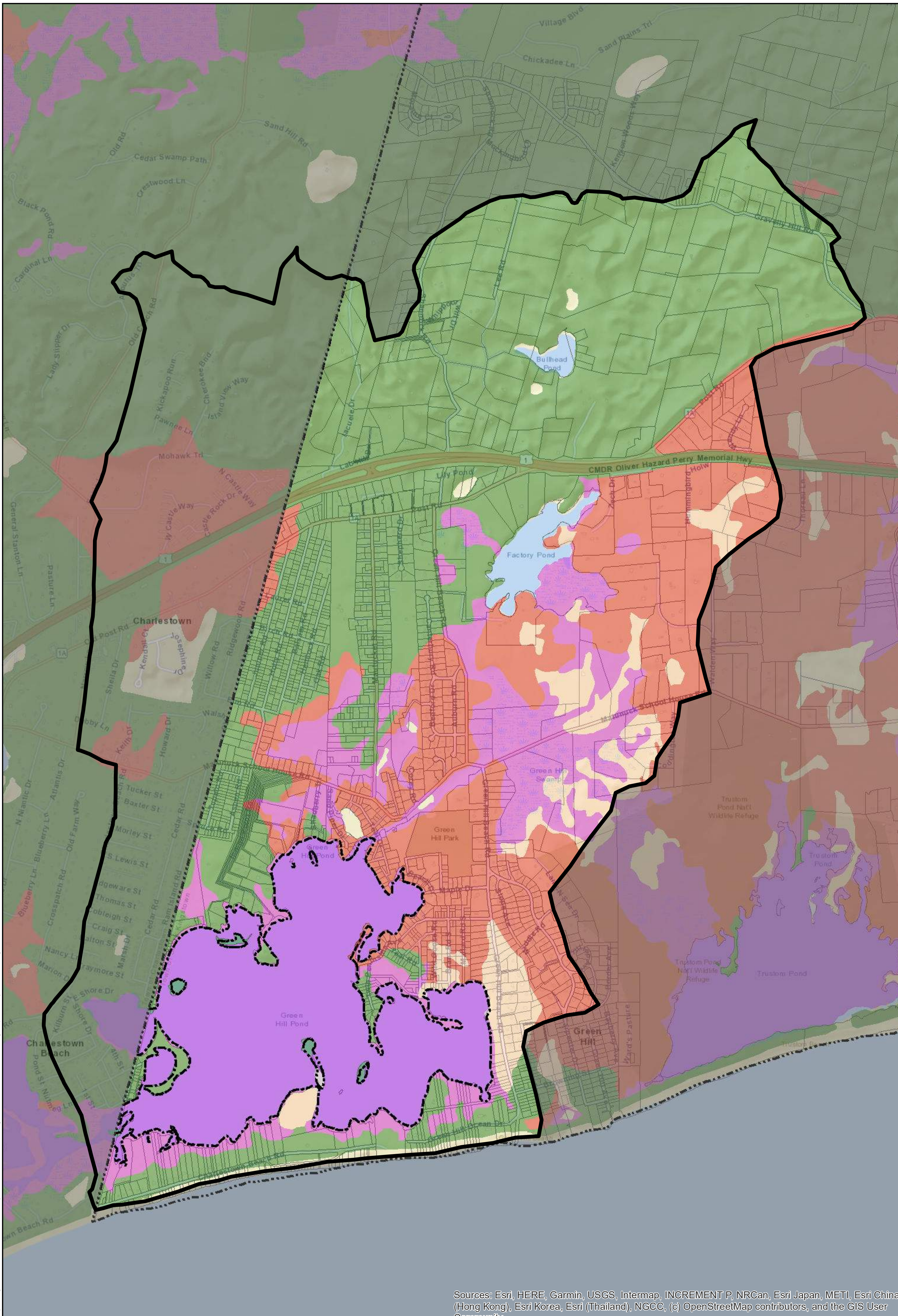
WOODARD & CURRAN

Project #: 233191

Map Created: March 2021

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources:**

Figure 2-4: Soils



Soils

South Kingstown, RI

Greenhill Pond Watershed

Figure 2-4

Legend

- Green Hill Pond Watershed
- Town Boundary
- Parcel

Hydrologic Soil Group

- A
- B
- C
- D

0 0.125 0.25 0.5 Miles

N

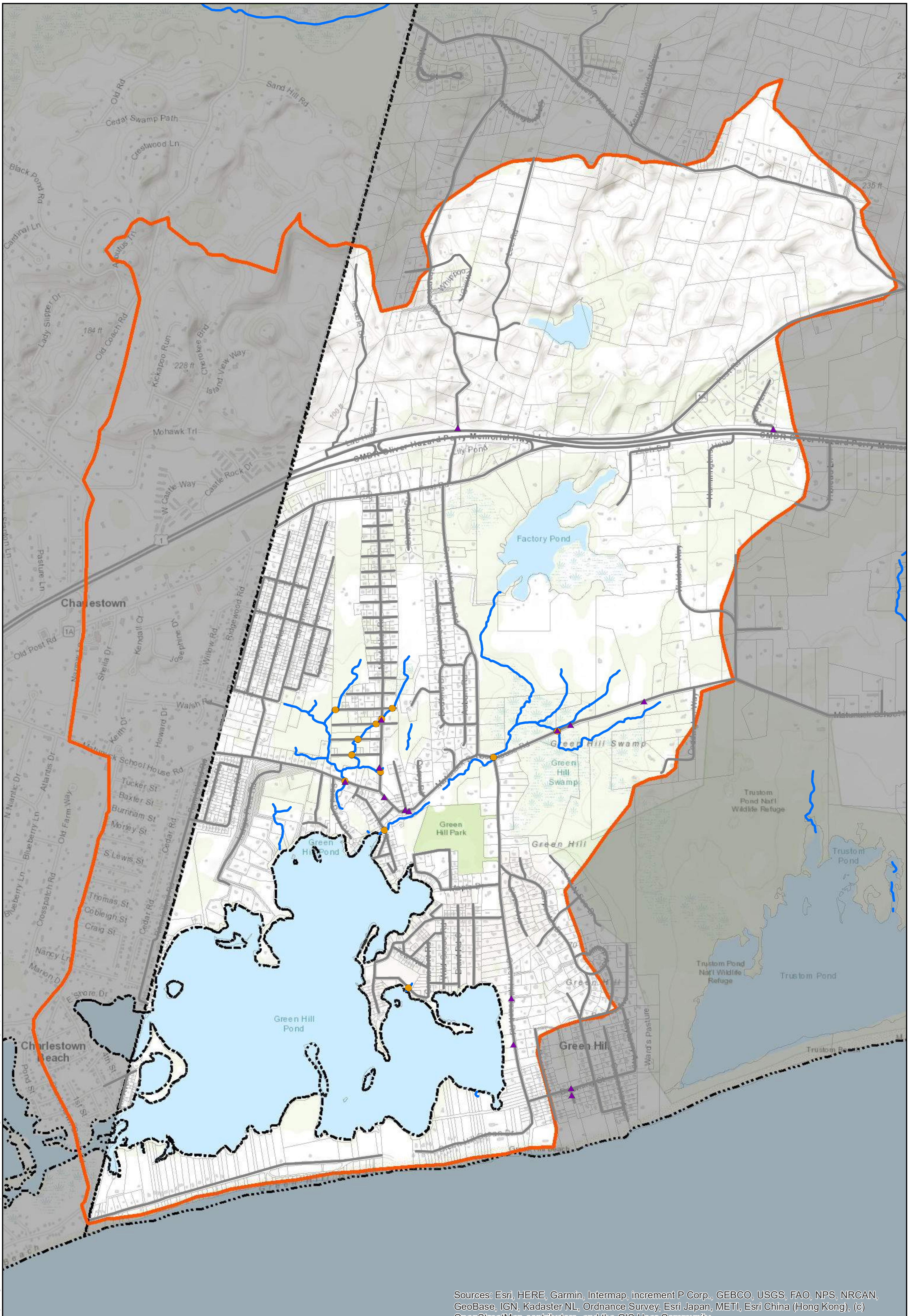
WOODARD & CURRAN

Project #: 233191

Map Created: March 2021

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources:**

Figure 2-5: Stream Hydrography and Road Centerline Intersections



Stream Hydrography and Road Centerline Intersections

South Kingstown, RI

Greenhill Pond Watershed

Figure 2-5

Legend

- Green Hill Pond Watershed
- Town Boundary
- Parcel
- Road
- Culvert
- Stream/Road Intersection
- Freshwater River/Stream

0 0.125 0.25 0.5 Miles

N

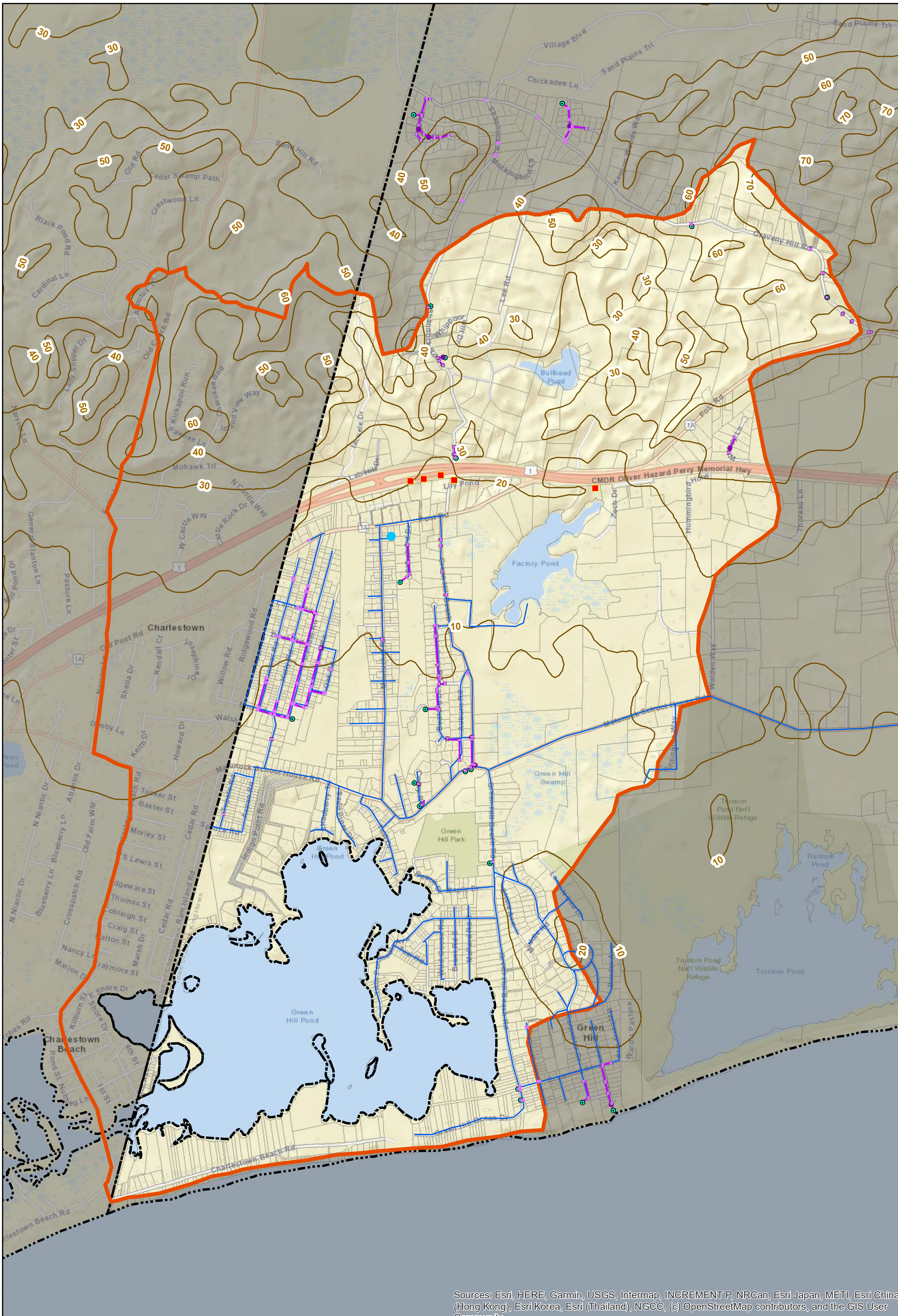
WOODARD & CURRAN

Project #: 233191

Map Created: March 2021

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources:**

Figure 2-6: Stormwater and Water Systems Infrastructure



Stormwater and Water Systems Infrastructure

South Kingstown, RI

Greenhill Pond Watershed

Figure 2-6

Legend

- Green Hill Pond Watershed
- Town Boundary
- Parcel
- Contour 10 ft
- Drainage Catchbasin
- Drainage Manhole
- Drainage Outlet
- Drainage Pipe
- Water Tank
- Water Line
- RIDOT Outfall

0 0.125 0.25 0.5 Miles

N

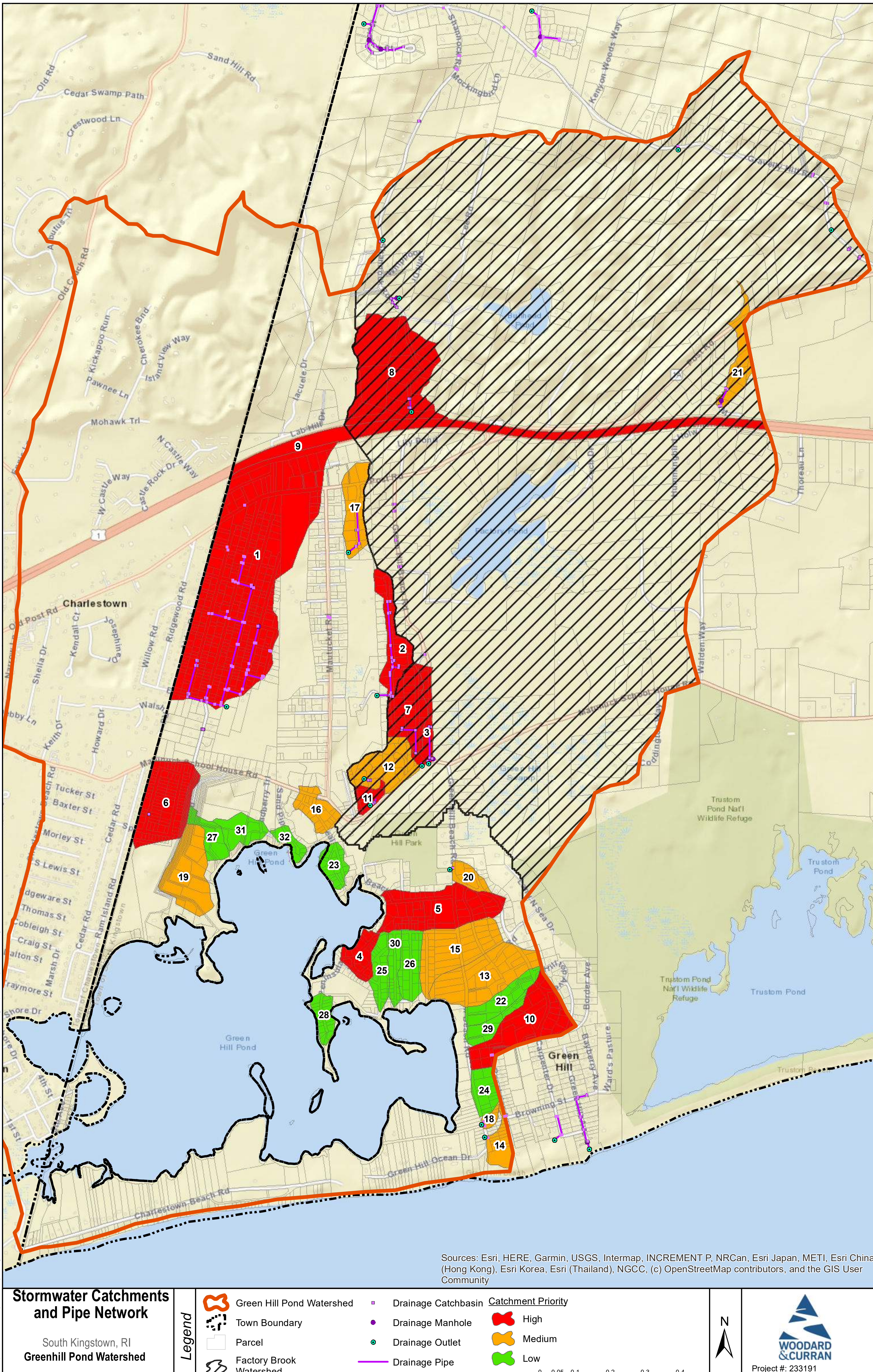
WOODARD & CURRAN

Project #: 233191

Map Created: March 2021

Figure Exported: 12/10/2021 By: eweesby Using: \\woodardcurran.net\shared\Projects\0233191.00 South Kingstown Stormwater Retrofit Design\wip\GIS\Projects\South Kingstown Stormwater and Water.mxd

Figure 3-1: Stormwater Catchments and Pipe Network



Stormwater Catchments and Pipe Network

South Kingstown, RI

Greenhill Pond Watershed

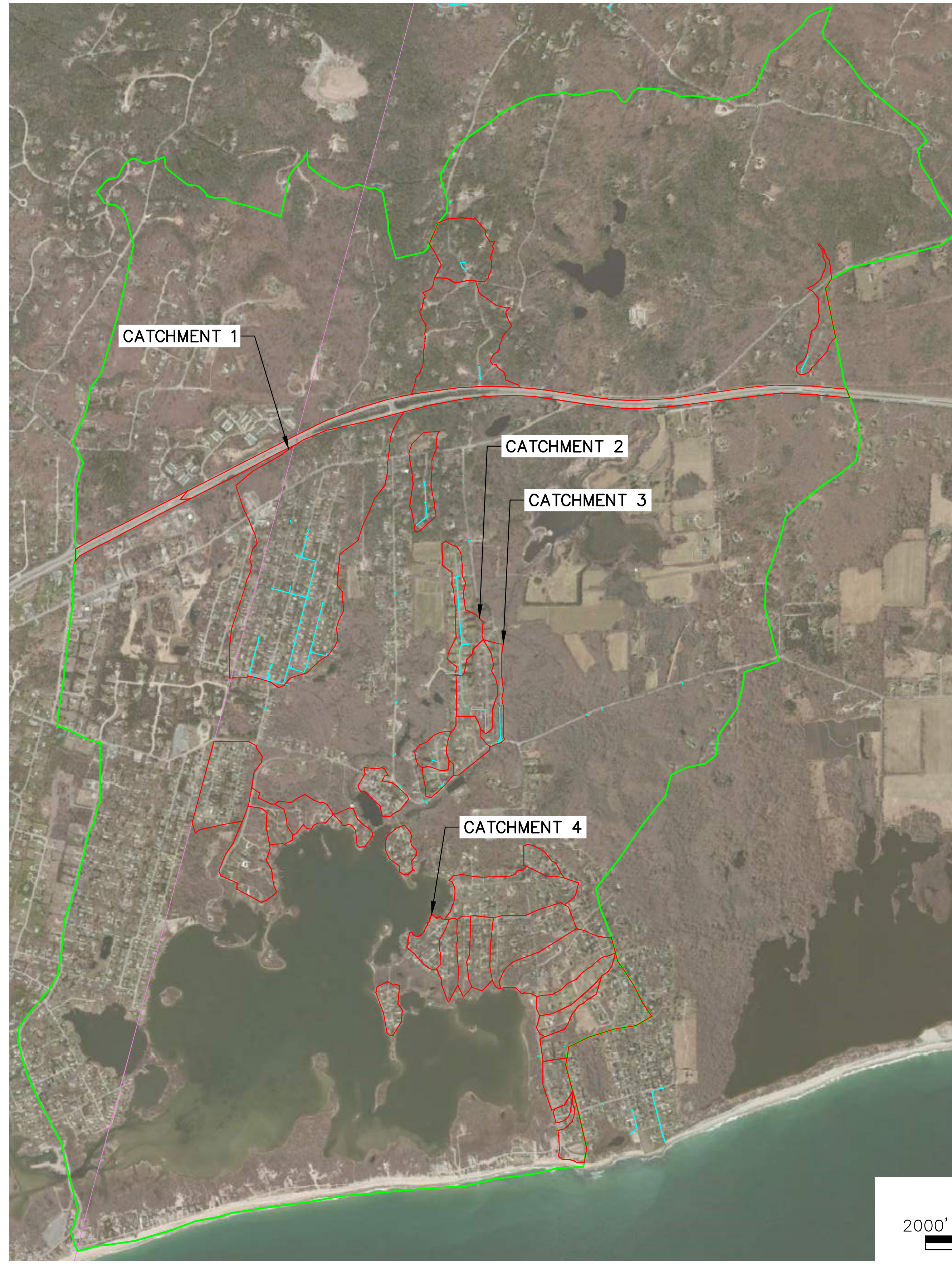
Figure 3-1

Project #: 233191
Map Created: March 2021

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources:**

Figure 4-1: Overall Watershed with Catchment Areas

LEGEND	
GREEN HILL POND WATERSHED	(green line)
TOWN LINE	(pink line)
CATCHMENT AREA	(red line)
SUBSURFACE DRAIN PIPE	(cyan line)
DRAINAGE STRUCTURE	●



N

2000' 0 2000' 4000'

BAR SCALE
1" = 2000'
CHECK GRAPHIC SCALE BEFORE USING

33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
WOODARD & CURRAN
COMMITMENT & INTEGRITY DRIVE RESULTS

GREEN HILL POND WATERSHED

DESIGNED BY: CNQ
DRAWN BY: CNQ
CHECKED BY: HCP
233191-DRAINAGE AREA MA*.dwg

TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: 1" = 2000'

FIGURE 4-1

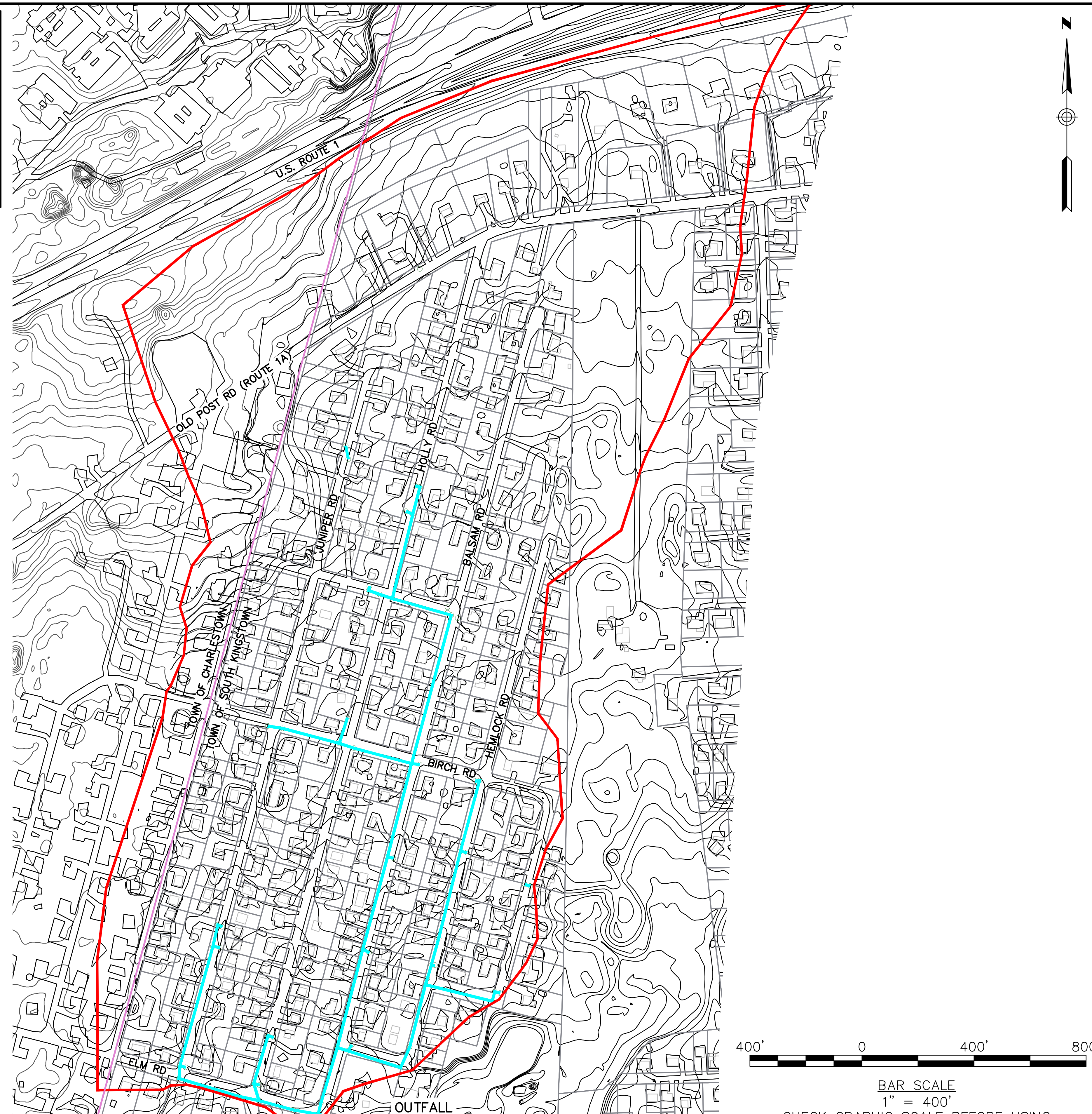
\\woodardcurran.net\shared\Projects\0233191.00 South Kingstown Stormwater Retrofit Design\wip\Drawings\Figures\233191-Drainage Area Maps.dwg, Sep 23, 2021 - 9:08am CNQUINN

Figure 4-2: Catchment 1 Delineation

LEGEND	
CATCHMENT AREA	
2' CONTOURS (NAVD88)	
IMPERVIOUS COVER	
BUILDING FOOTPRINT	
SUBSURFACE DRAIN PIPE	
DRAINAGE STRUCTURE	

INSET

SCALE: 1" = 5000'



BAR SCALE
1" = 400'
CHECK GRAPHIC SCALE BEFORE USING

WOODARD & CURRAN
33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

EXISTING CATCHMENT 1

DESIGNED BY: CNQ | CHECKED BY: HCP
DRAWN BY: CNQ | 233191-DRAINAGE AREA MA*.dwg

TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED

FIGURE 4-2

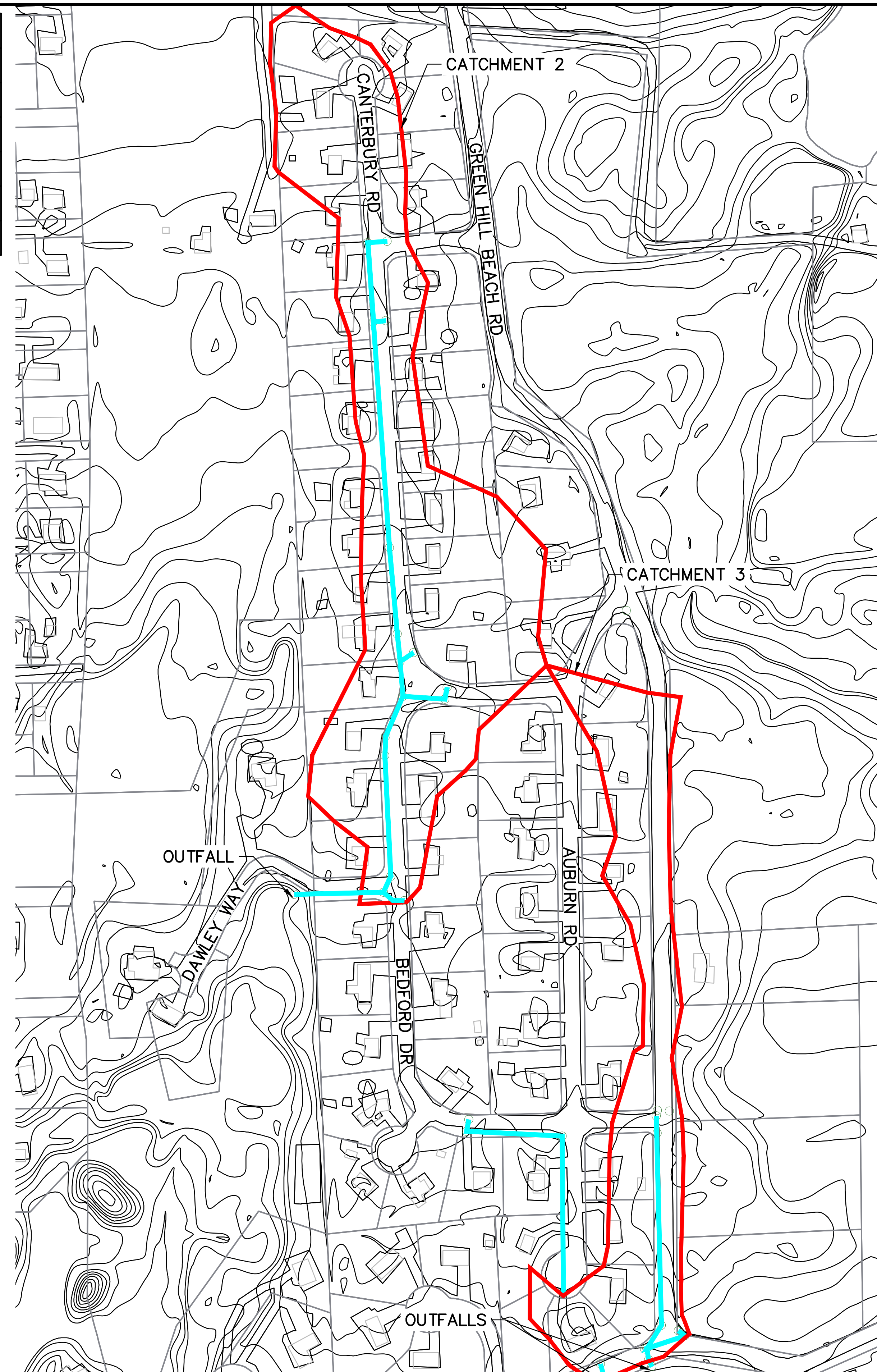
\\woodardcurran.net\shared\Projects\0233191.00 South Kingstown Stormwater Retrofit Design\wip\Drawings\Figures\233191-Drainage Area Maps.dwg, Sep 17, 2021 - 2:42pm CNQUINN

Figure 4-3 Catchments 2 & 3 Delineations

LEGEND	
CATCHMENT AREA	
2' CONTOURS (NAVD88)	
IMPERVIOUS COVER	
BUILDING FOOTPRINT	
SUBSURFACE DRAIN PIPE	
DRAINAGE STRUCTURE	

INSET

SCALE: 1" = 5000'



300' 0 300' 600'

BAR SCALE
1" = 300'
CHECK GRAPHIC SCALE BEFORE USING

33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
WOODARD & CURRAN
COMMITMENT & INTEGRITY DRIVE RESULTS

EXISTING CATCHMENT 2 & 3

DESIGNED BY: CNQ | CHECKED BY: HCP
DRAWN BY: CNQ | 233191-DRAINAGE AREA MA*.dwg

TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED

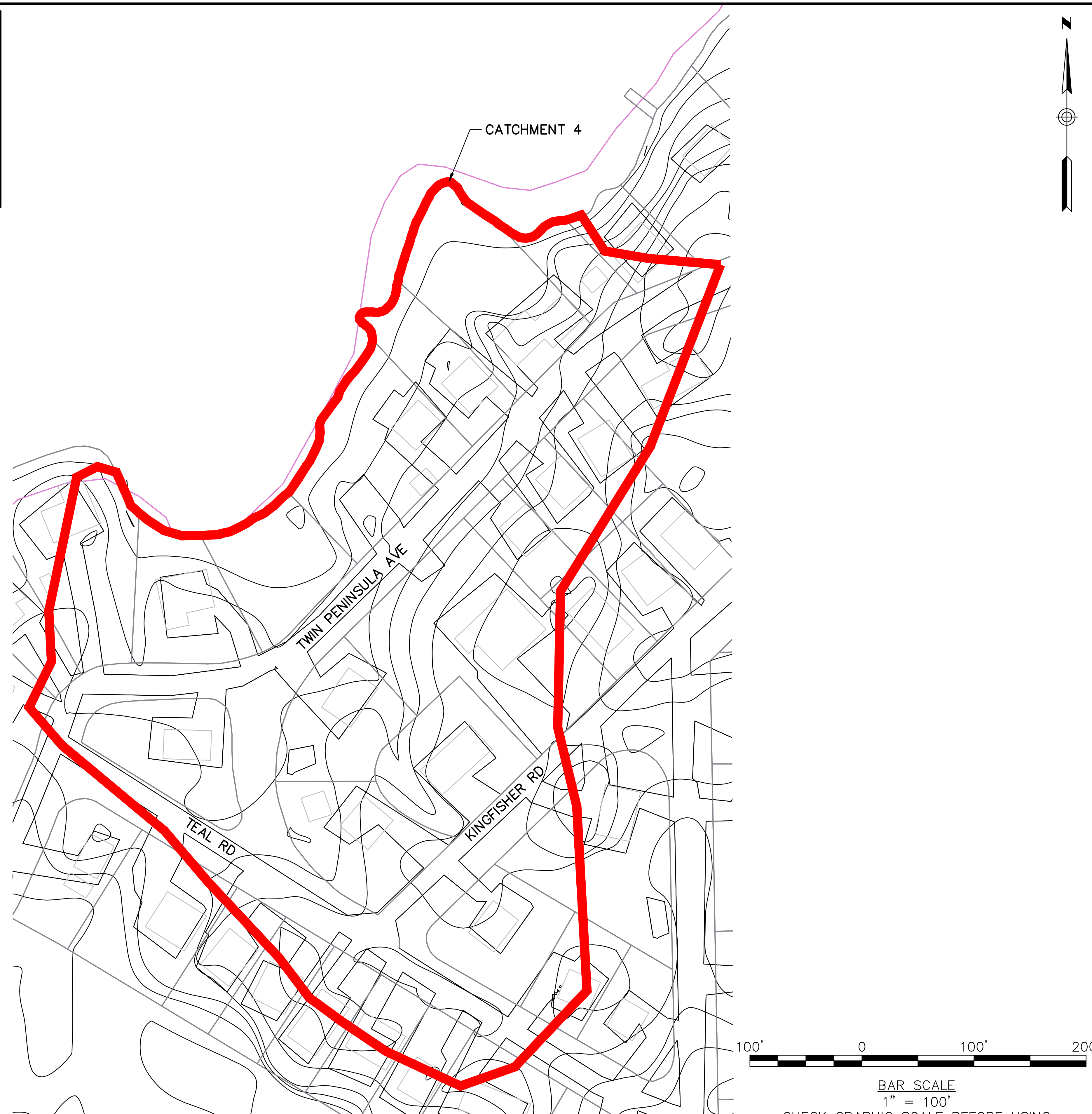
FIGURE 4-3

Figure 4-4: Catchment 4 Delineation

LEGEND		
CATCHMENT AREA		
2' CONTOURS (NAVD88)		
IMPERVIOUS COVER		
BUILDING FOOTPRINT		
SUBSURFACE DRAIN PIPE		
DRAINAGE STRUCTURE		

INSET

SCALE: 1" = 5000'



BAR SCALE

1" = 100'

100' 0 100' 200'

