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 4C. Opti-Tool Application for Two Pilot Drainage Areas (Outfall #2 and #7) to Evaluate Source Area Contributions and GI SCM Reduction Benefits

Prepared for:

U.S. EPA Region 1

In Cooperation With:

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

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Under Contract:

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

February 19, 2020

To:	Ray Cody, Mark Voorhees (US EPA Region 1)
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CC:	Project Technical Team
Date:	2/19/2020
Re:	Opti-Tool Application for Two Pilot Drainage Areas (Outfall #2 and #7) to Evaluate Source Area Contributions and Green Infrastructure (**GI**) and Stormwater Control Measure (**SCM**) Benefits (Task 4C)

1 EXECUTIVE SUMMARY

This memorandum presents the technical approach for the application of Opti-Tool (U.S. EPA, 2016) to the evaluation of the stormwater quantity and quality at two outfalls in Tisbury, MA under existing conditions and the expected benefits of implementing Green Infrastructure (**GI**) and Stormwater Control Measures (**SCM**) in the outfalls' drainage areas. The approach is supported by a rainfall analysis that assessed the number of discharge-producing days that could be eliminated by capturing and infiltrating surface runoff through implementing GI SCM opportunities for a range of storm sizes. The study demonstrates that distributed GI SCM practices can provide cost-effective solutions that achieve volume and load reduction targets while also effectively integrating within urbanized landscapes. An analytical framework and summary metrics are provided which can be readily customized and applied in other settings to inform stormwater management planning efforts. A comparison of flow volumes, flow duration curves, and total nitrogen (TN) loads delivered at the two selected outfall locations before and after the implementation of GI SCM opportunities is presented. Cost-effectiveness curves are provided to visualize the level of investment needed to obtain a range of flow volume and TN load reductions. Summary tables present the optimal level of SCM implementation for various land uses.

Summarized study results are presented in Table 1. The results suggest that GI SCM practices can infiltrate approximately 50.7 million gallons of stormwater volume within the combined catchments of outfall #2 and #7 (129 acres) if sizing those infiltration practices to capture 0.35 inches of runoff from the impervious cover. This equates to an 80% reduction in annual stormwater volume compared to existing, baseline conditions. The total estimated cost to achieve this overall reduction in both outfalls was approximately $1,160,000. This cost represents an optimization goal of reducing stormwater volume. The solution would achieve a co-benefit of approximately 90% reduction in TN. Additionally, assuming a moderate infiltration rate of 1.02 in/hr (U.S. EPA, 2019a), the optimized solution would also result in a 62%-75% reduction in average annual bacteria loading. The estimated cost for flow volume reduction was $0.02 per gallon for both outfalls. The implementation of GI SCM practices was also optimized for TN reduction, a target solution that achieved a 91% reduction in loading would also have the co-benefit of achieving an 80% reduction in annual stormwater volume. The estimated cost to achieve this overall reduction in both outfalls was approximately $1,174,000. Cost estimates assume no cost-sharing or use of town labor and equipment, which could help lower costs. The costs for TN load reduction varied by outlet, the cost for removing a pound of TN was between $1,700 and $2,000. While actual costs may vary depending on local conditions, the cost estimates provide a useful comparison of relative differences in optimization scenarios. Overall, it appears that an optimized solution that focuses on either stormwater volume or TN load reduction can achieve similar reductions for both benefits for approximately the same costs.

Table 1 Summary of Analyses Results for Tisbury, MA Outlets #2 and #7,

	Outfall #2	Outfall #7
Baseline Average Flow Volume (gallons/yr)	23,193,061	40,174,307
Baseline Average TN Load (lbs/yr)	261.87	420.63
Flow Volume Removed (gallons/yr)	18,551,813	32,192,534
TN Load Removed (lbs/yr)	233.27	386.14
Cost per Gallon Flow Removed ($)	$0.02	$0.02
Cost per Pound TN Removed ($)	$1,727	$1,996
Total Cost	**$406,122**	**$753,076**

Strategically optimizing the selection and placement of distributed SCMs within highly urbanized settings through continuous simulation can help to develop management strategies that are more cost-effective than the traditional approach of sizing SCMs at fixed locations to treat a design storm. The flood mitigation benefits of GI SCM are especially valuable in urbanized areas with poor stormwater transmission where even relatively small storms can result in flooding. The relatively small size of distributed GI facilities substantially increases the feasibility of treating runoff from impervious surfaces in constrained developed spaces and achieving meaningful water quantity and quality benefits. This application of Opti-Tool demonstrates that relatively small GI facilities and SCMs can provide a cost-effective stormwater management approach in an opportunity-limited, urban setting like Tisbury, MA. Additionally, this study highlights the value of conducting strategic planning to address stormwater impacts for achieving multiple water resource goals. The results of this study are based on an assessment of a twenty-one-year time series of simulated overland flow. The modeling focused on watershed-scale hydrologic processes including the conversion of rainfall to runoff and the capture and infiltration of that runoff. The modeling did not include an explicit representation of Tisbury's stormwater conveyance network, therefore hydraulic processes such as transportation losses and pipe surcharge are not simulated. Despite these limitations, the modeling provides valuable insight into the existing conditions in Tisbury and the potential benefit of GI SCM opportunities.

2 RAINFALL ANALYSIS FOR TISBURY GAUGE

Green infrastructure and SCM opportunities can be built to capture a range of storm sizes. Prior to running an Opti-Tool-based optimization, a simplified, spreadsheet-based analysis was conducted to assess the potential benefits of implementing GI SCM opportunities over a range of sizes designed to capture runoff depths ranging from 0.1 to 2.0 inches.

A twenty-one year (Jan 1998 – Dec 2018) hourly precipitation timeseries was analyzed to determine the average annual number of daily precipitation events and their respective depths in order to assess the benefits of implementing GI SCM opportunities of various sizes. A dry year (year-2001), wet year (year-2018), and an average year (year-2012) were also estimated based on the total precipitation and the number of rain days (Table 2). Based on the analysis, an event exceeding 1.5 inches in 24 hours is very likely to occur in Tisbury, MA in any given year (Figure 1). A less frequent event, one which exceeds 4.2 inches, has an approximately 10% chance of occurring in any given year. While these numbers represent probabilities for annual maximum 24-hr rainfall, surprisingly, over 50% of total annual precipitation events (24-hr rainfall) in Tisbury are 0.1 inches or less in-depth (Table 3). Figure 2 shows the number of precipitation days that can be captured by implementing infiltration GI SCM opportunities over a range of sizes. Since over 50% of annual events are 0.1 inches or less in-depth, sizing infiltration GI SCM opportunities throughout the community to capture 0.1 inches of runoff can be expected to reduce the number of discharge days by the same amount.

The rainfall analysis provides important results at the conceptual level that highlight the benefit of implementing small, distributed GI SCM. The analysis is especially applicable in communities where occurrences of flooding, algal blooms, and bacteria-related beach closings may occur multiple times a year. For Tisbury, implementing relatively small infiltration systems designed to capture 0.2 inches is estimated

Table 2. Number of rain days, maximum daily, and annual rainfall depth for 21 years (1998-2018) in Tisbury, MA.

Year	Total Rainfall (in./year)	Maximum Rainfall (in./day)	No. of Rain Days
1998	44.5	2.54	145
1999	36.3	2.57	133
2000	39.9	2.81	153
2001	27.5	2.65	147
2002	40.1	1.51	153
2003	41.5	3.40	135
2004	37.3	3.84	129
2005	42.6	3.03	132
2006	43.4	4.16	141
2007	33.7	2.12	135
2008	39.2	2.43	138
2009	42.8	3.70	143
2010	46.3	4.18	119
2011	43.8	4.26	133
2012	40.5	2.33	137
2013	40.4	1.92	147
2014	40.3	2.27	122
2015	37.5	2.71	115
2016	30.8	2.02	100
2017	46.5	3.05	133
2018	51.8	3.13	137
Long-Term Average:	**40.3**	**2.88**	**134**

Dry Year Average Year Wet Year

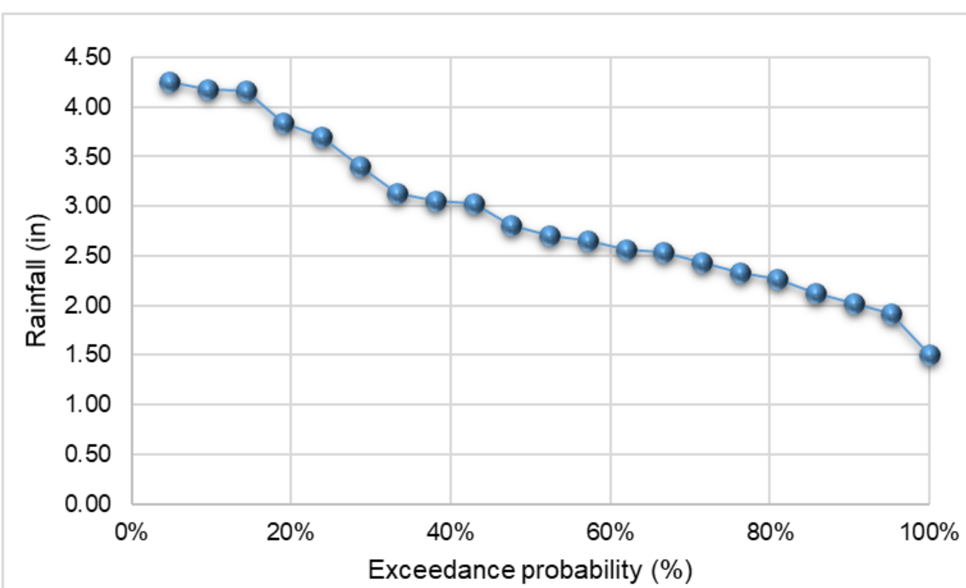

Figure 1. Exceedance probability for maximum daily rainfall depths for 21 years (1998-2018) in Tisbury, MA.

Table 3. The number of storms captured/retained and percent of discharge days eliminated with infiltration SCMs of various sizes.

Infiltration SCM Size to Capture Runoff Depth from Impervious Surfaces (in.)	Captured Number of 24-hour Storms (per year)	% Number of Discharge Days Eliminated (per year)
0.1	73	54%
0.2	88	66%
0.3	98	73%
0.4	105	78%
0.5	110	82%
0.6	114	85%
0.7	118	88%
0.8	120	90%
0.9	123	92%
1.0	125	93%
1.1	126	94%
1.2	128	96%
1.3	129	96%
1.4	129	96%
1.5	130	97%
1.6	131	98%
1.7	131	98%
1.8	132	99%
1.9	132	99%
2.0	132	99%

