City of Somerville

Municipal Vulnerability Preparedness Grant

Green Stormwater Infrastructure Flooding and Water Quality Benefits Analyses

Prepared for:

City of Somerville

By:

Stantec

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1.0 Purpose

This memorandum summarizes the potential flooding reduction and pollutant removal induced by targeted implementation of green stormwater infrastructure (GSI) technologies within six identified opportunity (study) areas in Somerville, MA. The main objective of this work is to determine the effectiveness of stormwater management practice (SMP) implementation in reducing street flooding and improving water quality with respect to existing system conditions.

2.0 Background

Six study areas were selected with collaboration from the City of Somerville (the City) to represent a variety of neighborhood types. The selected areas encompass locations where the City's existing stormwater model was suspected to be missing critical information and warranted refinement, areas of potential public and private GSI implementation, and areas slated for redevelopment. The six study areas range in size from 35 to 90 acres, and include portions of West Somerville, Davis Square, Ward Two, East Somerville, Gilman Square, and Winter Hill.

The hydraulic model was refined within these areas and calibrated using data from thirteen temporary flow meters. The newly refined and calibrated model was used to estimate flood impacts of public and private GSI implementation.

Public SMP elements analyzed herein were identified in Stantec's Green Stormwater Infrastructure Feasibility Study Memo (Ref. 1) as SMP types. These SMP types include rain gardens, bump outs, green roofs, permeable pavement, planter boxes, and subsurface trenches. Ref. 1 describes the process in which 50 sites for the SMP types were selected. Appendix A of Ref. 1 shows maps of the six study areas and provides SMP details including location, type, footprint, and contributing area. Private SMP implementation includes disconnection of rooftops from collection system and permeable pavements in driveways.

3.0 Quantification of Public SMP Implementation Flood Benefits

Existing system conditions were modeled using the City of Somerville's recently refined and calibrated computational ICM-v6.5 2D model (model), along with implemented boundary conditions for external inflows and water levels. The SMP implementation scenario was modeled by adding the SMP types identified in Ref. 1 to the model using ICM's Sustainable Urban Drainage System (SUDS) control objects. SUDS is United Kingdom's terminology for Low Impact Development (LID) technologies. Hereafter, SMP and SUDS are interchangeable. To showcase the effectiveness of SMP implementation in providing flood reduction in the study areas, the following storms were selected for analysis: 1-year, 6-hour, 10-year, 24-hour and, 100-year, 24-hour under future climate change year 2030 and 2070 time horizons, each with sea level rise (SLR)-induced water levels as boundary conditions.

3.1 Methodology

SMPs were added to the model utilizing the most suitable ICM SUDS control object; for example, bumpouts were simulated as rain gardens, rather than vegetative swales. All SMP types used for this study are listed in Table 1, along with their ICM equivalent SUDS unit and siting parameters. Impervious runoff area in existing subcatchments was reduced as needed, based on the contributing area that was reallocated to the overlaying SUDS control object. In this manner, the initial impervious area (under existing conditions) equals non-SMP plus SMP-treated impervious areas (under SMP conditions). Impervious areas in ICM include streets, parking lots, and roofs.

Table 1. SMP and corresponding SUDS control objects in the ICM hydraulic model

SMP Type	SUDS in ICM	Siting Parameters
Bumpout	Rain Garden	• Parking lane present (bumpout width to the limit of parking)
		• Two-way streets at least 26' wide (to allow for emergency vehicle access)
Planter Box	Bio-retention Cell	• Sidewalk width at least 9' wide (3' wide planter with 6' walking zone, per standard design)
Subsurface Trench	Infiltration Trench	• Available SMP footprint and drainage, but not enough space for a bumpout or planter box
Rain Garden	Rain Garden	• City properties outside of public right-of-way
		• Ability to manage impervious area without impeding on the site's purpose (e.g. inhibiting adequate sidewalks or drive aisles within parking lots)
Green Roof	Green Roof	• New construction
		• Public buildings slated for substantial renovation (including structural upgrades to building)
Porous Pavement	Permeable Pavement	• City properties outside of public right-of-way
		• No space to implement surface practice

The attribute table of the SUDS control objects in ICM was updated based on design parameters, including storage thickness and soil porosity, which are listed in Table 2 and shown in Appendix A design schematics. ICM default values were used in cases where parameters were not available in either Table 2 or Appendix A design schematics. Soil parameters were updated based on ArcGIS data layers; when no ArcGIS data was available, soil was assumed to be sandy clay loam because it is the most common across the study areas.