CHECK GRAPHIC SCALE BEFORE USING

WOODARD & CURRAN
33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

EXISTING CATCHMENT 4

DESIGNED BY: CNQ	CHECKED BY: HCP
DRAWN BY: CNQ	233191-DRAINAGE AREA MA*.dwg

TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED

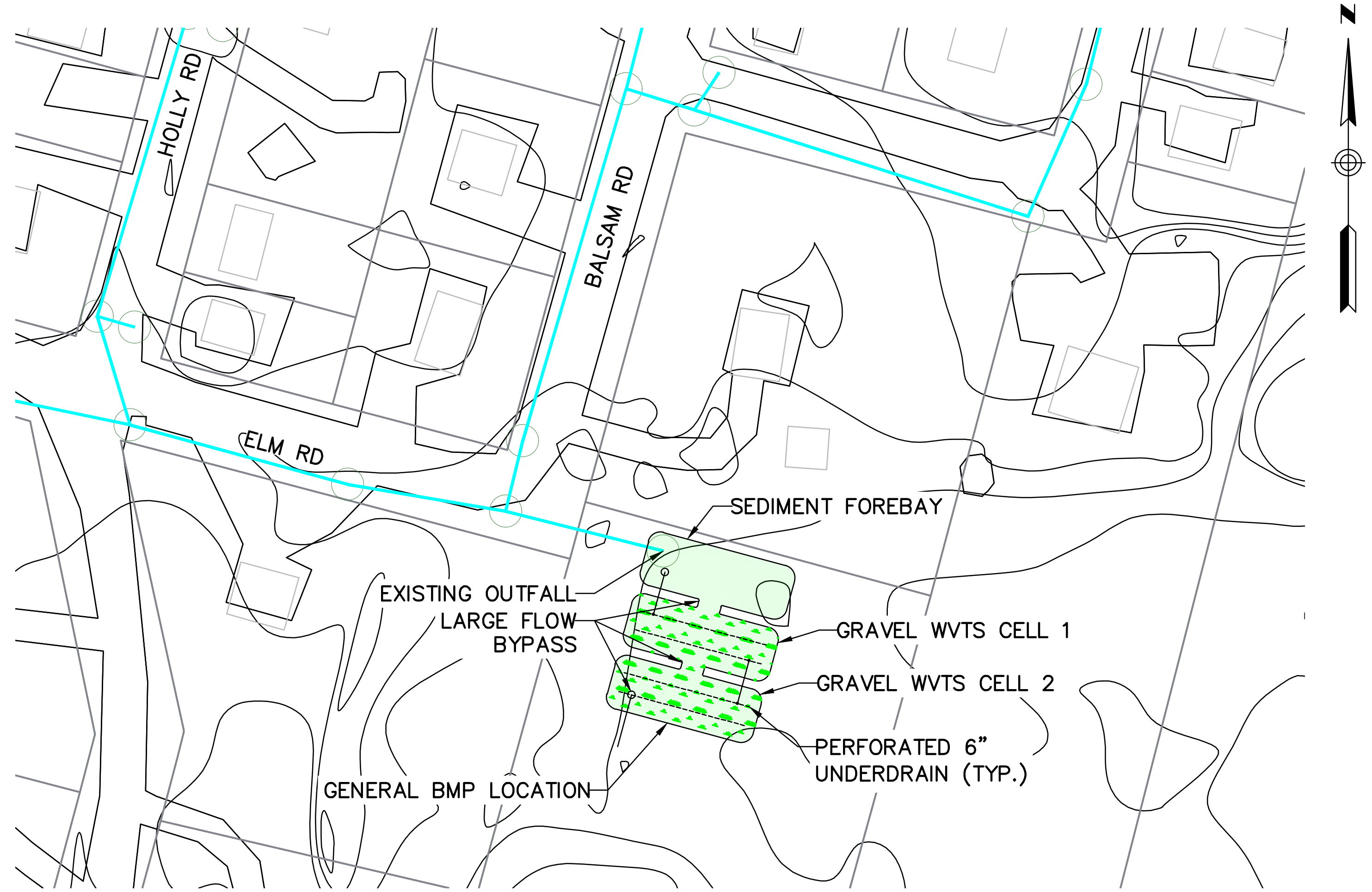
FIGURE 4-4

\\woodardcurran.net\shared\Projects\0233191.00 South Kingstown Stormwater Retrofit Design\wip\Drawings\Figures\233191-Drainage Area Maps.dwg, Sep 17, 2021 - 2:46pm CNQUINN

Figure 6-1: Catchment 1 10% Concept Design

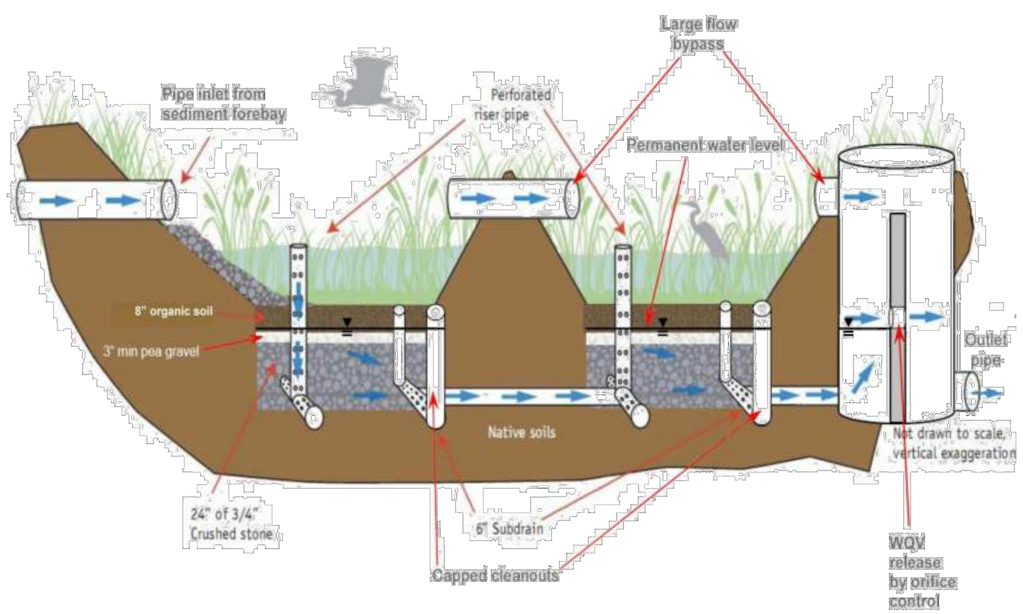
INSET
SCALE: 1" = 5000'

LAND USE	DRAINAGE AREA (AC.) (% OF TOTAL AREA)	
	PERVIOUS	IMPERVIOUS
COMMERCIAL	1.0 (0.9%)	0.7 (0.6%)
RESIDENTIAL	63.6 (54.6%)	21.9 (18.8%)
HIGHWAY	–	0.3 (0.3%)
UNDEVELOPED/ RURAL	27.7 (23.8%)	1.2 (1.0%)
TOTAL	92.3 (79.3%)	24.1 (20.7%)



PLAN VIEW
SCALE: 1" = 100'

100' 0 100' 200'
BAR SCALE
1" = 100'
CHECK GRAPHIC SCALE BEFORE USING



Adapted from UNHSC, 2009

GRAVEL WVTS
SCALE: NOT TO SCALE


VIEW OF PROPOSED GRAVEL WVTS LOCATION
SCALE: NOT TO SCALE

WOODARD & CURRAN
33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

CATCHMENT 1
10% CONCEPT DESIGN

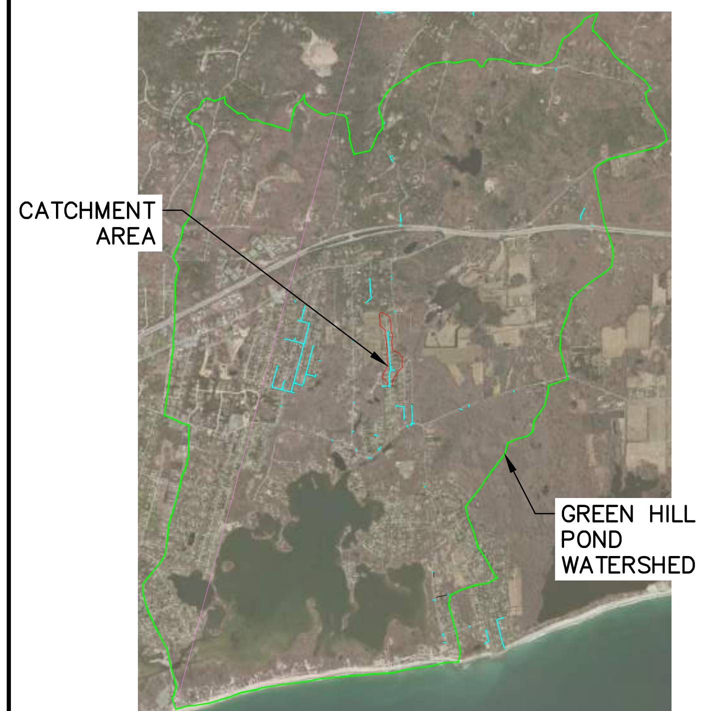
DESIGNED BY: CNQ
DRAWN BY: CNQ
CHECKED BY: HCP
233191-CATCHMENT 1.dwg

TOWN OF SOUTH KINGSTOWN
GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED
FIGURE 6-1

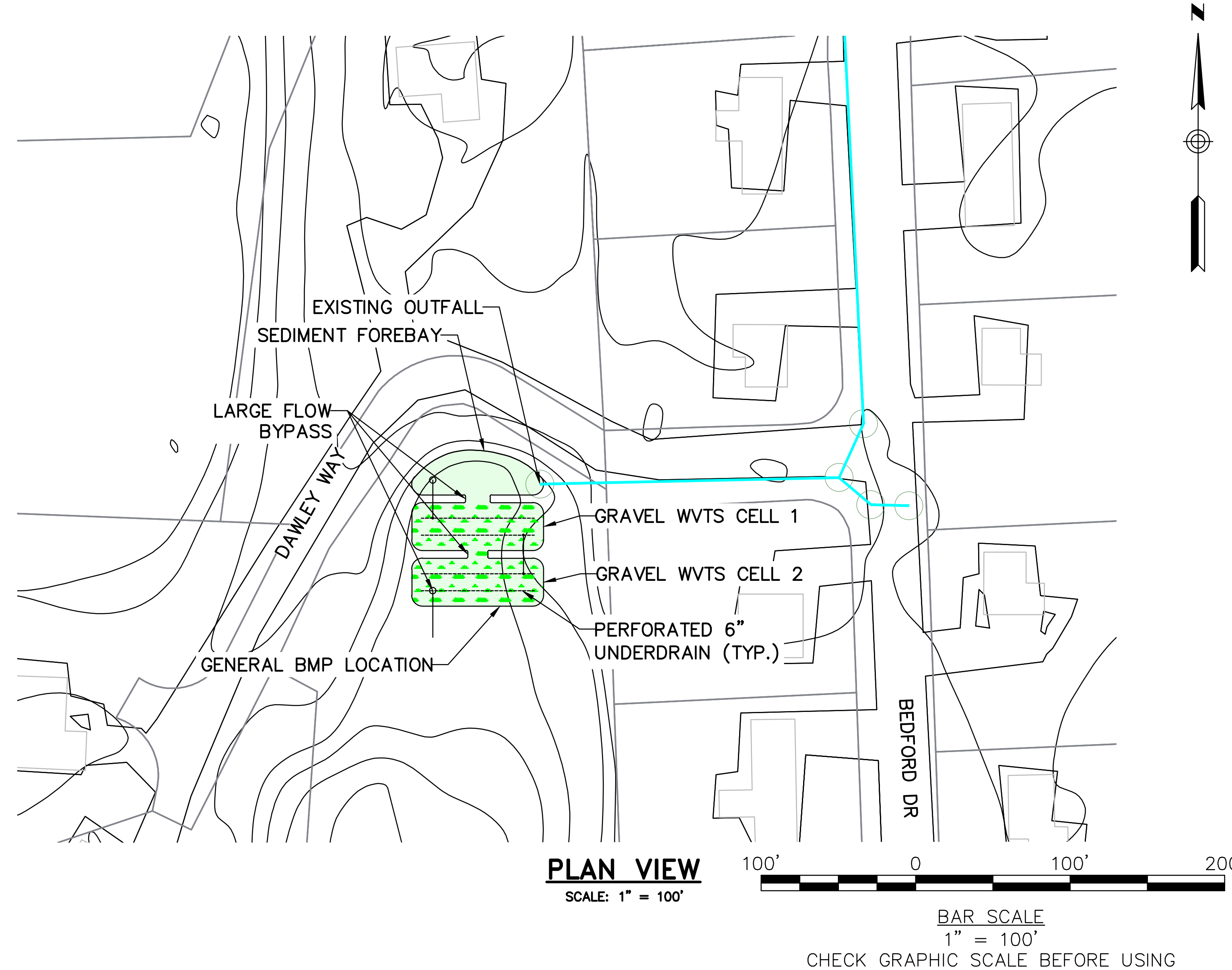
\\woodardcurran.net\shared\Projects\0233191.00 South Kingstown Stormwater Retrofit Design\wip\Drawings\Figures\233191-Catchment 1.dwg, Sep 17, 2021 – 3:22pm CNQUINN

Figure 6-2: Catchment 2 10% Concept Design

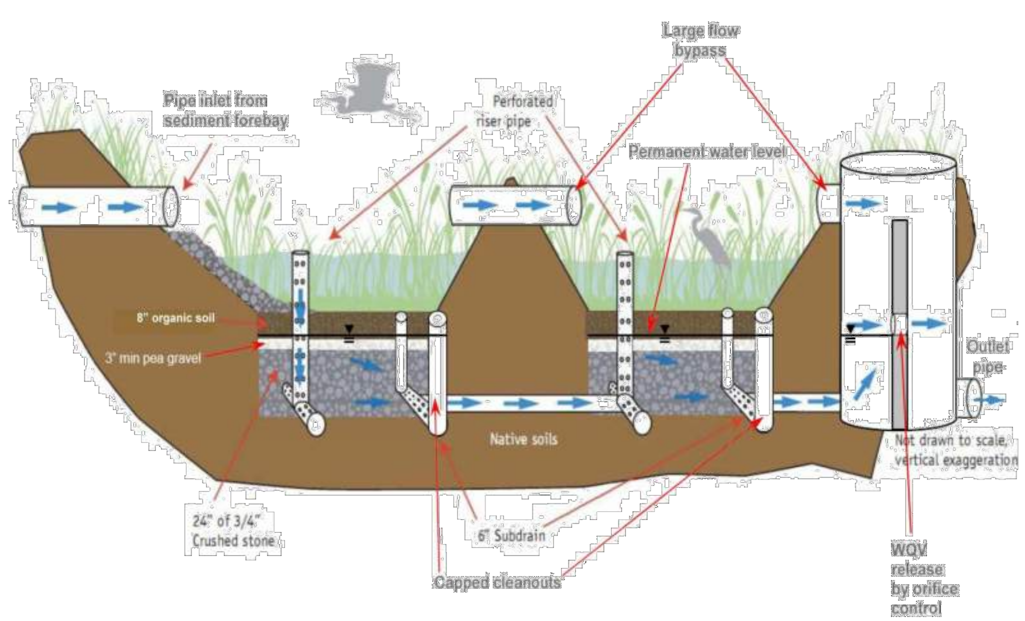


INSET
SCALE: 1" = 5000'

LAND USE	DRAINAGE AREA (AC.) (% OF TOTAL AREA)	
	PERVIOUS	IMPERVIOUS
RESIDENTIAL	7.4 (74.8%)	2.4 (24.2%)
UNDEVELOPED/ RURAL	0.1 (1.0%)	–
TOTAL	7.5 (75.8%)	2.4 (24.2%)



PLAN VIEW
SCALE: 1" = 100'



Adapted from UNHSC, 2009

GRAVEL WVTS
SCALE: NOT TO SCALE

VIEW OF PROPOSED GRAVEL WVTS LOCATION
SCALE: NOT TO SCALE

WOODARD & CURRAN
33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

CATCHMENT 2
10% CONCEPT DESIGN

DESIGNED BY: CNQ | CHECKED BY: HCP
DRAWN BY: CNQ | 233191-CATCHMENT 2.dwg

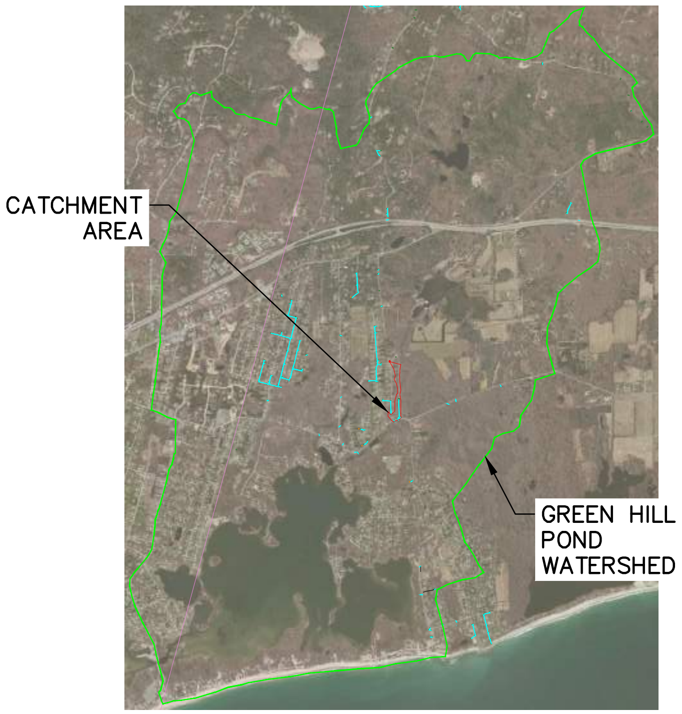
TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED

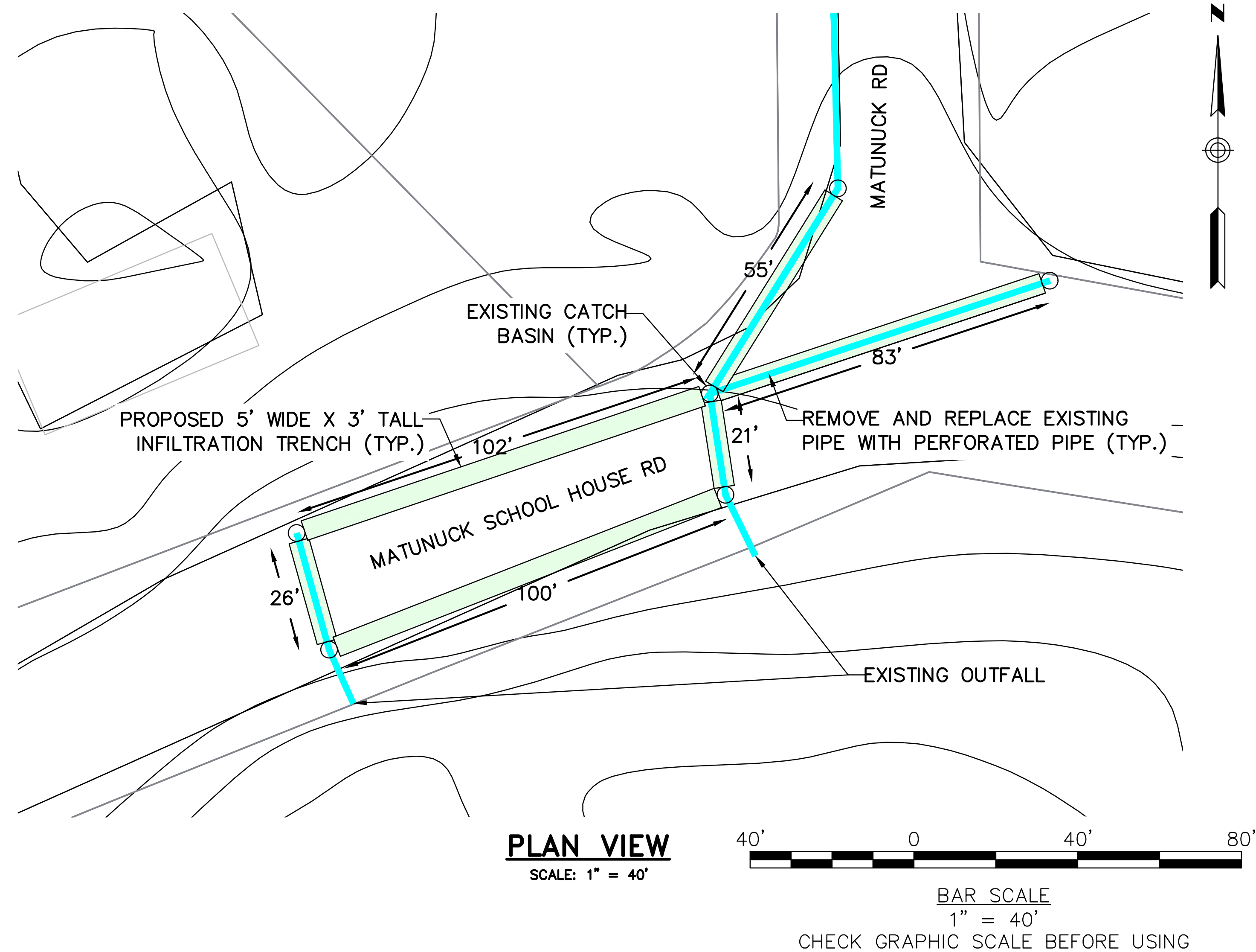
FIGURE 6-2

Figure 6-3: Catchment 3 10% Concept Design

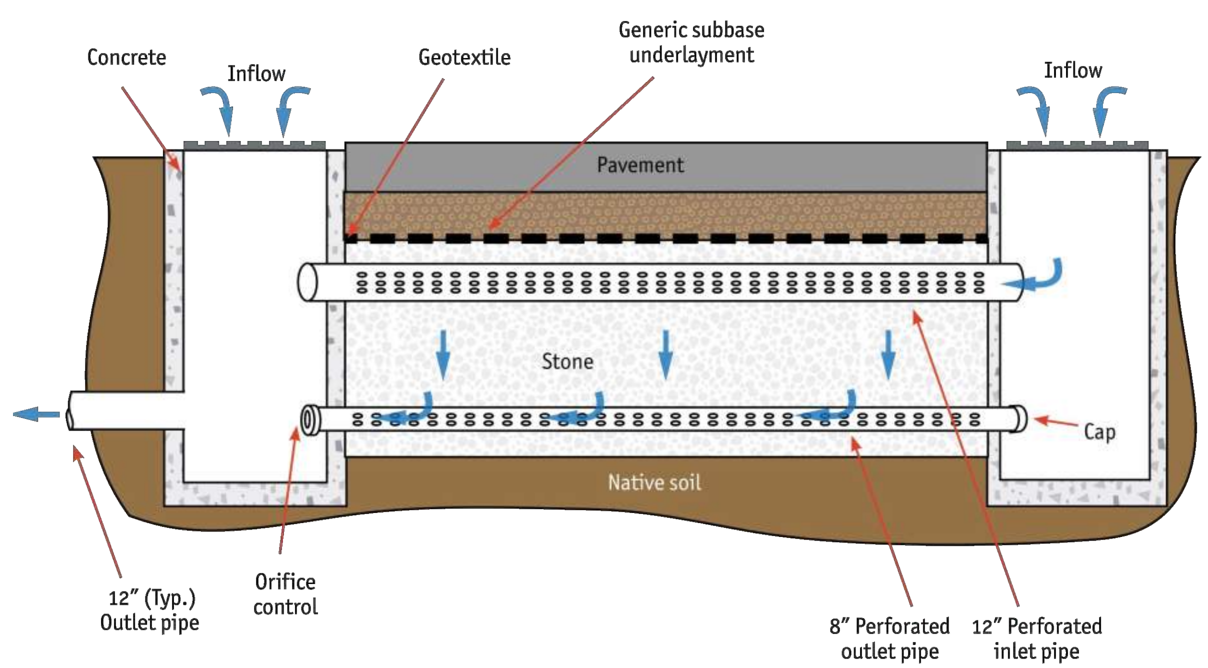


INSET
SCALE: 1" = 5000'

LAND USE	DRAINAGE AREA (AC.) (% OF TOTAL AREA)	
	PERVIOUS	IMPERVIOUS
RESIDENTIAL	3.1 (73.8%)	0.1 (2.4%)
UNDEVELOPED/ RURAL	0.4 (9.5%)	0.6 (14.3%)
TOTAL	3.5 (83.3%)	0.7 (16.7%)



PLAN VIEW
SCALE: 1" = 40'



INFILTRATION TRENCH
SCALE: NOT TO SCALE

VIEW OF PROPOSED INFILTRATION TRENCH LOCATION
SCALE: NOT TO SCALE

33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
WOODARD & CURRAN
COMMITMENT & INTEGRITY DRIVE RESULTS

CATCHMENT 3
10% CONCEPT DESIGN

DESIGNED BY:	CNQ	CHECKED BY:	HCP
DRAWN BY:	CNQ	233191-CATCHMENT 3.dwg	

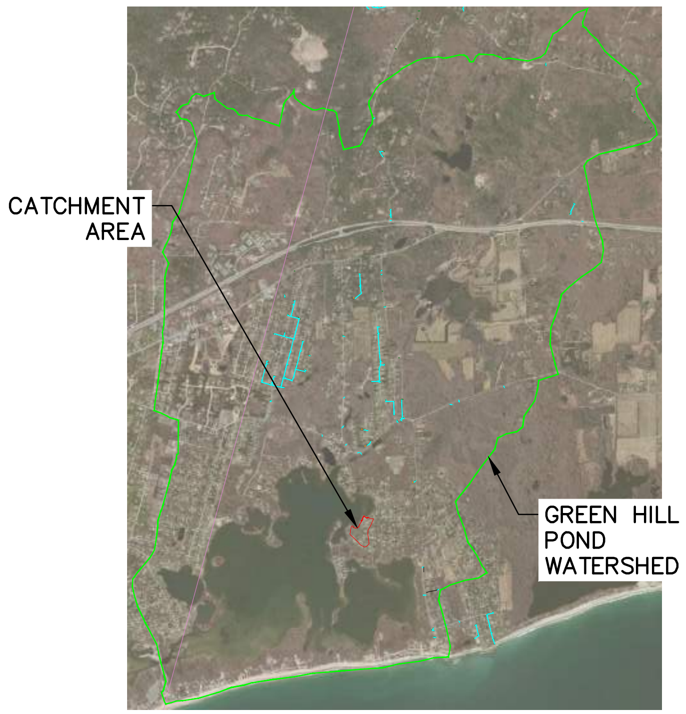
TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED

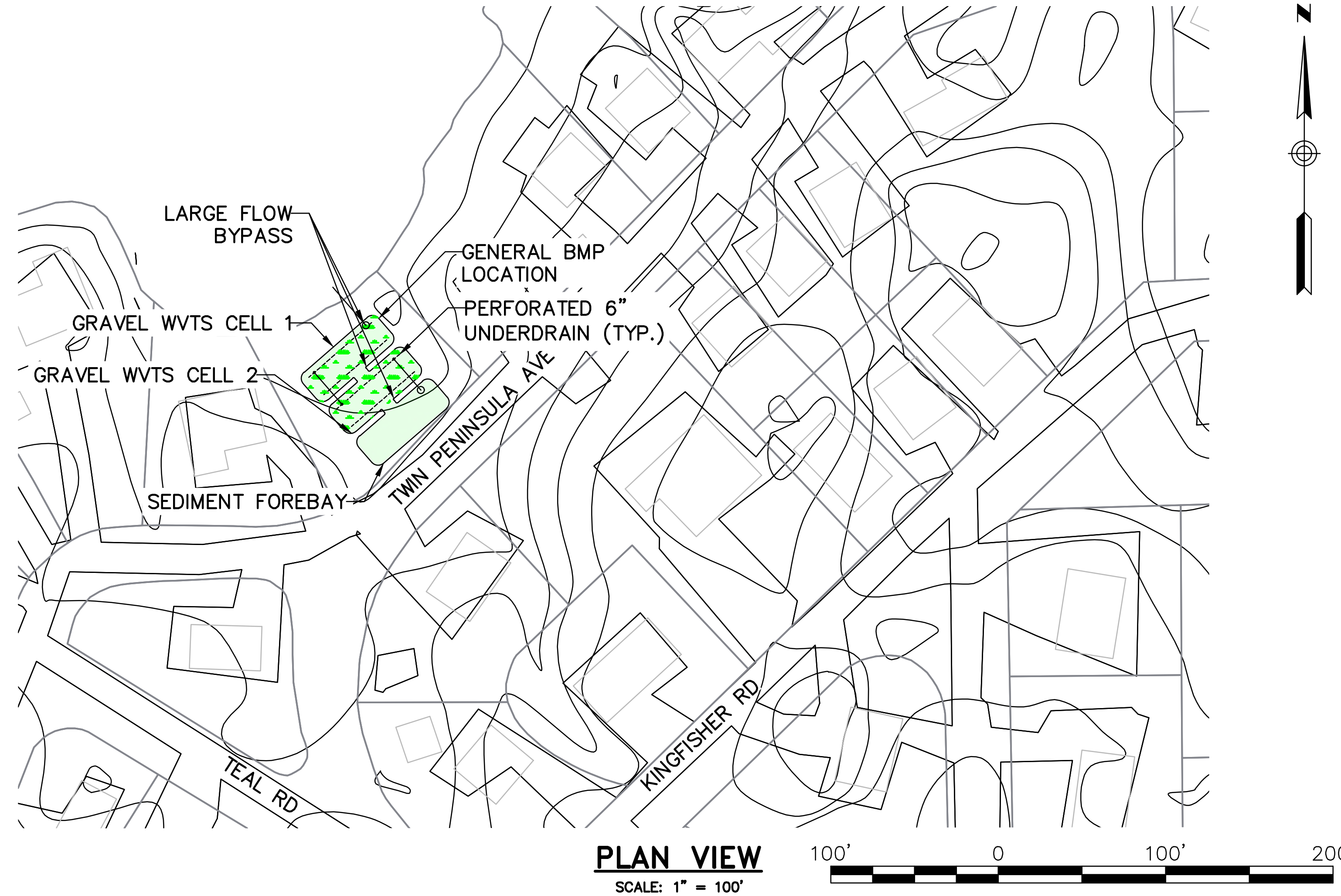
FIGURE 6-3

Figure 6-4: Catchment 4 10% Concept Design

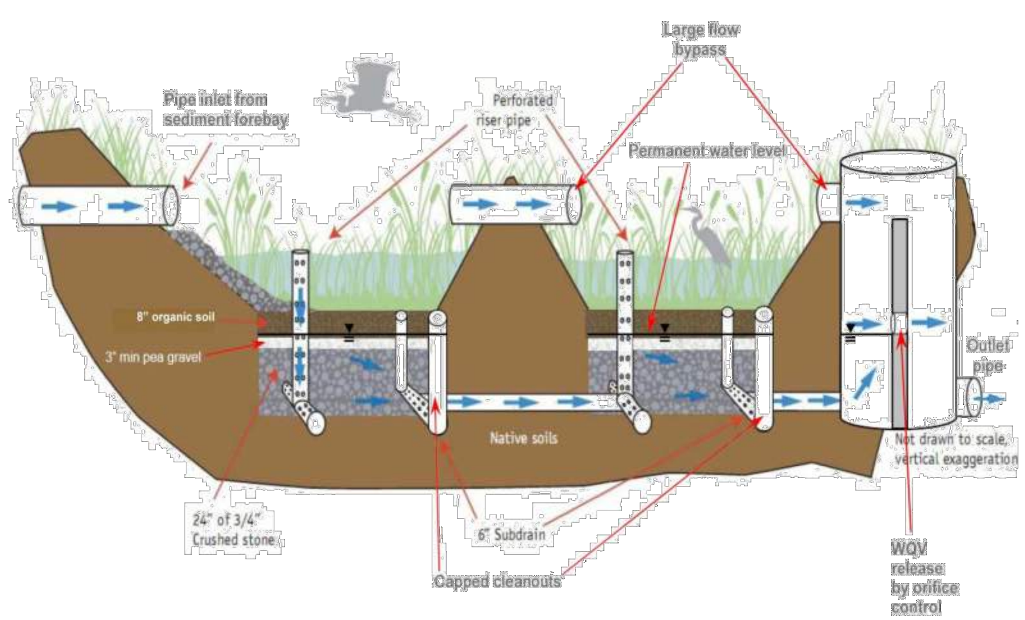


INSET
SCALE: 1" = 5000'

LAND USE	DRAINAGE AREA (AC.) (% OF TOTAL AREA)	
	PERVIOUS	IMPERVIOUS
RESIDENTIAL	3.6 (72.0%)	1.4 (28.0%)



PLAN VIEW
SCALE: 1" = 100'



Adapted from UNHSC, 2009

GRAVEL WVTS
SCALE: NOT TO SCALE

VIEW OF PROPOSED GRAVEL WVTS LOCATION
SCALE: NOT TO SCALE

WOODARD & CURRAN
33 Broad Street Floor 7
Providence, Rhode Island 02903
800.985.7897 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

CATCHMENT 4
10% CONCEPT DESIGN

DESIGNED BY: CNQ	CHECKED BY: HCP
DRAWN BY: CNQ	233191-CATCHMENT 4.dwg

TOWN OF SOUTH KINGSTOWN

GREEN HILL POND NITROGEN REDUCTION ANALYSIS

JOB NO: 0233191.00
DATE: SEPTEMBER 2021
SCALE: AS NOTED

FIGURE 6-4

\\woodardcurran.net\shared\Projects\0233191.00 South Kingstown Stormwater Retrofit Design\wip\Drawings\Figures\233191-Catchment 4.dwg, Sep 17, 2021 - 3:20pm CNQUINN

APPENDIX B: TOTAL NITROGEN LOAD CALCULATIONS

COMMITMENT & INTEGRITY DRIVE RESULTS
WOODARD & CURRAN
33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	9/16/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Green Hill Pond Watershed TN Load Calculations

Watershed Area - Commercial

Watershed Area 34.3
Pervious 17.3
Impervious 16.9

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.49
Mean Concentration of the Pollutant (Commercial) (mg/L)	C	2.1
Contributing Drainage Area (ac)	A	34.3
Pollutant Export Load (lbs/year)	L	355.8

Watershed Area - Residential

Watershed Area 989.3
Pervious 708.4
Impervious 280.9

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.31
Mean Concentration of the Pollutant (Residential) (mg/L)	C	2.1
Contributing Drainage Area (ac)	A	989.3
Pollutant Export Load (lbs/year)	L	6,344.4

Watershed Area - Highways

Watershed Area 31.5
Pervious 9.8
Impervious 21.7

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.67
Mean Concentration of the Pollutant (Highway) (mg/L)	C	2.3
Contributing Drainage Area (ac)	A	31.5
Pollutant Export Load (lbs/year)	L	486.2

Watershed Area - Undeveloped/Rural

Watershed Area 1,930.0
Pervious 1,858.4
Impervious 71.7

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.08
Mean Concentration of the Pollutant (Undeveloped/Rural) (mg/L)	C	1.74
Contributing Drainage Area (ac)	A	1,930.0
Pollutant Export Load (lbs/year)	L	2,800.4

Net TN Export Load (lbs/year)	**9,986.8**

COMMITMENT & INTEGRITY
DRIVE RESULTS

WOODARD
&CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	10/1/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Commodore Perry Highway (Route 1) TN Load Calculations

Route 1 - Highways		
Watershed Area	**31.5**	
Pervious	**9.8**	
Impervious	**21.7**	
Pollutant of Concern		**TN**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.67
Mean Concentration of the Pollutant (Highway) (mg/L)	**C**	2.3
Contributing Drainage Area (ac)	**A**	31.5
Pollutant Export Load (lbs/year)	**L**	486.2

Net TN Export Load (lbs/year)	**486.2**

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	9/16/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Catchment 1 TN Load Calculations

Catchment 1 - Commercial

Watershed Area 1.7
Pervious 1.0
Impervious 0.7

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.43
Mean Concentration of the Pollutant (Commercial) (mg/L)	C	2.1
Contributing Drainage Area (ac)	A	1.7
Pollutant Export Load (lbs/year)	L	15.3

Catchment 1 - Residential

Watershed Area 85.6
Pervious 63.6
Impervious 22.0

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.28
Mean Concentration of the Pollutant (Residential) (mg/L)	C	2.1
Contributing Drainage Area (ac)	A	85.6
Pollutant Export Load (lbs/year)	L	504.6

Catchment 1 - Highways

Watershed Area 0.3
Pervious 0.0
Impervious 0.3

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.82
Mean Concentration of the Pollutant (Highway) (mg/L)	C	2.3
Contributing Drainage Area (ac)	A	0.3
Pollutant Export Load (lbs/year)	L	6.1

Catchment 1 - Undeveloped/Rural

Watershed Area 28.8
Pervious 27.7
Impervious 1.2

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.09
Mean Concentration of the Pollutant (Undeveloped/Rural) (mg/L)	C	1.74
Contributing Drainage Area (ac)	A	28.8
Pollutant Export Load (lbs/year)	L	43.1

Net TN Export Load (lbs/year)	**569.1**

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI				
PROJECT:	Green Hill Pond Stormwater Retrofit Design				
DESIGNED BY:	CNQ		DATE:	9/16/2021	
CHECKED BY:	HCP		DATE:		
PROJECT NO.	233191.00	SHEET NO.	1	OF	1

Catchment 2 TN Load Calculations

Catchment 2 - Residential

Watershed Area	**9.8**
Pervious	**7.4**
Impervious	**2.4**

Pollutant of Concern		**TN**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.27
Mean Concentration of the Pollutant (Residential) (mg/L)	**C**	2.1
Contributing Drainage Area (ac)	**A**	9.8
Pollutant Export Load (lbs/year)	**L**	55.8

Catchment 2 - Undeveloped/Rural

Watershed Area	**0.1**
Pervious	**0.1**
Impervious	**0.0**

Pollutant of Concern		**TN**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.05
Mean Concentration of the Pollutant (Undeveloped/Rural) (mg/L)	**C**	1.74
Contributing Drainage Area (ac)	**A**	0.1
Pollutant Export Load (lbs/year)	**L**	0.1

Net TN Export Load (lbs/year)	**55.8**

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	9/16/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Catchment 3 TN Load Calculations