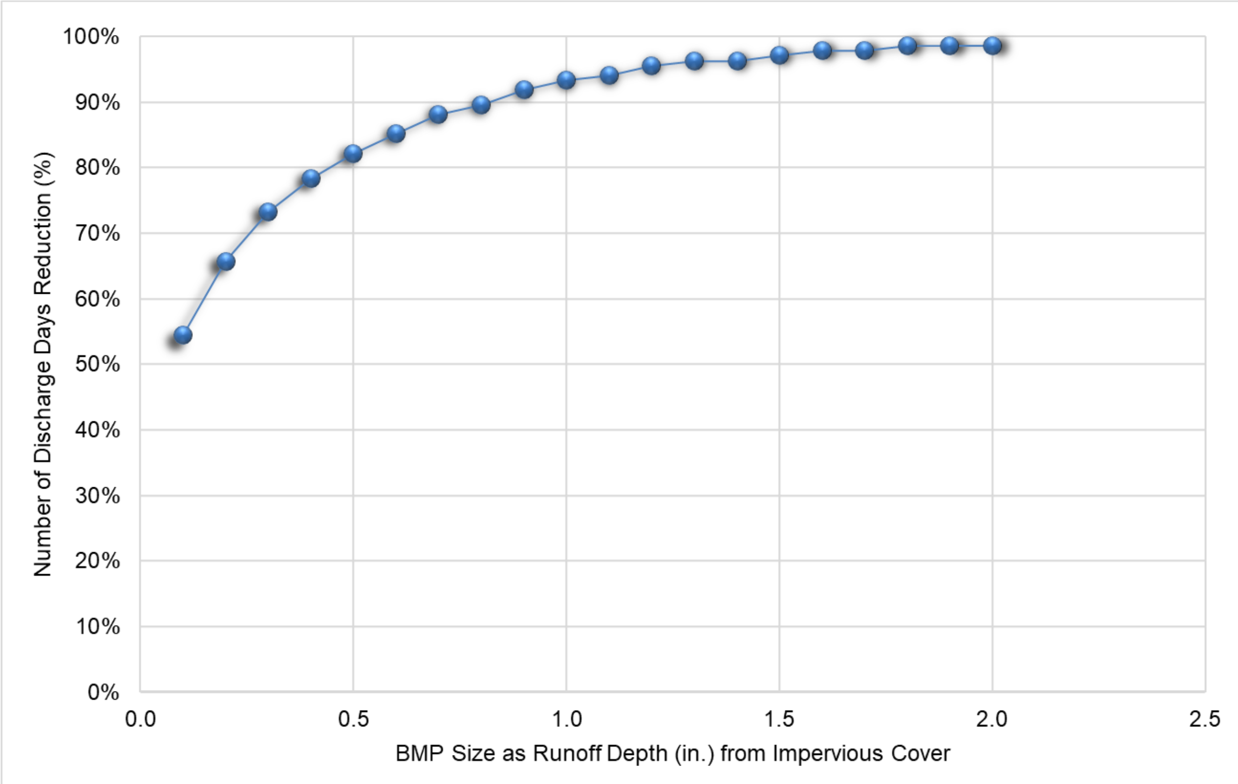

Figure 2. Comparison of SCM size to percent number of discharge days reduction.

to eliminate 66% of the days that would have otherwise resulted in stormwater discharge. The results also provide a strong foundation on which additional analyses using Opti-Tool optimization and continuous simulation can provide further insights into the benefits of GI SCM implementation.

3 OUTFALLS (#2 AND #7) CATCHMENTS CHARACTERISTICS

The study areas were adjacent catchments draining to two stormwater outfalls (Figure 3) in the town of Tisbury MA. The sub-catchments to each catch basin within the study area were auto-delineated using 1-meter high-resolution elevation data in ArcGIS software (Figure 4). The outfalls are located off the shore of the municipality. The catchments varied in size and land cover. The area distribution for Hydrologic Response Units (HRUs), unique land segments with an attribute of land use, land cover, soil, and slope combinations, in these two catchments is shown in Table 4. The catchment draining to outfall #2 was approximately 66% impervious surfaces, while the larger catchment draining to outfall #7 was approximately 40% impervious surfaces (Table 5). The previously completed Task 4B memo (U.S. EPA, 2019b) provides a detailed discussion on the development of Hydrologic Response Units (HRUs) for the area, including summary figures of hydrologic soil groups, land use, land cover, and slope in the area.

Table 4. HRU area distribution in drainage catchments to selected two outfall locations.

HRU	Land Use	Catchment Area (acres)		
		Catchment #2	Catchment #7	Total
1001	Forest	0.060	1.611	1.670
2001	Agriculture	-	-	-
3001	Commercial	17.973	11.378	29.352
4001	Industrial	-	-	-
5001	Low Density Residential	-	-	-
6001	Medium Density Residential	2.010	21.760	23.770
7001	High Density Residential	0.918	0.900	1.818
8001	Transportation	0.473	1.937	2.410
9001	Open Land	0.002	0.449	0.451
11110	Developed Pervious-A-Low	1.118	18.037	19.156
11120	Developed Pervious-A-Med	2.336	22.628	24.963
11130	Developed Pervious-A-High	0.935	6.880	7.814
11210	Developed Pervious-B-Low	-	-	-
11220	Developed Pervious-B-Med	-	-	-
11230	Developed Pervious-B-High	-	-	-
11310	Developed Pervious-C-Low	4.390	0.476	4.866
11320	Developed Pervious-C-Med	1.634	0.490	2.123
11330	Developed Pervious-C-High	0.429	0.115	0.545
11410	Developed Pervious-D-Low	0.000	0.006	0.006
11420	Developed Pervious-D-Med	-	0.033	0.033
11430	Developed Pervious-D-High	-	0.010	0.010
12110	Forest Pervious-A-Low	0.069	3.402	3.470
12120	Forest Pervious-A-Med	0.116	4.480	4.596
12130	Forest Pervious-A-High	0.079	1.745	1.824
12210	Forest Pervious-B-Low	0.020	-	0.020
12220	Forest Pervious-B-Med	0.012	-	0.012

HRU	Land Use	Catchment Area (acres)		
		Catchment #2	Catchment #7	Total
12230	Forest Pervious-B-High	-	-	-
13110	Agriculture Pervious-A-Low	-	-	-
13120	Agriculture Pervious-A-Med	-	-	-
13130	Agriculture Pervious-A-High	-	-	-
13210	Agriculture Pervious-B-Low	-	-	-
13220	Agriculture Pervious-B-Med	-	-	-
13230	Agriculture Pervious-B-High	-	-	-
Total Area		32.573	96.336	128.908

Table 5. Pervious and impervious areas for catchments draining to outfalls #2 and #7

	Total Area (acres)	Impervious Area (acres)			Pervious Area (acres)
		Roofs	Other Impervious	Total Impervious	
Outfall #2 Catchment	32.6	6.2 (19.0%)	15.2 (46.8%)	21.4 (65.8%)	11.1 (34.2%)
Outfall #7 Catchment	96.3	12.4 (12.9%)	25.6 (26.6%)	38.0 (39.5%)	58.3 (60.5%)

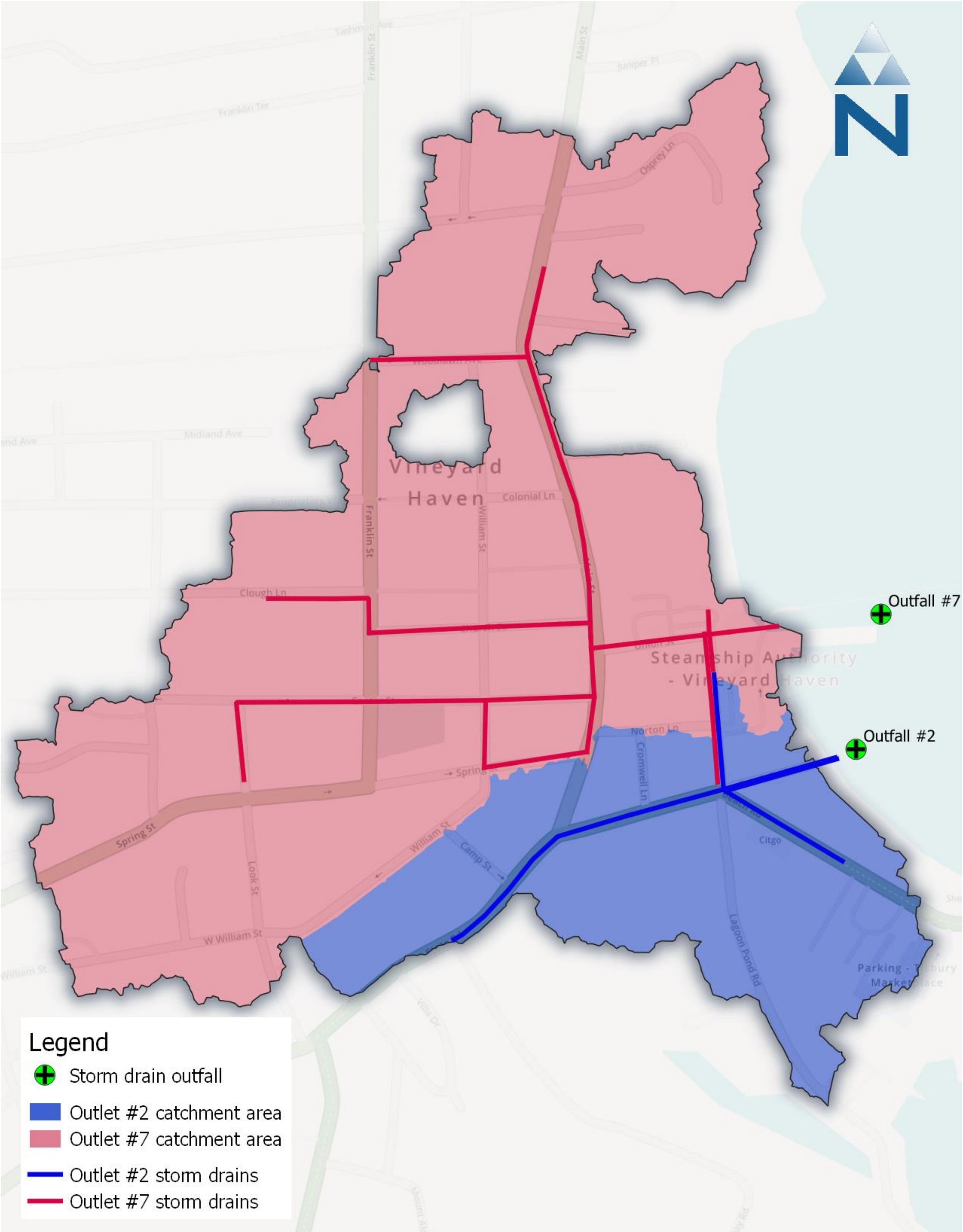

Figure 3.Storm drains, outfalls, and catchment areas

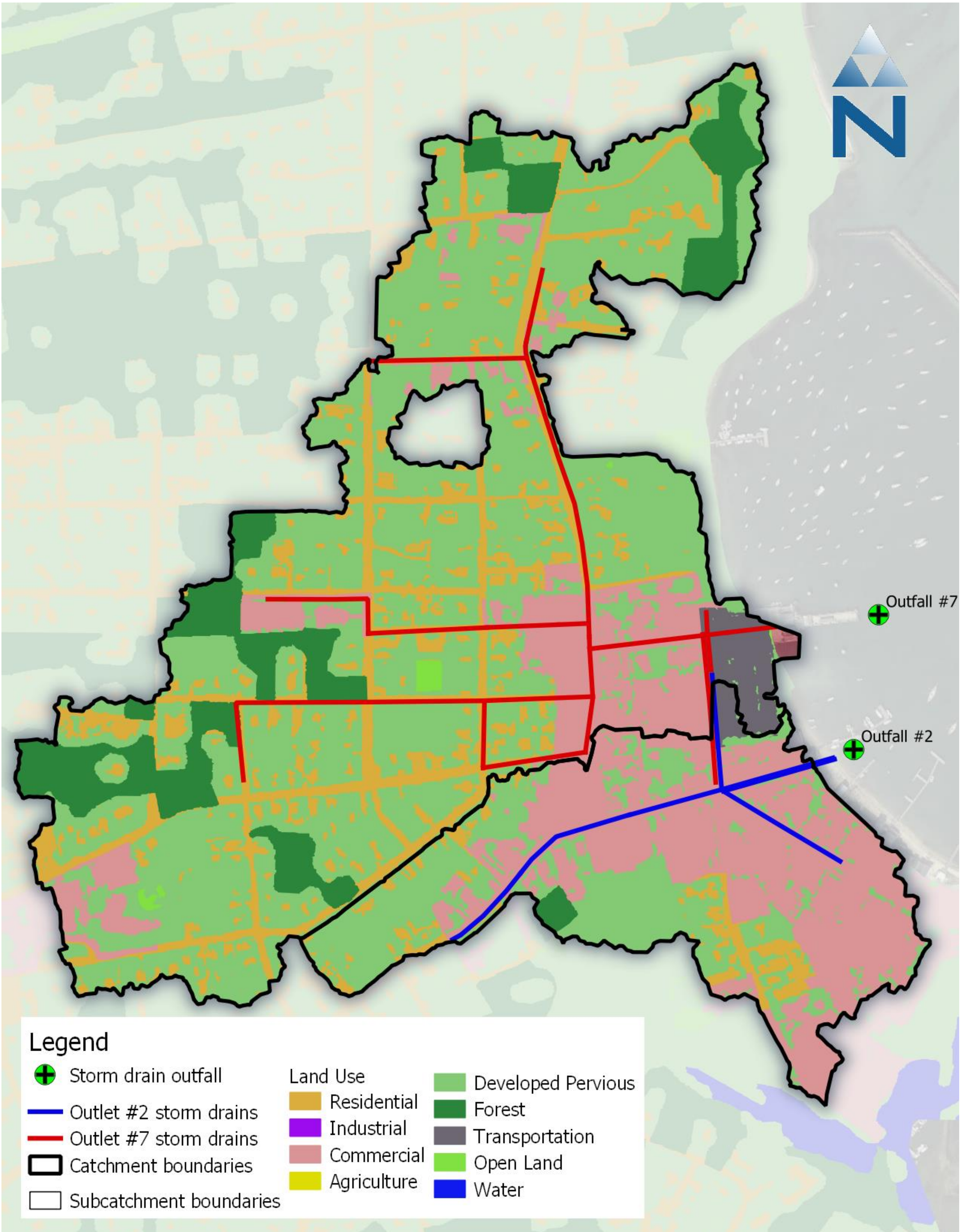

Figure 4. Sub-catchment delineation and major land uses in the drainage areas to outfall #2 and #7.