Table 2. SMP Design Parameters

Control object	Berm height (in)	Storage depth (in)	Vegetation volume fraction	Surface roughness (Manning's (n)	Surface slope (%)	Swale side slope (%)	Pavement thickness (in)	Pavement void ratio
Green roof	-	4	0.1	0.04	-	-	-	-
Bio-retention cell (Planter Box)	9	6	0.1	0.04	0	-	-	-
Permeable pavement	-	8	-	0.016	2	-	4	0.2
Vegetative Swale (Bumpout)	9	6	0.1	0.04	0	-	-	-
Infiltration trench (Subsurface Trench)	-	48	-	0.04	-	-	-	-
Rain Garden	18	6	0.1	0.04	0.3	33	-	-

Control object	Impervious surface fraction	Permeability (in/hr)	Pavement clogging factor	Soil class	Soil thickness (in)	Soil porosity	Field capacity	Wilting point
Green roof	-	-	-	same as sub-catchment	4	0.2	-	-
Bio-retention cell (Planter Box)	-	-	-		36	-	-	-
Permeable pavement	0	10	-		8	0.4	0.3	0.15
Vegetative Swale (Bumpout)	-	-	-		48	0.3	-	-
Infiltration trench (Subsurface Trench)	-	-	-		48	0.4	0.3	0.15
Rain Garden	-	-	-		48	0.3	-	-

Control object	Conductivity (in/hr)	Conductivity slope	Suction head (in)	Barrel height (in)	Storage thickness (in)	Storage void ratio	Seepage rate (in/hr)	Storage clogging factor
Green roof	-	-	-	-	-	-	-	-
Bio-retention cell (Planter Box)	-	-	-	-	6	0.32	0.4	0
Permeable pavement	-	-	-	-	8	0.4	0.4	0
Vegetative Swale (Bumpout)	-	-	-	-	-	-	-	-
Infiltration trench (Subsurface Trench)	-	-	-	-	-	0.3	2.0	0
Rain Garden	-	-	-	-	54	-	0.4	-

Control object	Flow coefficient	Flow exponent	Offset height (in)	Delay (hours)	Flow capacity (in/hr)	Mat thickness (in)	Mat void fraction	Mat roughness (Manning's n)
Green roof	-	-	-	-	-	3	0.5	0.1
Bio-retention cell (Planter Box)	0	0.5	0	-	-	-	-	-
Permeable pavement	0	0.5	0	-	-	-	-	-
Vegetative Swale (Bumpout)	-	-	-	-	-	-	-	-
Infiltration trench (Subsurface Trench)	0	0.5	0	-	-	-	-	-
Rain Garden	0	0.5	0	-	-	-	-	-

Table 3 summarizes the total SMP footprint and contributing area for each study area, relative to each study area's size. Area 10 has both the largest SMP tributary area (acres) and SMP tributary area percentage of total area. SMPs in areas 2, 3, and 8, and 11 have similar SMP percentage of total area, ranging from 3.11% to 5.29%.