Catchment 3 - Residential

Watershed Area 4.1

Pervious 3.1

Impervious 1.0

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.27
Mean Concentration of the Pollutant (Residential) (mg/L)	C	2.1
Contributing Drainage Area (ac)	A	4.1
Pollutant Export Load (lbs/year)	L	23.0

Catchment 3 - Undeveloped/Rural

Watershed Area 1.0

Pervious 0.4

Impervious 0.6

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.60
Mean Concentration of the Pollutant (Undeveloped/Rural) (mg/L)	C	1.74
Contributing Drainage Area (ac)	A	1.0
Pollutant Export Load (lbs/year)	L	10.6

Net TN Export Load (lbs/year)	**33.6**

COMMITMENT & INTEGRITY DRIVE RESULTS
WOODARD & CURRAN
33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	9/16/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Catchment 4 TN Load Calculations

Catchment 4 - Residential		
Watershed Area		**5.0**
Pervious		**3.6**
Impervious		**1.4**
Pollutant of Concern		**TN**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.29
Mean Concentration of the Pollutant (Residential) (mg/L)	**C**	2.1
Contributing Drainage Area (ac)	**A**	5.0
Pollutant Export Load (lbs/year)	**L**	30.8

Net TN Export Load (lbs/year)	**30.8**

APPENDIX C: BACTERIA LOAD CALCULATIONS

COMMITMENT & INTEGRITY
DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	9/16/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Green Hill Pond Watershed Bacteria Load Calculations

Watershed Area - Commercial

Watershed Area		**34.3**
Pervious		**17.3**
Impervious		**16.9**
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.49
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	4,600
Contributing Drainage Area (ac)	**A**	34.3
Pollutant Export Load (billion colonies/year)	**L**	3,541.6

Watershed Area - Residential

Watershed Area		**989.3**
Pervious		**708.4**
Impervious		**280.9**
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.31
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	7,000
Contributing Drainage Area (ac)	**A**	989.3
Pollutant Export Load (billion colonies/year)	**L**	96,099.1

Watershed Area - Highways

Watershed Area		**31.5**
Pervious		**9.8**
Impervious		**21.7**
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.67
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	1,700
Contributing Drainage Area (ac)	**A**	31.5
Pollutant Export Load (billion colonies/year)	**L**	1,633.0

Watershed Area - Undeveloped/Rural

Watershed Area		**1,930.0**
Pervious		**1,858.4**
Impervious		**71.7**
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.08
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	300
Contributing Drainage Area (ac)	**A**	1,930.0
Pollutant Export Load (billion colonies/year)	**L**	2,194.0

Net Bacteria Export Load (billion colonies/year)	**103,467.7**

COMMITMENT & INTEGRITY
DRIVE RESULTS

WOODARD
&CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI				
PROJECT:	Green Hill Pond Stormwater Retrofit Design				
DESIGNED BY:	CNQ		DATE:	10/1/2021	
CHECKED BY:	HCP		DATE:		
PROJECT NO.	233191.00	SHEET NO.	1	OF	1

Commodore Perry Highway (Route 1) Bacteria Load Calculations

Route 1 - Highways		
Watershed Area	**31.5**	
Pervious	**9.8**	
Impervious	**21.7**	
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.67
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	1,700
Contributing Drainage Area (ac)	**A**	31.5
Pollutant Export Load (billion colonies/year)	**L**	1,633.0

Net Bacteria Export Load (billion colonies/year)	**1,633.0**

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI				
PROJECT:	Green Hill Pond Stormwater Retrofit Design				
DESIGNED BY:	CNQ		DATE:	9/16/2021	
CHECKED BY:	HCP		DATE:		
PROJECT NO.	233191.00	SHEET NO.	1	OF	1

Catchment 1 Bacteria Load Calculations

Catchment 1 - Commercial

Watershed Area	**1.7**	
Pervious	**1.0**	
Impervious	**0.7**	
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.43
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	4,600
Contributing Drainage Area (ac)	**A**	1.7
Pollutant Export Load (billion colonies/year)	**L**	152.0

Catchment 1 - Residential

Watershed Area	**85.6**	
Pervious	**63.6**	
Impervious	**22.0**	
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.28
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	7,000
Contributing Drainage Area (ac)	**A**	85.6
Pollutant Export Load (billion colonies/year)	**L**	7,643.0

Catchment 1 - Highways

Watershed Area	**0.3**	
Pervious	**0.0**	
Impervious	**0.3**	
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.82
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	1,700
Contributing Drainage Area (ac)	**A**	0.3
Pollutant Export Load (billion colonies/year)	**L**	20.5

Catchment 1 - Undeveloped/Rural

Watershed Area	**28.8**	
Pervious	**27.7**	
Impervious	**1.2**	
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.09
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	300
Contributing Drainage Area (ac)	**A**	28.8
Pollutant Export Load (billion colonies/year)	**L**	33.8

Net Bacteria Export Load (billion colonies/year)	**7,849.3**

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI				
PROJECT:	Green Hill Pond Stormwater Retrofit Design				
DESIGNED BY:	CNQ		DATE:	9/16/2021	
CHECKED BY:	HCP		DATE:		
PROJECT NO.	233191.00	SHEET NO.	1	OF	1

Catchment 2 Bacteria Load Calculations

Catchment 2 - Residential

Watershed Area	**9.8**
Pervious	**7.4**
Impervious	**2.4**

Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.27
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	7,000
Contributing Drainage Area (ac)	**A**	9.8
Pollutant Export Load (billion colonies/year)	**L**	844.5

Catchment 2 - Undeveloped/Rural

Watershed Area	**0.1**
Pervious	**0.1**
Impervious	**0.0**

Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.05
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	300
Contributing Drainage Area (ac)	**A**	0.1
Pollutant Export Load (billion colonies/year)	**L**	0.0

Net Bacteria Export Load (billion colonies/year)	**844.5**

COMMITMENT & INTEGRITY
DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI				
PROJECT:	Green Hill Pond Stormwater Retrofit Design				
DESIGNED BY:	CNQ		DATE:	9/16/2021	
CHECKED BY:	HCP		DATE:		
PROJECT NO.	233191.00	SHEET NO.	1	OF	1

Catchment 3 Bacteria Load Calculations

Catchment 3 - Residential

Watershed Area 4.1

Pervious 3.1

Impervious 1.0

Pollutant of Concern		Bacteria
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.27
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	C'	7,000
Contributing Drainage Area (ac)	A	4.1
Pollutant Export Load (billion colonies/year)	L	349.1

Catchment 3 - Undeveloped/Rural

Watershed Area 1.0

Pervious 0.4

Impervious 0.6

Pollutant of Concern		Bacteria
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.60
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	C'	300
Contributing Drainage Area (ac)	A	1.0
Pollutant Export Load (billion colonies/year)	L	8.3

Net Bacteria Export Load (billion colonies/year)	**357.4**

COMMITMENT & INTEGRITY
DRIVE RESULTS

WOODARD
&CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	9/16/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Catchment 4 Bacteria Load Calculations

Catchment 4 - Residential		
Watershed Area		**5.0**
Pervious		**3.6**
Impervious		**1.4**
Pollutant of Concern		**Bacteria**
Rainfall Depth (in/year)	**P**	49
Rainfall Correction Factor	**Pj**	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	**Rv**	0.29
Flow-Weighted Mean Bacteria Concentration (#col/100ml)	**C'**	7,000
Contributing Drainage Area (ac)	**A**	5.0
Pollutant Export Load (billion colonies/year)	**L**	466.9

Net Bacteria Export Load (billion colonies/year)	**466.9**

APPENDIX D: COST-BENEFIT CALCULATIONS

COMMITMENT & INTEGRITY DRIVE RESULTS
WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	8/13/2021
CHECKED BY:	HCP	DATE:	8/17/2021
PROJECT NO.	233191.00	SHEET NO.	1

Cost-Benefit Comparison - Gravel WVTS

Gravel WVTS - Catchment 1

Treatment Depth (inch)	0.1	0.2	0.4	0.6	0.8	1.0
TN Load Reduction (%)	22%	33%	48%	57%	64%	68%
Bacteria Load Reduction (%)	30%	47%	66%	73%	75%	76%
WQv (CF)	8,748	17,496	34,992	52,488	69,984	87,480
Approximate Footprint (SF)	4,500	9,000	17,500	26,500	35,000	44,000
System Cost ($)	$79,000	$158,000	$315,000	$473,000	$630,000	$788,000
Land Acquisition Cost ($)	$16,000	$32,000	$62,000	$93,000	$123,000	$154,000
Total Cost ($)	$95,000	$190,000	$377,000	$566,000	$753,000	$942,000
TN Removed (lbs/year)	125.2	187.8	273.1	324.4	364.2	387.0
TN Cost-Benefit ($/lb)	**$758.83**	**$1,011.77**	**$1,380.20**	**$1,744.95**	**$2,067.55**	**$2,434.35**
Bacteria Removed (billion colonies/year)	2,377.6	3,705.7	5,142.1	5,701.0	5,871.3	5,971.0
Bacteria Cost-Benefit ($/billion colonies)	**$39.96**	**$51.27**	**$73.32**	**$99.28**	**$128.25**	**$157.76**

Gravel WVTS - Catchment 2

Treatment Depth (inch)	0.1	0.2	0.4	0.6	0.8	1.0
TN Load Reduction (%)	22%	33%	48%	57%	64%	68%
Bacteria Load Reduction (%)	30%	47%	66%	73%	75%	76%
WQv (CF)	874	1,748	3,495	5,243	6,991	8,738
Approximate Footprint (SF)	500	1,000	2,000	3,000	3,500	4,500
System Cost ($)	$8,000	$16,000	$32,000	$48,000	$63,000	$79,000
Land Acquisition Cost ($)	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Total Cost ($)	$9,000	$17,000	$33,000	$49,000	$64,000	$80,000
TN Removed (lbs/year)	12.3	18.4	26.8	31.8	35.7	37.9
TN Cost-Benefit ($/lb)	**$733.10**	**$923.16**	**$1,232.01**	**$1,540.51**	**$1,792.02**	**$2,108.25**
Bacteria Removed (billion colonies/year)	255.8	398.7	553.2	613.4	631.7	642.4
Bacteria Cost-Benefit ($/billion colonies)	**$35.18**	**$42.64**	**$59.65**	**$79.89**	**$101.32**	**$124.53**

Gravel WVTS - Catchment 4

Treatment Depth (inch)	0.1	0.2	0.4	0.6	0.8	1.0
TN Load Reduction (%)	22%	33%	48%	57%	64%	68%
Bacteria Load Reduction (%)	30%	47%	66%	73%	75%	76%
WQv (CF)	491	983	1,965	2,948	3,931	4,913
Approximate Footprint (SF)	500	500	1,000	1,500	2,000	2,500
System Cost ($)	$5,000	$9,000	$18,000	$27,000	$36,000	$45,000
Land Acquisition Cost ($)	$0	$0	$0	$0	$0	$0
Total Cost ($)	$5,000	$9,000	$18,000	$27,000	$36,000	$45,000
TN Removed (lbs/year)	6.8	10.2	14.8	17.6	19.7	21.0
TN Cost-Benefit ($/lb)	**$737.39**	**$884.87**	**$1,216.69**	**$1,536.87**	**$1,825.03**	**$2,147.10**
Bacteria Removed (billion colonies/year)	141.4	220.4	305.8	339.1	349.2	355.1
Bacteria Cost-Benefit ($/billion colonies)	**$35.36**	**$40.83**	**$58.86**	**$79.63**	**$103.09**	**$126.71**

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	8/13/2021
CHECKED BY:	HCP	DATE:	8/17/2021
PROJECT NO.	233191.00	SHEET NO.	1

Cost-Benefit Comparison - CB Retrofit/Infiltration Trench

Infiltration Trench - Catchment 1

Treatment Depth (inch)	**0.1**	0.2	0.4
TN Load Reduction (%)	59%	76%	90%
Bacteria Load Reduction (%)	24%	40%	61%
WQv (CF)	8,748	17,496	34,992
System Cost ($)	$132,000	$263,000	$525,000
TN Removed (lbs/year)	335.7	432.5	512.2
TN Cost-Benefit ($/lb)	**$393.15**	**$608.11**	**$1,025.08**
Bacteria Removed (billion colonies/year)	1,916.8	3,130.3	4,763.8
Bacteria Cost-Benefit ($/billion colonies)	**$68.86**	**$84.02**	**$110.21**

Number of CBs in Catchment	59
Average Volume per Retrofitted CB	150
Available Treatment Volume	8,863

Infiltration Trench - Catchment 2

Treatment Depth (inch)	0.1	**0.2**	0.4
TN Load Reduction (%)	59%	79.5%	90%
Bacteria Load Reduction (%)	24%	45.5%	61%
WQv (CF)	874	1,748	3,495
System Cost ($)	$14,000	$27,000	$53,000
TN Removed (lbs/year)	32.9	44.4	50.2
TN Cost-Benefit ($/lb)	**$425.22**	**$608.61**	**$1,055.30**
Bacteria Removed (billion colonies/year)	206.2	384.3	512.5
Bacteria Cost-Benefit ($/billion colonies)	**$67.89**	**$70.27**	**$103.41**

Number of CBs in Catchment	17
Average Volume per Retrofitted CB	150
Available Treatment Volume	2,554

Infiltration Trench - Catchment 3

Treatment Depth (inch)	0.1	**0.2**	0.4
TN Load Reduction (%)	59%	79.5%	90%
Bacteria Load Reduction (%)	24%	45.5%	61%
WQv (CF)	584	1,168	2,337
System Cost ($)	$9,000	$18,000	$36,000
TN Removed (lbs/year)	19.8	26.7	30.3
TN Cost-Benefit ($/lb)	**$453.68**	**$673.39**	**$1,189.65**
Bacteria Removed (billion colonies/year)	87.3	162.6	216.9
Bacteria Cost-Benefit ($/billion colonies)	**$103.13**	**$110.70**	**$165.99**

Number of CBs in Catchment	8
Average Volume per Retrofitted CB	150
Available Treatment Volume	1,202

Notes:
1. Calculations assume entire impervious area within catchment drains to a catch basin
2. Load reduction assumes an infiltration rate of 0.52 in/hr, which is conservative for HSG B soils.
3. Catch basin data was not available for CBs within the Charlestown portion of Catchment 1.
4. Zero catch basins are located within Catchment 4.

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	8/13/2021
CHECKED BY:	HCP	DATE:	8/17/2021
PROJECT NO.	233191.00	SHEET NO.	1

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

Gravel WVTS Cost-Benefit Comparison Chart

	Treatment Depth (inch)	0.1	0.2	0.4	0.6	0.8	1.0
Catchment 1	System Cost ($)	$95,000	$190,000	$377,000	$566,000	$753,000	$942,000
	TN Removed (lb/year)	125.2	187.8	273.1	324.4	364.2	387.0
	TN Cost-Benefit ($/lb)	$758.83	$1,011.77	$1,380.20	$1,744.95	$2,067.55	$2,434.35
	Bacteria Removed (billion colonies/year)	2377.6	3705.7	5142.1	5701.0	5871.3	5971.0
	Bacteria Cost-Benefit ($/billion colonies)	$39.96	$51.27	$73.32	$99.28	$128.25	$157.76
Catchment 2	System Cost ($)	$9,000	$17,000	$33,000	$49,000	$64,000	$80,000
	TN Removed (lb/year)	12.3	18.4	26.8	31.8	35.7	37.9
	TN Cost-Benefit ($/lb)	$733.10	$923.16	$1,232.01	$1,540.51	$1,792.02	$2,108.25
	Bacteria Removed (billion colonies/year)	255.8	398.7	553.2	613.4	631.7	642.4
	Bacteria Cost-Benefit ($/billion colonies)	$35.18	$42.64	$59.65	$79.89	$101.32	$124.53
Catchment 4	System Cost ($)	$5,000	$9,000	$18,000	$27,000	$36,000	$45,000
	TN Removed (lb/year)	6.8	10.2	14.8	17.6	19.7	21.0
	TN Cost-Benefit ($/lb)	$737.39	$884.87	$1,216.69	$1,536.87	$1,825.03	$2,147.10
	Bacteria Removed (billion colonies/year)	141.4	220.4	305.8	339.1	349.2	355.1
	Bacteria Cost-Benefit ($/billion colonies)	$35.36	$40.83	$58.86	$79.63	$103.09	$126.71

COMMITMENT & INTEGRITY DRIVE RESULTS

WOODARD & CURRAN

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	8/13/2021
CHECKED BY:	HCP	DATE:	8/17/2021
PROJECT NO.	233191.00	SHEET NO.	1

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

Infiltration Trench Cost-Benefit Comparison Chart

	Treatment Depth (inch)	0.1	0.2	0.4
Catchment 1	System Cost ($)	$132,000	$263,000	$525,000
	TN Removed (lb/year)	335.7	432.5	512.2
	TN Cost-Benefit ($/lb)	$393.15	$608.11	$1,025.08
	Bacteria Removed (billion colonies/year)	1916.8	3130.3	4763.8
	Bacteria Cost-Benefit ($/billion colonies)	$68.86	$84.02	$110.21
Catchment 2	System Cost ($)	$14,000	$27,000	$53,000
	TN Removed (lb/year)	32.9	44.4	50.2
	TN Cost-Benefit ($/lb)	$425.22	$608.61	$1,055.30
	Bacteria Removed (billion colonies/year)	206.2	384.3	512.5
	Bacteria Cost-Benefit ($/billion colonies)	$67.89	$70.27	$103.41
Catchment 3	System Cost ($)	$9,000	$18,000	$36,000
	TN Removed (lb/year)	19.8	26.7	30.3
	TN Cost-Benefit ($/lb)	$453.68	$673.39	$1,189.65
	Bacteria Removed (billion colonies/year)	87.3	162.6	216.9
	Bacteria Cost-Benefit ($/billion colonies)	$103.13	$110.70	$165.99

STORMWATER MANAGEMENT SYSTEM

OPERATIONS & MAINTENANCE MEASURES AND NOTES

Catch Basin Retrofit/Infiltration Trench Systems	
Objective: *Maintain the infiltration and conveyance capacity of the infiltration trench and catch basin system.*	
Frequency	***Measure***
Ongoing/As Needed	• Avoid placement of snow on top of catch basin grates. • Inspect catch basin grates for damage. Repair as needed. Grates shall not be welded to the frame so that the structure can be inspected and maintained. • Remove obstructions that may limit runoff from entering the catch basin, including sediment, trash, debris, and leaves. Dispose of material in accordance with applicable regulations. • Remove sediment from bottom of catch basin whenever the depth of sediment is greater than or equal to half the sump depth. Dispose of sediment in accordance with applicable regulations.
After Heavy Rainfall Events[1]	• During the six months immediately after construction, inspect the system after the first two precipitation events of at least 1.0 inch to ensure that the system is functioning properly. Thereafter, inspections shall be conducted on an annual basis and after heavy rainfall events. • Inspect for ponded water at catch basin 24-hours or several days after event. If water is ponded, it may indicate that the trench or perforated pipe is clogged. Trench can be flushed through the catch basin or cleanouts using a hose or vacuum equipment.

[1] At a minimum, an event accumulating approximately 2.7 inches of rainfall in a 24-hour period.

Gravel Wet Vegetated Treatment Systems	
Objective: *Preserve the treatment capacity of the gravel wet vegetated treatment systems.*	
Frequency	***Measure***
Ongoing/As Needed	• Inspect sediment forebay, basin, and outlet control structure for sediment, debris and other obstructions that may impede flow. Remove materials with rakes rather than heavy construction equipment. Remove and dispose of sediment and debris in accordance with applicable regulations. • Sediment shall be cleaned out of the sediment forebay when it accumulates to a depth of more than ½ the design depth. • Remove sediment from the basin bottom when its accumulation exceeds one inch. • Inspect basin and outlet control structure for structural damage. Repair damage as needed. Repaired infrastructure shall be restored according to original design specifications. • Observe the water level in the basin. Verify that the water level is decreasing, and the water is filtering through the gravel layer to the underdrain. Flush treatment cells as needed using a hose or vacuum equipment. • Inspect forebay and basin for erosion along embankments. Repair as needed. • Inspect plantings. Replace vegetation as needed to achieve a minimum 50% coverage. Cut and remove dead or dying vegetation.
After Heavy Rainfall Events[1]	• During the six months immediately after construction, inspect the system after the first two precipitation events of at least 1.0 inch to ensure that the system is functioning properly. Thereafter, inspections shall be conducted on an annual basis and after heavy rainfall events. • Inspect forebay for ponded water 24-hours or several days after event. If water is ponded inside the sediment forebay, it may indicate that the bottom of the forebay or outlet control structure has failed or is clogged. To rehabilitate a failed sediment forebay, strip accumulated sediment from the bottom. The bottom of the forebay must be scarified and tilled to induce infiltration.
NOTIFICATION:	
As needed	• Notify Owner of any system repairs needed and/or operational problems

[1] At a minimum, perform inspections once a year and/or after an event accumulating 2.7 inches of rainfall in a 24-hour period.

APPENDIX E: CATCH BASIN RETROFIT CALCULATIONS

WOODARD & CURRAN
COMMITMENT & INTEGRITY DRIVE RESULTS

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	7/26/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1 / 1

Catch Basin Retrofit Analysis

Watershed Area - Residential	
Watershed Area	0.07
Pervious	0.00
Impervious	0.07

Pollutant of Concern		TN
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.95
Mean Concentration of the Pollutant	C	2.1
Contributing Drainage Area (ac)	A	0.1
Pollutant Export Load (lbs/year)	L	**1.4**

Watershed Area - Residential	
Watershed Area	0.07
Pervious	0.00
Impervious	0.07

Pollutant of Concern		Bacteria
Rainfall Depth (in/year)	P	49
Rainfall Correction Factor	Pj	0.9
Runoff Coefficient (Rv=0.05+0.009*I%)	Rv	0.95
Flow-Weighted Mean Bacteria	C'	7,000
Contributing Drainage Area (ac)	A	0.1
Pollutant Export Load (billion colonies/year)	L	**21.1**

Green Hill Pond Watershed

Number of Town-Owned CBs	Drainage Area per CB (Acres)	TN Generated (lbs/year)	Bacteria Generated (billion colonies/year)	Treated Depth of Runoff (inch)	Average Storage Volume per CB (CF)	TN Removal Efficiency (%)	TN Load Reduction (lbs/year)	Bacteria Removal Efficiency (%)	Bacteria Load Reduction (billion colonies/year)
133	0.07	1.4	21.1	0.55	140	93.8%	**174.1**	71.9%	**2023.1**

NOTES:

1. Assumed a drainage area of 0.07 acres (3,000 SF) of residential impervious area. Individual catch basin subcatchments were not delineated.
2. Potential P load reduction assumes an infiltration rate of 0.52 in/hr, which is conservative for HSG B soils.
3. Catch basin data was not available for CBs within the Charlestown portion of the Watershed.

APPENDIX F: GROUNDWATER RECHARGE VOLUME CALCULATIONS

COMMITMENT & INTEGRITY
DRIVE RESULTS

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	7/26/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1

Standard #3: Stormwater Treatment Calculations - Catchment 1

Per RI Stormwater Management, Design, and Installalton Rules (250-RICR-150-10-8)

Groundwater Recharge Volume - Per Section 8.8

$$Re_v = \frac{1" \times F \times I}{(12"/1')}$$

Re_v = Groundwater Recharge Volume (CF)
F = Recharge Factor Based on HSG
I = New Impervious Area (SF)

HSG	Recharge Factor (F)
A	0.60
B	0.35
C	0.25
D	0.10

Recharge Volume Calculation				
Catchment 1	HSG A	HSG B	HSG C	HSG D
Impervious Area (SF)	936,019	113,739	0	0
Recharge Factor	0.6	0.35	0.25	0.1
Recharge Volume (CF)	46,801	3,317	0	0

Total Recharge Volume = 50,118 CF

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	7/26/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1

Standard #3: Stormwater Treatment Calculations - Catchment 2

Per RI Stormwater Management, Design, and Installalton Rules (250-RICR-150-10-8)

Groundwater Recharge Volume - Per Section 8.8

$$Re_v = \frac{1" \times F \times I}{(12"/1')}$$

Re_v = Groundwater Recharge Volume (CF)
F = Recharge Factor Based on HSG
I = New Impervious Area (SF)

HSG	Recharge Factor (F)
A	0.60
B	0.35
C	0.25
D	0.10

Recharge Volume Calculation				
Catchment 1	HSG A	HSG B	HSG C	HSG D
Impervious Area (SF)	39,524	65,337	0	0
Recharge Factor	0.6	0.35	0.25	0.1
Recharge Volume (CF)	1,976	1,906	0	0

Total Recharge Volume = 3,882 CF

COMMITMENT & INTEGRITY
DRIVE RESULTS

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	7/26/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1

Standard #3: Stormwater Treatment Calculations - Catchment 3

Per RI Stormwater Management, Design, and Installalton Rules (250-RICR-150-10-8)

Groundwater Recharge Volume - Per Section 8.8

$$Re_v = \frac{1" \times F \times I}{(12"/1')}$$

Re_v = Groundwater Recharge Volume (CF)
F = Recharge Factor Based on HSG
I = New Impervious Area (SF)

HSG	Recharge Factor (F)
A	0.60
B	0.35
C	0.25
D	0.10

Recharge Volume Calculation				
Catchment 1	HSG A	HSG B	HSG C	HSG D
Impervious Area (SF)	0	70,106	0	0
Recharge Factor	0.6	0.35	0.25	0.1
Recharge Volume (CF)	0	2,045	0	0

Total Recharge Volume = 2,045 CF

COMMITMENT & INTEGRITY
DRIVE RESULTS

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	7/26/2021
CHECKED BY:	HCP	DATE:	
PROJECT NO.	233191.00	SHEET NO.	1

Standard #3: Stormwater Treatment Calculations - Catchment 4

Per RI Stormwater Management, Design, and Installalton Rules (250-RICR-150-10-8)

Groundwater Recharge Volume - Per Section 8.8

$$Re_v = \frac{1" \times F \times I}{(12"/1')}$$

Re_v = Groundwater Recharge Volume (CF)
F = Recharge Factor Based on HSG
I = New Impervious Area (SF)

HSG	Recharge Factor (F)
A	0.60
B	0.35
C	0.25
D	0.10

Recharge Volume Calculation				
Catchment 1	HSG A	HSG B	HSG C	HSG D
Impervious Area (SF)	17,556	41,402	0	0
Recharge Factor	0.6	0.35	0.25	0.1
Recharge Volume (CF)	878	1,208	0	0

Total Recharge Volume = 2,085 CF

APPENDIX G: NON-STRUCTURAL CALCULATIONS

WOODARD & CURRAN

COMMITMENT & INTEGRITY DRIVE RESULTS

33 Broad Street, 7th Floor
Providence, Rhode Island, 02903
Tel: 800.985.7897 Fax: 401.273.5087

CLIENT:	South Kingstown, RI		
PROJECT:	Green Hill Pond Stormwater Retrofit Design		
DESIGNED BY:	CNQ	DATE:	7/26/2021
CHECKED BY:	HCP	DATE:	8/17/2021
PROJECT NO.	233191.00	SHEET NO.	1 OF 1

Non-Structural Nitrogen Reduction Analysis - Green Hill Pond Watershed

RIGIS Land Use and Land Cover (2011 Data)	TN Export Rate (lbs/ac/year)	Land Cover (acres)	Non-Structural BMP TN Load Reduction (lbs/year)			
		Paved	Enhanced Sweeping (Mechanical Broom)	Catch Basin Cleaning	Organic Waste / Leaf Litter Collection	Total Reduction
All Residential	14.1	34.6	22.0	6.0	24.4	52.3
Agricultural	11.3	0.1	0.1	0.0	0.1	0.1
Forest	11.3	16.5	8.4	1.0	9.3	18.8
		Net Reduction (lbs/year)	30.4	7.0	33.8	**71.2**

NOTES:

1. Analysis includes Town-Owned paved roadway and paved areas. Analysis does not include private or state-owned roadways or gravel roadways.
2. Enhanced sweeping credit assumes MA MS4 Appendix F requirements are met for weekly sweeping and an annual sweeping frequency of 0.75 (excludes Dec-Feb). Assumes paved roadways are swept; gravel roadways were excluded from this credit analysis.
3. Catch basin cleaning credit assumes MA MS4 Appendix F requirements are met (semi-annual cleaning frequency).
4. Catch basin cleaning credit assumes an average impervious, residential drainage area of 0.07 AC (3,000± SF) per catch basin (101 residential, 22 forest) within the watershed. Individual catchment delineations were not performed.
5. Apparent leaching catch basins within the watershed are not included in the catch basin cleaning credits.
6. Enhanced organic waste and leaf litter collection credit assumes MA MS4 Appendix F requirements are met (weekly removal from September 1-December 1).

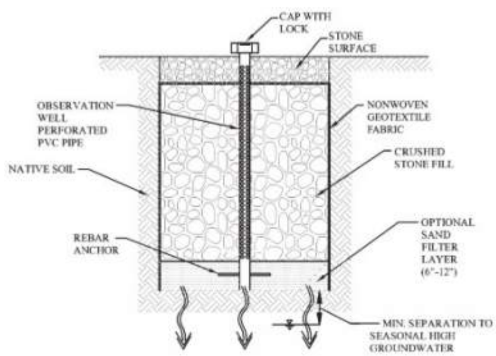
APPENDIX H: REFERENCE

Infiltration Trench Factsheet

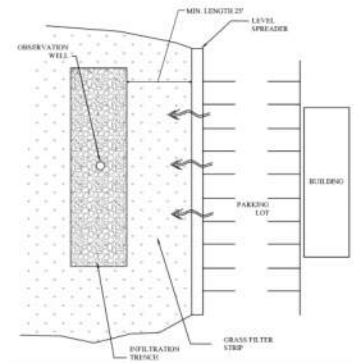
Infiltration Trench is a practice that provides temporary storage of runoff using the void spaces within the soil/sand/gravel mixture that is used to backfill the trench for subsequent infiltration into the surrounding sub-soils. Performance results for the infiltration trench can be used for all subsurface infiltration practices including systems that include pipes and/or chambers that provide temporary storage. Also, the results for this BMP type can be used for bio-retention systems that rely on infiltration when the majority of the temporary storage capacity is provided in the void spaces of the soil filter media and porous pavements that allow infiltration to occur. General design specifications for infiltration trench systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Cross Section



Plan View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 86

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

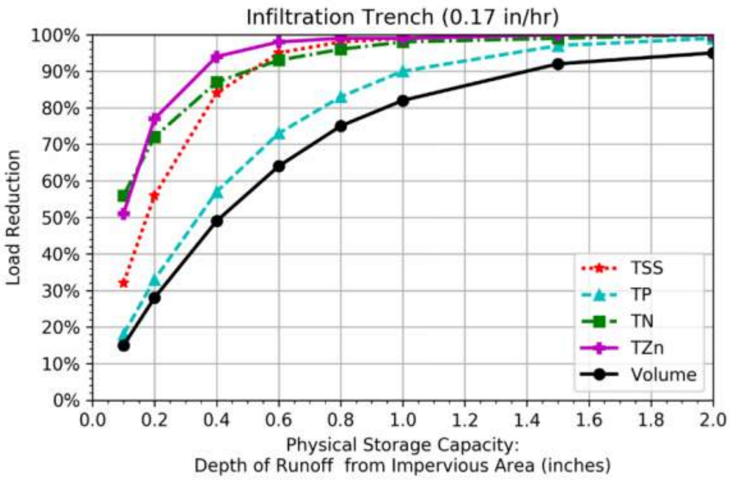
Cost

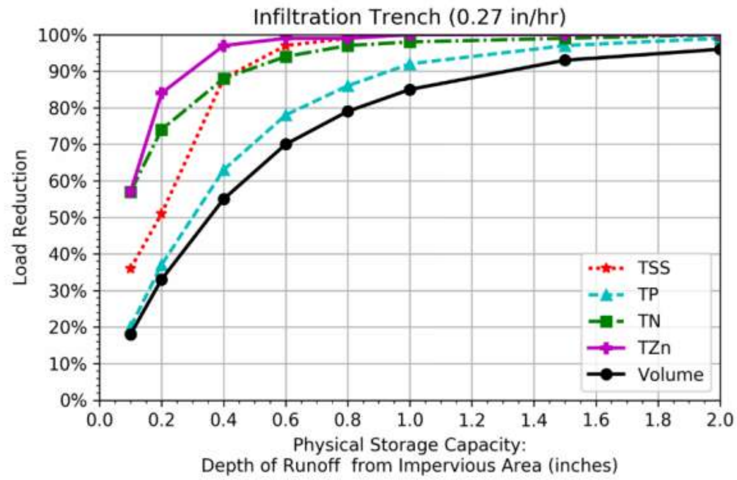
	Materials and Installation Cost ($/ft^3) (2020)	Design Cost ($/ft^3) (2020)	Total Cost ($/ft^3) (2020)[1,2]
Rural	8.33	4.49	12.82
Mixed	16.67	8.97	25.64
Urban	25.00	13.46	38.46

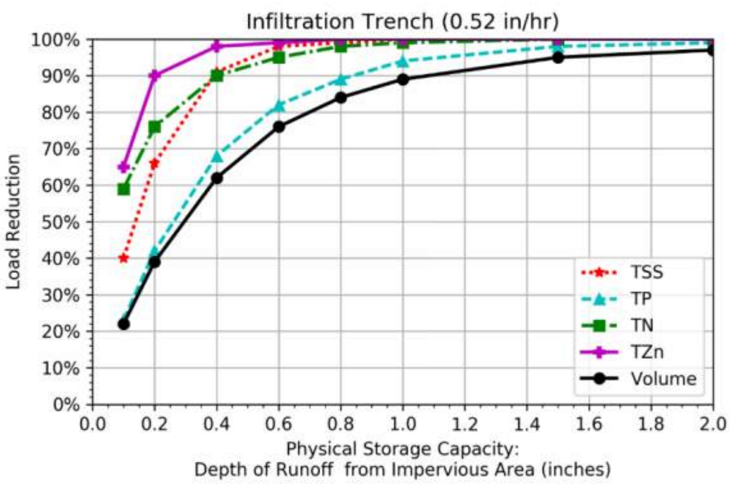
[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

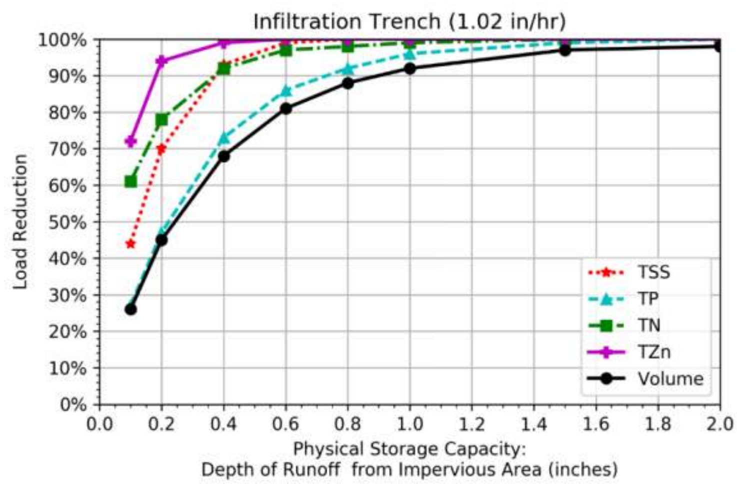
Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

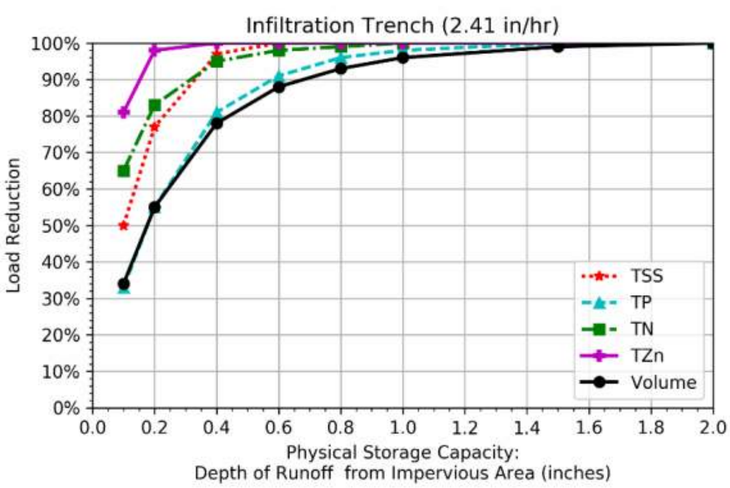
BMP Performance Curves for Soil Infiltration Rate: Infiltration Trench