4 TECHNICAL APPROACH

The Opti-Tool provides the ability to evaluate options for determining the best mix of GI SCM opportunities to achieve water quantity and quality goals. The tool incorporates long-term runoff responses in the form of HRU timeseries for regional climate conditions that are calibrated to regionally representative stormwater data and annual average pollutant load export rates from nine major land uses. The tool uses regionally representative SCM cost functions and regionally calibrated SCM performance parameters for various pollutants, including total nitrogen (TN), to calculate long-term cumulative load reductions for a variety of structural controls. Green infrastructure and SCMs simulated by the tool include infiltration systems, bio-filtration, and gravel wetlands.

The technical approach for applying the Opti-Tool is organized into three general steps:

1. Develop stormwater management categories for SCMs known to be highly effective at reducing storm flows and removing nitrogen (e.g., shallow filtration, infiltration, biofiltration) based on the site suitability analysis of GIS layers;
2. Estimate the available opportunity by SCM type (i.e., physical footprint area) within each management category and summarize the upstream impervious drainage area that can be managed for each management category, and
3. Set up and run the Opti-Tool application to identify the most cost-effective combination of SCM options that achieve the desired management objectives.

4.1 Stormwater Management Categories

Spatial data analyses were previously conducted (U.S. EPA, 2018) to characterize watershed features and identify the corresponding stormwater management categories that were suitable for application with the Opti-Tool for the two outfall catchments. The GIS data used for the evaluation of stormwater management categories for the Tisbury catchments included: land use coverage, impervious cover, Hydrologic Soil Group (HSG), and LiDAR-derived Digital Elevation Model (DEM) for ground slopes. All data are from Massachusetts GIS (MassGIS) data layers.

Table 6, previously presented in U.S. EPA (2018), presents the siting criteria used for all potential GI SCM opportunities in Tisbury, which were derived from GIS analysis. Based on the dominant HSG of 'A' within the two catchments, the assessed GI SCM opportunities all fell under the "infiltration" management category (Figure 5). For this pilot study, it was assumed that rooftops could be disconnected by redirecting their runoff to infiltrations trenches, while all other types of impervious areas, such as roads and driveways, could be disconnected by diverting their runoff to infiltration basins. Both public and private property were assumed to be available for GIS SCM implementation.

Table 6. Potential stormwater management categories and SCM types in the Opti-Tool

Land Use	Landscape Slope (%)	Within 100 feet of Coastline?	Within 25 feet of Structure?	Soil Group	Management Category	SCM Type(s) in Opti-Tool
Pervious Area	<= 15	Yes	Yes	All	Less likely for onsite SCM	--
		No	No	A/B/C	Infiltration	Surface Infiltration Basin (e.g., Rain Garden)
				D	Biofiltration	Biofiltration (e.g., Enhanced Bioretention with ISR and underdrain option)
	> 15	--	--	--	Less likely for onsite SCM	--
Impervious Area	<= 5	Yes	Yes	All	Less likely for onsite SCM	--
		No	No	A/B/C	Infiltration	Infiltration Trench
				D	Shallow filtration	Porous Pavement
	> 5	--	--	--	Less likely for onsite SCM	--

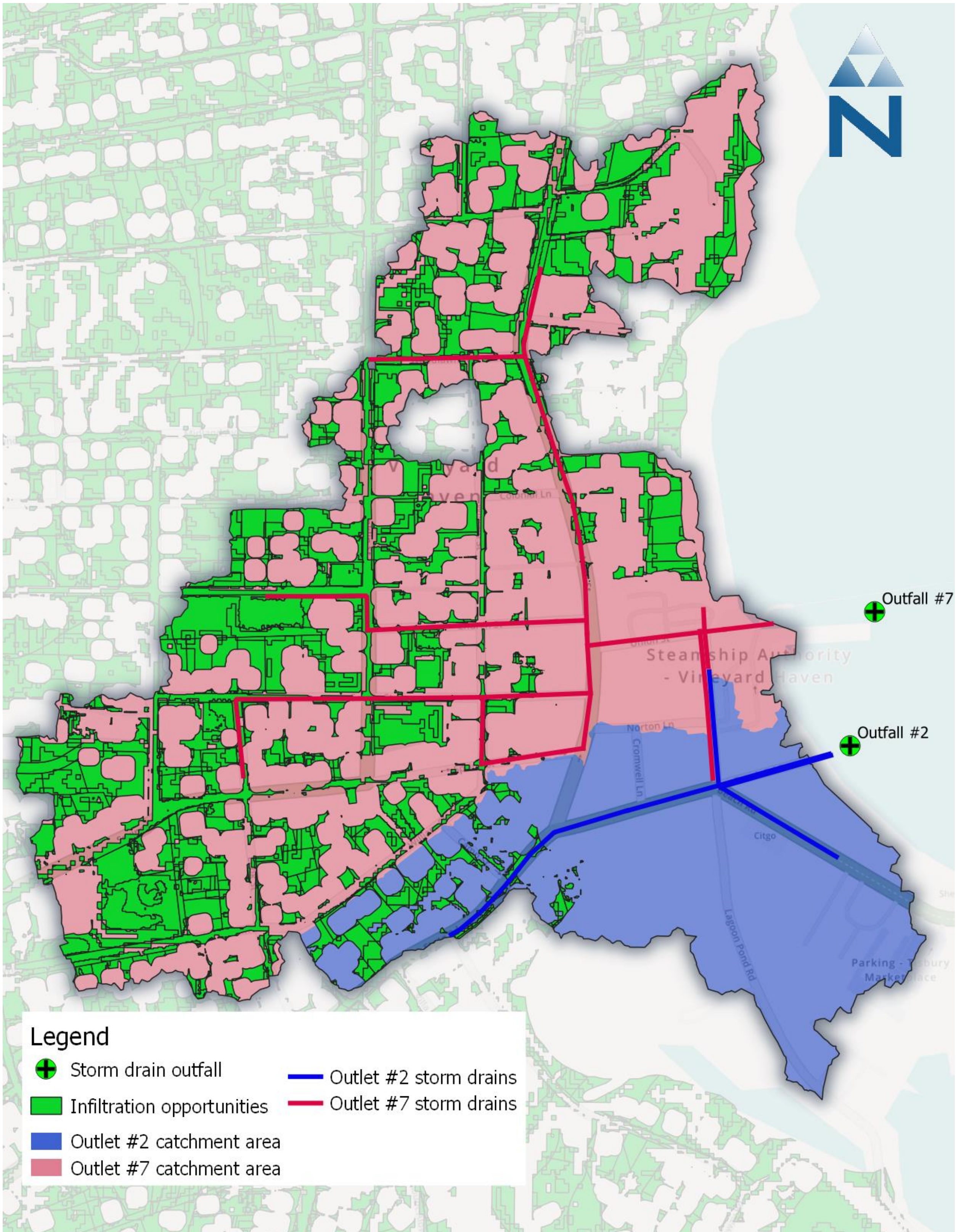

Figure 5. Infiltration-based GI SCM opportunities in the two outfall catchments.

4.2 Estimating SCM Footprints and Drainage Treatment Areas

The distribution of the SCM opportunity areas (i.e., SCM footprints) was estimated by land use category group. This distribution represents the maximum available SCM footprint in the pilot watersheds, based on GIS spatial data analysis, and does not necessarily represent the feasibility of such opportunity areas. The treated impervious areas by land use group were split into two categories; roofs and others (Table 7). The total drainage treatment area was 59 Acres of impervious surface, this represents all impervious surfaces in the study catchment (Table 5). While all impervious surfaces were routed to an SCM, treatment was contingent on the SCM size. For this case study, the maximum SCM footprints that could be considered during optimization were limited the capture up to 2 inches of runoff from the impervious drainage areas by land use group (Table 8).

The GI SCM types are derived from five land uses having the possibility of either an infiltration trench or an infiltration basin placed on it, due to most land uses having both roofs and other types of impervious areas. However, the transportation land use only included impervious road surfaces associated with it, therefore the land use category contained no roofs and no opportunities for infiltration trenches.

Table 7. SCM-treated impervious area (drainage treatment area)

Land cover/Land use	Impervious Type	Drainage Treatment Area (acres)		
		Catchment 2	Catchment 7	Total
Forest	Roofs	0.048	0.237	0.285
	Other	0.011	1.373	1.384
Commercial	Roofs	4.893	3.678	8.571
	Other	13.080	7.700	20.78
Medium Density Residential	Roofs	0.915	7.953	8.868
	Other	1.095	13.807	14.902
High Density Residential	Roofs	0.283	0.358	0.641
	Other	0.635	0.543	1.178
Transportation	Other	0.473	1.937	2.41
Open Land	Roofs	-	0.026	0.026
	Other	-	0.423	0.423
Total	Roofs	**6.491**	**12.437**	**18.928**
	Other	**14.942**	**25.598**	**40.54**

Table 8 Potential SCM opportunity areas (maximum footprints) in the two outfall catchments

Land cover/Land use	Impervious Type	SCM Type	Maximum Footprint (acres)		
			Catchment 2	Catchment 7	Total
Forest	Roofs	Infiltration trench - A	0.003	0.014	0.017
	Other	Infiltration basin - A	0.001	0.114	0.115
Commercial	Roofs	Infiltration trench - A	0.220	0.211	0.431
	Other	Infiltration basin - A	0.257	0.642	0.899
Medium Density Residential	Roofs	Infiltration trench - A	0.039	0.457	0.496
	Other	Infiltration basin - A	0.091	1.150	1.241
High Density Residential	Roofs	Infiltration trench - A	0.001	0.021	0.022
	Other	Infiltration basin - A	0.027	0.045	0.072
Transportation	Other	Infiltration basin - B	0.039	0.161	0.2
Open Land	Roofs	Infiltration trench - A	-	0.001	0.001
	Other	Infiltration basin - A	-	0.035	0.035
Total	Roofs	Infiltration trench	**0.289**	**0.728**	**1.017**
	Other	Infiltration basin	**0.389**	**2.123**	**2.512**

4.3 Opti-Tool Setup

The following steps were performed to set up the Opti-Tool for the pilot sub-watershed.