Table 3. SMP footprint and treatment areas used in the hydraulic model

	SMP Type	Rain Garden	Porous Pavement	Green Roof	Subsurface Trench	Planter	Bumpout	Total SMP Treated Area
Area 2 (91ac approx.)	SMP Footprint (acres)	0	0	0	0.11	0	0.03	0.14
	SMP Tributary Area (acres)	0	0	0	1.82	0	1.25	3.07
	SMP Footprint as Percent of Total Area	0%	0%	0%	0.13%	0%	0.03%	0.15%
	SMP Tributary Area as Percent of Total Area	0%	0%	0%	2.01%	0%	1.39%	3.54%
Area 3 (67ac approx.)	SMP Footprint (acres)	0	0	0.05	0.04	0	0.28	0.37
	SMP Tributary Area (acres)	0	0	0.14	1.22	0	2.20	3.57
	SMP Footprint as Percent of Total Area	0%	0%	0.08%	0.06%	0%	0.41%	0.55%
	SMP Tributary Area as Percent of Total Area	0%	0%	0.21%	1.81%	0%	3.26%	5.29%
Area 8 (71ac approx.)	SMP Footprint (acres)	0	0	0	0.01	0	0.11	0.12
	SMP Tributary Area (acres)	0	0	0	0.23	0	1.99	2.22
	SMP Footprint as Percent of Total Area	0%	0%	0%	0.02%	0%	0.15%	0.17%
	SMP Tributary Area as Percent of Total Area	0%	0%	0%	0.32%	0%	2.80%	3.11%
Area 10 (35ac approx.)	SMP Footprint (acres)	0	0	0	0.14	0	0.10	0.24
	SMP Tributary Area (acres)	0	0	0	3.20	0	2.05	5.26
	SMP Footprint as Percent of Total Area	0%	0%	0%	0.41%	0%	0.28%	0.69%
	SMP Tributary Area as Percent of Total Area	0%	0%	0%	9.04%	0%	5.79%	14.83%
Area 11 (38ac approx.)	SMP Footprint (acres)	0	0	0	0.03	0	0.06	0.10
	SMP Tributary Area (acres)	0	0	0	0.93	0	0.75	1.68
	SMP Footprint as Percent of Total Area	0%	0%	0%	0.08%	0%	0.17%	0.25%
	SMP Tributary Area as Percent of Total Area	0%	0%	0%	2.45%	0%	1.97%	4.42%
Area 12 (43ac approx.)	SMP Footprint (acres)	0.03	0.21	0	0	0	0.11	0.35
	SMP Tributary Area (acres)	0.33	0.21	0	0	0	4.09	4.63
	SMP Footprint as Percent of Total Area	0.06%	0.48%	0%	0%	0%	0.26%	0.80%
	SMP Tributary Area as Percent of Total Area	0.76%	0.48%	0%	0%	0%	9.45%	10.69%

3.2 Results

The model was run with the design storm events and associated water level boundary conditions under SLR, under both existing and SMP implementation conditions. The storm and SLR scenarios are listed below:

- 1 year 6 hour 2030, 1 year 2030 SLR
- 1 year 6 hour 2070, 1 year 2070 SLR
- 10 year 24 hour 2030, 1 year 2030 SLR
- 10 year 24 hour 2070, 1 year 2070 SLR
- 100 year 24 hour 2030, 1 year 2030 SLR
- 100 year 24 hour 2070, 1 year 2070 SLR

Appendix B shows simulated peak flood depth maps under scenarios with and without SMP implementation for the design storms listed above. Peak flood depths range from 0.5-ft to over 3-ft, correlating with light to dark blue, respectively. Figure 1 shows maximum flood depth under existing and SMP conditions during the 10-year 2070 storm, 1-year 2070 SLR scenario in Study Area 10. The implementation of SMPs induces a slight reduction of flooding extents at several locations, including along West Adams St, at the intersection of Chetwynd Rd and Hillsdale Rd, and at the intersection of West Adams St and Conwell Ave.