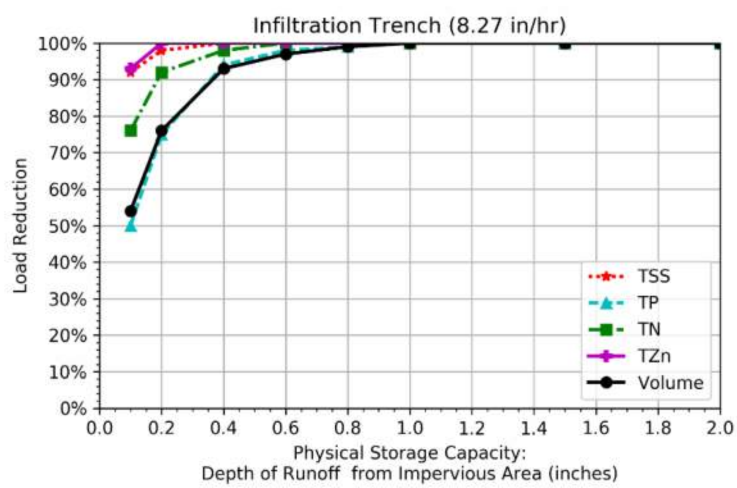












BMP Performance Tables for Soil Infiltration Rate: Infiltration Trench

		Cumulative Load Reduction				
Infiltration Rate (in/hr)	Depth of Runoff from Impervious Area (inches)	TSS	Phosphorus	Nitrogen	Zinc	Runoff Volume
0.17	0.1	32%	18%	56%	51%	15%
	0.2	56%	33%	72%	77%	28%
	0.4	84%	57%	87%	94%	49%
	0.6	95%	73%	93%	98%	64%
	0.8	98%	83%	96%	99%	75%
	1.0	99%	90%	98%	99%	82%
	1.5	100%	97%	99%	100%	92%
	2.0	100%	99%	100%	100%	95%
0.27	0.1	36%	20%	57%	57%	18%
	0.2	51%	37%	74%	84%	33%
	0.4	88%	63%	88%	97%	55%
	0.6	97%	78%	94%	99%	70%
	0.8	99%	86%	97%	99%	79%
	1.0	100%	92%	98%	100%	85%
	1.5	100%	97%	99%	100%	93%
	2.0	100%	99%	100%	100%	96%
0.52	0.1	40%	23%	59%	65%	22%
	0.2	66%	42%	76%	90%	39%
	0.4	91%	68%	90%	98%	62%
	0.6	98%	82%	95%	99%	76%
	0.8	99%	89%	98%	100%	84%
	1.0	100%	94%	99%	100%	89%
	1.5	100%	98%	100%	100%	95%
	2.0	100%	99%	100%	100%	97%

BMP Performance Tables for Soil Infiltration Rate: Infiltration Trench

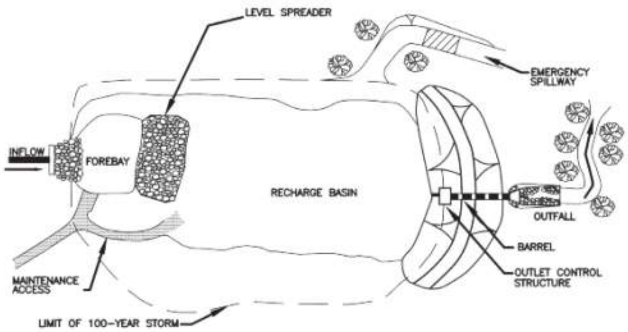
		Cumulative Load Reduction				
Infiltration Rate (in/hr)	Depth of Runoff from Impervious Area (inches)	TSS	Phosphorus	Nitrogen	Zinc	Runoff Volume
1.02	0.1	44%	27%	61%	72%	26%
	0.2	70%	47%	78%	94%	45%
	0.4	93%	73%	92%	99%	68%
	0.6	99%	86%	97%	100%	81%
	0.8	100%	92%	98%	100%	88%
	1.0	100%	96%	99%	100%	92%
	1.5	100%	99%	100%	100%	97%
	2.0	100%	100%	100%	100%	98%
2.41	0.1	50%	33%	65%	81%	34%
	0.2	77%	55%	83%	98%	55%
	0.4	97%	81%	95%	100%	78%
	0.6	100%	91%	98%	100%	88%
	0.8	100%	96%	99%	100%	93%
	1.0	100%	98%	100%	100%	96%
	1.5	100%	100%	100%	100%	99%
	2.0	100%	100%	100%	100%	100%
8.27	0.1	92%	50%	76%	93%	54%
	0.2	98%	75%	92%	100%	76%
	0.4	100%	94%	98%	100%	93%
	0.6	100%	98%	100%	100%	97%
	0.8	100%	99%	100%	100%	99%
	1.0	100%	100%	100%	100%	100%
	1.5	100%	100%	100%	100%	100%
	2.0	100%	100%	100%	100%	100%

Infiltration Basin Factsheet

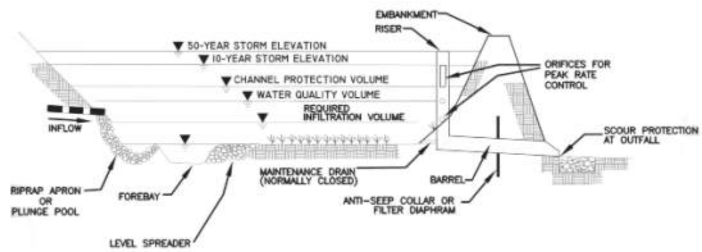
Infiltration Basin represents a practice that provides temporary surface storage of runoff (e.g. ponding) for subsequent infiltration into the ground. Appropriate practices for use of the surface infiltration performance estimates include infiltration basins, infiltration swales (not conveyance swales), rain gardens, and bio-retention systems that rely on infiltration and provide the majority of storage capacity through surface-ponding. If an infiltration system includes both surface storage through ponding and a lesser storage volume within the void spaces of a coarse filter media, then the physical storage volume capacity used to determine the long-term cumulative phosphorus removal efficiency from the infiltration basin performance curves would be equal to the sum of the surface storage volume and the void space storage volume. General design specifications for infiltration basin systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 90

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

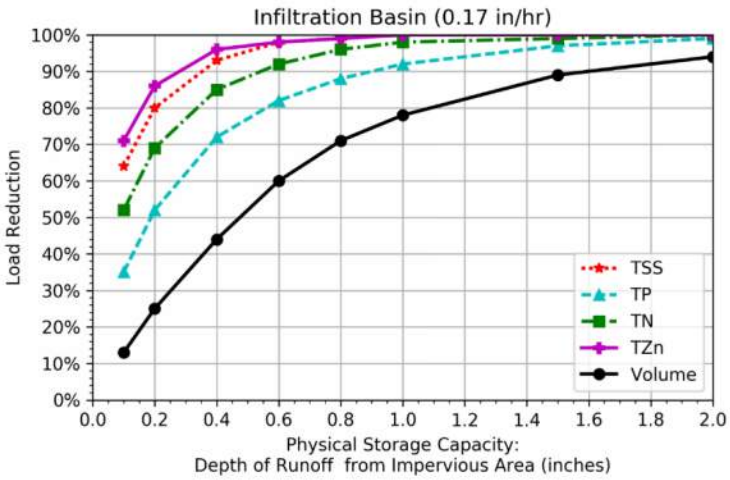
Cost

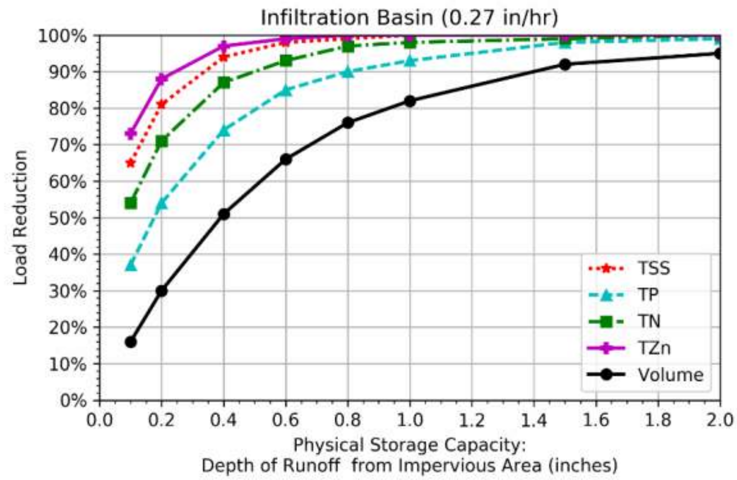
	Materials and Installation Cost ($/ft^3) (2020)	Design Cost ($/ft^3) (2020)	Total Cost ($/ft^3) (2020)[1,2]
Rural	4.17	2.24	6.41
Mixed	8.33	4.49	12.82
Urban	12.50	6.73	19.23

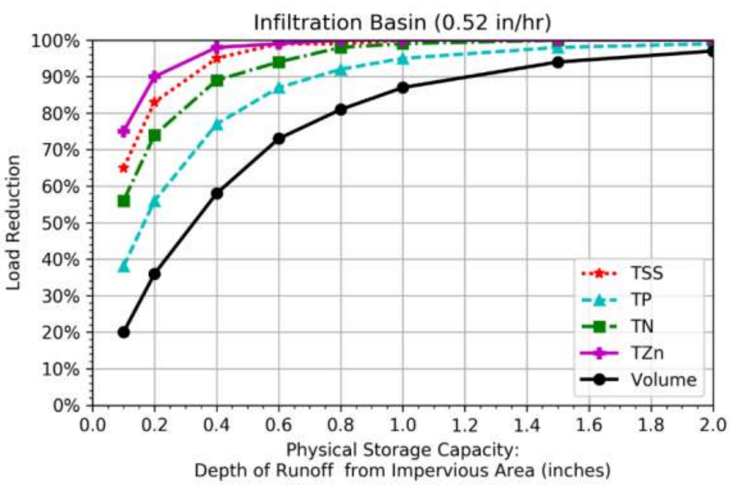
[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

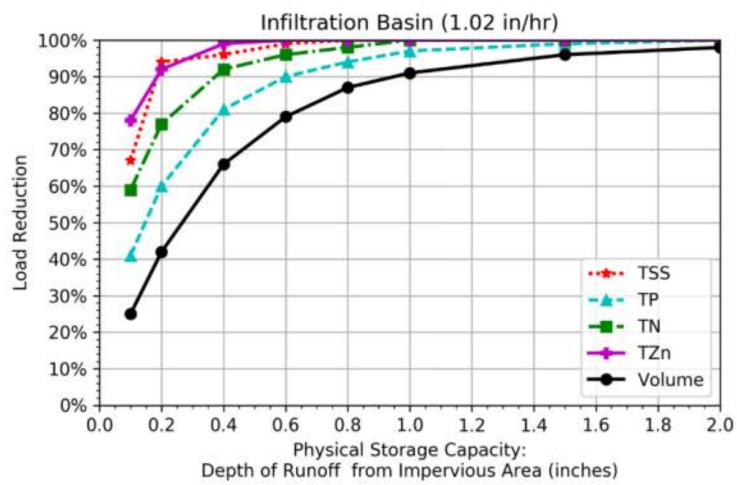
Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

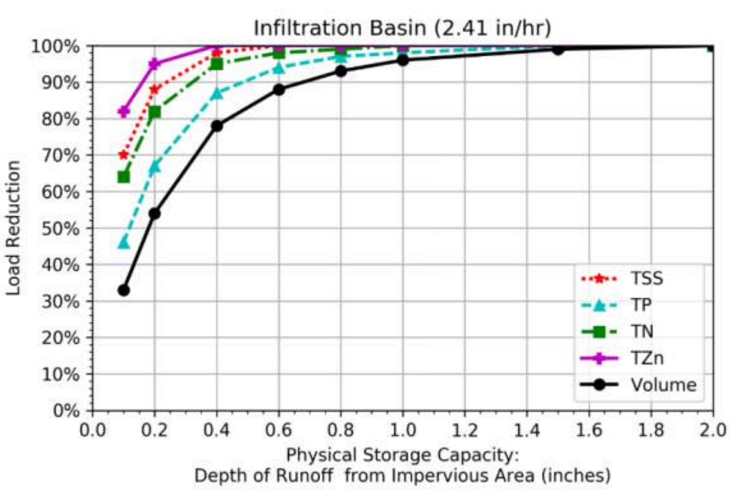
BMP Performance Curves for Soil Infiltration Rate: Infiltration Basin

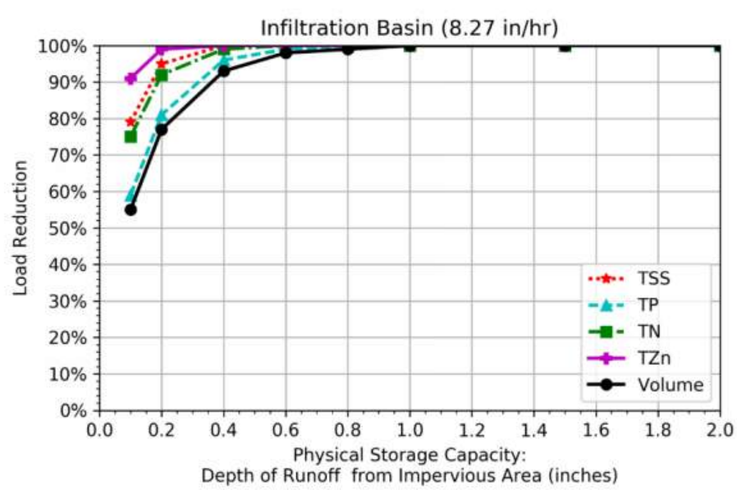












BMP Performance Tables for Soil Infiltration Rate: Infiltration Basin

		Cumulative Load Reduction				
Infiltration Rate (in/hr)	Depth of Runoff from Impervious Area (inches)	TSS	Phosphorus	Nitrogen	Zinc	Runoff Volume
0.17	0.1	64%	35%	52%	71%	13%
	0.2	80%	52%	69%	86%	25%
	0.4	93%	72%	85%	96%	44%
	0.6	98%	82%	92%	98%	60%
	0.8	99%	88%	96%	99%	71%
	1.0	100%	92%	98%	100%	78%
	1.5	100%	97%	99%	100%	89%
	2.0	100%	99%	100%	100%	94%
0.27	0.1	65%	37%	54%	73%	16%
	0.2	81%	54%	71%	88%	30%
	0.4	94%	74%	87%	97%	51%
	0.6	98%	85%	93%	99%	66%
	0.8	99%	90%	97%	100%	76%
	1.0	100%	93%	98%	100%	82%
	1.5	100%	98%	99%	100%	92%
	2.0	100%	99%	100%	100%	95%
0.52	0.1	65%	38%	56%	75%	20%
	0.2	83%	56%	74%	90%	36%
	0.4	95%	77%	89%	98%	58%
	0.6	99%	87%	94%	99%	73%
	0.8	99%	92%	98%	100%	81%
	1.0	100%	95%	99%	100%	87%
	1.5	100%	98%	100%	100%	94%
	2.0	100%	99%	100%	100%	97%

BMP Performance Tables for Soil Infiltration Rate: Infiltration Basin

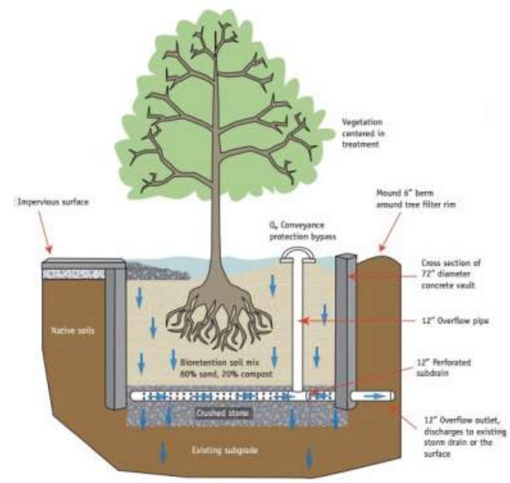
		Cumulative Load Reduction				
Infiltration Rate (in/hr)	Depth of Runoff from Impervious Area (inches)	TSS	Phosphorus	Nitrogen	Zinc	Runoff Volume
1.02	0.1	67%	41%	59%	78%	25%
	0.2	94%	60%	77%	92%	42%
	0.4	96%	81%	92%	99%	66%
	0.6	99%	90%	96%	100%	79%
	0.8	100%	94%	98%	100%	87%
	1.0	100%	97%	100%	100%	91%
	1.5	100%	99%	100%	100%	96%
	2.0	100%	100%	100%	100%	98%
2.41	0.1	70%	46%	64%	82%	33%
	0.2	88%	67%	82%	95%	54%
	0.4	98%	87%	95%	100%	78%
	0.6	100%	94%	98%	100%	88%
	0.8	100%	97%	99%	100%	93%
	1.0	100%	98%	100%	100%	96%
	1.5	100%	100%	100%	100%	99%
	2.0	100%	100%	100%	100%	100%
8.27	0.1	79%	59%	75%	91%	55%
	0.2	95%	81%	92%	99%	77%
	0.4	100%	96%	99%	100%	93%
	0.6	100%	99%	100%	100%	98%
	0.8	100%	100%	100%	100%	99%
	1.0	100%	100%	100%	100%	100%
	1.5	100%	100%	100%	100%	100%
	2.0	100%	100%	100%	100%	100%

Biofiltration Factsheet

Biofiltration is a practice that provides temporary storage of runoff for filtering through an engineered soil media. The storage capacity is typically made of void spaces in the filter media and temporary ponding at the surface of the practice. Once the runoff has passed through the filter media it is collected by an under-drain pipe for discharge. The performance curve for this control practice assumes zero infiltration. If a filtration system has subsurface soils that are suitable for infiltration, then user should use either the performance curves for the infiltration trench or the infiltration basin depending on the predominance of storage volume made up by free standing storage or void space storage. Depending on the design of the manufactured or packaged bio-filter systems such as tree box filters may be suitable for using the bio-filtration performance results. Design specifications for biofiltration systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Profile view of a Tree Box Filter. The underdrain makes the system one example of a biofiltration system.



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 116

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

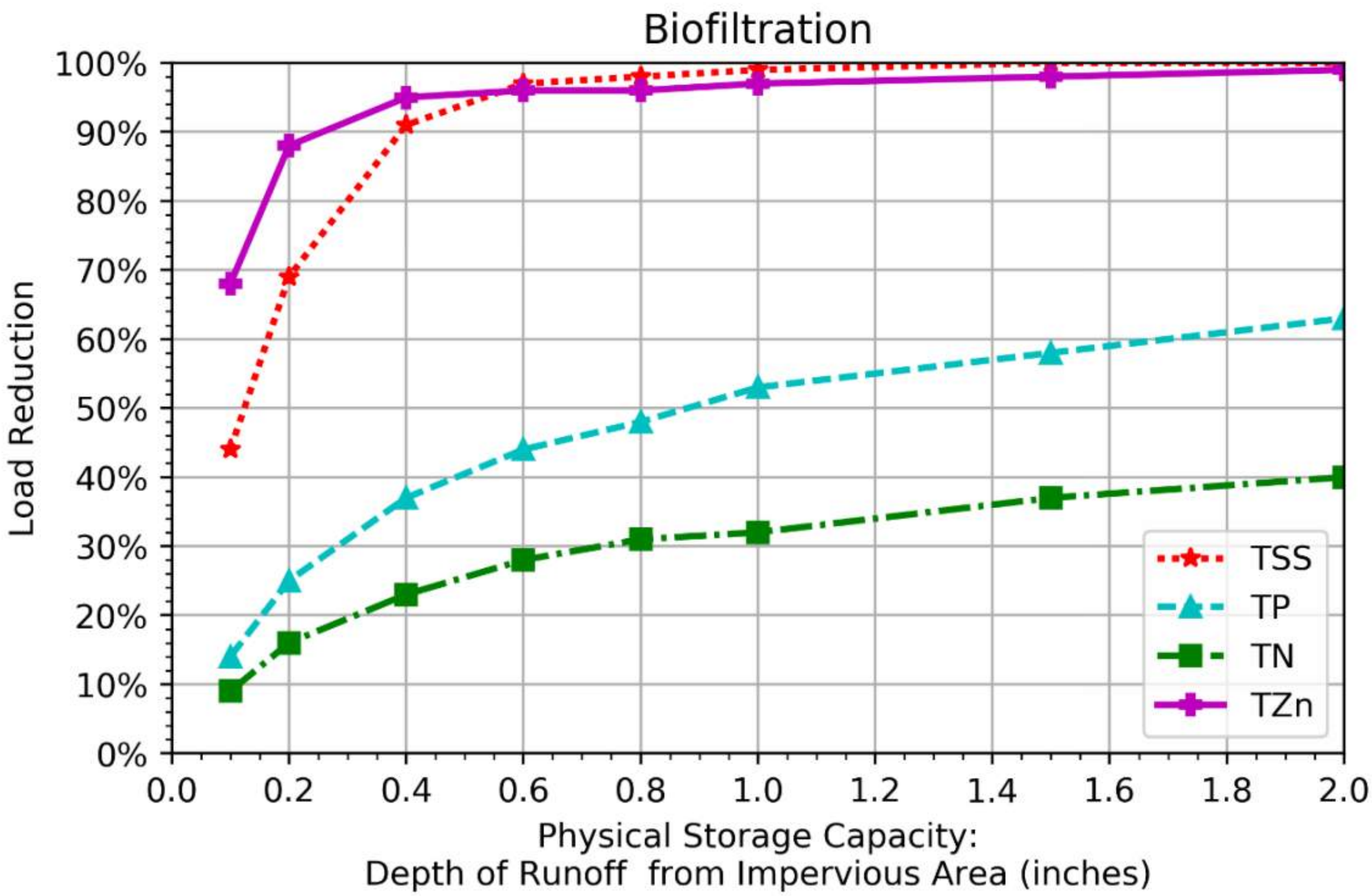
Cost

	Materials and Installation Cost ($/ft^3) (2020)	Design Cost ($/ft^3) (2020)	Total Cost ($/ft^3) (2020)[1,2]
Rural	10.32	5.55	15.87
Mixed	20.63	11.11	31.74
Urban	30.95	16.66	47.61

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Biofiltration



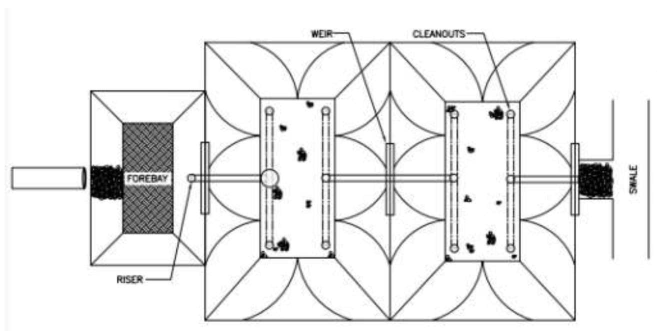
Biofiltration BMP Performance Table								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	44%	69%	91%	97%	98%	99%	100%	100%
Cumulative Phosphorus Load Reduction	14%	25%	37%	44%	48%	53%	58%	63%
Cumulative Nitrogen Load Reduction	9%	16%	23%	28%	31%	32%	37%	40%
Cumulative Zinc Phosphorus Load Reduction	68%	88%	95%	96%	96%	97%	98%	99%

Gravel Wetlands Factsheet

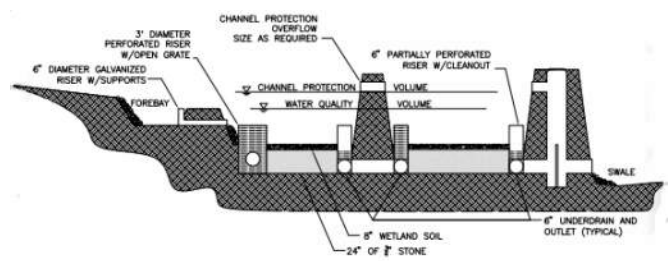
Gravel Wetlands consists of one or more flow-through constructed wetland cells, preceded by a forebay. The cells are filled with a gravel media, supporting an organic substrate that is planted with wetland vegetation. During low-flow storm events, the systems is designed to promote subsurface horizontal flow through the gravel media, allowing contact with the root zone of the wetland vegetation. The gravel and planting media support a community of soil microorganisms. Water quality treatment occurs through microbial, chemical, and physical processes within this media. Treatment may also be enhanced by vegetative uptake.. General design specifications for infiltration basin systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 80

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

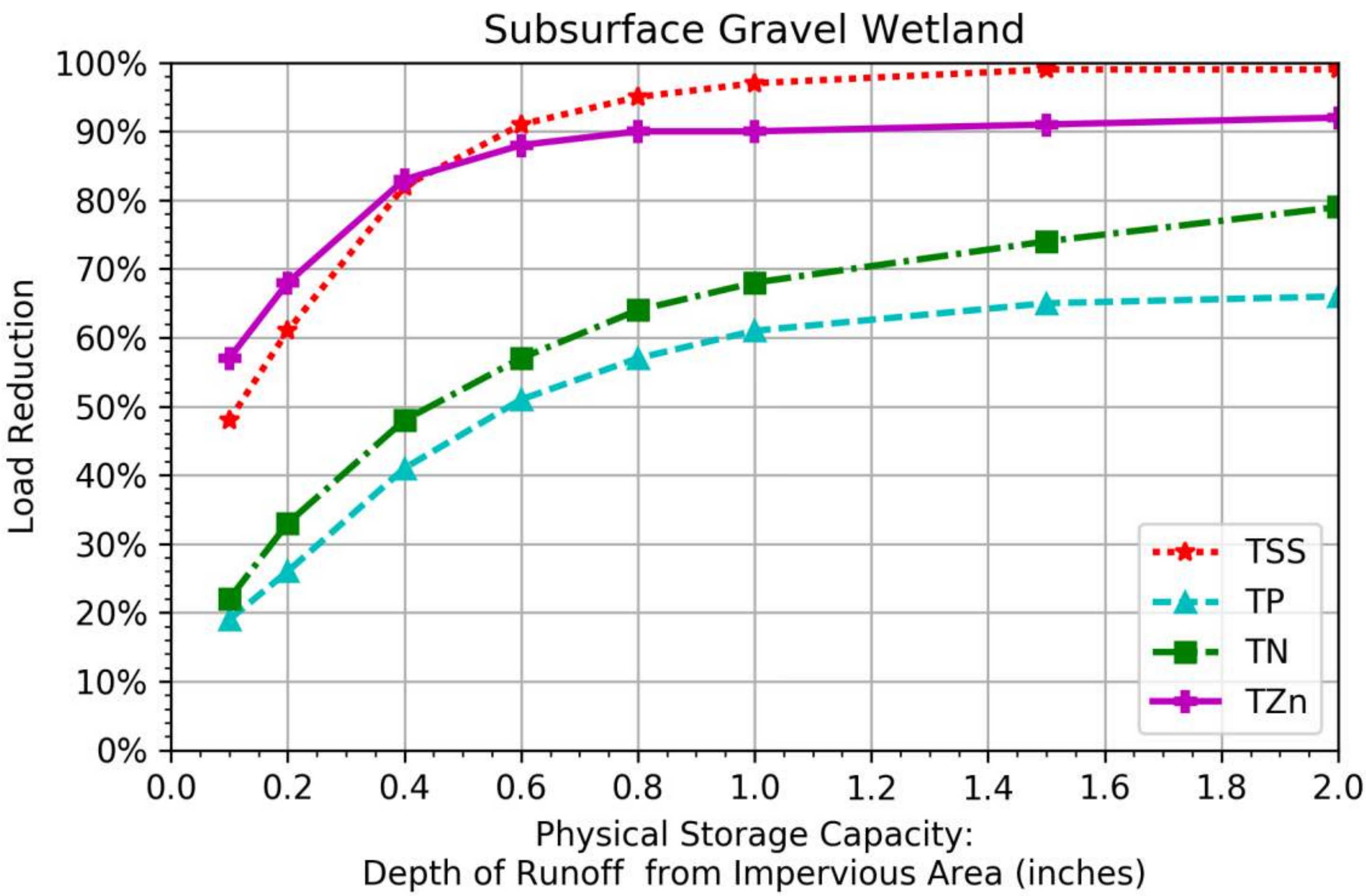
Cost

	Materials and Installation Cost ($\$/ft^3$) (2020)	Design Cost ($\$/ft^3$) (2020)	Total Cost ($\$/ft^3$) (2020)[1,2]
Rural	5.86	3.15	9.01
Mixed	11.71	6.31	18.02
Urban	17.57	9.46	27.03

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

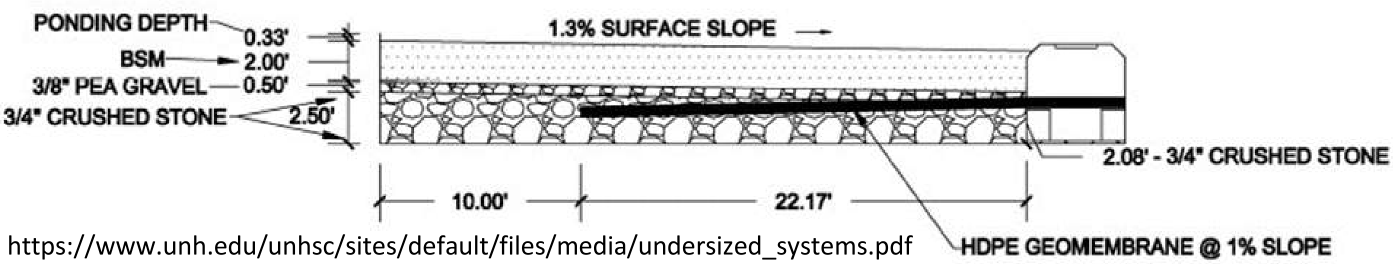
BMP Performance Curve for Gravel Wetlands



Gravel Wetland BMP Performance Table								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	48%	61%	82%	91%	95%	97%	99%	99%
Cumulative Phosphorus Load Reduction	19%	26%	41%	51%	57%	61%	65%	66%
Cumulative Nitrogen Load Reduction	22%	33%	48%	57%	64%	68%	74%	79%
Cumulative Zinc Phosphorus Load Reduction	57%	68%	83%	88%	90%	90%	91%	92%

Enhanced Biofiltration with Internal Storage Reservoir (ISR) Factsheet

Enhanced Biofiltration is a practice the provides temporary storage of runoff for filtering through an engineered soil media, augmented for enhanced phosphorus removal, followed by detention and denitrification in a subsurface internal storage reservoir (ISR) comprised of gravel. Runoff flows are routed through filter media and directed to the underlying ISR via an impermeable membrane for temporary storage. An elevated outlet control at the top of the ISR is designed to provide a retention time of at least 24 hours in the system to allow for sufficient time for denitrification and nitrogen reduction to occur prior to discharge. The design storage capacity for using the cumulative performance curves is comprised of void spaces in the filter media, temporary ponding at the surface of the practice and the void spaces in the gravel ISR. The cumulative phosphorus load reduction curve for this control is intended to be used for systems in which the filter media has been augmented with materials designed and/or known to be effective at capturing phosphorus. If the filter media is not augmented to enhance phosphorus capture, then the phosphorus performance curve for the Bio-Filter should be used for estimating phosphorus load reductions. The University of New Hampshire Stormwater Center (UNHSC) developed the design of this control practice and a design templated can be found at UNHSC's website.



https://www.unh.edu/unhsc/sites/default/files/media/undersized_systems.pdf

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

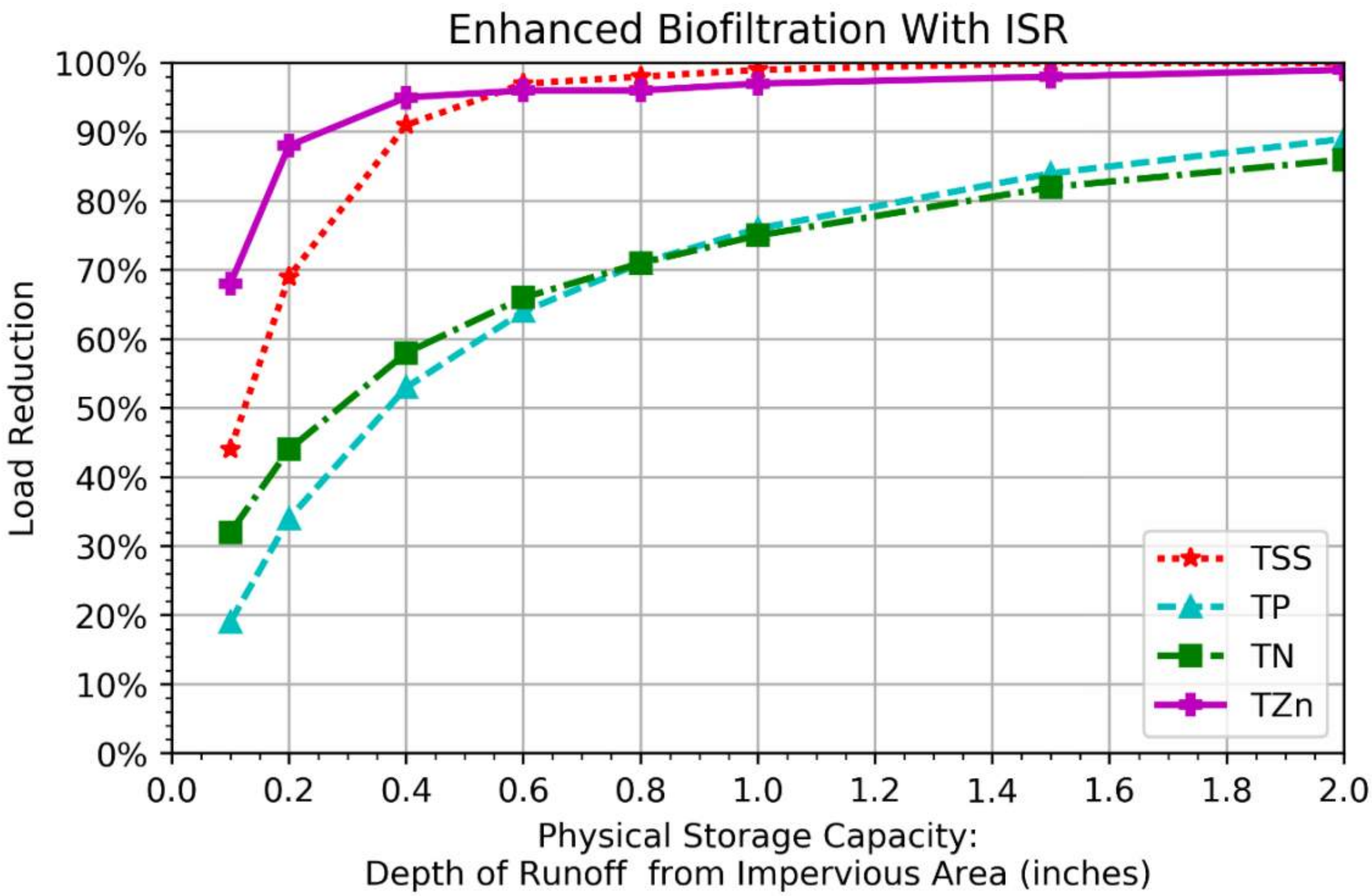
Cost

	Materials and Installation Cost ($/$ft^3$) (2020)	Design Cost ($/$ft^3$) (2020)	Total Cost ($/$ft^3$) (2020)[1,2]
Rural	10.42	5.61	16.02
Mixed	20.83	11.22	32.05
Urban	31.25	16.83	48.07

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Enhanced Biofiltration w/ ISR



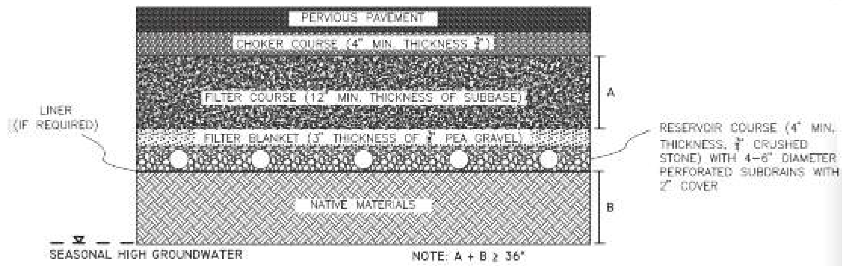
Enhanced Biofiltration w/ ISR BMP Performance Table: Long-Term Phosphorus & Nitrogen Load Reduction								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	44%	69%	91%	97%	98%	99%	100%	100%
Cumulative Phosphorus Load Reduction	19%	34%	53%	64%	71%	76%	84%	89%
Cumulative Nitrogen Load Reduction	32%	44%	58%	66%	71%	75%	82%	86%
Cumulative Zinc Phosphorus Load Reduction	68%	88%	95%	96%	96%	97%	98%	99%

Porous Pavement Factsheet

Porous Pavement consists of a porous surface, base, and sub-base materials which allow penetration of runoff through the surface into underlying soils. The surface materials for porous pavements can consist of paving blocks or grids, pervious asphalt, or pervious concrete. These materials are installed on a base which serves as a filter course between the pavement surface and the underlying sub-base material. The sub-base material typically comprises a layer of crushed stone that not only supports the overlying pavement structure, but also serves as a reservoir to store runoff that penetrates the pavement surface until it can percolate into the ground. General design specifications for porous pavement systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 120