1. **Establish baseline condition:** Unit-area HRU timeseries for the period of interest (Jan 1998 – Dec 2018) were used as the boundary condition to the SCM simulation model. The Opti-Tool provides a utility tool that runs the SWMM models, calibrated to Region 1 specific land use average annual loading export rates, and generates the HRU hourly time series in the format needed for the Opti-Tool. The HRU hourly timeseries were developed using the hourly rainfall and temperature data from a local rain gage located at the Martha Vineyard's airport.
2. **Set Management objective:** The management objective was to identify the most cost-effective stormwater controls (types and sizes) for achieving a wide range of TN loading, stormwater volume, and storm flow rate reductions at the two outfall locations.
3. **Set Optimization target:** Cost effectiveness-curves for average annual TN load and average annual stormwater volume reduction were developed.
4. **Incorporate Land use information:** The area distribution for the major land use groups within the pilot watershed was estimated. Each land use group in the model was assigned the corresponding unit-area HRU timeseries.
5. **Incorporate SCM information:** Two SCM types, infiltration trench and infiltration basin, were selected for six major land use categories based on the Management Category analysis. SCM specifications were set using the default parameters and SCM cost function available in the Opti-Tool (Table 9). Impervious drainage areas were assigned to be treated by each SCM type in the model.
6. **Run optimization scenario:** The simulation period (Jan 1998 – Dec 2018), the stormwater metrics of concern (flow volume and TN loading), the objective function (minimize cost) were defined and input files were created for the optimization runs. The optimization was performed using the continuous simulation SCM model to reflect actual long-term precipitation conditions that included a wide range of actual storm sizes to find the optimal SCM storage capacities that provided the most cost-effective solution at the watershed scale. Each optimization run generated a CE-Curve showing the optimal solutions frontier for a wide range of stormwater volume and TN load reduction targets.

Table 9. SCM design specifications

General Information	SCM Parameters	Infiltration Trench - A	Infiltration Basin - A	Infiltration Basin - B
SCM Dimensions	Surface Area (ac)	Table 8	Table 8	Table 8
Surface Storage Configuration	Orifice Height (ft)	0	0	0
	Orifice Diameter (in.)	0	0	0
	Rectangular or Triangular Weir	Rectangular	Rectangular	Rectangular
	Weir Height (ft)/Ponding Depth (ft)	0.5	2	2
	Crest Width (ft)	30	30	30
Soil Properties	Depth of Soil (ft)	6	0	0
	Soil Porosity (0-1)	0.4	0.4	0.4
	Vegetative Parameter A	0.9	0.9	0.9

General Information	SCM Parameters	Infiltration Trench - A	Infiltration Basin - A	Infiltration Basin - B
	Soil Infiltration (in/hr)	8.27	8.27	2.41
Underdrain Properties	Consider Underdrain Structure?	No	No	No
	Storage Depth (ft)	0	0	0
	Media Void Fraction (0-1)	0	0	0
	Background Infiltration (in/hr)	8.27	8.27	2.41
Cost Parameters	Storage Volume Cost ($/ft3)	$12.49	$6.24	$6.24
Cost Function Adjustment	SCM Development Type	New SCM in Developed Area	New SCM in Developed Area	New SCM in Developed Area
	Cost Adjustment Factor	2	2	2
Decay Rates	TN (1/hr)	0.13	0.27	0.27
Underdrain Removal Rates	TN (%, 0-1)	0	0	0

5 RESULTS

5.1 Outfall #7

5.1.1 Stormwater Volume

The optimal mix of GI SCM types and sizes was assessed for the management objective of flood mitigation through a reduction in stormwater volume. Figure 6 presents the cost-effectiveness curve (CE-Curve) for the stormwater volume reduction objective for outlet #7. The blue diamonds form the most cost-effective combination of GI SCM configurations for reducing flow volume. The grey dots on the curve are inferior solutions; compared to these solutions, cheaper alternatives exist that would achieve the same flow volume reduction. The red triangle presents a theoretical target solution. The target solution generally represents some environmentally beneficial, socially acceptable, and economically feasible goals. The cost estimates are based on regional unit cost information for the control types, a 35% add-on for engineering and contingencies and a site factor multiplier to account for anticipated difficulties associated with installations. For this analysis, a multiplier of 2X was assumed for all controls.

The target solution presented in Figure 6 shows that it would cost $750,000 to achieve an 80% reduction in annual average flow volume. All costs presented in Opti-Tool derived CE-Curves are intended for planning level purposes and meant to highlight *relative* cost differences between various solutions. The CE curve presented in Figure 6 demonstrates how relative cost differences are relatively lower for reductions of 0% to approximately 80%, but the rate at which solutions become more expensive quickly increases for reductions higher than 80%.

Table 10 presents the optimized mix of GI SCM opportunity implementation which achieved an 80% reduction in annual flow volume. Design depths ranged from 0.10 to 1.47 inches. Overall, the solution was equivalent to a total design storage volume of 0.35 inches. Based on the rainfall analysis presented in section 2, the target solution would result in an 76% reduction in the annual number of runoff discharge days from the impervious surfaces being treated. While it is important to note that a reduction in annual discharge days is not directly comparable to a reduction in annual flow volume, both metrics provide valuable quantification of the potential benefits of GI SCM implementation.

The reduction in peak flows resulting from achieving the target solution, which focused on flow volume, can be seen in Figure 7. Peak flows across the driest, wettest and average years were all reduced compared to the baseline simulation reflecting existing conditions. Figure 8 highlights the impact of the target solution to storm hydrographs over selected periods of rainfall and runoff. A storm occurring on 5/17/2012 had the peak flow reduced from approximately 17 cubic feet per second (cfs) in the baseline condition to approximately 4.5 cfs in the optimized solution, a reduction of close to 74%. Other storms, occurring in March 2012, had their respective runoff contribution from treated impervious surfaces eliminated due to the optimized GI SCM implementation.

The impact of the target solution on the entire range of flow rates was also assessed. Figure 9 presents flow duration curves for both the baseline and optimized solutions. The curves characterize the storm flows of various magnitudes discharging from the outlet. The analysis assumes that the outlet is in good condition and not clogged or otherwise obstructed. The graph only includes data from days in which rainfall and discharge occurred. The graph demonstrates that for the same exceedance probability, the optimized scenario had lower flows for all but the largest and most infrequent storms. For storms that occur only 5% of the time (infrequent larger storm events that cause runoff), the optimized solution reduced the total flow at Outfall #7 from about 9 to 2 cfs, a reduction of about 78%. For more frequently occurring storms, whose flows exceeded more than 20% in baseline conditions, the total flow at Outfall #7 was reduced from 3 to 0.06 cfs, a reduction of about 98%. From the curve, the larger reductions occur for the more frequent *comparatively* smaller storm events, meaning that overall, more precipitation is being infiltrated and recharging the aquifer.

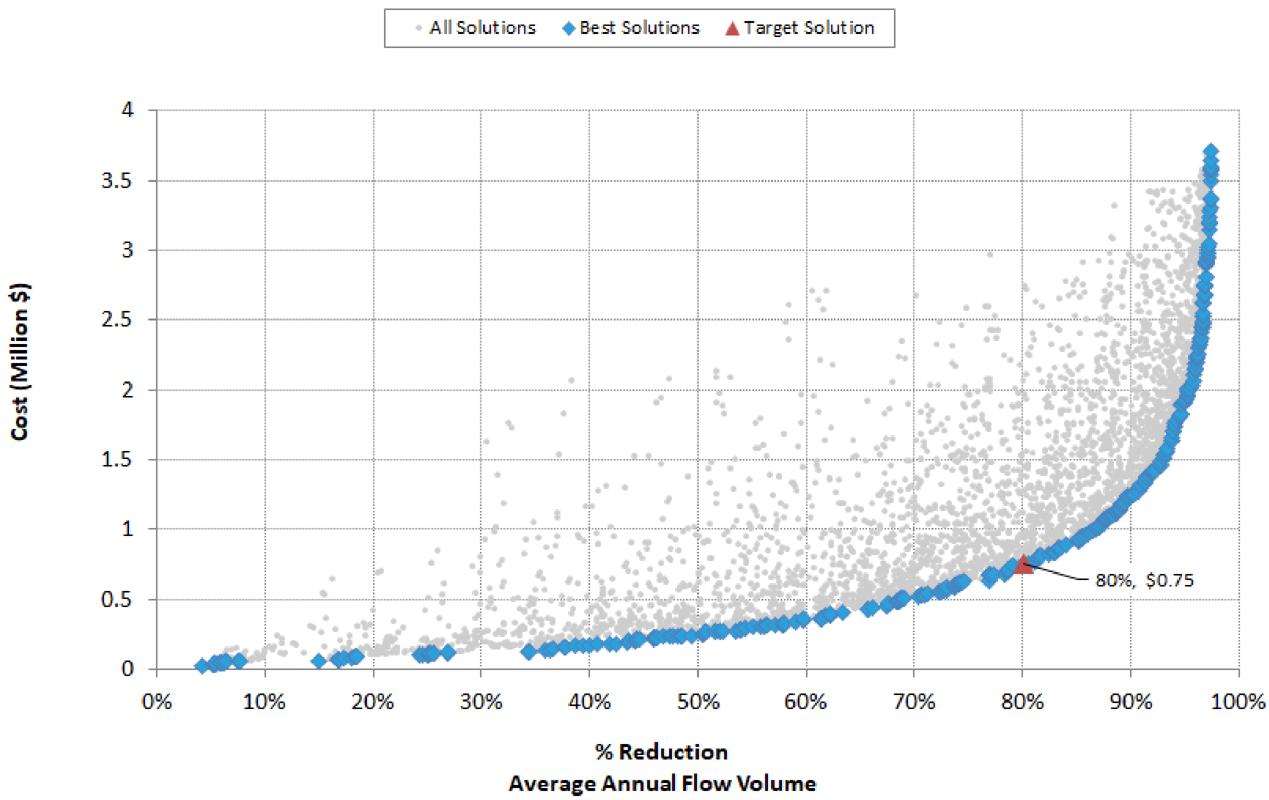

Figure 6. Opti-Tool Outfall cost effectiveness curve for annual average flow volume for outfall #7

Table 10. Optimized GI SCM opportunities for achieving an 80% reduction in annual average storm volume at outfall #7

SCMID	SCM Type	Land Use	Treated Impervious Area (acres)	Runoff Depth (in.)	SCM Storage Capacity (gallon)	SCM Cost ($)
SCM1	Infiltration Basin - A	Forest	1.37	0.30	11,186	$18,662
SCM2	Infiltration Trench - A	Forest	0.24	0.89	5,803	$19,380
SCM3	Infiltration Basin - A	Commercial	7.7	0.40	83,636	$139,532
SCM4	Infiltration Trench - A	Commercial	3.68	0.40	39,951	$133,410
SCM5	Infiltration Basin - A	Medium Density Residential	13.81	0.40	149,968	$250,196
SCM6	Infiltration Trench - A	Medium Density Residential	7.95	0.20	43,191	$144,228
SCM7	Infiltration Basin - A	High Density Residential	0.54	0.10	1,474	$2,460
SCM8	Infiltration Trench - A	High Density Residential	0.36	0.40	3,884	$12,970
SCM9	Infiltration Basin - B	Transportation	1.94	0.30	15,778	$26,322
SCM10	Infiltration Basin - A	Open Land	0.42	0.10	1,149	$1,916
SCM11	Infiltration Trench - A	Open Land	0.03	1.47	1,198	$4,000
		Total	**38.04**	**0.35**	**357,217**	**$753,076**

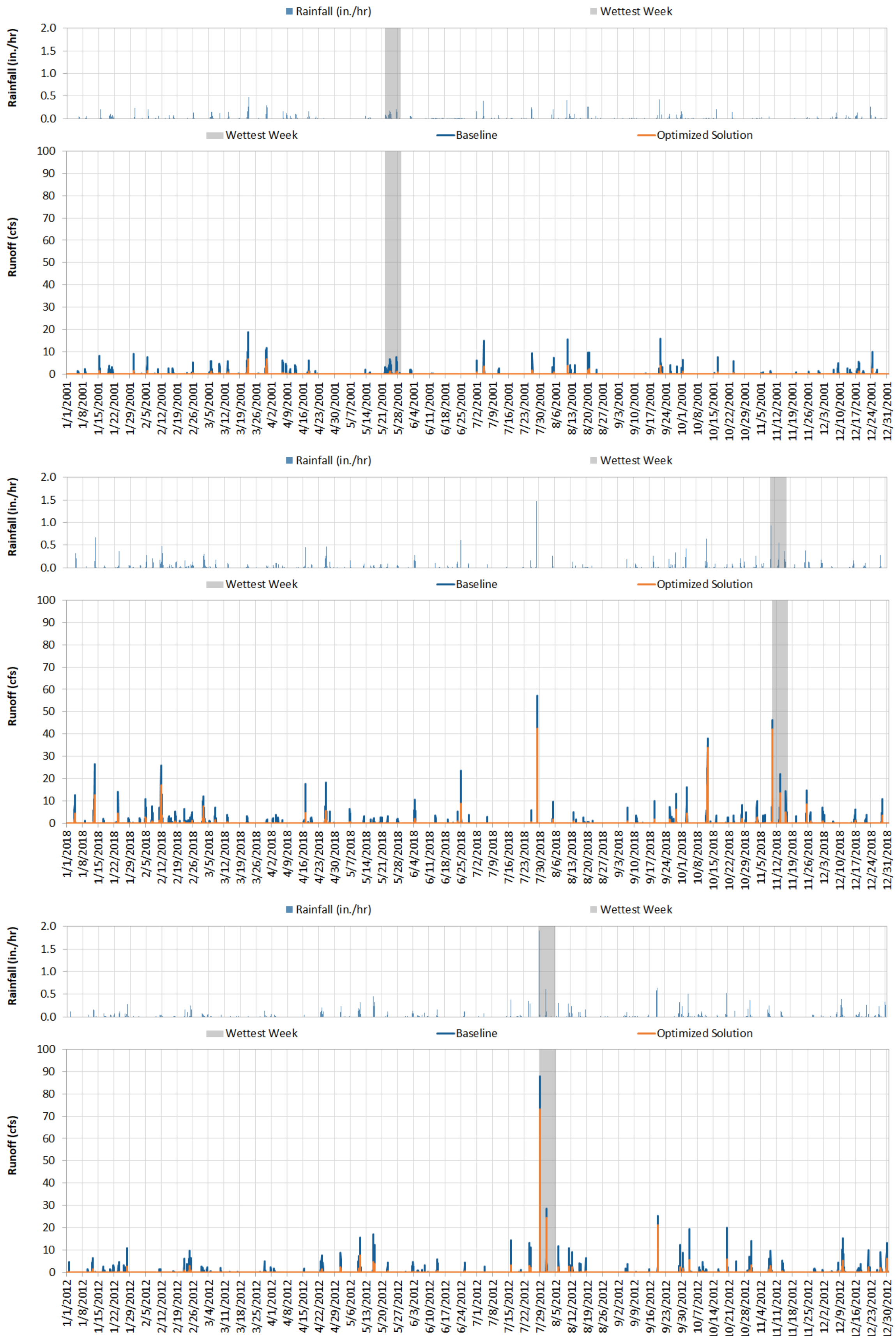

Figure 7. Rainfall and runoff for the driest (top), wettest (middle), and average years (bottom) for outfall #7. Grey area highlights the wettest week for the time period shown.

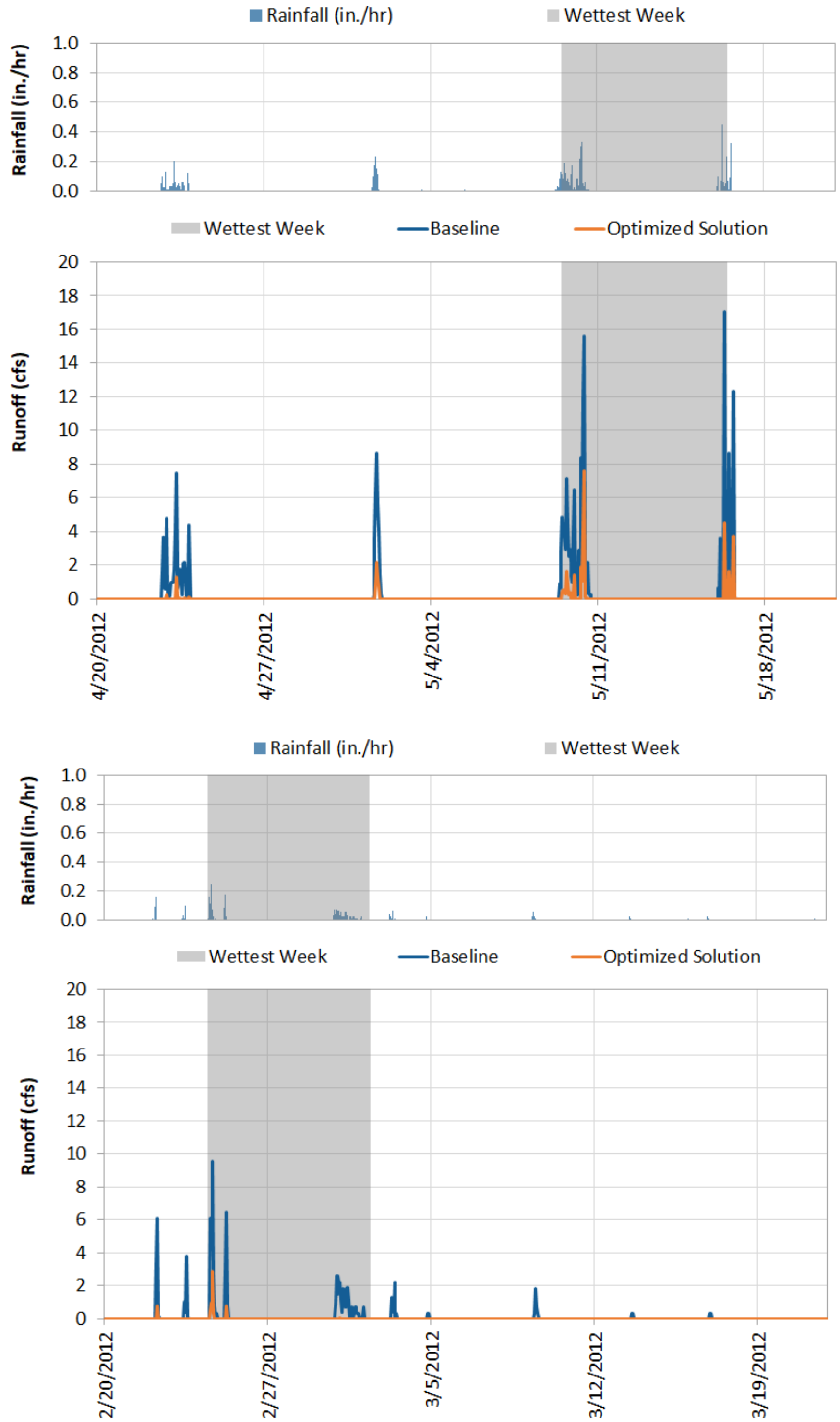

Figure 8. Selected periods of rainfall and runoff for outfall #7 during 2012, a year representing an average amount of precipitation for Tisbury, MA. Grey area highlights the wettest week for the time period shown.

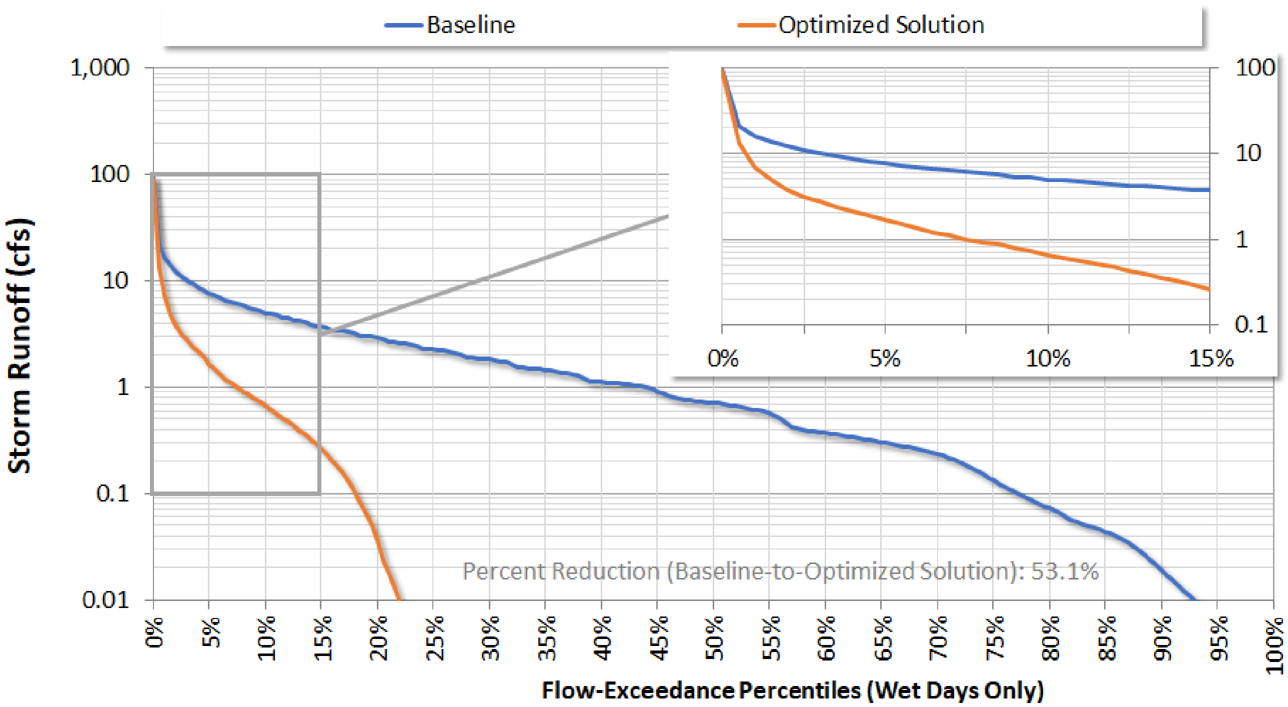

Figure 9. Opti-Tool derived flow duration curves (wet days only) for outfall #7

This not only reduces flooding in the Commercial district but helps to restores the hydrologic and hydrogeologic imbalance caused by the relatively high percentage (40%) of impervious cover that characterizes the catchment draining to Outfall #7. During all days which had rainfall and discharge, the baseline conditions show that 77% of flows were equal to or greater than 0.1 cfs. The optimized solution reduced the frequency of 0.1 cfs or greater flows to approximately 17%. A 0.1 cfs flow was as frequent in the optimized scenario as a 2 cfs flow was in the baseline scenario. The flow rate over all wet days was reduced by an average of 53% due to GI SCM implementation.

5.1.2 Total Nitrogen

Figure 10 presents the CE curve for optimizing average annual TN load reduction at outfall #7. The highlighted target solution achieved 92% reduction in TN loading. This solution was chosen because it also achieved an 80% reduction in average annual storm flow volume. However, since the solution was optimized for TN reduction, the characteristics of the GI SCM implementation were different. The solution achieves a 92% reduction in TN, with a co-benefit of 80% reduction in storm flow volume would cost approximately $770,600 (Table 11). The cost is approximately $17,600 more expensive (2.3% higher) than it would be to achieve the same volume reduction based on volume reduction optimization. Cost differences are due in part to the variable nature of TN export. While the impervious surfaces simulated in this study all convert the same amount of rainfall to runoff, different land use types export TN at differing rates. Therefore, optimization may have allocated more resources to treating land uses with higher TN concentrations. Cost-effectiveness is a function of the efficiency of a GI SCM opportunity at treating TN as well as how much TN is in the baseline runoff. Conveying runoff with very high concentrations of TN with a GI SCM opportunity that has relatively low efficiency can still be more cost effective than treating relatively clean water with a GI SCM opportunity with very high efficiency.