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

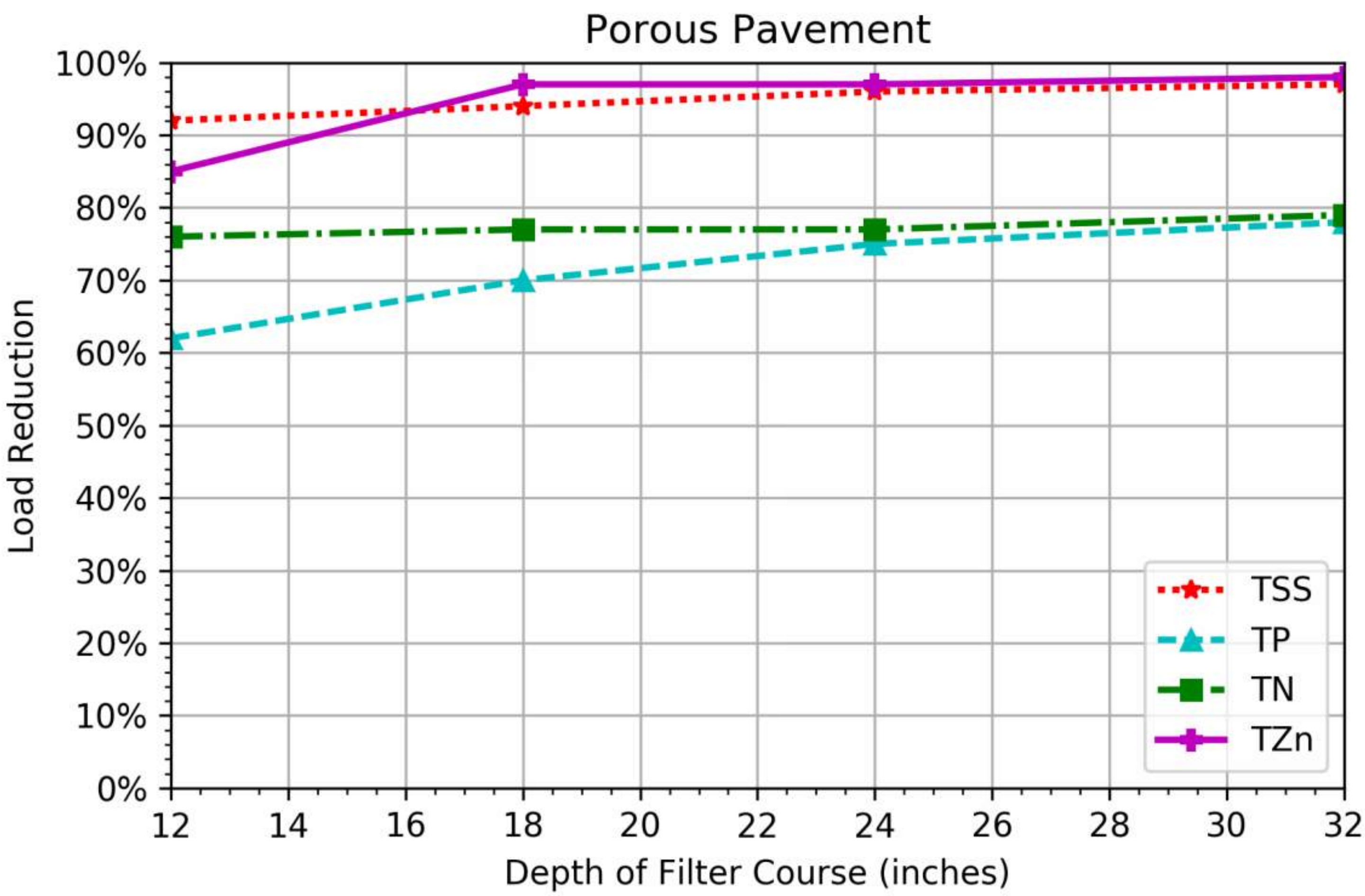
Cost

	Materials and Installation Cost ($/ft³) (2020)		Design Cost ($/ft³) (2020)		Total Cost ($/ft³) (2020)[1,2]	
	Porous Asphalt	Porous Concrete	Porous Asphalt	Porous Concrete	Porous Asphalt	Porous Concrete
Rural	3.55	12.06	1.91	6.49	5.46	18.55
Mixed	7.10	24.12	3.82	12.99	10.92	37.11
Urban	10.65	36.18	5.73	19.48	16.38	55.66

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Porous Pavement



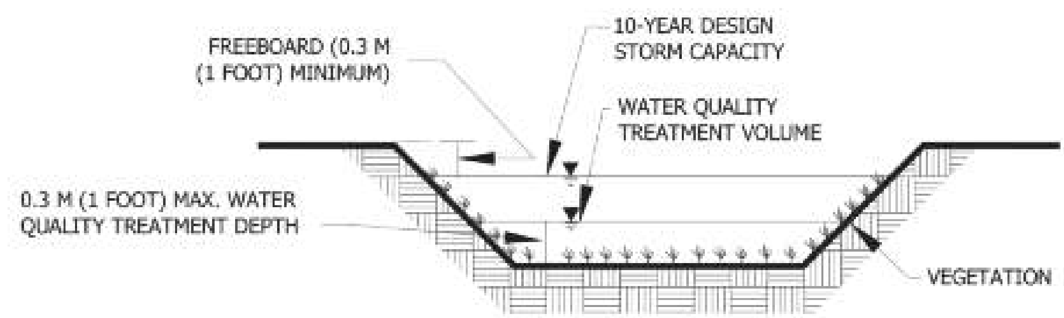
Porous Pavement BMP Performance Table				
BMP Capacity: Depth of Filter Course Area (inches)	12	18	24	32
Cumulative TSS Phosphorus Load Reduction	92%	94%	96%	97%
Cumulative Phosphorus Load Reduction	62%	70%	75%	78%
Cumulative Nitrogen Load Reduction	76%	77%	77%	79%
Cumulative Zinc Phosphorus Load Reduction	85%	97%	97%	98%

Grass Swale Factsheet

Grass Swale is a system which consists of a vegetated channel with check dams designed to convey and treat stormwater runoff. The design of allows filtration through the vegetation and check dams and infiltration through the subsurface soil media. Vegetation for the swale is selected based on mowing requirements, expected design flow, and site soil conditions. The channel should be designed to carry the max design flow within the design depth while preventing erosion within the channel. General design specifications for grass swale systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 145

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

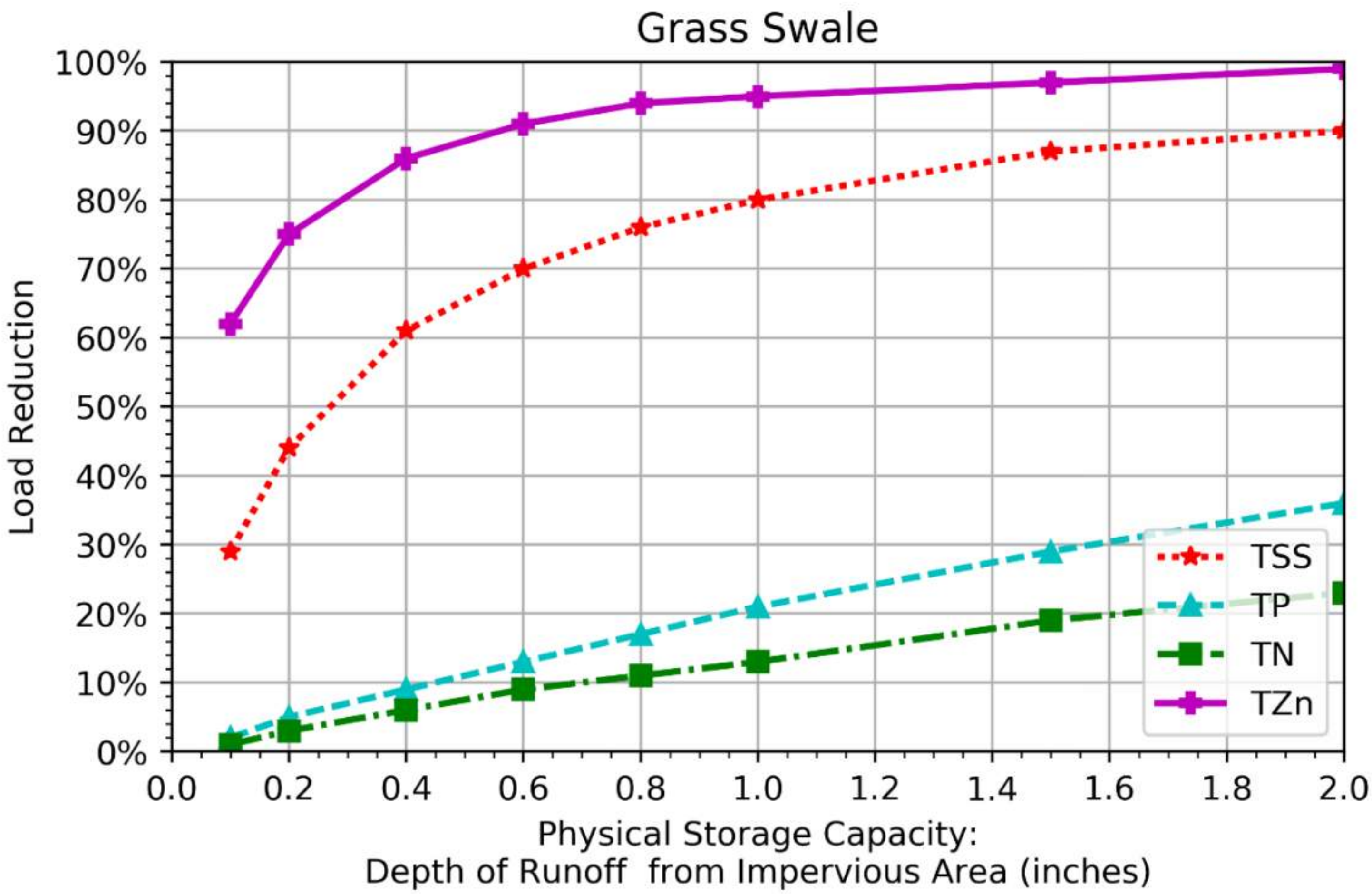
General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

[1] EPA Memorandum “Methodology for developing cost estimates for Opti-Tool.” Februrary 20, 2016

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Grass Swale



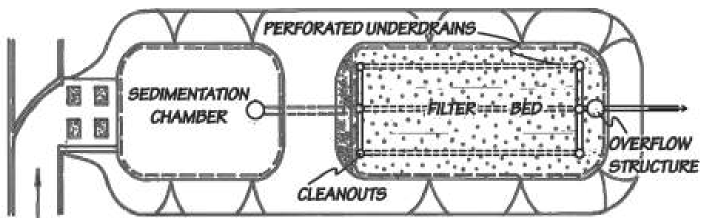
Grass Swale BMP Performance Table								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	29%	44%	61%	70%	76%	80%	87%	90%
Cumulative Phosphorus Load Reduction	2%	5%	9%	13%	17%	21%	29%	36%
Cumulative Nitrogen Load Reduction	1%	3%	6%	9%	11%	13%	19%	23%
Cumulative Zinc Phosphorus Load Reduction	62%	75%	86%	91%	94%	95%	97%	99%

Sand Filter Factsheet

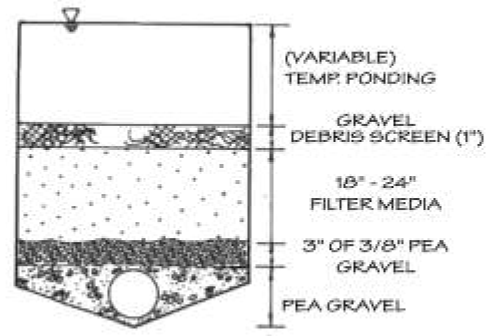
Sand Filter is a system which provides filtering of runoff through a sand filter media and temporary storage of runoff within the void spaces prior to discharge by way of an underdrain. Sand filters are generally used for overflow conditions of the primary BMP, and as such often include a pretreatment device to allow coarse settlements to settle out of the water. The top surface of the filter is kept clear of vegetation. General design specifications for sand filter systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Section View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 104

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

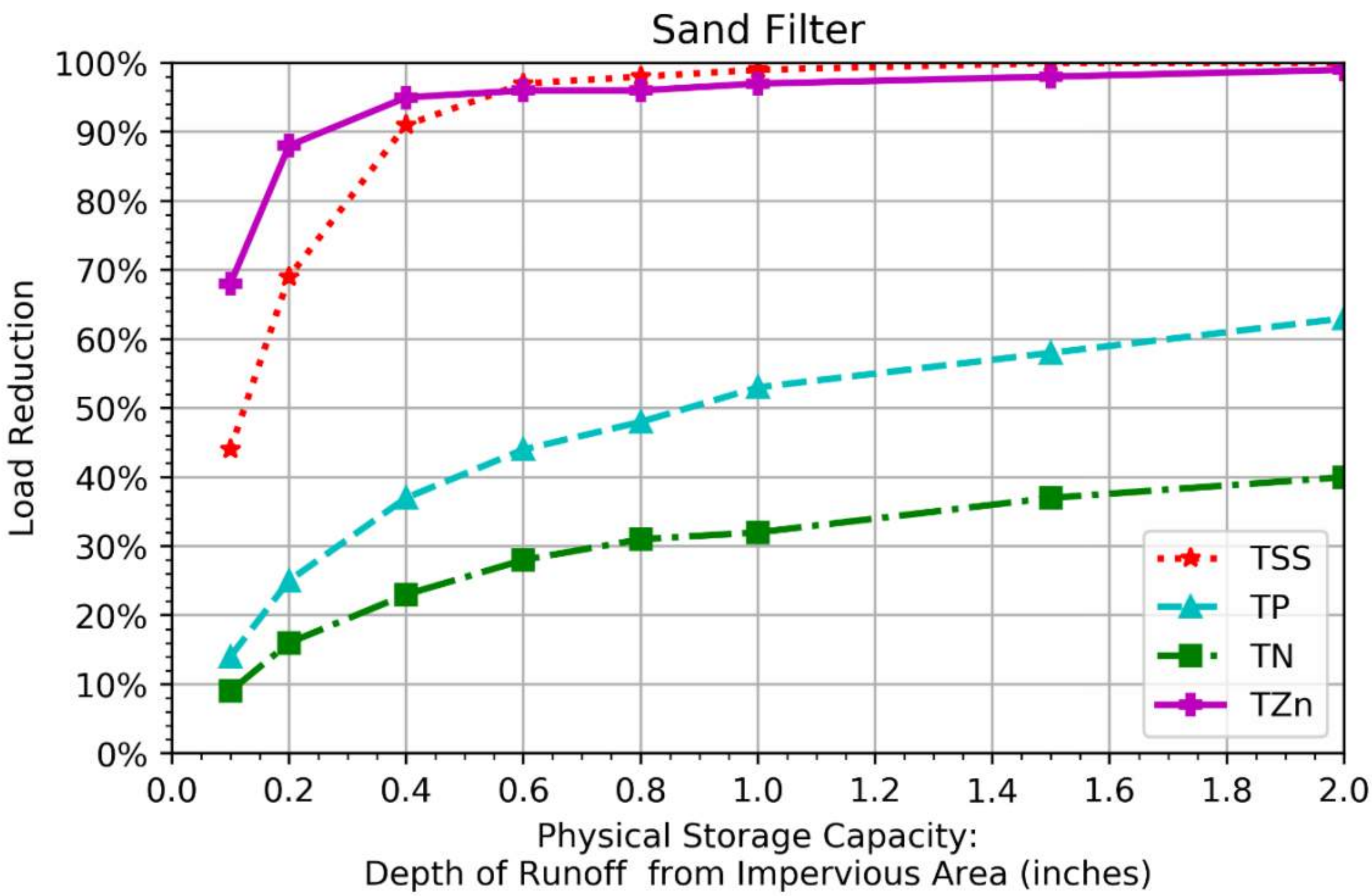
Cost

	Materials and Installation Cost ($/ft³) (2020)	Design Cost ($/ft³) (2020)	Total Cost ($/ft³) (2020)[1,2]
Rural	11.97	6.44	18.41
Mixed	23.93	12.89	36.82
Urban	35.90	19.33	55.23

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Sand Filter



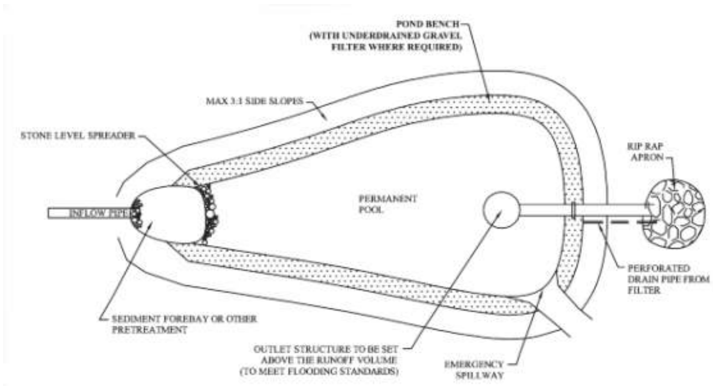
Sand Filter BMP Performance Table								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	44%	69%	91%	97%	98%	99%	100%	100%
Cumulative Phosphorus Load Reduction	14%	25%	37%	44%	48%	53%	58%	63%
Cumulative Nitrogen Load Reduction	9%	16%	23%	28%	31%	32%	37%	40%
Cumulative Zinc Phosphorus Load Reduction	68%	88%	95%	96%	96%	97%	98%	99%

Wet Pond Factsheet

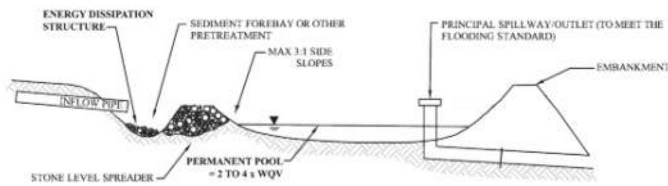
Wet Pond is a class of systems designed to maintain a permanent pool of water year-round. The pool allows for pollutant removal via settling, biological uptake, and decomposition. This allows the system to treat both sediment loads and its commonly associated pollutants along with treating dissolved nutrients through the pond's biological processes. For areas where water temperature is a concern, an underdrained gravel trench in the bench area around the permanent pool can allow for the extended release of stormwater, minimizing risk of clogging. General design specifications for wet pond systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 61

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

Cost

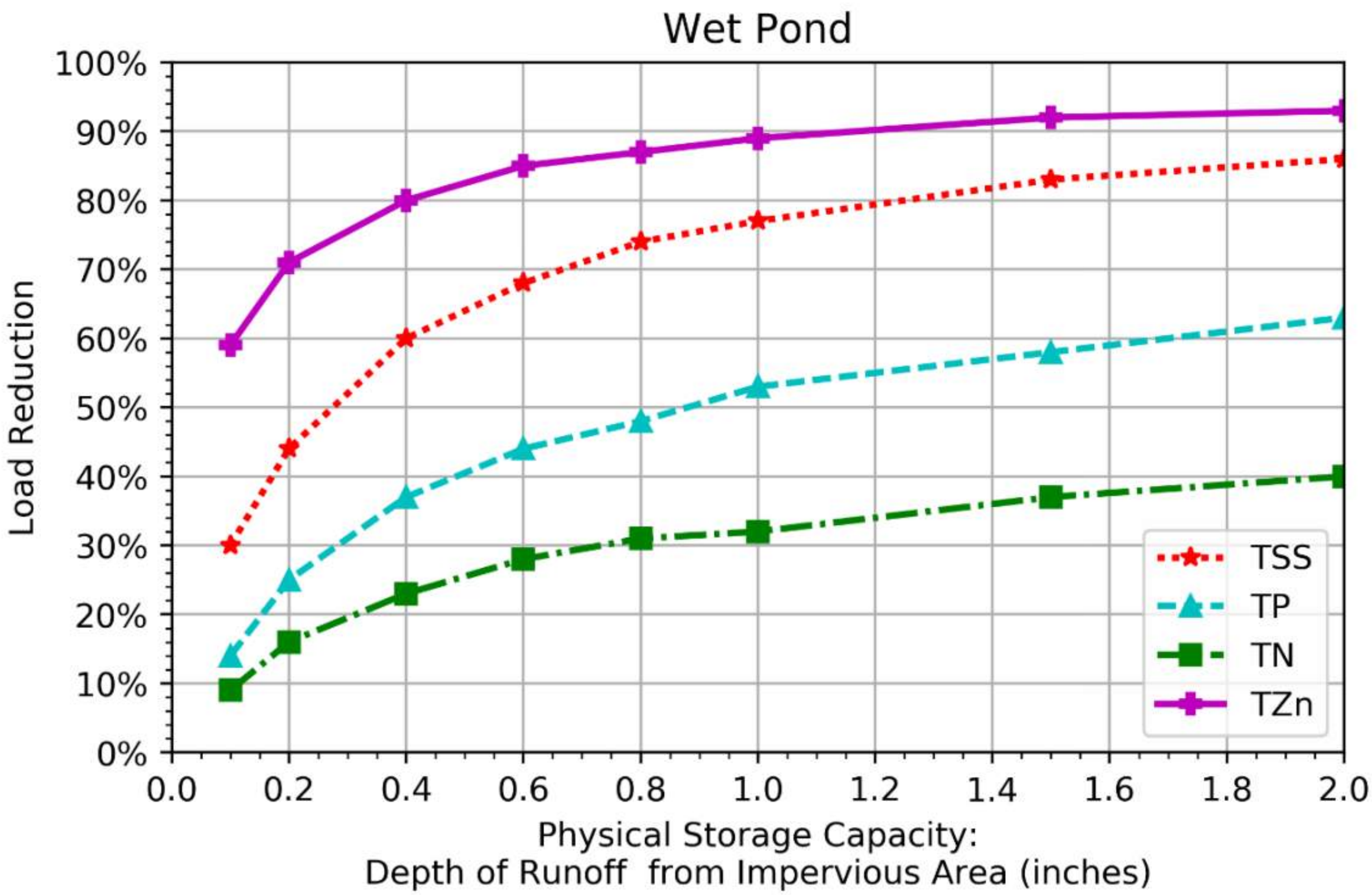
	Materials and Installation Cost ($/ft^3) (2020)	Design Cost ($/ft^3) (2020)	Total Cost ($/ft^3) (2020)[1,2]
Rural	4.54	2.44	6.98
Mixed	9.07	4.89	13.96
Urban	13.61	7.33	20.94

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016

[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire
Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Wet Pond



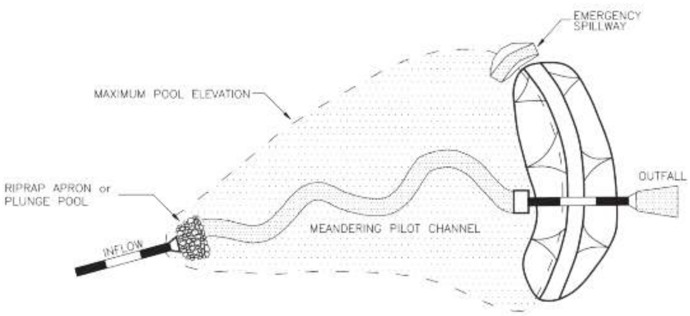
Wet Pond BMP Performance Table								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	30%	44%	60%	68%	74%	77%	83%	86%
Cumulative Phosphorus Load Reduction	14%	25%	37%	44%	48%	53%	58%	63%
Cumulative Nitrogen Load Reduction	9%	16%	23%	28%	31%	32%	37%	40%
Cumulative Zinc Phosphorus Load Reduction	59%	71%	80%	85%	87%	89%	92%	93%

Extended Dry Detention Basin Factsheet

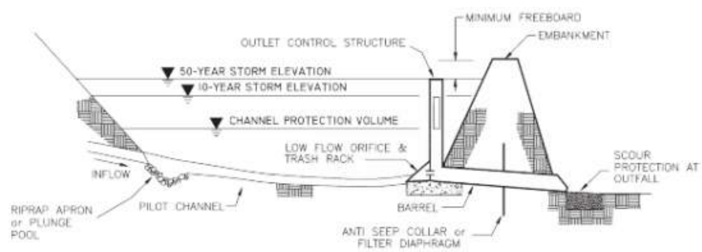
Detention Basin consists of a type of system which is primarily intended to provide flood protection by containing the flow within an excavated area and gradually releasing it over the course of a design length of time, with extended dry detention basins typically having a detention time of 24 hours. This reduces the intensity of peak flows, and the detention time allows the treatment of some pollutants, particularly those associated with suspended solids. A detention basin may be combined with other BPMs to combine detention with other treatment methods. Dry detention basins are often referred to as dry ponds, due to their similarity in design to wet ponds. General design specifications for detention basin systems are provided in the most recent version of *The New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection and Design*.

Sample Design

Plan View



Profile View



Examples images from the *New Hampshire Stormwater Manual, Volume 2,* p. 159

Pollutant Export Rate by Land Use[1]

Source Category by Land Use	Land Surface Cover	P Load Export Rate[1] (lbs./acre/year)	N Load Export Rate[2] (lbs./acre/year)
Commercial (COM) and Industrial (IND)	Directly connected impervious	1.78	15
Multi-Family (MFR) and High-Density Residential (HDR)	Directly connected impervious	2.32	14.1
Medium-Density Residential (MDR)	Directly connected impervious	1.96	14.1
Low-Density Residential (LDR) - "Rural"	Directly connected impervious	1.52	14.1

[1] From NH Small MS4 General Permit, Appendix F

General Equations

Physical Storage Capacity: Depth of Runoff * Drainage Area
Cost: Physical Storage Capacity * Cost Index * Adjustment Factor[1]
Yearly Pollutant Removal: Pollutant Load Export Rate * Drainage Area * Efficiency

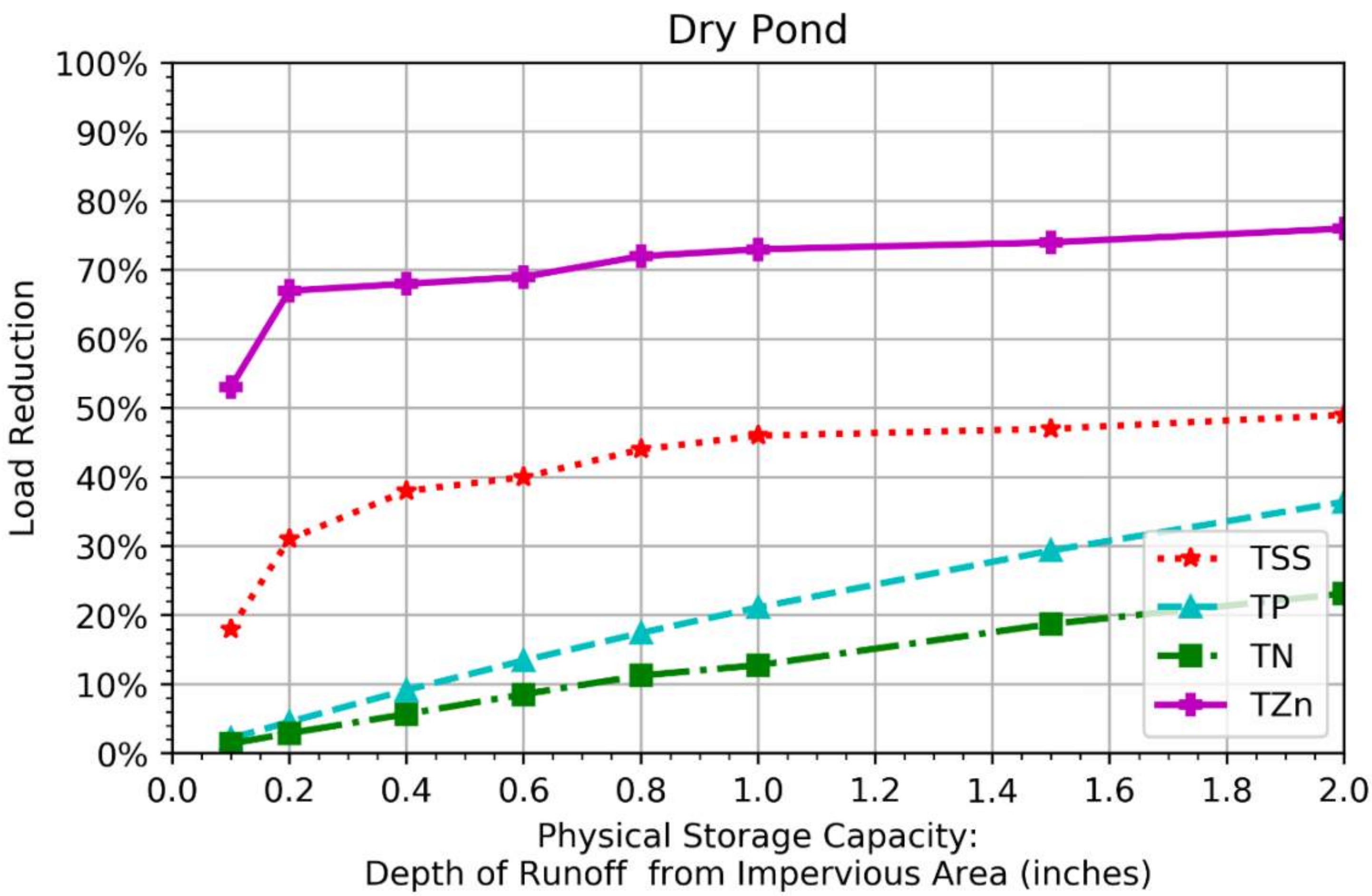
Cost

	Materials and Installation Cost ($/ft^3) (2020)	Design Cost ($/ft^3) (2020)	Total Cost ($/ft^3) (2020)[1,2]
Rural	4.54	2.44	6.98
Mixed	9.07	4.89	13.96
Urban	13.61	7.33	20.94

[1] EPA Memorandum "Methodology for developing cost estimates for Opti-Tool." Februrary 20, 2016
[2] Converted from 2010 to 2020 dollars using U.S. Department of Labor (USDOL). (2012). Bureau of Labor Statistics consumer price index inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

Prepared By:
University of New Hampshire Stormwater Center
Durham, NH
www.unh.edu/unhsc
January 2020

BMP Performance Curve for Extended Dry Detention Basin



Dry Pond BMP Performance Table								
BMP Capacity: Depth of Runoff from Impervious Area (inches)	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Cumulative TSS Phosphorus Load Reduction	18%	31%	38%	40%	44%	46%	47%	49%
Cumulative Phosphorus Load Reduction	2%	5%	9%	13%	17%	21%	29%	36%
Cumulative Nitrogen Load Reduction	1%	3%	6%	9%	11%	13%	19%	23%
Cumulative Zinc Phosphorus Load Reduction	53%	67%	68%	69%	72%	73%	74%	76%

Tisbury MA Impervious Cover Disconnection (ICD) Project: An Integrated Stormwater Management Approach for Promoting Urban Community Sustainability and Resilience

A technical direct assistance project funded by the U.S. EPA Southeast New England Program (SNEP)

Task 4D. Develop Planning Level GI SCM Performance Curves for Estimating Cumulative Reductions in SW-Related Indicator Bacteria

Prepared for:

U.S. EPA Region 1

In Cooperation With:

Town of Tisbury, MA
Tisbury Waterways
Martha's Vineyard Commission
Massachusetts Department of Transportation

Prepared by:

Paradigm Environmental
University of New Hampshire Stormwater Center
Great Lakes Environmental Center

Under Contract:

Blanket Purchase Agreement: BPA-68HE0118A0001-0003
Requisition Number: PR-R1-18-00375
Order: 68HE0118F0011

September 30, 2019

To:	Ray Cody, Mark Voorhees (US EPA Region 1)
From:	Khalid Alvi, David Rosa, Ryan Murphy (Paradigm Environmental)
CC:	Project Technical Team
Date:	9/30/2019
Re:	Develop Planning Level Green Infrastructure (**GI**) Stormwater Control Measure (**SCM**) Performance Curves for Estimating Cumulative Reductions in SW-Related Indicator Bacteria (Task 4D)

1 EXECUTIVE SUMMARY

This memorandum presents the technical approach for developing planning-level green infrastructure (**GI**) stormwater control measure (**SCM**) performance curves for indicator bacteria load reduction for use within Opti-Tool (U.S. EPA, 2016). The resulting curves provide estimates of relative cumulative bacteria load reductions that can be expected from the implementation of various SCMs. Consistent with the other performance curves previously developed for the New England region (EPA Region 1), the cumulative indicator bacteria performance curves provide estimates of the overall net reductions accomplished by SCMs for all storm events that have occurred over an extended period of time (1998–2018). Consequently, the curves reflect the known primary dynamic processes involved with both the generation of stormwater runoff pollution including the build-up of pollutants on impervious surfaces and the frequency and intensity of precipitation, as well as the continuous routing of runoff flow and pollutants through treatment processes in SCMs. While these curves provide reasonable long-term performance (in terms of annual average load reduction and should not be substituted with event mean concentration reduction) expectations of various SCM types and sizes, they are not suitable for estimating SCM bacteria load reductions for a single design storm event or for quantifying expected changes in indicator bacteria concentrations.

When applying these curves to specific sites and watersheds, baseline bacteria loading should be estimated from local monitoring data if available. Otherwise, the bacteria loading rates provided in Opti-Tool could be used to estimate cumulative bacteria loads to assist users in developing planning level information that quantifies the expected overall long-term benefits of various SCMs for addressing waterbody bacteria impairments. Use of these curves is especially encouraged in cases where quantification of SCM benefits otherwise rely on a single published SCM removal rate for a specific design storm or water quality volume that may not be applicable to the size or type of SCMs being assessed.

The Storm Water Management Model (SWMM) (U.S. EPA. 2015) and the System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) GI simulation engine (U.S. EPA. 2009) were utilized in curve development to estimate stormwater quantity and quality boundary conditions and establish relationships between SCM storage capacity and bacteria load reduction, respectively. A literature review identified event mean concentration (EMC), unit area loading values, and SWMM buildup/washoff values used to establish boundary conditions. The SCM efficiency values were also derived from values in the literature review.

Several factors may contribute to bacteria removal efficiency within an SCM with the major mechanisms being physical processes including sedimentation, sorption, and filtration. However, other factors impacting bacteria removal include SCM holding time, temperature, sunlight, salinity, and predation. Careful consideration of SCM types and associated processes is necessary when applying these curves to specific sites and watersheds. For example, it is well documented that infiltration practices are highly effective at achieving bacterial reductions as runoff exfiltrates through subsoils. Consequently, practitioners may confidently select infiltration SCMs to address excessive SW bacteria loading wherever site conditions are favorable for infiltration. However, there is greater uncertainty in bacteria removal performances associated with flow-through SCMs that rely primarily on sedimentation or vegetative filtering because of the potential bacterial regrowth and subsequent entrainment during storm events resulting in the SCM becoming a source of bacteria to surface waters. Generally, users should first consider infiltration SCMs followed by filtering systems and last other SCMs to address excessive SW bacterial loading.

While such due diligence can help facilitate the implementation of SCMs that can achieve the estimated bacteria load reductions given local conditions, there is still a large amount of uncertainty involved in estimating both bacterial loading and long-term cumulative performances of SCMs especially for flow-through SCMs. The removal curves provide estimates of bacterial load removal efficiency based on the literature rather than detailed model calibrations of individual SCMs with extensive performance data. Consequently, the curves represent planning level information for developing management plans and quantifying potential benefits. SCMs intended to achieve the reductions presented in Opti-Tool should be installed and maintained in a manner that promotes the identified bacteria removal processes and mechanisms. Regular inspections and ambient water quality monitoring are recommended to help ensure that the SMCs are operating as expected.

2 INTRODUCTION

Performance curves representing indicator bacteria (*E. coli*) load reductions that may be achieved by SCM treatment of stormwater were developed based on simulated runoff from impervious Hydrologic Response Units (**HRUs**). The curves may also be applied to other indicator bacteria, such as *Enterococcus* load reductions if the underlying mechanisms for the SCM performance are similar to other indicator bacteria. The SCM performance curves represent long-term average annual indicator bacteria load reductions (as a percent) that can be expected for a wide range of SCM storage capacities. Rainfall-runoff response timeseries from impervious HRUs were simulated using the **SWMM** hydrology model (U.S. EPA. 2015). The SCM performance curves were developed using the **SUSTAIN** GI simulation engine (U.S. EPA. 2009) through Opti-Tool (U.S. EPA. 2016). This modeling approach has previously been used to provide performance curves for total nitrogen (TN), total phosphorus (TP)), sediments (Total Suspended Sediment (TSS)), and zinc (Zn). Both models (SWMM and SUSTAIN) for Opti-Tool were calibrated using New England's regional monitoring data, observed pollutant event mean concentrations (**EMCs**) in stormwater runoff and observed inflow/outflow pollutant concentrations from stormwater SCMs that were studied to assess pollutant reduction performances. HRU timeseries for bacteria were developed for the impervious surfaces of the urbanized New England community of Tisbury, MA, located on Martha's Vineyard. A literature review identified concentration, loading, and buildup/washoff values used to develop the timeseries. The resulting concentrations and loadings represent generalized conditions for purposes of SCM performance curve development and do not reflect the specific bacteria loading conditions in Tisbury, MA. A literature review was also completed to identify SCM efficiency values to include in SUSTAIN GI simulation. For a given depth of runoff volume storage capacity from the impervious cover by an SCM, the curves provide an estimated bacteria load reduction given as a percentage of total loading. Due to a lack of literature values for SCM removal efficiencies for *Enterococcus*, the rates for *E. col*i were used for both fecal bacteria indicators.