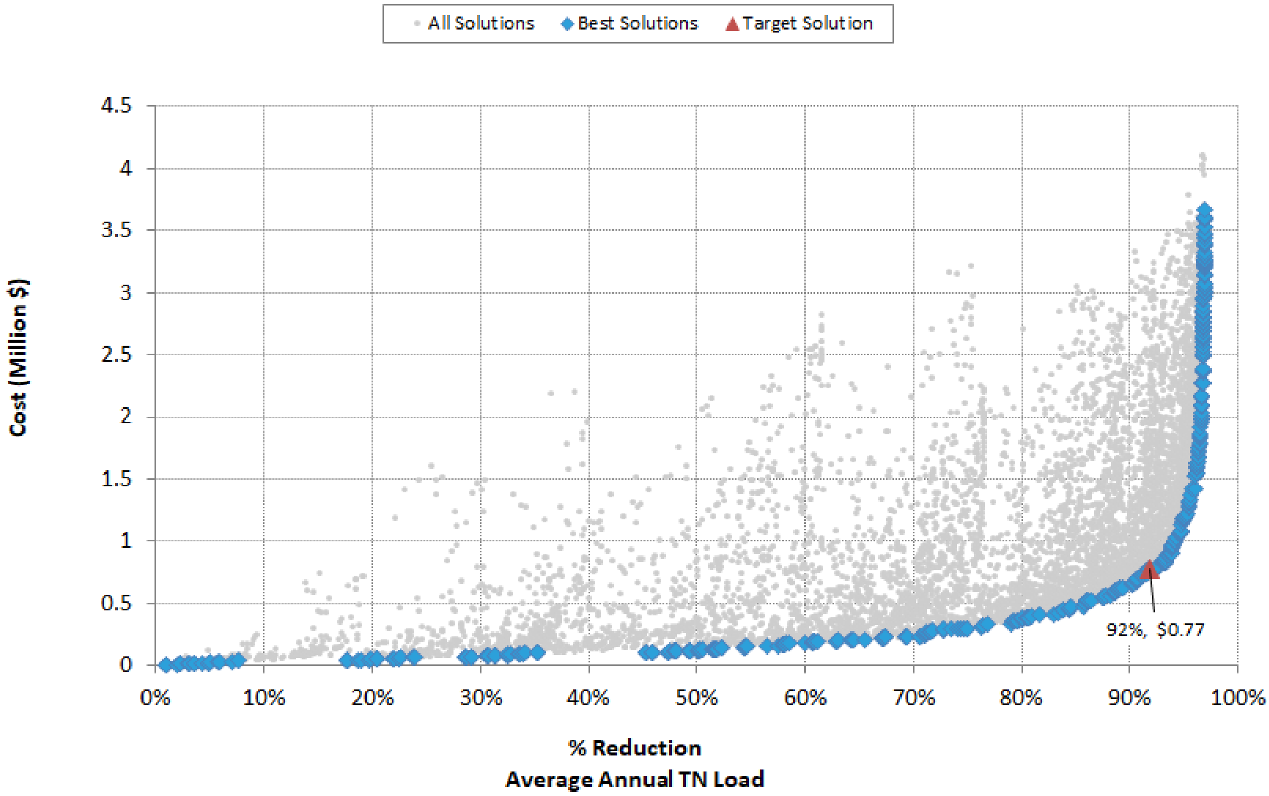

Figure 10. Opti-Tool cost effectiveness curve for TN annual average load reduction for outfall #7

Table 11. Optimized GI SCM opportunities for achieving a 92% reduction in annual TN loading at outfall #7

SCMID	SCM Type	Land Use	Treated Impervious Area (acres)	Runoff Depth (in.)	SCM Storage Capacity (gallon)	SCM Cost ($)
SCM1	Infiltration Basin - A	Forest	1.37	0.30	11,186	$18,662
SCM2	Infiltration Trench - A	Forest	0.24	0.49	3,224	$10,766
SCM3	Infiltration Basin - A	Commercial	7.7	0.20	41,818	$69,766
SCM4	Infiltration Trench - A	Commercial	3.68	0.40	39,951	$133,410
SCM5	Infiltration Basin - A	Medium Density Residential	13.81	0.30	112,476	$187,648
SCM6	Infiltration Trench - A	Medium Density Residential	7.95	0.40	86,381	$288,458
SCM7	Infiltration Basin - A	High Density Residential	0.54	0.30	4,423	$7,378
SCM8	Infiltration Trench - A	High Density Residential	0.36	0.89	8,738	$29,180
SCM9	Infiltration Basin - B	Transportation	1.94	0.20	10,519	$17,548
SCM10	Infiltration Basin - A	Open Land	0.42	0.20	2,297	$3,832
SCM11	Infiltration Trench - A	Open Land	0.03	1.47	1,198	$4,000
		Total	**38.04**	**0.31**	**322,211**	**$770,650**

5.2 Outfall #2

5.2.1 Stormwater Volume

Outfall # 2 was also assessed for the optimal mix of GI SCM types to achieve the management objective of flood mitigation through a reduction in stormwater volume. Figure 11 presents the CE-curve for the stormwater volume reduction objective for outlet #2. The target solution presented in Figure 11 shows that it would cost $410,000 to achieve an 80% reduction in annual average flow volume. The same percent reduction was estimated to cost approximately $750,000 for outlet #7. The estimated costs are useful for planning purposes because they suggest that it would cost twice as much to obtain an 80% reduction in storm volume for outlet #7 as it would for outlet #2 because of almost double impervious footprints in the contributing drainage area to outlet #7. It is important to note that outlet #2 has a smaller contributing drainage area.

Table 12 presents the optimized mix of GI SCM opportunity implementation which achieved an 80% reduction in annual flow volume. Design depths ranged from 0.15 to 1.75 inches. Like outfall #7, the solution for outfall #2 was equivalent to a total design storage volume of 0.35 inches (weighted average of design depths based on impervious area treated).

The impact of achieving the target solution, which focused on flow volume, on peak flows, can be seen in Figure 12. Peak flows across the driest, wettest and average years were all reduced compared to the baseline simulation reflecting existing conditions. Figure 13 highlights the impact of the target solution to storm hydrographs over selected periods of rainfall and runoff. The same storm assessed for outlet #7, which occurring on 5/17/2012 had the peak flow reduced from approximately 11 cfs in the baseline condition to approximately 3 cfs in the optimized solution, a reduction of about 73%. Other storms had their respective discharge eliminated due to the optimized implementation.

The impact of the target solution on the entire range of flow rates was also assessed. Figure 15 presents flow duration curves for both the baseline and optimized solutions. The curves characterize the storm flows of various magnitudes discharging from the outlet. The graph only includes data from days in which rainfall and discharge occurred. The graph demonstrates that for the same exceedance probability, the optimized scenario had lower flows for all but the largest and most infrequent storms. For storms that occur only 5% of the time (infrequent larger storm events that cause runoff), the optimized solution reduced the total flow at Outfall #2 from about 3 to 1 cfs, a reduction of about 67%. For more frequently occurring storms, whose flows exceeded more than 20% in baseline conditions, the total flow at Outfall #2 was reduced from 1.75 to 0.01 cfs, a reduction of about 99%. From the curve, the larger reductions occur for the more frequent *comparatively* smaller storm events, meaning that overall, more precipitation is being infiltrated and recharging the aquifer. This not only reduces flooding in the Commercial district but helps to restores the hydrologic and hydrogeologic imbalance caused by the relatively high percentage (66%) of impervious cover that characterizes the catchment draining to Outfall #2

During all days which had rainfall and discharge, the baseline conditions show that 73% of flows were equal to or greater than 0.1 cfs. The optimized solution reduced the frequency of 0.1 cfs or greater flows to approximately 15%. A 0.1 cfs flow was as frequent in the optimized scenario as a 2 cfs flow was in the baseline scenario. The flow rate over all wet days was reduced by an average of 57% due to GI SCM implementation.

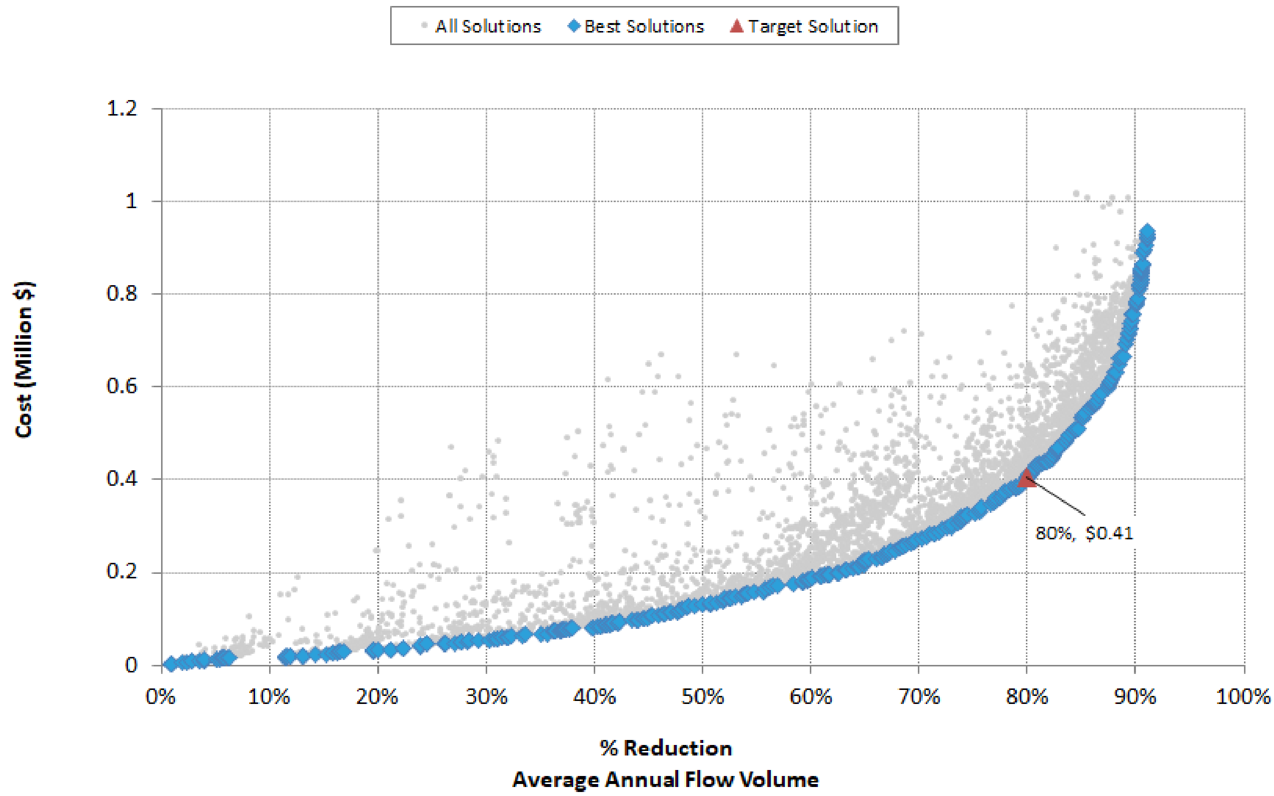

Figure 11. Opti-Tool Outfall cost effectiveness curve for annual average flow volume for outfall # 2

Table 12. Optimized GI SCM opportunities for achieving an 80% reduction in annual average storm volume at outfall #2

SCMID	SCM Type	Land Use	Treated Impervious Area (acres)	Runoff Depth (in.)	SCM Storage Capacity (gallon)	SCM Cost ($)
SCM1	Infiltration Basin - A	Forest	0.01	1.32	359	$600
SCM2	Infiltration Trench - A	Forest	0.05	1.75	2,382	$7,954
SCM3	Infiltration Basin - A	Commercial	13.08	0.38	133,886	$223,366
SCM4	Infiltration Trench - A	Commercial	4.89	0.24	31,206	$104,208
SCM5	Infiltration Basin - A	Medium Density Residential	1.1	0.50	14,867	$24,802
SCM6	Infiltration Trench - A	Medium Density Residential	0.92	0.30	7,428	$24,804
SCM7	Infiltration Basin - A	High Density Residential	0.63	0.21	3,573	$5,962
SCM8	Infiltration Trench - A	High Density Residential	0.28	0.15	1,113	$3,716
SCM9	Infiltration Basin - B	Transportation	0.47	0.50	6,420	$10,710
		Total	**21.43**	**0.35**	**201,234**	**$406,122**

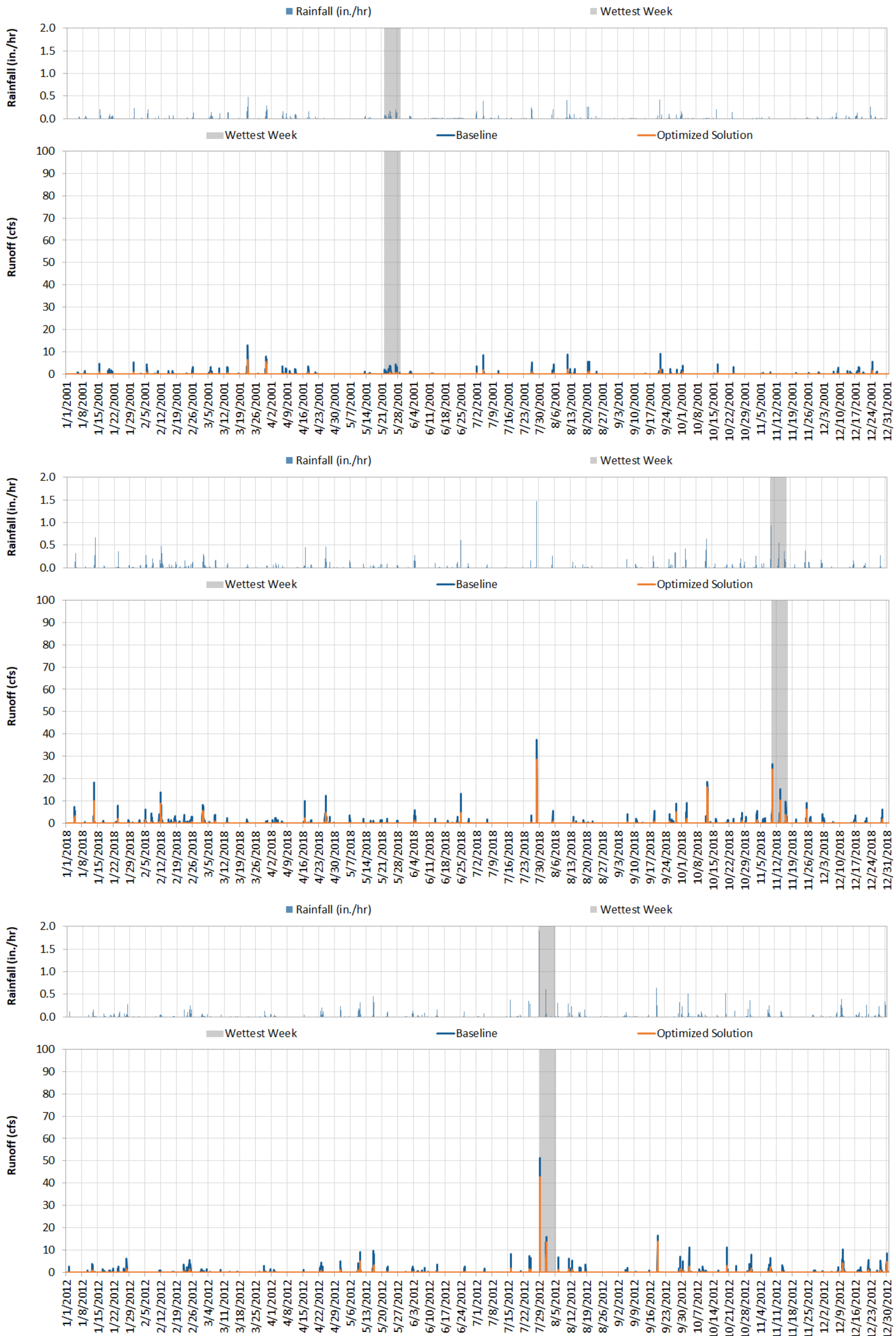

Figure 12. Rainfall and runoff for the driest (top), wettest (middle), and average years (bottom) for outfall #2

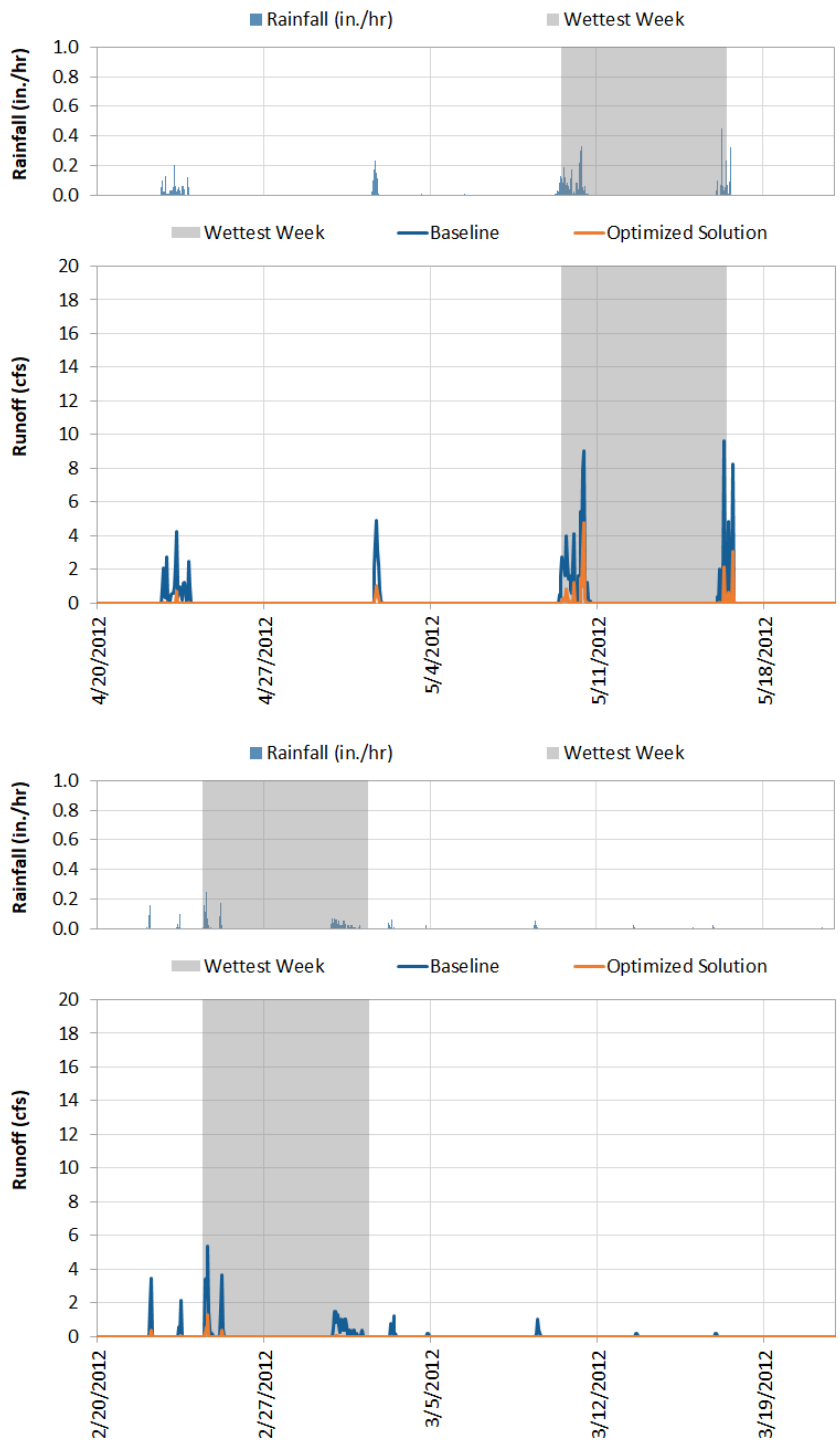

Figure 13. Selected periods of rainfall and runoff for outfall #2 during 2012, a year representing an average amount of precipitation for Tisbury, MA.

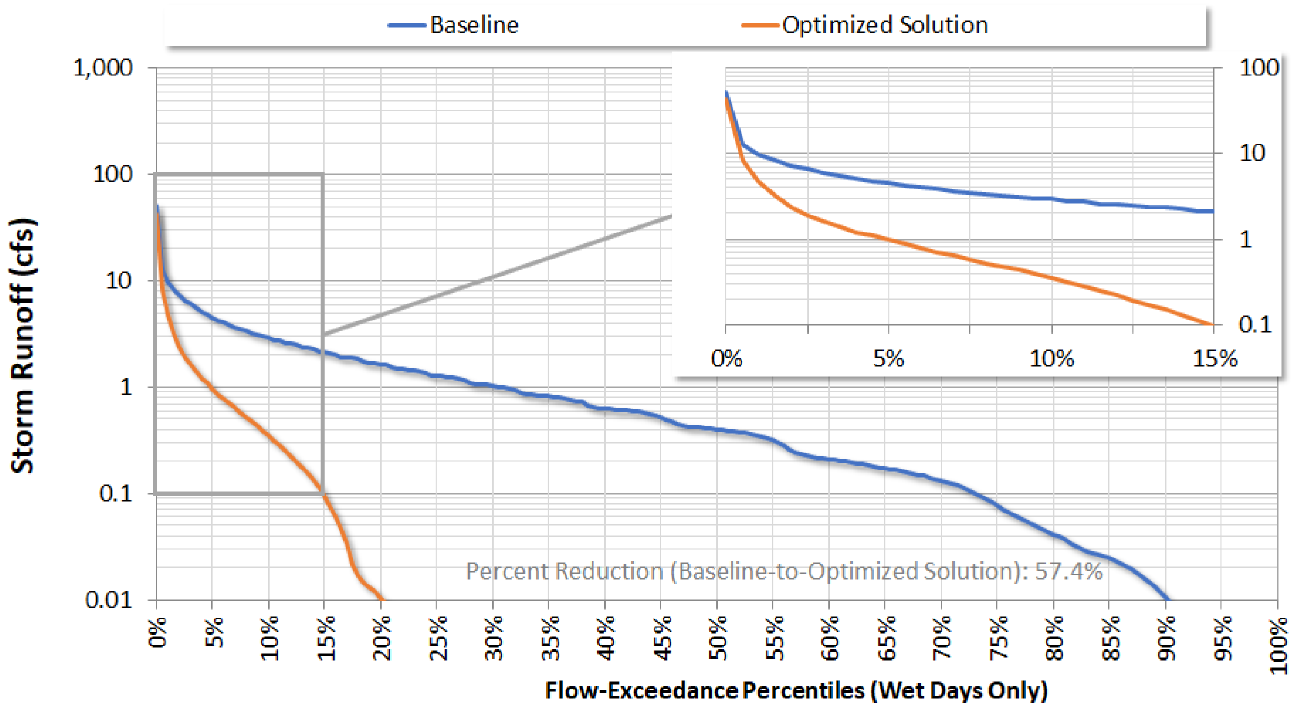

Figure 14. Opti-Tool derived flow duration curves for outfall #2

5.2.1 Total Nitrogen

Figure 15 presents the CE curve for optimizing average annual TN load reduction at outfall #2. The highlighted target solution achieved 89% reduction in TN loading. This solution was chosen because it also achieved an 80% reduction in storm flow. However, since the solution was optimized for TN reduction, the characteristics of the GI SCM implementation were different. The 92% reduction in TN, with a co-benefit of 80% reduction in storm flow would cost approximately $402,000 (Table 13). The cost is approximately $4,000 less expensive (1% lower) than it would be to achieve the same volume reduction based on volume reduction optimization. Cost differences are due in part to the variable nature of TN export. While the impervious surfaces simulated in this study all convert the same amount of rainfall to runoff, different land use types export TN at differing rates. Therefore, optimization may have allocated more resources to treating land uses with higher TN concentrations.