3 IMPERVIOUS HRU TIMESERIES FOR INDICATOR BACTERIA

The SUSTAIN model requires hourly timeseries of flow and pollutant load as a boundary condition to run. To develop impervious HRU timeseries, the HRU SWMM hydrology model, developed previously for Opti-Tool, was used for hourly flow simulation. The same model was updated for water quality by adding two fecal bacteria indicators (*E. coli* and *Enterococcus*). The hourly precipitation timeseries and daily air temperature data collected at the Martha's Vineyard Airport was used in the HRU SWMM model to represent the local patterns of precipitation, including dry periods between storm events when pollutants accumulate on impervious surfaces. The output timeseries from the SWMM model were formatted for the Opti-Tool using a utility tool, *SWMM2Opti-Tool*, available in the Opti-Tool package. The following subsections describe the steps for developing the impervious HRU timeseries for indicator bacteria.

3.1 Literature Review

3.1.1 Introduction

A literature review was conducted to find stormwater related EMCs (MPN[1]/100 ml) and average annual export rates (MPN/ac/yr) for *E. coli* and *Enterococcus* from impervious land cover. Recent journal publications, conference papers, and data from the national stormwater quality database (NSQD) were reviewed to obtain information specific to these types of indicator bacteria. Several published sources of bacteria EMCs from urban areas were identified and summarized. A limited number of observed average annual export rates were found, therefore the literature review was expanded to include published export rates for fecal coliform. The literature review also included an evaluation of previous SWMM models and associated buildup/washoff values for *E. coli* and *Enterococcus*.

3.1.2 Event Mean Concentrations

An EMC is a flow proportional concentration of a pollutant, when applied to bacteria it is calculated as the total constituent number of bacteria divided by total runoff volume for a single event. Several physical, biological, and chemical factors can impact the fate and transport of microbes within a watershed, including temperature, moisture, sunlight, nutrients, settling, adsorption/desorption processes, hydrologic processes and predation (Ferguson et al., 2003). While sanitary sewage pollution contamination can contribute to high bacteria concentrations, elevated levels are often observed in areas not impacted by sewage (Shergill and Pitt, 2004). Unsurprisingly, monitoring studies often show tremendous variability in bacteria concentrations (Table 1-1). Figure 1-1 and Figure 1-2 summarize the EMCs for residential, commercial, industrial, and transportation land uses. Residential areas generally had the highest *E. coli* EMCs, followed by commercial, industrial, and transportation. While residential EMS were also relatively high for *Enterococcus*, the highest observed EMC (Stein et al., 2008) was from commercial land. Additionally, transportation had a higher EMC than industrial land uses. However, care should be taken in drawing conclusions about the relative bacteria loading from different impervious surfaces given the limited and highly variable data.

Because of the uncertainty associated with bacteria EMCs, models such as the water treatment model (WTM) use the median urban runoff value for fecal coliform from National Urban Runoff Program (NURP) data (Pitt, 1998) of 20,000 MPN/100 ml as the default model value for bacteria (Caraco, 2013). Table 1-1 presents published EMC for *E. coli* and *Enterococcus* from developed land uses. Values with associated error, designated with a ± in Table 1-1 indicate EMCs reported as a mean of multiple events, potentially from multiple sites of the same land use. EMCs from six studies as well as the NSQD were found for *E. coli.* Only three studies were identified that reported EMCs for *Enterococcus*.

EMCs for *E. coli* ranged from a low of 5/100 ml from a parking lot (transportation land use) in Maryland (Li and Davis, 2009) to a high of $(5.3 \pm 1.7) \times 10^5$/100 ml from recreational land in California (Stein et al., 2008). Hathaway and Hunt (2010) found a mean *E. coli* EMC of 2.5671×10^3/100 ml from an urban watershed in Raleigh, North Carolina, although individual samples ranged from 0.71×10^3 to 85.233×10^3 /100 ml. Additionally, Hathaway and Hunt (2010) found a mean *Enterococcus* EMC of 2.155×10^3/100 ml from the same urban watershed, although individual samples ranged from 1.306×10^3 to 181.846×10^3/100 ml. *Enterococcus* EMCs from urban land uses in California ranged from $(8.9 \pm 4.4) \times 10^3$ from transportation to $(1.4 \pm 0.82) \times 10^5$ from recreational areas (Stein, 2008).

[1] where, MPN refers to "most probable number". Fecal coliform and E. coli in compost or leachate is usually reported in MPN per g compost or MPN per 100 mL water (or leachate). MPN/100ml is a statistical probability of the number of organisms. Refer to, American Public Health Association, American Water Works Association, Water Environment Federation (2012), Standard Methods for the Examination of Water and Waste Water. Depending on circumstances, US EPA may prefer MPN rather than Colony Forming Units (CFU) (actual plate count) "because a colony in a CFU test might have originated from a clump of bacteria instead of an individual, the count is not necessarily a count of separate individuals." Environmental Regulations and Technology. Control of Pathogens and Vector Attraction in Sewage Sludge (Including Domestic Septage) Under 40 CFR Part 503, EPA/625/R-92/013 (https://www.epa.gov/sites/production/files/2015-04/documents/control_of_pathogens_and_vector_attraction_in_sewage_sludge_july_2003.pdf).

3.1.3 Export rates

Studies of bacteria export from urban areas relied on stream sampling for estimates. Therefore, there is additionally uncertainty associated with applying these rates to areas such as Tisbury, MA where stormwater is not conveyed to a receiving stream or river but is instead discharged directly into a coastal ecosystem. Line et al. (2008) monitored stream concentrations of fecal coliform from industrial and residential sites in North Carolina. Loading from these urban areas ranged from 180,024 to 477,654 million MPN/ac/yr. These values were higher than observed *E. coli* loading estimated in Maryland from a watershed consisting of medium-to-high density residential and open urban land uses resulted (EA Engineering, 2010) (Table 1-2). CDM (2012) estimated loading from several sites in Boston's municipal separate storm sewer system (MS4). Export was highly variable, *E. coli* ranged from 22 billion CFU/ac/yr to 1.4 trillion CFU/ac/yr. Site imperviousness ranged from 25% to 94%, although the loading estimates did not distinguish between urban land use types.

3.1.4 Buildup/Washoff Values

The pollutant buildup and washoff functions in SWMM are similar to the equations developed for the accumulation and washoff of dust and dirt on street surfaces (APWA, 1969; Sartor et al., 1974). Previous applications of SWMM to simulate the buildup and washoff of *E. coli* and *Enterococcus* were reviewed and summarized. Two studies were identified, one for Boston's MS4 (CMD Smith, 2012) and another for the city of Lakewood, Ohio (CT Consultants, 2016). Both studies relied on local bacteria monitoring data to calibrate the models. The calibrated parameter values for both studies are presented in Table 1-3.

Table 1-1 Observed Event Mean Concentration (EMC) for *E. coli* and *Enterococci* by land use type

	EMC (MPN/100ml)				
Land use	**Residential**	**Recreational**	**Commercial**	**location**	**Source**
E. coli	$(3.0 \pm 1.8) \times 10^4$ (Low Residential)	$(5.3 \pm 1.7) \times 10^5$	$(1.1 \pm 0.88) \times 10^4$	CA	Stein, 2008
	$(8.2 \pm 7.7) \times 10^3$ (High Residential)	-	-	CA	Stein, 2008
	2.938×10^3	-	-	NC	Krometis et al., 2009
	$1 \times 10^1 – 3.5 \times 10^4$	-	-	MA	NSQD
	25.671×10^3 (Medium Residential)	-	-	NC	Hathaway and Hunt, 2010
Enterococcus	2.166×10^4	-	-	NC	Krometis et al., 2009
	$(5.5 \pm 3.7) \times 10^4$ (Low Residential)	$(1.4 \pm 0.82) \times 10^5$	$(7.7 \pm 9.2) \times 10^4$	CA	Stein et al, 2008
	$(2.7 \pm 3.6) \times 10^4$ (High Residential)	-	-	CA	Stein et al, 2008
	25.155×10^3 (Medium Residential)	-	-	NC	Hathaway and Hunt, 2010
	18.00×10^3 (Multifamily)		13.00×10^3	MA	Breault et al., 2002
	27.00×10^3 (Single Family)			MA	Breault et al., 2002

	EMC (MPN/100ml)				
Land use	**Urban**	**Industrial**	**Transportation**	**location**	**Source**
E. coli	-	$(3.8 \pm 2.3) \times 10^3$	$(1.4 \pm 2.7) \times 10^3$	CA	Stein, 2008
	10.846×10^3	-	-	TN, TX, WA, WI	Schueler, 2000
	15.01×10^3	-	-	NC	McCarthy et al., 2012
	-	-	5	MD	Li and Davis, 2009
	-	-	92	MD	Li and Davis, 2009
	$25.671 \times 10^3 \pm 24.393 \times 10^3$	-	-	NC	Hathaway and Hunt, 2010
Enterococcus	-	$(2.1 \pm 2.2) \times 10^4$	$(8.9 \pm 4.4) \times 10^3$	CA	Stein et al, 2008

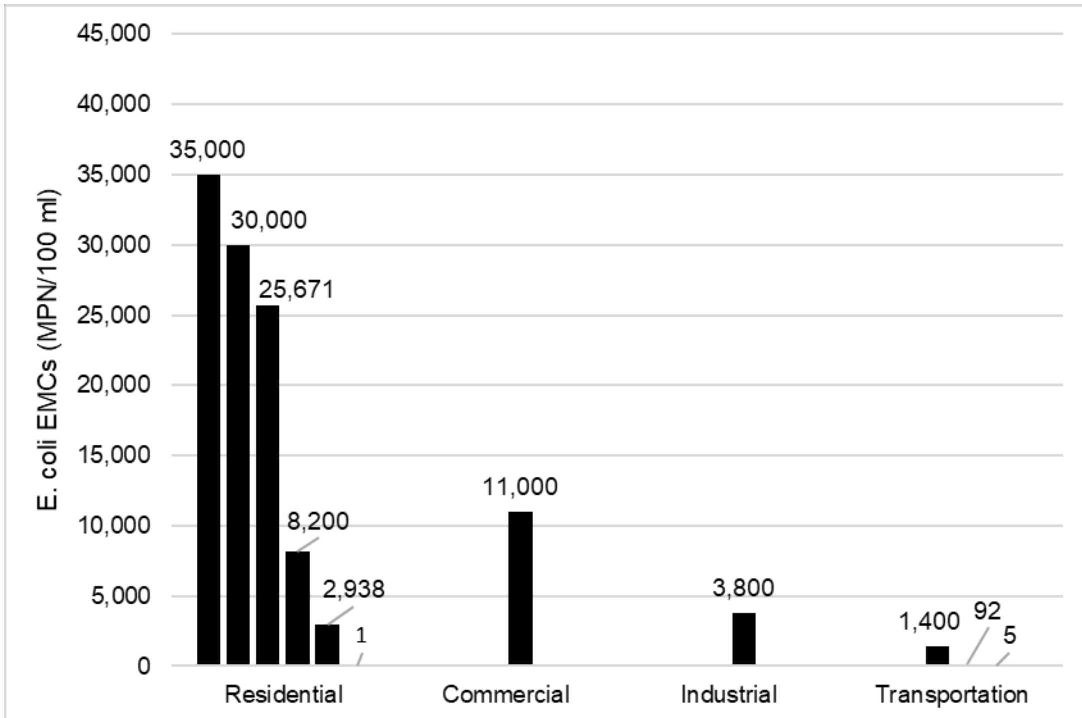


Figure 1-1. Mean observed EMCs for *E. coli* from literature (See Table 1-1)

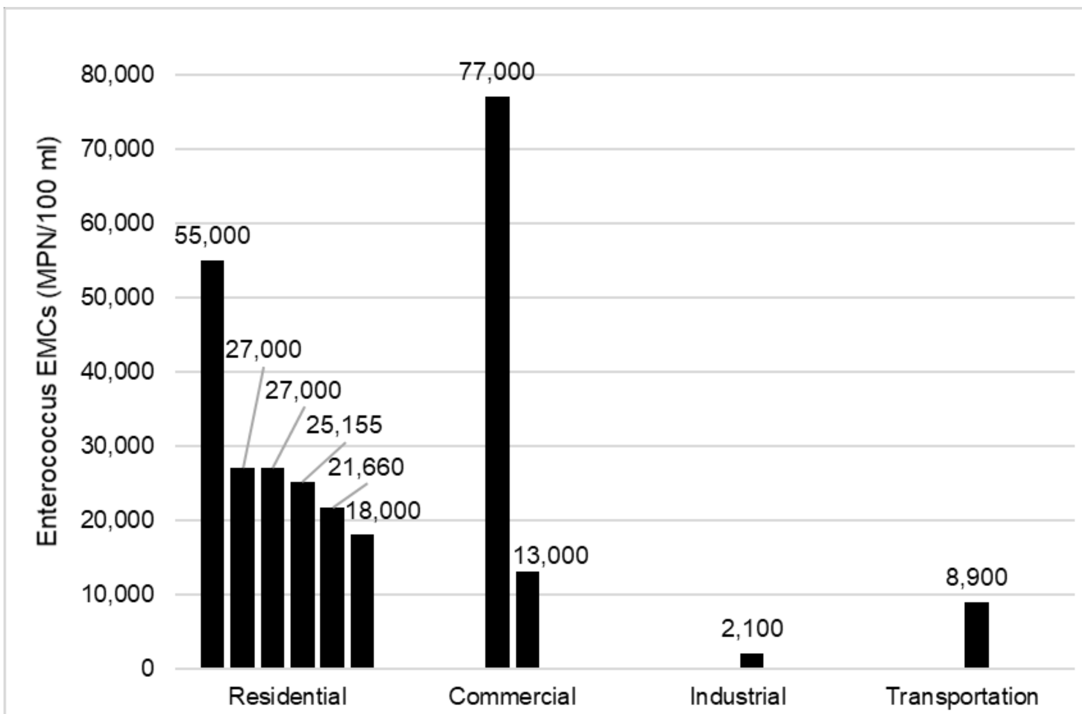


Figure 1-2. Mean observed EMCs for *Enterococcus* from literature (See Table 1-1)

Table 1-2 . Observed Bacteria Loading from urban areas

	Land use	Billion MPN/ac/yr	Source
Fecal Coliform	Urban	190.024 – 477.654	(Line et al, 2008)
E. coli	Open Urban	13.789 – 60.482	(EA Engineering, 2010)
	Residential/Commercial	9.00 – 3.80	
	Various	22 - 1,397	CDM Smith, 2012*
Enterococcus	Various	64 – 930	CDM Smith, 2012*

*Units in CFUs, not MPN

Table 1-3 Summary of previously calibration SWMM buildup and washoff values for *E. coli* and *Enterococcus*

		Study Location	
		Boston, MA	Lakewood, OH
(Single-family) Low-density residential			
Buildup Equation		Exponential	Saturation
Max per acre (C1)	E. coli	85.6×10^{9}	6.9×10^{11}
	Enterococci	26.6×10^{9}	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	2	10
	Enterococci	2	-
Washoff Equation		Exponential	Exponential
Coefficient – C1	E. coli	18	10
	Enterococci	18	-
Exponent – C2	E. coli	2.2	0.5
	Enterococci	2.2	-
(Multi- family) Medium density residential			
Buildup Equation		Exponential	Saturation
Max per acre (C1)	E. coli	85.6×10^{9}	2.5×10^{10}
	Enterococci	25.6×10^{9}	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	2	10
	Enterococci	2	-
Washoff Equation		Exponential	Exponential
Coefficient – C1	E. coli	18	10
	Enterococci	18	-
Exponent – C2	E. coli	2.2	0.5
	Enterococci	2.2	-
High density residential			
Buildup Equation		Exponential	Saturation
Max per acre (C1)	E. coli	-	1.41×10^{11}
	Enterococci	-	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	-	10
	Enterococci	-	-
Washoff Equation		Exponential	Exponential
Coefficient – C1	E. coli	-	10
	Enterococci	-	-
Exponent – C2	E. coli	-	0.5
	Enterococci	-	-
Commercial			
Buildup Equation		Exponential	Saturation
Max per acre (C1)	E. coli	0.42×10^{9}	1.4×10^{12}
	Enterococci	0.72×10^{9}	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	2	10
	Enterococci	2	-

		Study Location	
		Boston, MA	Lakewood, OH
Washoff Equation		Exponential	Exponential
Coefficient – C1	E. coli	18	10
	Enterococci	18	-
Exponent – C2	E. coli	2.2	0.5
	Enterococci	2.2	-
Industrial			
Buildup Equation		Exponential	Saturation
Max per acre (C1)	E. coli	1.26×10^9	1.4×10^{12}
	Enterococci	2.12×10^9	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	2	10
	Enterococci	2	-
Washoff Equation		Exponential	Exponential
Coefficient – C1	E. coli	18	10
	Enterococci	18	-
Exponent – C2	E. coli	2.2	0.5
	Enterococci	2.2	-
Transportation			
Buildup Equation		Exponential	NA
Max per acre (C1)	E. coli	0.001×10^9	-
	Enterococci	0.002×10^9	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	2	-
	Enterococci	2	-
Washoff Equation		Exponential	NA
Coefficient – C1	E. coli	18	-
	Enterococci	18	-
Exponent – C2	E. coli	2.2	
	Enterococci	2.2	-
Open Space			
Buildup Equation		Exponential	Saturation
Max per acre (C1)	E. coli	126×10^9	1.25×10^{10}*
	Enterococci	214×10^9	-
C2 - Buildup rate constant (1/days) or Days to ½ max buildup	E. coli	2	10*
	Enterococci	2	-
Washoff Equation		Exponential	Exponential
Coefficient – C1	E. coli	18	10*
	Enterococci	18	-
Exponent – C2	E. coli	2.2	0.5
	Enterococci	2.2	-

Buildup in SWMM can occur as either a mass per unit of sub catchment area or per unit of curb length (Rossman, 2010). The amount of buildup is a function of antecedent dry weather days. The user can choose a power, exponential, or saturation function to compute buildup, or use an external time series to describe the rate of buildup per day as a function of time (Rossman, 2010). CMD Smith (2012) used an exponential buildup and a rate constant (1/days) of 2, which is equivalent to 0.3 days to reach ½ max buildup. Alternatively, CT Consultants (2016) used the saturation function and a value of 10 days to reach ½ max buildup. The exponential function builds up pollutants very rapidly, then slows down to the maximum value while the saturation function has a less rapid buildup and a more gradual approach to the maximum value. Additionally, CMD Smith (2012) also added a term to represent bed load growth of bacteria to account for the potential for rapid population changes within the collection system, although this had minimal impact on overall model results.

SWMM can simulate washoff on user-defined land use categories using exponential, rating curve, or EMC functions. Exponential functions have been used to describe the washoff of dust and dirt from streets (Sartor et al., 1974). SWMM relies on user defined values for washoff coefficients and exponents, the runoff rate per unit area and the pollutant buildup in mass units to calculate exponential washoff. Both CDM Smith (2012) and CT Consultants (2016) used the exponential function to simulate washoff, with coefficients ranging from 10 to 18 and exponents ranging from 0.5 to 2.2.

3.1.5 Conclusions

Results of studies on the export of bacteria from urban watersheds had highly variable results; observed EMCs range over orders of magnitude. Fewer studies evaluated *Enterococcus* than *E. coli* and limited data was found on observed bacteria loading from urban areas. Previous studies using SWMM to model bacteria buildup and washoff relied on both exponential and saturation buildup functions. Using functions originally developed for the buildup and washoff of dust and dirt on streets to simulate the export of organisms is a simplified approach to a complex phenomenon. Several factors that can influence the propagation and die-off of bacteria in a watershed are necessarily omitted. For any bacteria export modeling effort, robust local monitoring data can help to inform model calibration and increase confidence in modeling results.

3.2 Climate Data (Precipitation and Air Temperature)

Historical climate data for the latest 21 years (1998 – 2018) from local gages at Martha's Vineyard airport was used for impervious HRU timeseries development. The climate data included:

- Hourly continuous precipitation timeseries (in/hr)
- Daily minimum and maximum temperature timeseries (°F)

The climate data was reviewed for its completeness and quality. After QA/QC was complete, the annual and monthly summary statistics were estimated to review and identify any data gaps/issues. The data was then formatted to the required input format for the HRU SWMM model. Additional discussion of climate data can be found in the task 4B memo "Opti-Tool Analyses for Quantifying Stormwater Runoff Volume and Pollutant Loadings from Watershed Source Areas (Task 4B)".

3.3 HRU SWMM Model (Initial Setup and Run)

Local climate data was used to update the boundary conditions in the Opti-Tool HRU SWMM model. Buildup/wash off parameters for modeling indicator bacteria load on the impervious HRU were initially set to the calibrated parameters used for Boston's MS_4 (CMD Smith, 2012). The model output timeseries was used to statistically summarize the predicted indicator bacteria EMC distributions and average annual pollutant export rates. For further analysis, box and whisker plots and bar graphs were created to compare these model timeseries to literature values.

3.4 HRU Timeseries (Hourly Flow and Bacteria Concentration and Load Estimates)

SWMM model output timeseries were structured into the required format for the SUSTAIN model using a spreadsheet-based utility tool, SWMM2Opti-Tool, available in Opti-Tool (Figure 3-3). The HRU timeseries format for the Opti-Tool is identical to the format needed in SUSTAIN (the Opti-Tool uses the SUSTAIN model as a backend GI simulation engine).

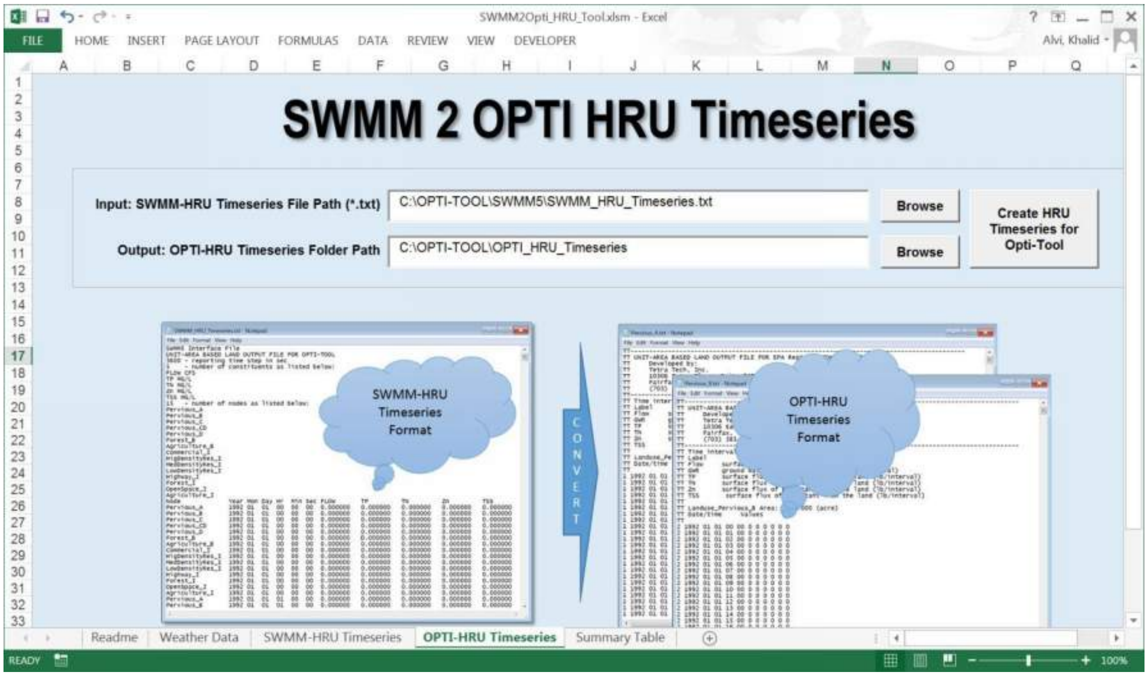


Figure 3-3. The user interfaces for *SWMM2Opti-Tool*, a utility to reformat SWMM output to Opti-Tool HRU timeseries.

Figure 3-4 and Figure 3-5 present simulated *E. coli* and *Enterococci* concentrations, respectfully, based on the calibrated buildup/washoff values from CDM Smith (2012). Bacteria concentrations were highest from residential land uses and lowest from transportation. These results are reflective of the maximum buildup values attributed to each land use (Table 1-3). Maximum buildup for residential land uses was set to 85.6 x 10^9 MPN/acre while the maximum buildup on transportation land uses was set to 0.001 x 10^9 MPN/acre. Sources of *E. coli* and *Enterococcus* include both human and animal sources. Therefore, it is not surprising that bacteria export is lower from transportation land uses than from other land uses where it is more likely to find warm blooded animals interacting with the land surface. Additionally, this pattern is representative of the EMCs presented in Figure 1-1. The median simulated *E. coli* concentrations from residential areas of 33,651/100ml is similar to observed EMCs found in the literature. Based on NSWD data, the highest *E. coli* EMC from residential land uses in Massachusetts was 35,000 MPN/100ml. Relatively high EMCs were also observed by Stein (2008) who found *E. coli* EMCs of 30,000 ± 18,000 MPN/100ml from residential areas in California. Simulated concentrations of *Enterococcu*s were generally lower than observed EMCs presented in Table 1-1. Data from Breault et al. (2002) was included in Figure 3-5 since median and upper and lower quartiles were reported and therefore allowed for visual comparison with the distribution of the simulated data. Observed values included data from single family and multifamily residential land uses as well as the entire Charles River Watershed. The median simulated concentration for residential land use was 10,456 MPN/100ml, which was lower than the median observed values. The lowest observed EMC was 13,000 CFU/100 ml observed in the Charles River watershed (Breault et al., 2002) while the highest was 55,000 ± 37,000 CFU/100 ml (Stein et al., 2008).

Figure 3-6 and Figure 3-7 present simulated *E. coli* and *Enterococci* unit area loading, respectfully, based on the calibrated buildup/washoff values from CDM Smith (2012). The values are generally in good agreement with observed data. The mean simulated *E. coli* unit area loading ranged from 0.32 to 1,753 billion/ac/yr while CDM Smith (2012) observed an *E. coli* export of 22 - 1,397 billion/ac/yr from Boston's MS_4. Simulated *Enterococcus* unit area loading ranged from 0.04 to 544.84 Billion/ac/yr, while observed loading from the Boston's MS_4 ranged from 64 – 930 Billion/ac/yr (Table 1-2). The unit area loadings for bacteria show the same trend as the concentrations. For example, *E. coli* has highest concentrations and loadings from residential land uses, followed by industrial, commercial, then transportation. This is expected given that loading was calculated as concentration multiplied by volume. While the four land uses have different build up-washoff values for bacteria, they all represent an impervious surface which converts the same amount of rainfall to runoff. The same stormwater volume applied to different concentrations will result in the same pattern of loading compared to concentration.

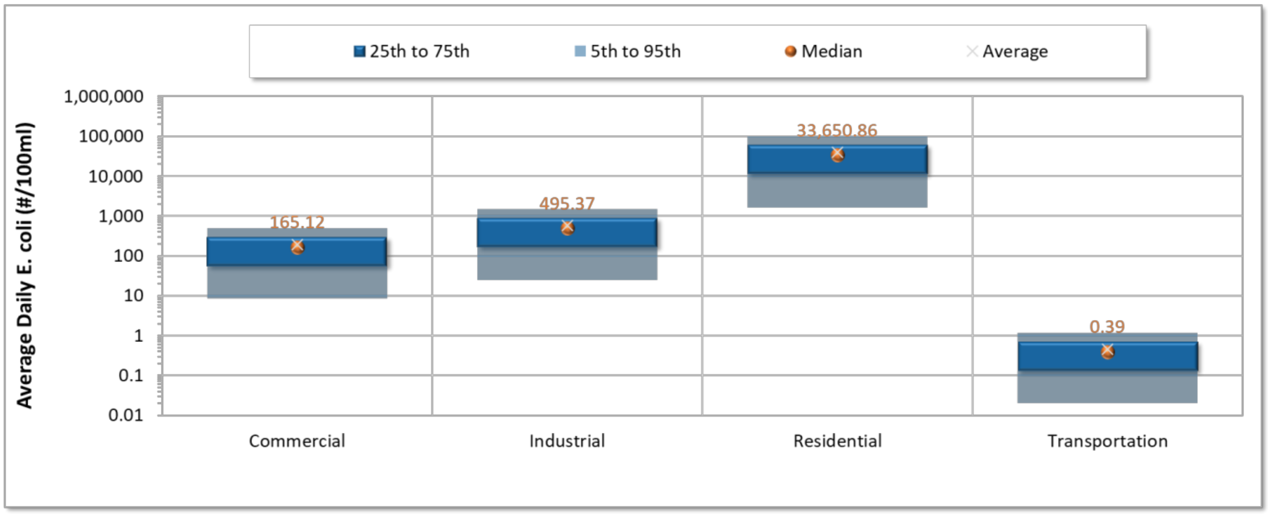


Figure 3-4. Simulated average daily *E. coli* concentrations from developed land uses in Tisbury, MA for the period

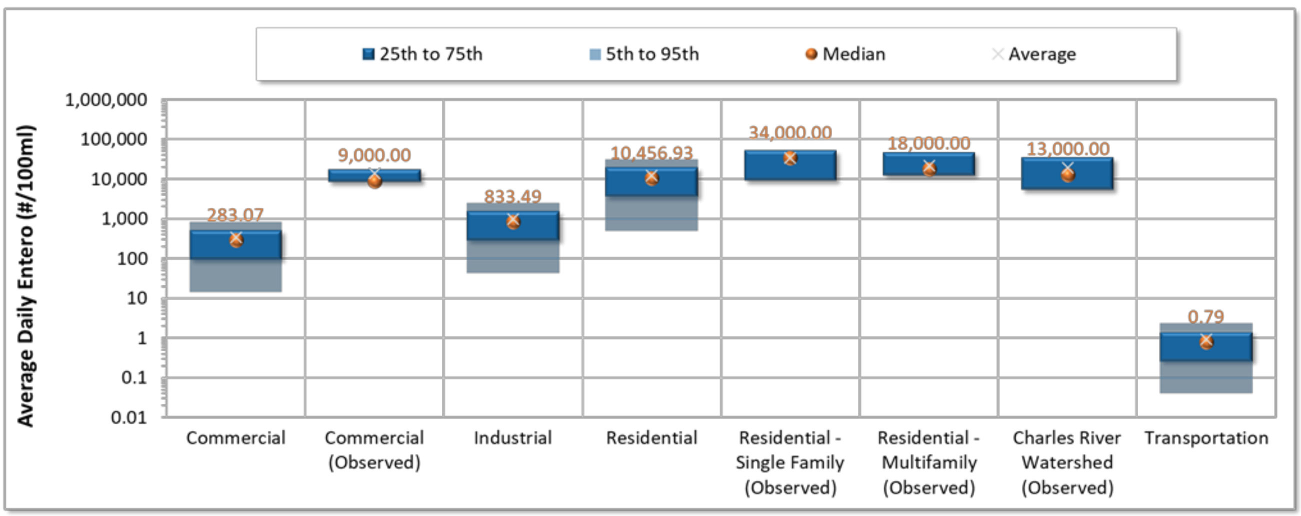


Figure 3-5. Simulated average daily Enterococci concentrations from developed land uses in Tisbury, MA for the period 1998-2018. (Observed data source: Breault et al., 2002)

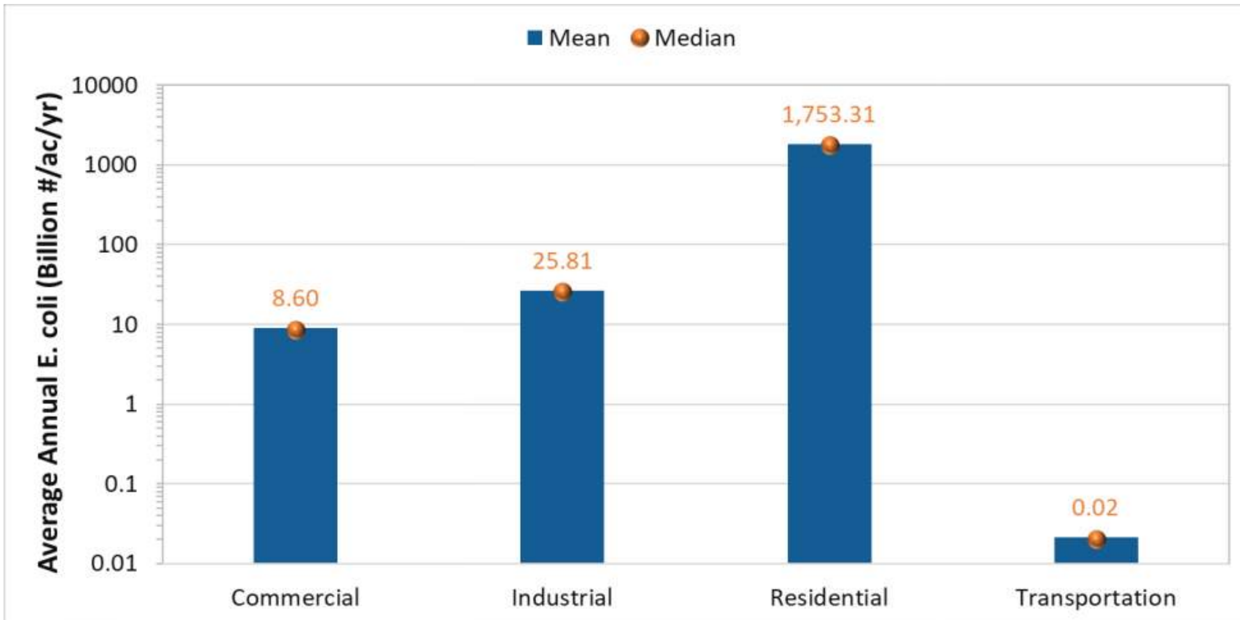


Figure 3-6. Average annual *E. coli* export from developed land uses in Tisbury, MA for the period 1998-2018.

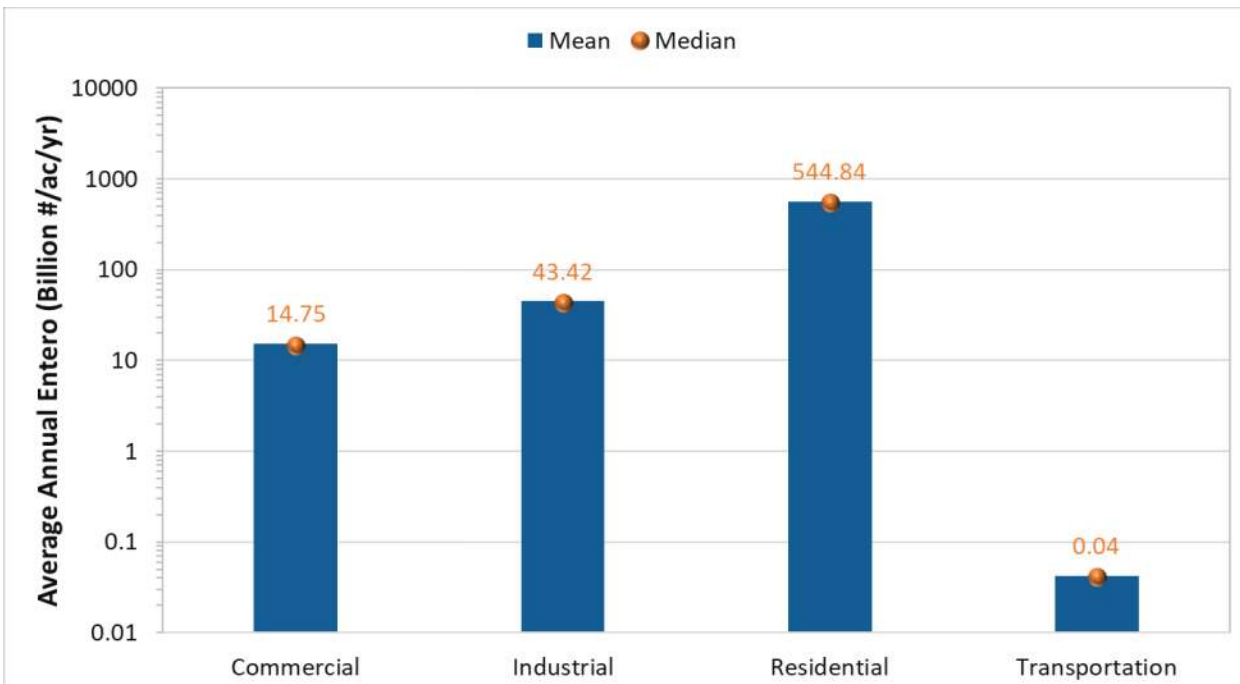


Figure 3-7. Average annual *Enterococcus* export from developed land uses in Tisbury, MA for the period 1998-2018.