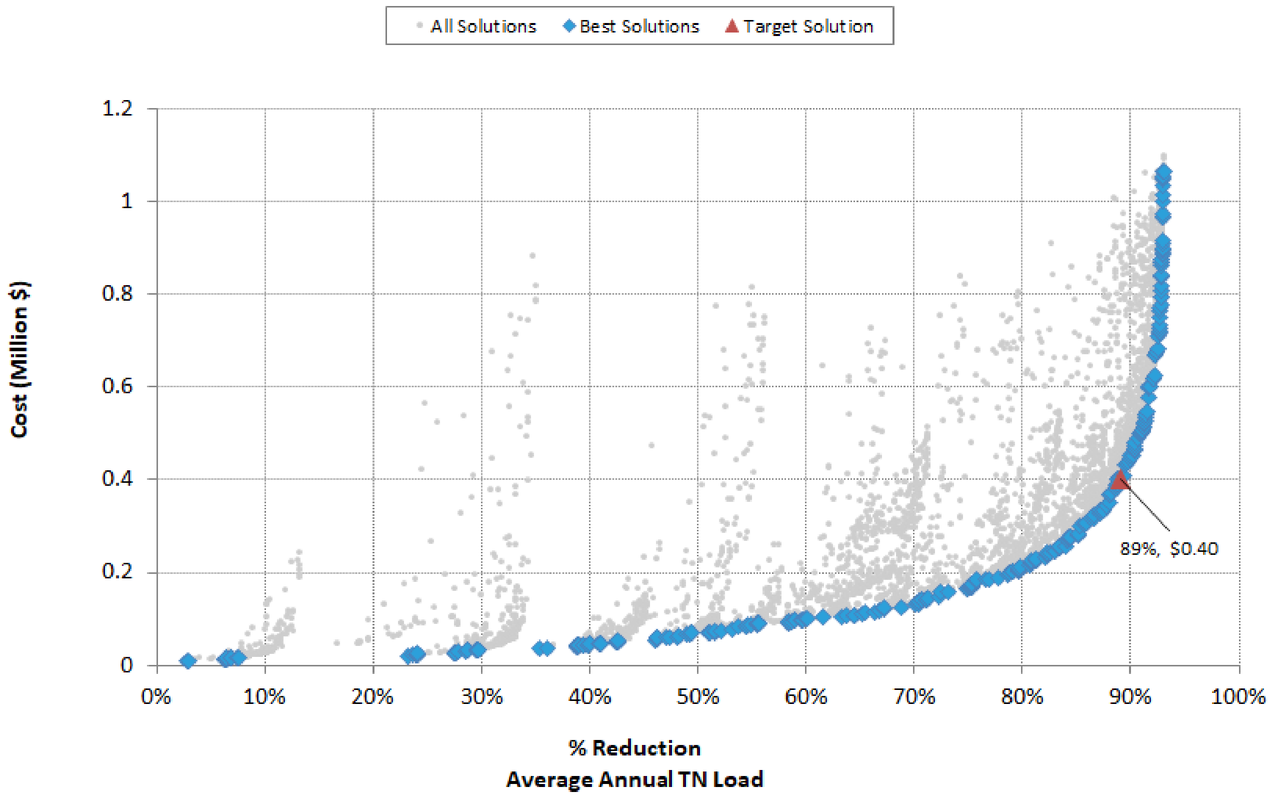

Figure 15. Opti-Tool Outfall cost effectiveness curve for TN annual average load reduction for outfall #2

Table 13. Optimized GI SCM opportunities for achieving an 89% reduction in annual average total nitrogen loading at outfall #2

SCMID	SCM Type	Land Use	Treated Impervious Area (acres)	Runoff Depth (in.)	SCM Storage Capacity (gallon)	SCM Cost ($)
SCM1	Infiltration Basin - A	Forest	0.01	0.44	120	$200
SCM2	Infiltration Trench - A	Forest	0.05	0.78	1,059	$3,536
SCM3	Infiltration Basin - A	Commercial	13.08	0.26	92,047	$153,564
SCM4	Infiltration Trench - A	Commercial	4.89	0.39	52,010	$173,680
SCM5	Infiltration Basin - A	Medium Density Residential	1.1	0.50	14,867	$24,802
SCM6	Infiltration Trench - A	Medium Density Residential	0.92	0.22	5,571	$18,604
SCM7	Infiltration Basin - A	High Density Residential	0.63	0.37	6,253	$10,432
SCM8	Infiltration Trench - A	High Density Residential	0.28	0.12	879	$2,934
SCM9	Infiltration Basin - B	Transportation	0.47	0.70	8,987	$14,994
		Total	**21.43**	**0.31**	**181,792**	**$402,746**

5.3 Outfall Summary

Table 14 presents a summary of the optimized solutions for reducing storm flow and TN at outlets #7 and #2. The cost of removing one gallon of stormwater volume from either of the outfalls was $0.02 while the cost for removing a pound of TN was $1,727 for outfall #2 and $1,996 for outfall #7. Outfall #7 had higher runoff and TN loading in the baseline conditions. This can be mainly attributed to the larger catchment area (almost double impervious footprints) contributing the Outfall #7. The percent reduction in TN load was similar for both outlets, GI SCM implementation reduced TN loading 89% for outfall #2 and 92% for outfall #7.

Table 14. Cost and effectiveness of LID SCM implementation within the catchments of two stormwater outlets in Tisbury, MA

	Outfall #2	Outfall #7
Baseline Average Flow Volume (gallons/yr)	23,193,061	40,174,307
Baseline Average TN Load (lbs/yr)	261.87	420.63
Flow Volume Removed (gallons/yr)	18,551,813	32,192,534
TN Load Removed (lbs/yr)	233.27	386.14
Cost per Gallon Flow Removed ($)	$0.02	$0.02
Cost per Pound TN Removed ($)	$1,727	$1,996

6 SUMMARY

The results of this pilot study provide quantitative results to support watershed-based GI management planning. Opti-Tool analyses helped to identify optimal stormwater controls, including GI SCM types and sizes, that could guide retrofitting strategies in the developed catchments of two stormwater outfalls in Tisbury, MA. This study highlights the computational power of optimization algorithms in Opti-Tool for evaluating thousands of possible GI SCM combinations to identify the most cost-effective solutions over a range of target reductions.

Eleven GI SCM opportunity types were considered which treated stormwater runoff from impervious surfaces associated with a variety of land uses. For both catchments, GI SCM implementation resulted in reduced flow volume, peak flows, and TN loading. Comparison of baseline and optimized flow duration curves demonstrate reduced flow magnitudes across nearly the entire range of flow storm flows, with only the largest, most infrequent storms generating approximately the same amount of runoff despite GI SCM implementation. A visual assessment of hydrographs for dry, wet, and average precipitation years demonstrated a reduction in peak flows. The impact on peak flows ranged from relatively small reductions for some large storms, to eliminating runoff and therefore peak flows for several smaller storms. Since the area underneath a hydrograph represents flow volume, the shape of the baseline optimized solution hydrographs also demonstrated reduced stormwater volume. The cost of removing a gallon of water from storm flows was estimated to be $0.02 for both outfalls. The average cost to remove a pound of TN was between $1,700 and $2,000. Whether optimizing for a management objective of reduced stormwater volume or reduce TN loading, the resulting cost-benefit analyses suggests that an approximately 80% reduction in volume and a 90% reduction in TN loading can be achieved at a total cost around $1,160,000 - $1,173,000 for implementing distributed infiltration practices sized to capture 0.35 inches (weighted average) of runoff from the impervious cover.

7 RECOMMENDATIONS

This study relied on surface runoff modeling to make conclusions about the benefits of GI SCM implementation for achieving goals of storm volume and TN load reduction. A more robust assessment would take into account the Tisbury stormwater routing network, including lengths and sizes of storm drains, as well as any reduced capacity in the system, such as clogged catch basins. Additionally, flow-related monitoring data can help inform design options and provide valuable data for future modeling efforts. For example, in-system flow depth, flow rate, and rainfall monitoring to document the frequency and duration of flooding events would be a practical and inexpensive approach to more fully inform Tisbury of the potential benefits of the GI SCM approach described herein. However, the data presented in this report provides strong support for the town of Tisbury to begin pursuing the implementation of GI SCM opportunities on both public and private lands.

Specific recommendations for goals are presented below.

Near-term goals (1 to 6 months)

- Review candidate locations for a pilot GI SCM opportunity installation. Consider design options, including rain gardens, infiltration trenches, rain barrels for rooftop disconnection that can be readily implemented in these drainage areas and throughout Tisbury.
- Consider development and adoption of implementation strategies to opportunistically incorporate GI SCMs into all feasible infrastructure projects on municipal lands and rights of ways and through typical redevelopment and urban renewal projects. This may involve an evaluation of local bylaws/ordinances relating to stormwater management.
- Begin recording flood events, including smaller-scale nuisance flooding. Information to record includes date and location of flooding, total rainfall depth, duration, pictures of the affected area. This information can help better characterize flooding in town with valuable qualitative and quantitative information.
- Clean out catch-basins and other components of the stormwater conveyance system.
- Consider a more frequent and consistent catch basin cleaning schedule.

Intermediate goals (6 months to 1.5 years)

- Adopt generic GI SCMs design templates suitable for Tisbury and gain experience through installation of pilot stormwater GI SCMs using town labor and equipment or local contractors Further, investigate optimal site design and supply chain opportunities.
- Adopt long-term GI SCM strategies for opportunistically implementing controls as part of municipal infrastructure related work and private redevelopment projects.
- Continue community engagement and outreach, use pilot SCM(s) to facilitate community adoption. Enlist community members (e.g., students) for planting rain gardens.
- Update stormwater infrastructure datasets to facilitate future hydraulic modeling of the system. Municipal GIS stormwater infrastructure datasets lack some data and appear to show some discrepancies with on-the-ground observations. Additional information that would facilitate hydraulic modeling include dimensions, such as depth, width, and invert elevations of catch basins, conveyance pipes, and outlets. Update the attribute table describing catch basins that are 'good', 'need cleaning' and 'need repair'.
- To the extent possible, incorporate the results of this project into Federal Emergency Management Agency (FEMA) Hazard Mitigation Plans (HMP). Although not all green infrastructure projects meet FEMA funding criteria, small-scale GI is potentially eligible for FEMA funding if the project meets certain requirements. Implementation of small-scale GI can demonstrate a tangible effect on flooding, particularly when implemented town-wide or areawide. In addition, DPW personnel can implement small-scale GI flexibly and cost-effectively. As stormwater-related flooding is highly correlated with impervious cover, projects or other efforts (e.g., ordinance/bylaws) aimed at

reducing impervious cover, particularly in combination with green infrastructure, can be effective strategies to include in Hazard Mitigation Plans.

Long-term goals (1.5 – 5 years)

- Use lessons learned from the pilot GI SCM implementation site to facilitate additional implementations on both private and public land.
- Continue to implement long-term strategies for installing GI SCMs throughout Tisbury as opportunities arise (e.g., municipal infrastructure work and redevelopment projects)
- Ensure that GI SCM opportunities receive adequate maintenance.
- Conduct a detailed hydrologic and hydraulic study that incorporates the rainfall-runoff analysis, simulation of the GI SCM being installed on the ground, and flow routing through the storm drain system accounting the backwater effects due to tidal influence at the outfall locations.

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