4 SCM PERFORMANCE CURVES FOR INDICATOR BACTERIA

The Opti-Tool previously included SCM performance curves (U.S. EPA. 2010) for estimating the cumulative pollutant load reductions from infiltration, filtration, and detention practices for nutrients (TP, TN), sediments (TSS) and Zn. The Opti-Tool performance curves for indicator bacteria were developed for the SCM types shown in Table 4-1. The SCM efficiencies for *E.coli* and *Enterococcu*s in Table 4-1 are based on an analysis of published data presented in Table 4-2. Since some of the SCMs used in Opti-Tool did not have published information on their bacteria load reduction efficiencies, it was necessary to equate the SCMs without data to those that did in Table 4-2. For example, the efficiencies attributed to Infiltration Basin, Infiltration Trench, and Sand Filter in Table 4-1 are based on data for media filters (Table 4-2) obtained from the International Stormwater BMP database (Clary et al., 2017). Additionally, only three studies with SCM efficiencies of *Enterococcu*s were identified. Due to insufficient data, efficiencies for *E. coli* were used for *Enterococcu*s. Since removal efficiencies were assumed to be identical, only curves for *E. coli* were developed.

Table 4-1. SCM types and associated removal efficiencies for developing indicator bacteria performance curves

SCM Type	Underdrain Option	*E. coli* Efficiency	*Enterococcus* Efficiency	Major Processes for Bacteria Removal
Biofiltration	Yes	0.76	0.76	Adsorption, filtration
Biofiltration with ISR	Yes	0.76	0.76	Adsorption, filtration
Dry Pond	No	0.64	0.64	Settling
Infiltration Basin	No	0.76	0.76	Adsorption, filtration
Infiltration Trench	No	0.76	0.76	Adsorption, filtration
Sand Filter	Yes	0.76	0.76	Filtration
Subsurface Gravel Wetland	Yes	0.60	0.60	Adsorption, filtration
Wet Pond	No	0.96	0.96	Settling

Table 4-1 includes the major processes that are assumed to be responsible for bacteria removal. However, the major mechanisms which remove bacteria in SMCs are not fully understood. While dominant removal processes include settling, filtration and adsorption, there are other biological and physical processes occurring in SCMs that may reduce bacteria concentrations as well as increase them. Settling is likely the dominant removal process occurring within the water column. Bacteria may enter a SCM 'free', existing as individual organisms/groups, or may be associated with particles. Bacteria attached to denser particles will tend to settle out of the water column more quickly than free phase organisms or those associated with less dense, more mobile particles. Characklis et al. (2005) found that an average of 30-55% of *E. Coli* and *Enterococcus* organisms were associated with settleable particles in stormwater samples. *E. coli* is a rod-shaped bacteria with a diameter ranging from 2-6 μm and a length ranging from 1.1-1.5 μm. Within porous soil media, adsorption is likely a major removal mechanism due to the small size of *E. coli* (Lan et al., 2010). Sorption rates can be affected by several factors, including media texture, organic matter, temperature, flow rate, ionic strength, pH, hydrophobicity, chemotaxis and electrostatic charge (Stevik et al., 2004). Temperature has also been cited as an important environmental factor for bacteria die-off, with increasing temperatures associated with higher removal rates (USEPA, 2006). Additionally, sun exposure can result in increased pathogen inactivation and removal through treatment by ultraviolet light.

The wet, nutrient rich environments found in many stormwater SCMs can limit their ability to reduce bacteria loading (Hathaway et al., 2008). Rusciano and Obropta (2007) found viable bacteria retained in the soil substrate of a bioretention column 36 days after performing the last stormwater simulation. SCMs can result in increased bacteria concentrations, indicated by negative values in Table 4-2. Performance data of infiltration SCMs only represents removal processes that occur within the infiltration SCM as filtered runoff is captured by an underdrain to assess performance of an in-system removal. Consequently, these data do not reflect the additional removal accomplished as exfiltrate flows through subsoils beyond the performance monitoring collection system. Runoff events that are completely captured and infiltrated achieve 100% removal of bacteria.

Unpublished research (Houle, et al., 2014) evaluated SCMs in New Hampshire whose primary treatment mechanisms included settling, enhanced settling using a hydrodynamic separator, and filtration. The results suggest SCMs using conventional settling techniques were often a source of bacteria, having higher outflow concentrations compared to inflow, especially during summer months when concentrations were highest and conditions for regrowth are most favorable. The study also found that systems using filtration and infiltration performed better, generally having lower concentrations in the outflow compared to inflow. Periods of high influent flow rates can cause turbulent conditions within SCMs, resuspending sediment and associated bacteria, resulting in possible increases in effluent concentrations. Sediment resuspension is more likely to occur in SCMs that are poorly designed, not well maintained, or have reached their design life (EPA, 2006). Zarriello et al (2002) estimated the effect of SCMs and street sweeping on reducing fecal coliform in the Lower Charles River, MA watershed. The SCMs treated runoff depths ranging from 0.25 to 1.0 and had a median removal efficiency for fecal coliform of 13%.

Bioretention areas, wet ponds and infiltration-based SCMs appear to be the most effective at reducing bacteria concentrations (Table 4-2). EPA (2006) found that settling was a contributing but not primary factory in bacteria removal and that bacteria concentrations decreased with time in a constructed wetland and dry pond. Bacteria load reduction may be higher in SCMs which limit the opportunity for sediment resuspension, such as infiltration based SCMs.

Table 4-2. – Observed SCM efficiencies for E. coli and Enterococcus

	SCM with published efficiency data							Location	Source
	Bioretention	**Grass swale**	**Dry detention**	**Media Filter**	**Wet Pond**	**Wetland**	**Wetland/ Retention Pond**		
	Opti-Tool equivalent								
	Biofiltration Biofiltration with ISR	NA	Dry Pond	Infiltration Basin/Trench, Sand Filter	Wet Pond	Subsurface gravel wetland	Wet Pond		
E. coli	0.71							NC	Hunt et al., 2008
	0.48 – 0.97							TX	Kim et al., 2012
	0.72 – 0.97							Laboratory & synthetic stormwater	Zhang et al., 2011
	0.71		0.05 - 0.14		0.18	0.22-0.92		North Carolina	Hathaway et al. 2008
	0.80	-0.26	0.64*	0.76*	0.96	0.64	0.80 – 0.96	National	Clary et al., 2017
Enterococcus	-0.76 – 0.01				0.49	0.06-0.93		NC	Hunt et al., 2008
			0.63			0.61	0.78	National	Clary et al., 2017
		-0.60	-1.96			0.21	0.78	NH	Houle et al., 2014 unpublished

*Data for fecal coliform

The following subsections describe the steps for developing the SCM performance curves for the indicator bacteria.

4.1 SUSTAIN SCM Model (Setup and Run)

The SUSTAIN GI module is a process-based continuous simulation model that requires two performance parameters to estimate cumulative load reduction: 1) a first-order decay rate in the ponded water column and 2) an underdrain pollutant removal rate to account for the filtration mechanism. These parameters were adjusted to predict SCM performance comparable to SCM efficiency numbers reported in the literature. A value of 0.1 was used as a default decay rate for *E.coli* for all SCMs. The model output timeseries were summarized into average annual pollutant loads with and without SCM simulation to estimate long-term pollutant load reductions. The SCM scenarios for a wide range of storage capacities, up to 2 inches of runoff depth from the impervious area, were developed for each SCM type listed in Table 4-1. Three hundred and sixty SCM simulation scenarios for 8 SCM types and a range of inifltraition rates for infiltration-based SCMs were developed and a continuous hourly flow and pollutant load simulation for 20 years were performed. Each SCM was sized to have a physical capacity to instantaneously store 20 runoff depths ranging from 0.1 to 2.0 inches from a 100% impervious drainage area. A wilting point of 0.01 was included in the representation of each SCM's soil layer to account for unavailable storage due to strongly retained water.

4.2 SCM Performance Curves (Storage Capacity versus Pollutant Load Reduction)

The SUSTAIN model output for each scenario was processed to estimate the indicator bacteria load reduction for modeled storage capacity to develop performance curves for SCMs listed in Table 4-1. Performance curves for SCMs from the Opti-Tool for *E. coli* are shown in Figure 4-1 - Figure 4-20. Appendix-A1, Appendix-A2, and Appendix-A3 contain the tabular data for the curves. The infiltration practices were the most effective SCMs for bacteria load reduction due the infiltration mechanism of water loss through background soil. The wet pond was the least effective due to the bottom sealed without any infiltration loss from the available storage. The performance curves reflect the effectiveness of infiltration techniques compared to ones relying on settling and filtration mechanism. Appendix-B shows SCMs design specifications modeled in the Opti-Tool to develop the performance curves. Appendix-C shows methods for determining stormwater control design volume for using the SCMs performance curves and provides crosswalk between stormwater control types and the SCMs available in Opti-Tool.

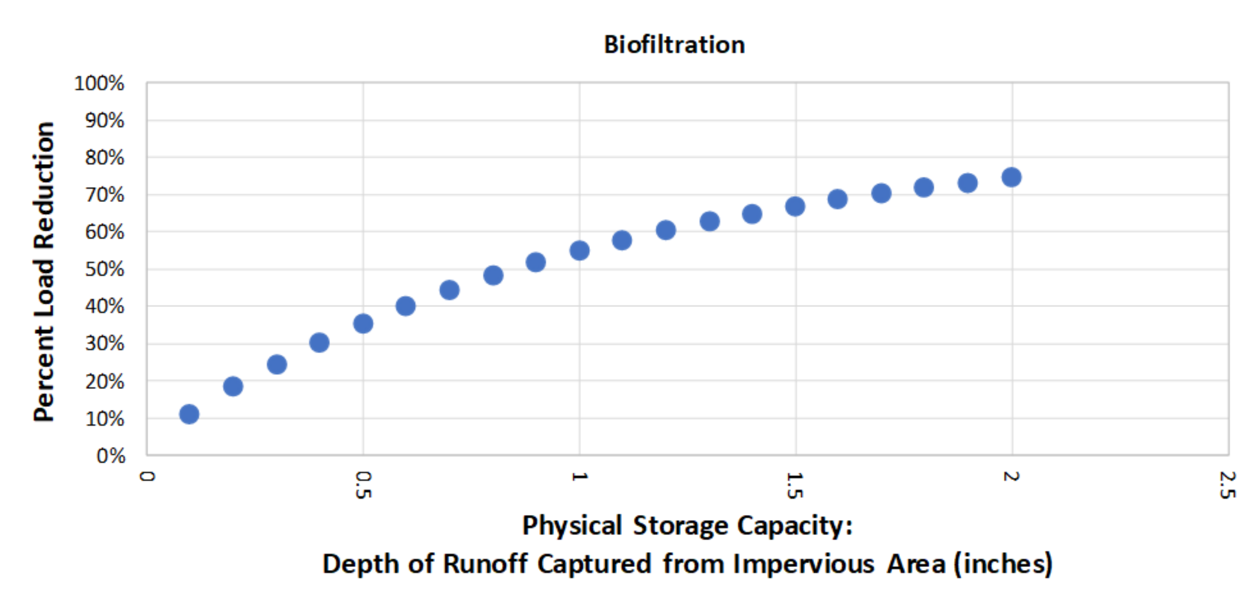


Figure 4-1. Biofiltration performance curve for annual average E. coli load reduction.

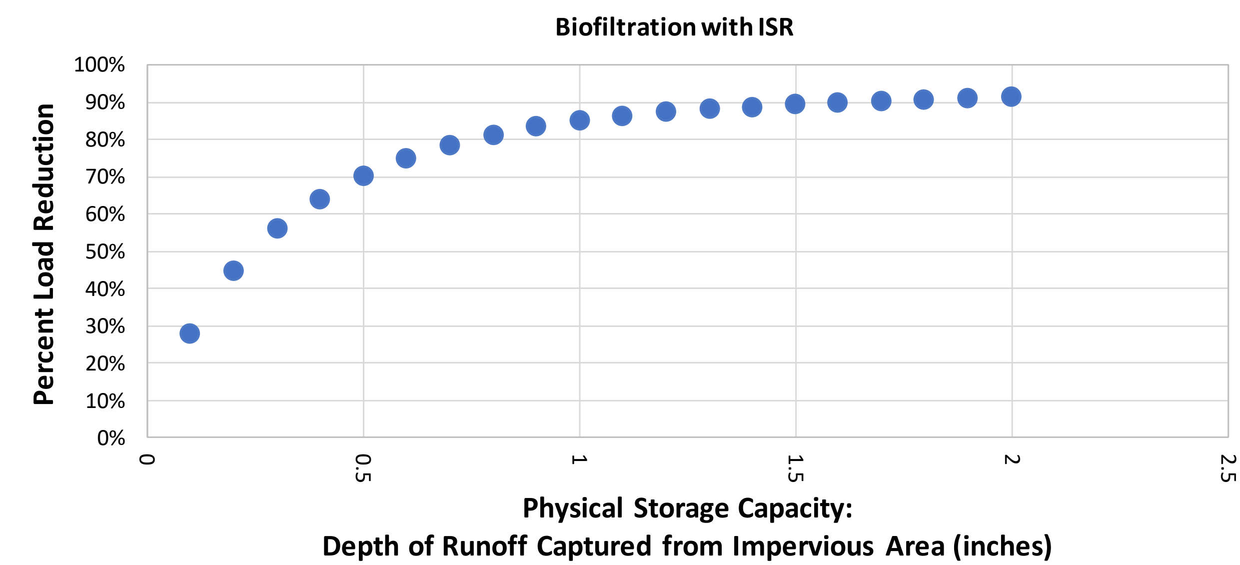


Figure 4-2. Biofiltration with ISR performance curve for annual average E. coli load reduction.

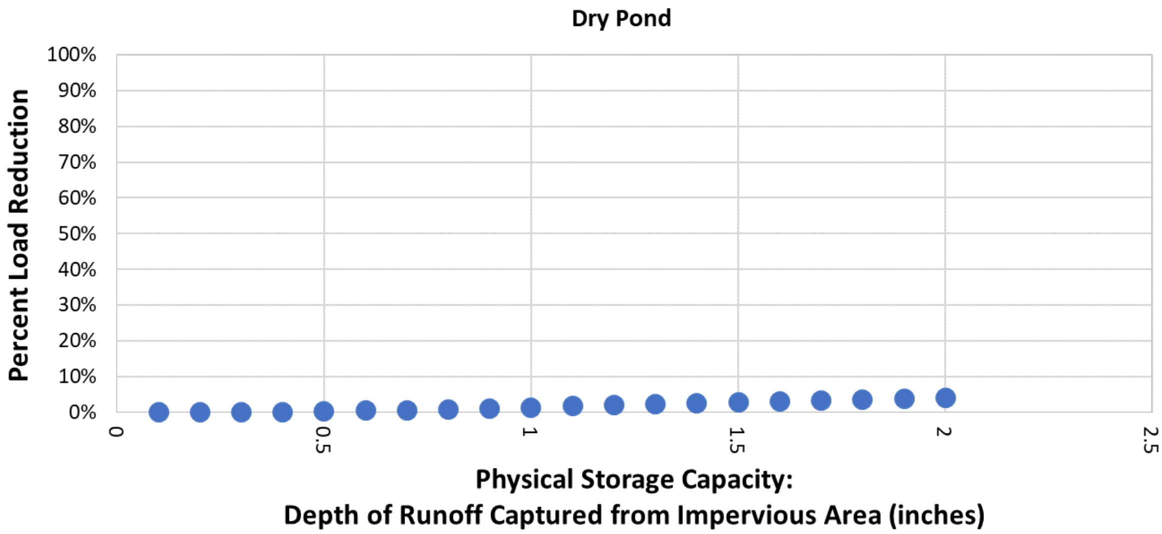


Figure 4-3. Dry Pond performance curve for annual average E. coli load reduction.

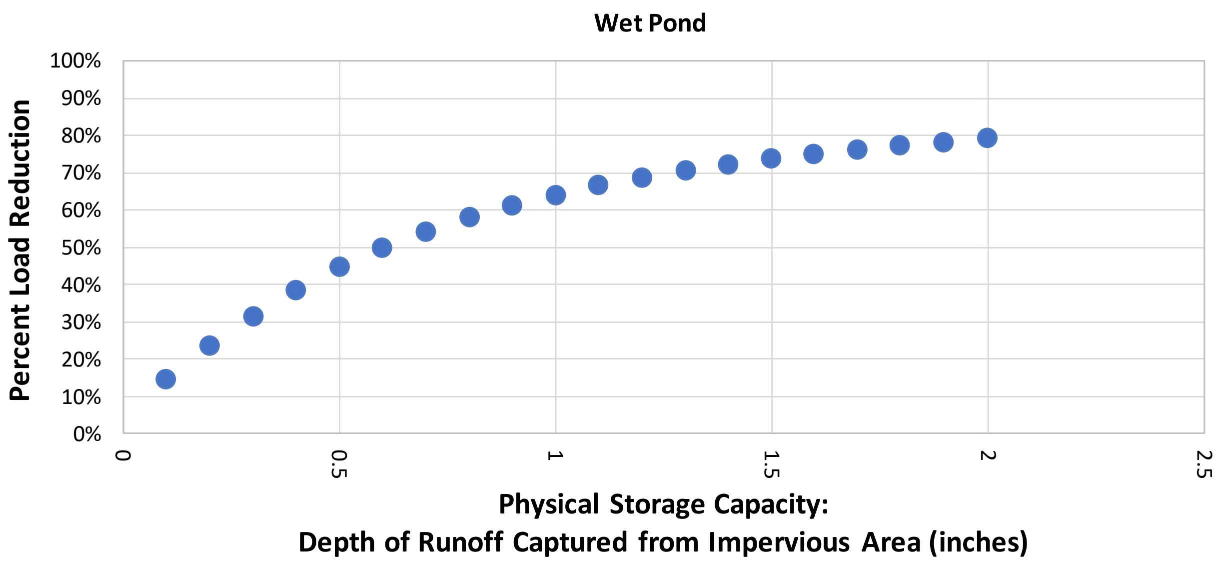


Figure 4-4. Wet Pond performance curve for annual average E. coli load reduction.

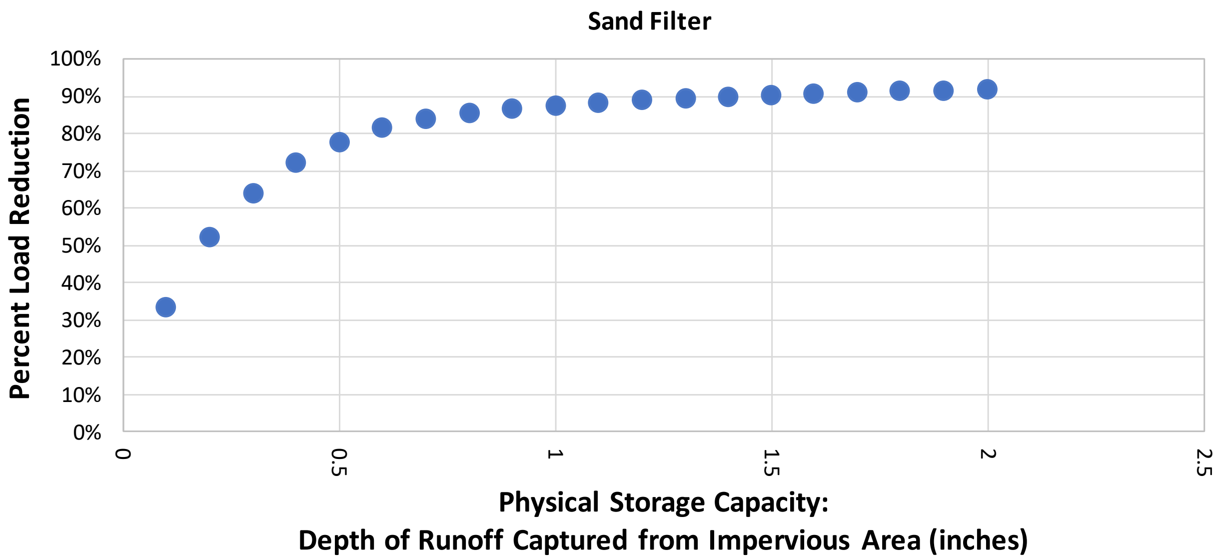


Figure 4-5. Sand Filter performance curve for annual average E. coli load reduction.

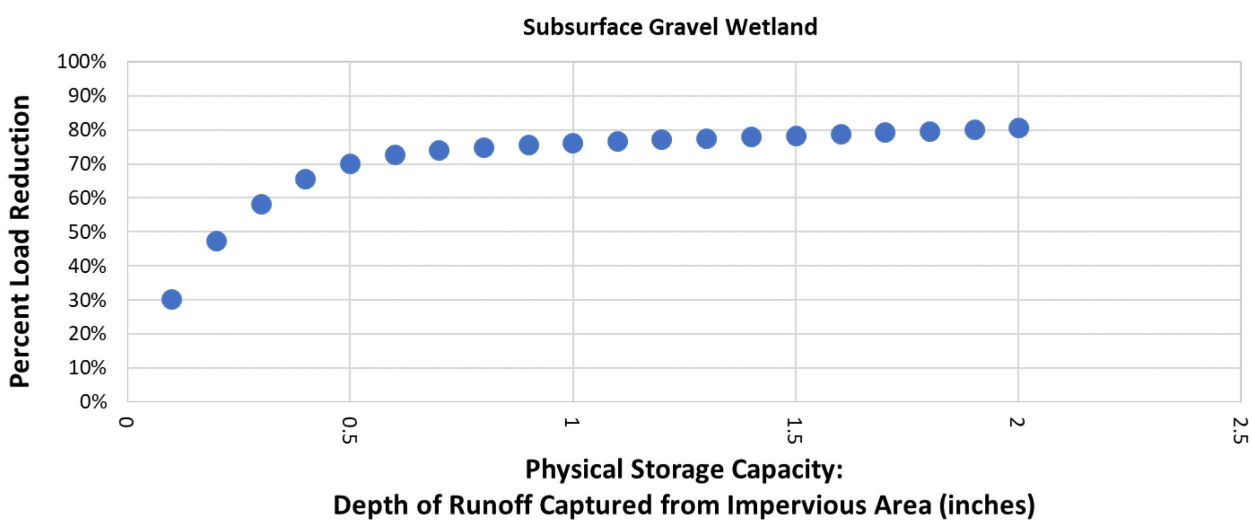


Figure 4-6. Subsurface Gravel Wetland performance curve for annual average E. coli load reduction.

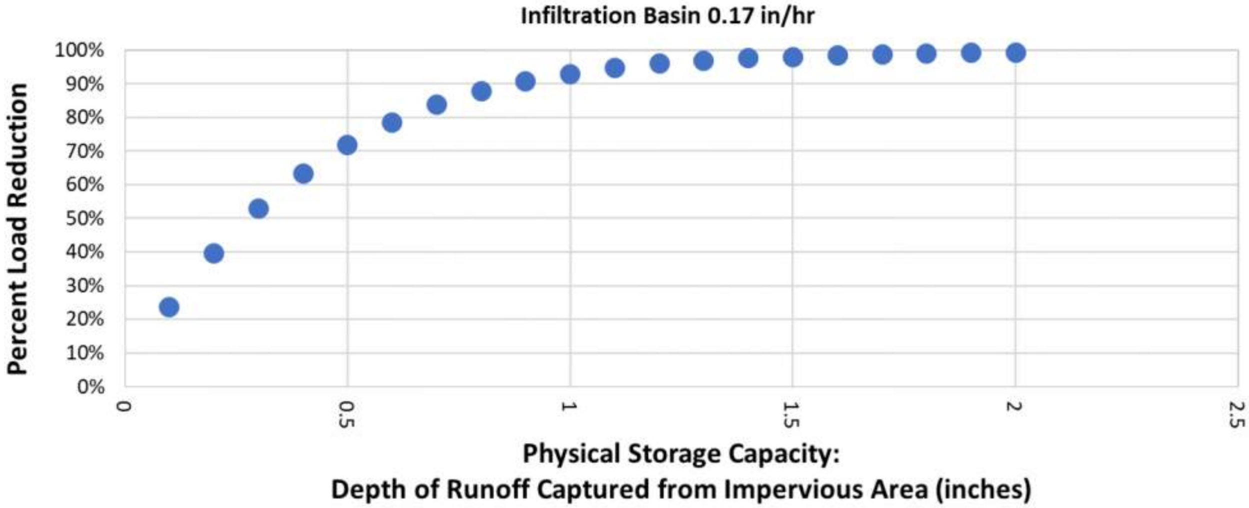


Figure 4-7. Infiltration Basin (0.17 in/hr) performance curve for annual average E. coli load reduction.

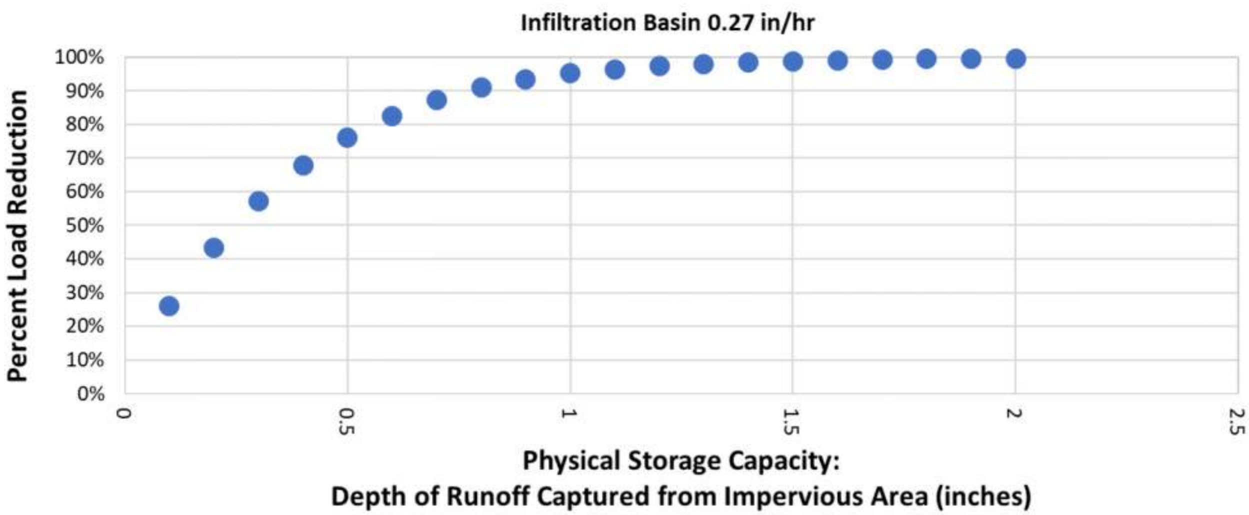


Figure 4-8. Infiltration Basin (0.27 in/hr) performance curve for annual average E. coli load reduction.

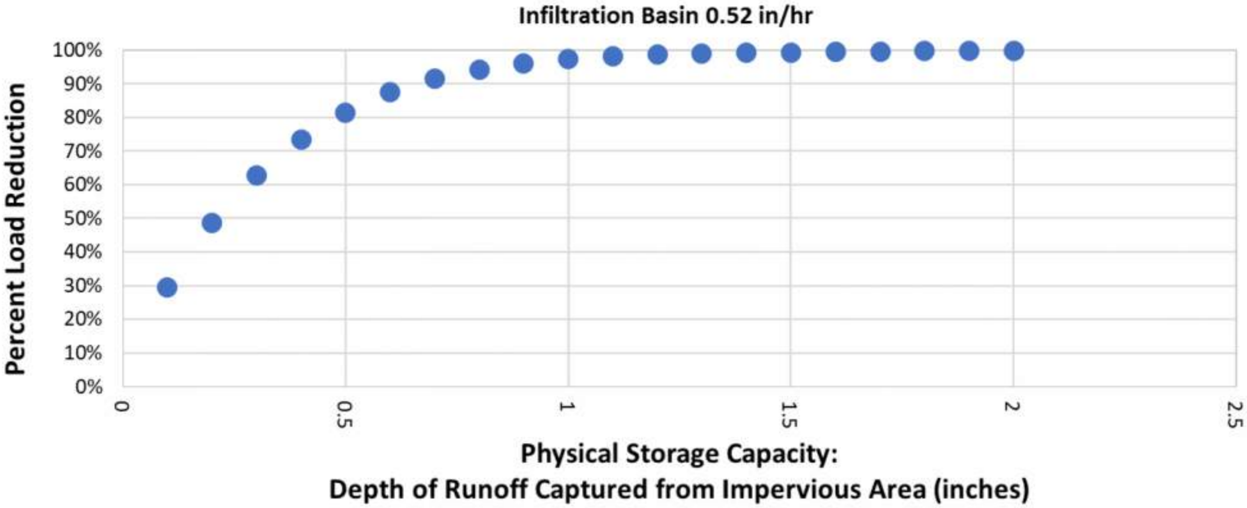


Figure 4-9. Infiltration Basin (0.52 in/hr) performance curve for annual average E. coli load reduction.

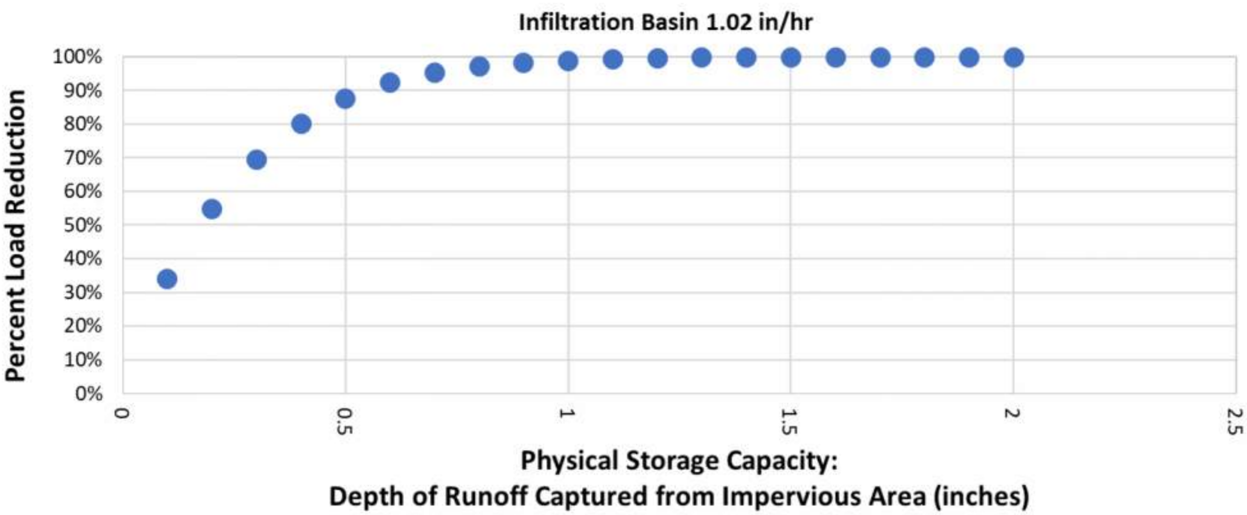


Figure 4-10. Infiltration Basin (1.02 in/hr) performance curve for annual average E. coli load reduction.

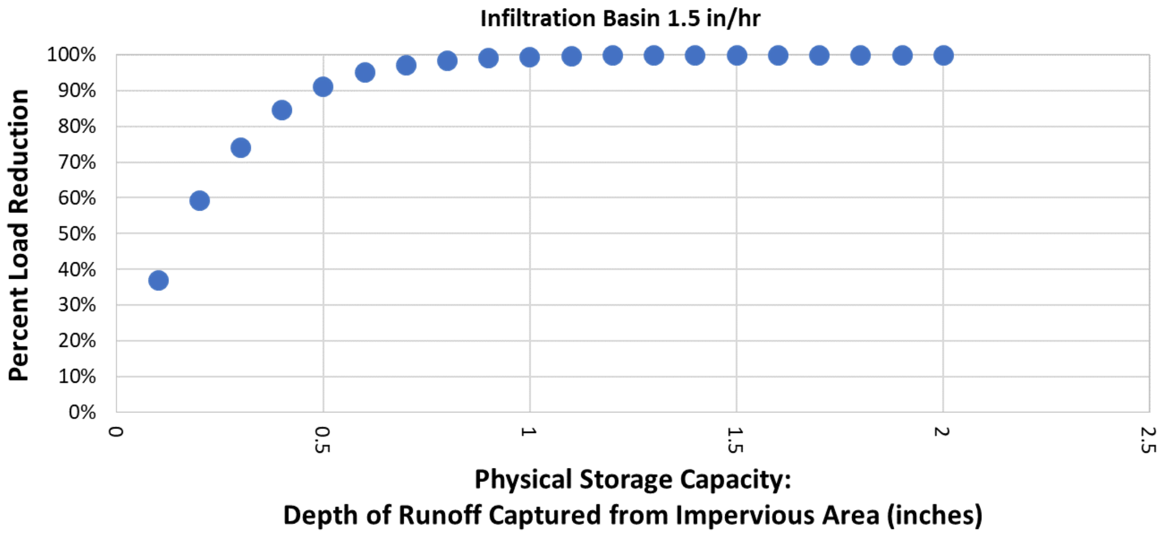


Figure 4-11. Infiltration Basin (1.50 in/hr) performance curve for annual average E. coli load reduction.

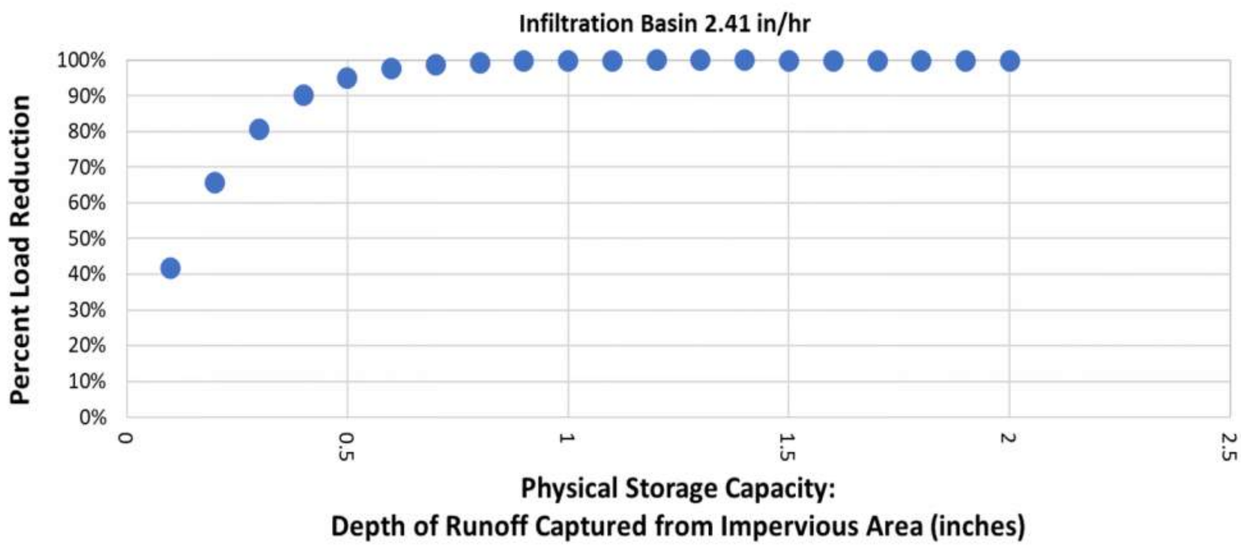


Figure 4-12. Infiltration Basin (2.41 in/hr) performance curve for annual average E. coli load reduction.

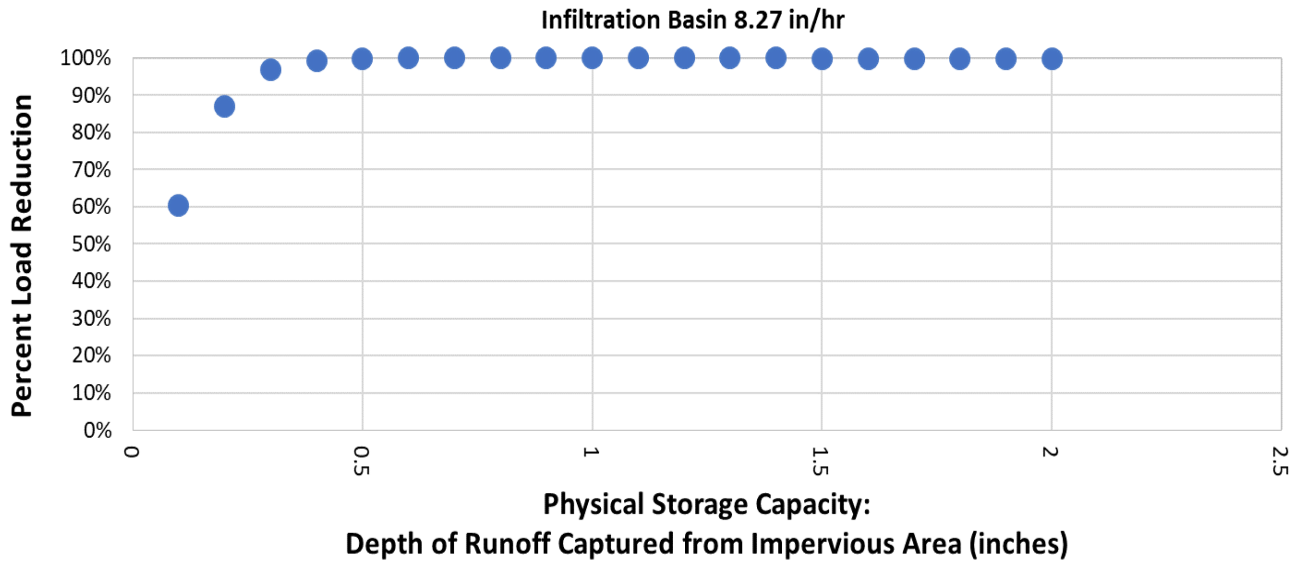


Figure 4-13. Infiltration Basin (8.27 in/hr) performance curve for annual average E. coli load reduction.

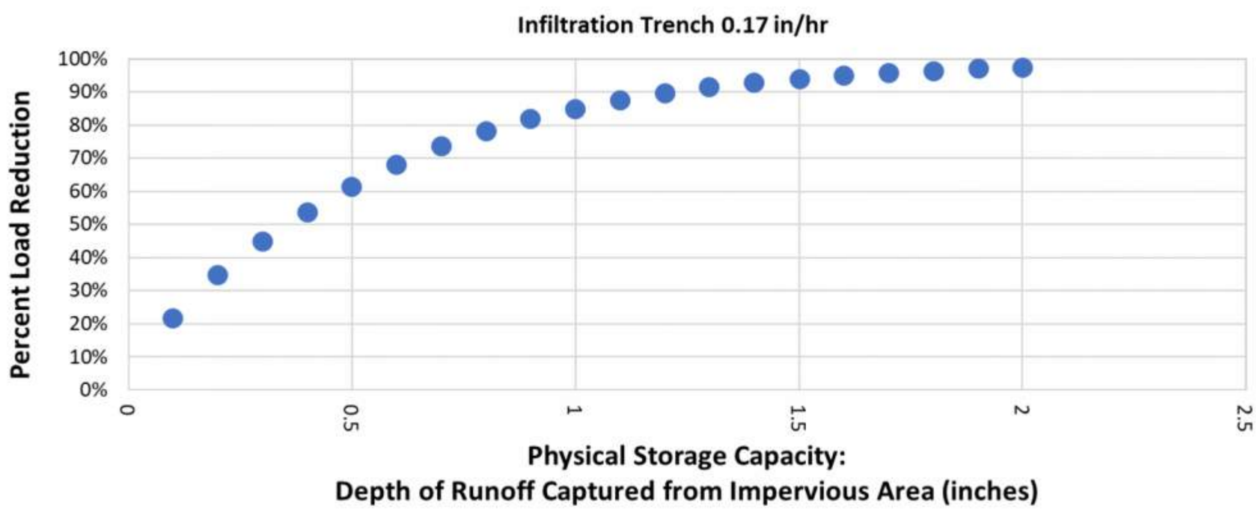


Figure 4-14. Infiltration Trench (0.17 in/hr) performance curve for annual average E. coli load reduction.

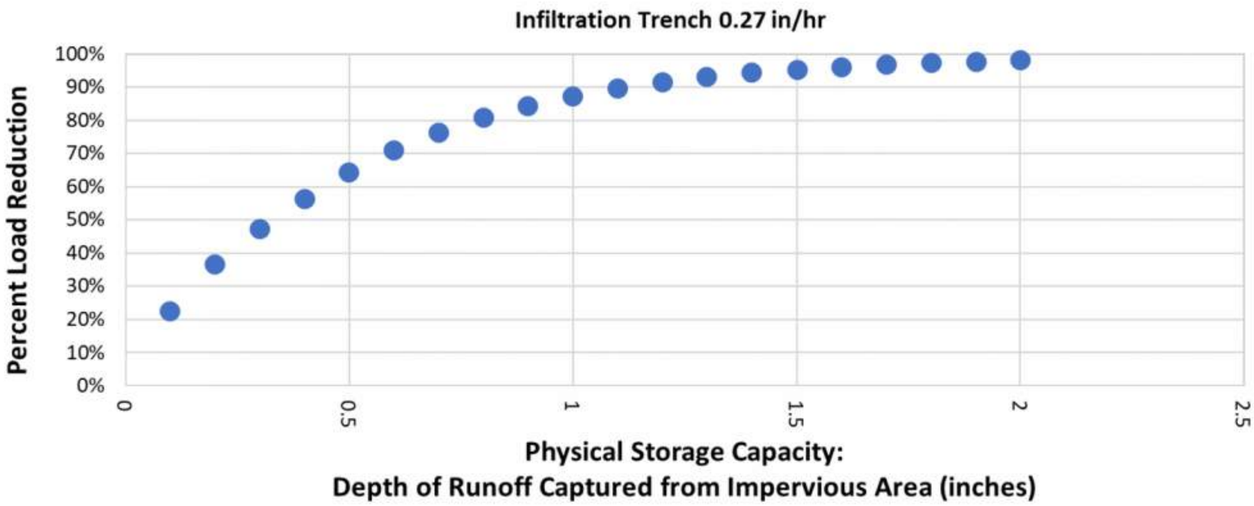


Figure 4-15. Infiltration Trench (0.27 in/hr) performance curve for annual average E. coli load reduction.

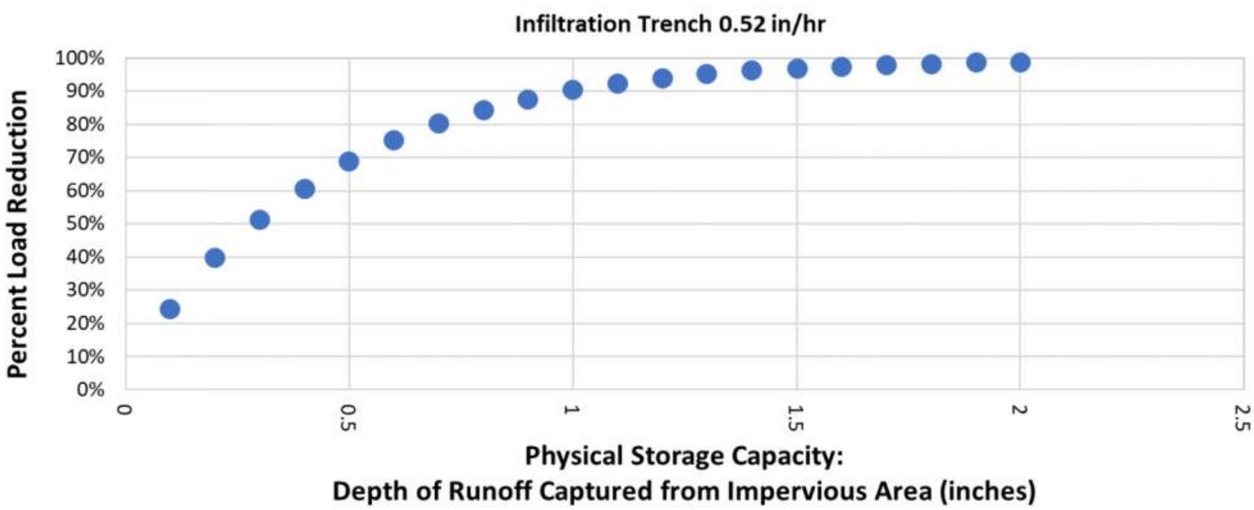


Figure 4-16. Infiltration Trench (0.52 in/hr) performance curve for annual average E. coli load reduction.

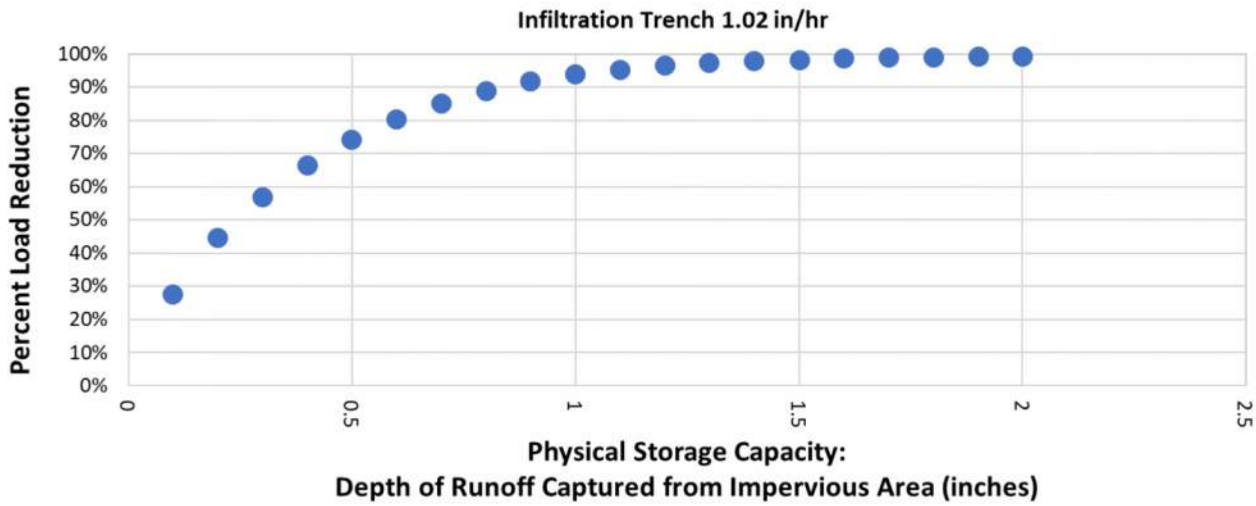


Figure 4-17. Infiltration Trench (1.02 in/hr) performance curve for annual average E. coli load reduction.

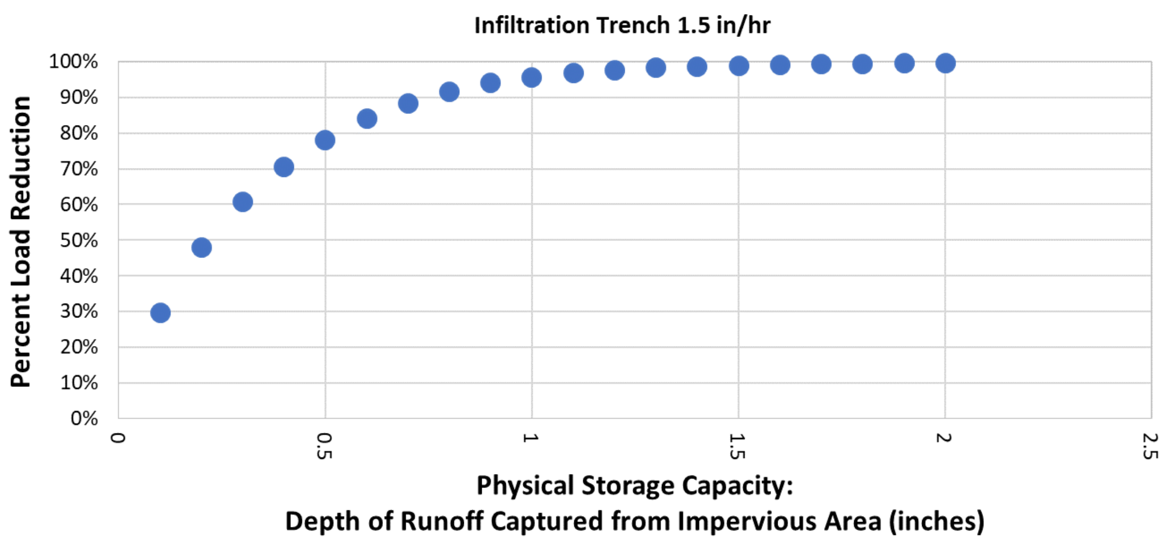


Figure 4-18. Infiltration Trench (1.50 in/hr) performance curve for annual average E. coli load reduction.

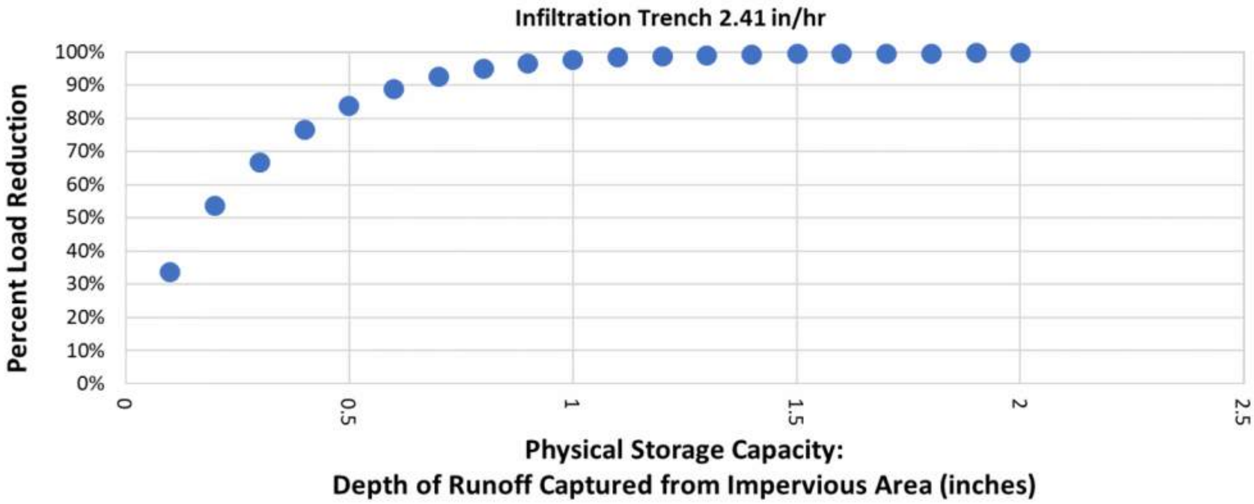


Figure 4-19. Infiltration Trench (2.41 in/hr) performance curve for annual average E. coli load reduction.

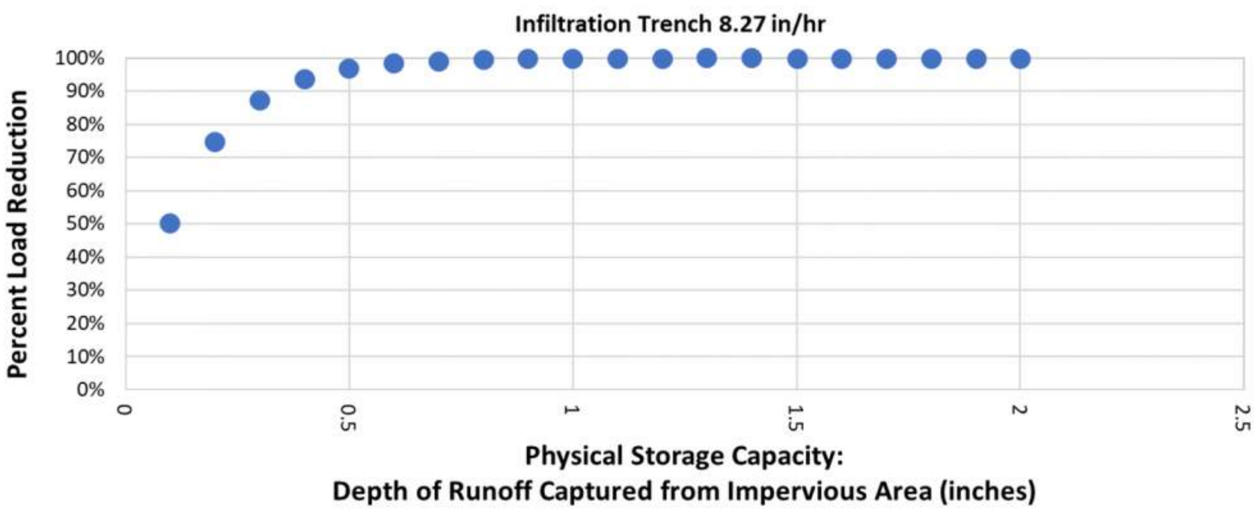


Figure 4-20. Infiltration Trench (8.27 in/hr) performance curve for annual average E. coli load reduction.

REFERENCES

APWA (American Public Works Association), 1969. Water Pollution Aspects of Urban Runoff. U.S. Department of the Interior, Federal Water Pollution Control Administration.

Breault, R. F., Sorenson, J.R., and P.K. Weiskel. 2002. Streamflow, Water Quality, and Contaminant Loads in the Lower Charles River Watershed, Massachusetts, 1999-2000

Caraco, D. 2013. Water Treatment Model (WTM) 2013 Documentation. Center for Watershed Protection.

CDM. 2012. 2012 Stormwater Model Report. Boston Water and Sewer Commission.

Characklis, G.W., Dilts, M.J., Simmons, O.D., Likirdopulos, C.A., Krometis, L.A.H., and Sobsey, M.D. (2005) Microbial partitioning to settleable particles in stormwater. Water Research 39 (9), 1773- 1782.

Clary, J., J. Jones, M. Leisenring, P. Hobson, and E Strecker. International Stormwater SCM Database 2016 Summary Statistics Final Report.

Clary, J. R. Pitt, B Streets. 2014. Pathogens in Urban Stormwater. Urban Water Resources Research Council Pathogens in Wet Weather Flows Technical Committee. Environmental and Water Resources Institute, American Society of Civil Engineers.

EA Engineering, Science and Technology, Inc. 2010. Chemical Data Analysis Ambient Station/Unnamed Tributary to Winters Run Harford County, Maryland. Prepared for Harford County Department of Public Works Division of Highways and Water Resources.

Hathaway, J.M. and W. F. Hunt. (2010). Evaluation of indicator bacteria export from an urban watershed. World Environmental and water Resource Congress 2010: Challenges of Change.

Hathaway, J.M., W.F. Hunt, J.D. Wright, and S Jadlocki. 2008. An Evaluation of Pathogen Removal in Stormwater Best Management Practices in Charlotte and Wilmington, North Carolina. Paper Number 084330. 2008 ASABE Annual International Meeting. Providence, RI.

Hathaway, J.M., W.F. Hunt, and S Jadlocki. 2009. Indicatory Bacteria Removal in Storm-Water Best Management Practices in Charlotte, North Carolina. Journal of Enviornmetnal Engineering. 135(12) pp 1275-1285.

Lan, Z., Seagren, E. Davis, A., and J. Karns. The capture and destruction of escherichia coli from simulated urban runoff using conventional bioretention media and iron oxide-coated sand. Water Environ. Res., 82 (2010), pp. 701-7.

Line, D.E. D.E. Line, N.M. White, W.W. Kirby-Smith, J.D. Potts. Fecal coliform export from four coastal North Carolina areas. Journal of the American Water Resources Association, 44 (3) (2008), pp. 606-617

Pitt, R. 1998. "Epidemiology and Stormwater Management." Stormwater Quality Management. CRC Lewis Publishers. New York, NY.

Rossman, L.A., 2010. Storm Water Management Model User’s Manual Version 5.0. United States Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Cincinnati, Ohio.

Rusciano, G. M., & Obropta, C. C. (2007). Bioretention column study: fecal coliform and total suspended solids reductions. Transactions of the ASABE, 50(4), 1261–1269.

Sartor, J.D., G.B. Boyd, and F.J. Agardy, 1974. Water Pollution Aspects of Street Surface Contaminants. Journal (Water Pollution Control Federation) 46(3):458-467.

Stevik, T. K., K. Aa, G. Ausland, and J. F. Hanssen. 2004. Retention and removal of pathogenic bacteria in wastewater percolating through porous media: A review. Water Res. 38(6): 1355-1367.

Shergill, S. S. and R Pitt. 2004. Quantification of Escherichia coli and enterococci levels in wet weather and dry weather flows. Proceedings of the Water Environment Federation 2004, (10), 746-774

United States Environmental Protection Agency (U.S. EPA). (2006). "Performance of storm water retention ponds and constructed wetlands in reducing microbial concentration." EPA-600-R-06-102, Office of Research and Development, Washington, DC.

U.S. EPA. 2016. *Opti-Tool – Opti-Tool for Stormwater and Nutrient Management User's Guide*. Prepared for: U.S. EPA Region 1, Boston, MA. Prepared by: Tetra Tech, Inc. Fairfax, VA.

U.S. EPA. 2015. *SWMM – Storm Water Management Model User's Manual Version 5.1.* (Publication No. EPA/600/R-14/413b, Revised September 2015)

U.S. EPA. 2010. *Stormwater Best Management Practices (SCM) Performance Analysis*. Prepared for: U.S. EPA Region 1, Boston, MA. Prepared by: Tetra Tech, Inc. Fairfax, VA.

U.S. EPA. 2009. *SUSTAIN – A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*. (Publication No. EPA/600/R-09/095, September 2009)

Zarriello, P.J., Breault, R.F., and P. K. Weiskel. 2002. Potential Effects of Structural Controls and Street Sweeping on Stormwater Loads to the Lower Charles River, Massachusetts. USGS Water-Resources Investigations Report 02-4220.

APPENDIX-A1: E. COLI AVERAGE ANNUAL LOAD REDUCTIONS (%) FOR BIOFILTRATION, BIOFILTRATION WITH ISR, DRY POND, WET POND, SAND FILTER, AND SUBSURFACE GRAEL WETLAND

Runoff Capture Depth (inches)	E. coli Average Annual Load Reduction (%)					
	Biofiltration	Biofiltration with ISR	Dry Pond	Wet Pond	Sand Filter	Subsurface Gravel Wetland
0.1	10.99%	27.89%	0.00%	14.52%	33.64%	30.29%
0.2	18.50%	44.92%	0.00%	23.70%	52.20%	47.21%
0.3	24.54%	56.12%	0.02%	31.56%	64.01%	58.14%
0.4	30.21%	64.16%	0.07%	38.59%	72.22%	65.51%
0.5	35.44%	70.24%	0.20%	44.69%	77.86%	70.07%
0.6	40.15%	74.98%	0.40%	49.94%	81.68%	72.63%
0.7	44.44%	78.61%	0.61%	54.40%	84.11%	74.00%
0.8	48.36%	81.41%	0.85%	58.17%	85.74%	74.80%
0.9	51.92%	83.50%	1.10%	61.39%	86.84%	75.51%
1.0	55.04%	85.14%	1.37%	64.16%	87.68%	76.07%
1.1	57.86%	86.36%	1.65%	66.57%	88.32%	76.51%
1.2	60.49%	87.38%	1.95%	68.68%	88.91%	77.06%
1.3	62.79%	88.19%	2.23%	70.54%	89.38%	77.52%
1.4	64.93%	88.85%	2.51%	72.21%	89.84%	77.92%
1.5	66.81%	89.39%	2.80%	73.69%	90.22%	78.39%
1.6	68.57%	89.86%	3.09%	75.01%	90.58%	78.87%
1.7	70.20%	90.27%	3.37%	76.22%	90.94%	79.31%
1.8	71.69%	90.65%	3.65%	77.29%	91.28%	79.77%
1.9	73.15%	91.00%	3.96%	78.27%	91.60%	80.22%
2.0	74.70%	91.29%	4.26%	79.20%	91.90%	80.67%

APPENDIX-A2: E. COLI AVERAGE ANNUAL LOAD REDUCTIONS (%) FOR INFILTRATION BASIN

Runoff Capture Depth (inches)	E. coli Average Annual Load Reduction (%) for Background Infiltration Rates						
	0.17 (in/hr)	0.27 (in/hr)	0.52 (in/hr)	1.02 (in/hr)	1.50 (in/hr)	2.41 (in/hr)	8.27 (in/hr)
0.1	23.58%	25.88%	29.56%	33.99%	36.93%	41.68%	60.24%
0.2	39.65%	43.40%	48.64%	54.79%	59.17%	65.64%	87.09%
0.3	52.82%	57.15%	62.71%	69.39%	74.05%	80.66%	96.90%
0.4	63.39%	67.71%	73.38%	80.00%	84.44%	90.06%	99.20%
0.5	71.91%	76.09%	81.52%	87.49%	91.08%	95.08%	99.76%
0.6	78.52%	82.48%	87.41%	92.30%	94.99%	97.59%	99.94%
0.7	83.76%	87.34%	91.44%	95.32%	97.20%	98.74%	99.99%
0.8	87.78%	90.86%	94.21%	97.12%	98.31%	99.34%	100.00%
0.9	90.70%	93.36%	96.05%	98.16%	98.98%	99.64%	100.00%
1.0	92.94%	95.16%	97.28%	98.77%	99.36%	99.82%	100.00%
1.1	94.65%	96.43%	98.08%	99.19%	99.62%	99.89%	100.00%
1.2	95.93%	97.34%	98.63%	99.46%	99.76%	99.93%	100.00%
1.3	96.87%	98.00%	99.01%	99.64%	99.83%	99.97%	100.00%
1.4	97.56%	98.49%	99.28%	99.74%	99.89%	99.99%	100.00%
1.5	98.10%	98.86%	99.47%	99.82%	99.94%	100.00%	100.00%
1.6	98.50%	99.14%	99.60%	99.88%	99.97%	100.00%	100.00%
1.7	98.81%	99.35%	99.70%	99.93%	99.98%	100.00%	100.00%
1.8	99.07%	99.51%	99.79%	99.95%	99.99%	100.00%	100.00%
1.9	99.28%	99.63%	99.85%	99.97%	100.00%	100.00%	100.00%
2.0	99.45%	99.72%	99.89%	99.98%	100.00%	100.00%	100.00%

APPENDIX-A3: E. COLI AVERAGE ANNUAL LOAD REDUCTIONS (%) FOR INFILTRATION TRENCH

Runoff Capture Depth (inches)	E. coli Average Annual Load Reduction (%) for Background Infiltration Rates						
	0.17 (in/hr)	0.27 (in/hr)	0.52 (in/hr)	1.02 (in/hr)	1.50 (in/hr)	2.41 (in/hr)	8.27 (in/hr)
0.1	21.59%	22.40%	24.42%	27.49%	29.70%	33.56%	50.19%
0.2	34.63%	36.48%	39.88%	44.54%	48.02%	53.55%	74.76%
0.3	44.86%	47.32%	51.17%	56.74%	60.77%	66.74%	87.14%
0.4	53.68%	56.34%	60.69%	66.50%	70.55%	76.44%	93.67%
0.5	61.44%	64.24%	68.73%	74.27%	78.13%	83.70%	96.77%
0.6	68.09%	70.95%	75.15%	80.39%	84.00%	88.83%	98.37%
0.7	73.54%	76.33%	80.17%	85.09%	88.39%	92.45%	99.07%
0.8	78.04%	80.69%	84.28%	88.85%	91.64%	94.90%	99.44%
0.9	81.79%	84.26%	87.60%	91.68%	93.99%	96.57%	99.64%
1.0	84.91%	87.18%	90.30%	93.77%	95.67%	97.59%	99.74%
1.1	87.49%	89.57%	92.38%	95.34%	96.84%	98.29%	99.81%
1.2	89.62%	91.52%	93.97%	96.47%	97.65%	98.75%	99.88%
1.3	91.36%	93.09%	95.24%	97.30%	98.24%	99.08%	99.93%
1.4	92.80%	94.38%	96.24%	97.93%	98.65%	99.33%	99.95%
1.5	94.03%	95.42%	97.01%	98.37%	98.96%	99.50%	99.96%
1.6	95.03%	96.26%	97.60%	98.71%	99.20%	99.61%	99.97%
1.7	95.85%	96.90%	98.05%	98.98%	99.37%	99.68%	99.98%
1.8	96.52%	97.44%	98.40%	99.19%	99.50%	99.74%	99.98%
1.9	97.08%	97.88%	98.70%	99.34%	99.60%	99.79%	99.99%
2.0	97.55%	98.22%	98.92%	99.46%	99.67%	99.83%	99.99%

APPENDIX-B: SCM DESIGN CONFIURATION FOR THE PERFORMANCE CURVES

General Information	BMP Parameters	Biofiltration	Biofiltration with ISR	Infiltration Basin	Infiltration Trench	Dry Pond	Wet Pond	Sand Filter	Subsurface Gravel Wetland
Surface Storage Configuration	Orifice Height (ft)	0	0	0	0	0	0	0	0
	Orifice Diameter (in.)	0	0	0	0	4	0	0	0
	Rectangular or Triangular Weir	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular
	Weir Height (ft)/Ponding Depth (ft)	0.5	0.33	2	0.5	6.0	6.0	0.5	2.2
	Crest Width (ft)	30	30	30	30	30	30	30	6
Soil Properties	Depth of Soil (ft)	2.5	2.0	0.001	6.0	0.001	0.001	2.5	0.67
	Soil Porosity (0-1)	0.2	0.45	0.4	0.4	0.3	0.3	0.3	0.4
	Vegetative Parameter A	0.9	0.6	0.9	0.9	0.1	0.1	0.8	0.9
	Soil Infiltration (in/hr)	2.5	4.5	background infiltration	background infiltration	0	0	2.5	4.4
Underdrain Properties	Consider Underdrain Structure?	Yes	Yes	No	No	No	No	Yes	Yes
	Storage Depth (ft)	1	2.5	0	0	0	0	1	2
	Media Void Fraction (0-1)	0.40	0.42	0	0	0	0	0.40	0.4
	Background Infiltration (in/hr)	0	0	see Appendix A2	see Appendix A3	0	0	0	0
Decay Rates	*E.coli* (1/hr)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Underdrain Removal Rates	*E.coli* (%, 0-1)	0.76	0.76	0.96	0.76	0.64	0.96	0.76	0.60

APPENDIX-C: METHOD FOR DETERMINING STORMWATER CONTROL DESIGN VOLUME (DSV) (I.E., CAPACITY) USING LONG-TERM CUMULATIVE PERFORMANCE CURVES

Stormwater Control Type	Description	Applicable Structural Stormwater Control Performance Curve	Equation for calculating Design Storage Capacity for Estimating Cumulative Reductions using Performances Curves
Infiltration Trench	Provides temporary storage of runoff using the void spaces within the soil/sand/gravel mixture that is used to backfill the trench for subsequent infiltration into the surrounding sub-soils.	Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour)	DSV = void space volumes of gravel and sand layers $DSV = (L \times W \times D_{stone} \times n_{stone}) + (L \times W \times D_{sand} \times n_{sand})$
Subsurface Infiltration	Provides temporary storage of runoff using the combination of storage structures (e.g., galleys, chambers, pipes, etc.) and void spaces within the soil/sand/gravel mixture that is used to backfill the system for subsequent infiltration into the surrounding sub-soils.	Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour)	DSV = Water storage volume of storage units and void space volumes of backfill materials. Example for subsurface galleys backfilled with washed stone: $DSV = (L \times W \times D)_{galley} + (L \times W \times D_{stone} \times n_{stone})$
Surface Infiltration	Provides temporary storage of runoff through surface ponding storage structures (e.g., basin or swale) for subsequent infiltration into the underlying soils.	Infiltration Basin (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour)	DSV = Water volume of storage structure before bypass. Example for linear trapezoidal vegetated swale $DSV = (L \times ((W_{bottom}+W_{top@Dmax})/2) \times D)$
Rain Garden/Bio-retention (no underdrains)	Provides temporary storage of runoff through surface ponding and possibly void spaces within the soil/sand/gravel mixture that is used to filter runoff prior to infiltration into underlying soils.	Infiltration Basin (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour)	DSV = Ponding water storage volume and void space volumes of soil filter media. Example for raingarden: $DSV = (A_{pond} \times D_{pond}) + (A_{soil} \times D_{soil} \times n_{soil\ mix})$
Tree Filter (no underdrain)	Provides temporary storage of runoff through surface ponding and void spaces within the soil/sand/gravel mixture that is used to filter runoff prior to infiltration into underlying soils.	Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour)	DSV = Ponding water storage volume and void space volumes of soil filter media. $DSV = (L \times W \times D_{ponding}) + (L \times W \times D_{soil} \times n_{soil\ mix})$
Bio-Filtration (w/underdrain)	Provides temporary storage of runoff for filtering through an engineered soil media. The storage capacity includes void spaces in the filter media and temporary ponding at the surface. After runoff has passed through the filter media it is collected by an under-drain pipe for discharge. Manufactured or packaged bio-filter systems such as tree box filters may be suitable for using the bio-filtration performance results.	Bio-filtration	DSV = Ponding water storage volume and void space volume of soil filter media. Example of a linear biofilter: $DSV = (L \times W \times D_{ponding}) + (L \times W \times D_{soil} \times n_{soil})$
Enhanced Bio-filtration w/ Internal Storage Reservoir (ISR) (no infiltration)	Based on design by the UNH Stormwater Center (UNHSC). Provides temporary storage of runoff for filtering through an engineered soil media, augmented for enhanced phosphorus removal, followed by detention and denitrification in a subsurface internal storage reservoir (ISR) comprised of gravel. An elevated outlet control at the top of the ISR is designed to provide a retention time of at least 24 hours in the system to allow for sufficient time for denitrification and nitrogen reduction to occur prior to discharge. The design storage capacity for using the cumulative performance curves is comprised of void spaces in the filter media, temporary ponding at the surface of the practice and the void spaces in the gravel ISR.	Enhanced Bio-filtration w/ISR	DSV = Ponding water storage volume and void space volume of soil filter media and gravel ISR. $DSV = (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{soil} \times n_{soil}) + (A_{ISR} \times D_{gravel} \times D_{gravel})$
Gravel Wetland	Provides temporary surface ponding storage of runoff in a vegetated wetland cell that is eventually routed to an underlying saturated gravel internal storage reservoir (ISR) for nitrogen treatment. Outflow is controlled by an elevated orifice that has its invert elevation equal to the top of the ISR layer and provides a retention time of at least 24 hours.	Gravel Wetland	DSV = pretreatment volume + ponding volume + void space volume of gravel ISR. $DSV = (A_{pretreatment} \times D_{preTreatment}) + (A_{wetland} \times D_{ponding}) + (A_{ISR} \times D_{gravel} \times n_{gravel})$
Porous Pavement with subsurface infiltration	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces of a subsurface gravel reservoir prior to infiltration into subsoils.	Infiltration Trench (6 infiltration rates: 0.17, 0.27, 0.52, 1.02, 2.41 and 8.27 inches per hour)	DSV = void space volumes of gravel layer $DSV = (L \times W \times D_{stone} \times n_{stone})$
Porous pavement w/ impermeable underliner w/underdrain	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces prior to discharge by way of an underdrain.	Porous Pavement	Depth of Filter Course = D_{FC}
Sand Filter w/underdrain	Provides filtering of runoff through a sand filter course and temporary storage of runoff through surface ponding and within void spaces of the sand and washed stone layers prior to discharge by way of an underdrain.	Sand Filter	DSV = pretreatment volume + ponding volume + void space volume of sand and washed stone layers. $DSV = (A_{pretreatment} \times D_{preTreatment}) + (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{sand} \times n_{sand}) + (A_{bed} \times D_{stone} \times n_{stone})$
Wet Pond	Provides treatment of runoff through routing through permanent pool.	Wet Pond	DSV= Permanent pool volume prior to high flow bypass $DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume)
Extended Dry Detention Basin	Provides temporary detention storage for the design storage volume to drain in 24 hours through multiple out let controls.	Dry Pond	DSV= Ponding volume prior to high flow bypass $DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume)
Dry Water Quality Swale/Grass Swale	Based on MA design standards. Provides temporary surface ponding storage of runoff in an open vegetated channel through permeable check dams. Treatment is provided by filtering of runoff by vegetation and check dams and infiltration into subsurface soils.	Water Quality Grass swale	DSV = Volume of swale at full design depth $DSV = L_{swale} \times A_{swale} \times D_{ponding\ swale}$

Definitions: **DSV**= Design Storage Volume = physical storage capacity to hold water; **VSV** = Void Space Volume; **L** = length, **W** = width, **D** = depth at design capacity before bypass, **n** = porosity fill material, **A**= average surface area for calculating volume; **Infiltration rate** = saturated soil hydraulic conductivity

WOODARD
&CURRAN