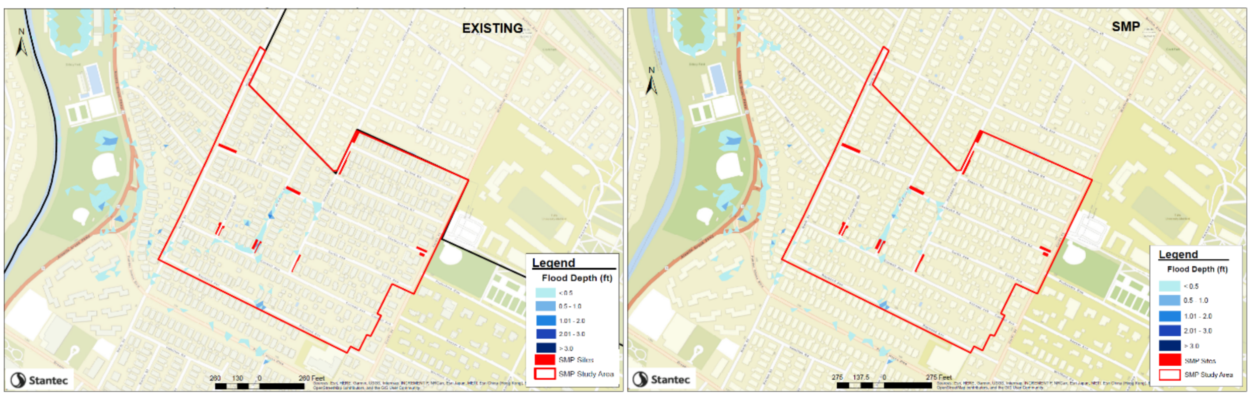

Figure 1. Maximum flood depth (ft) within Area 10 during the 10 year 2070 Storm, 1 year 2070 SLR under Existing and SMP conditions.

Tables 4 through 9 list simulated maximum flood volume within each of the six areas under various design storm events, with and without SMP implementation for 2030 and 2070 time horizons. The effectiveness of the SMP implementation is reflected by the *Difference* and *% Difference* columns in the tables. The negative difference reflects the reduction in flood volume (million gallons (MG), %) induced by SMP implementation. Results from Tables 4 through 9 are graphed in Appendix C, which includes bar graphs of flood depths with and without SMP implementation. In addition, the percent (%) difference trendline for the design storms and the volume difference (MG) are shown.

Table 4. Simulated flood volume (MG) removal within Area 2

Storm	Existing	With SMPs	Difference	% Difference
1 year 2030 Storm, 1 year 2030 SLR	0.852	0.771	-0.082	-9.6
1 year 2070 Storm, 1 year 2070 SLR	1.299	1.215	-0.084	-6.5
10 year 2030 Storm, 1 year 2030 SLR	5.212	5.011	-0.201	-3.8
10 year 2070 Storm, 1 year 2070 SLR	6.284	6.076	-0.207	-3.3
100 year 2030 Storm, 1 year 2030 SLR	10.710	10.501	-0.209	-1.9
100 year 2070 Storm, 1 year 2070 SLR	12.433	12.208	-0.226	-1.8

Table 5. Simulated flood volume (MG) removal within Area 3

Storm	Existing	With SMPs	Difference	% Difference
1 year 2030 Storm, 1 year 2030 SLR	0.000	0.000	0.000	0
1 year 2070 Storm, 1 year 2070 SLR	0.000	0.000	0.000	0
10 year 2030 Storm, 1 year 2030 SLR	0.765	0.675	-0.090	-11.7
10 year 2070 Storm, 1 year 2070 SLR	1.246	1.147	-0.099	-8.0
100 year 2030 Storm, 1 year 2030 SLR	3.216	3.050	-0.166	-5.2
100 year 2070 Storm, 1 year 2070 SLR	4.803	4.592	-0.211	-4.4

Table 6. Simulated flood volume (MG) removal within Area 8

Storm	Existing	With SMPs	Difference	% Difference
1 year 2030 Storm, 1 year 2030 SLR	1.982	1.960	-0.021	-1.1
1 year 2070 Storm, 1 year 2070 SLR	2.286	2.268	-0.018	-0.8
10 year 2030 Storm, 1 year 2030 SLR	5.286	5.266	-0.020	-0.4
10 year 2070 Storm, 1 year 2070 SLR	6.424	6.397	-0.027	-0.4
100 year 2030 Storm, 1 year 2030 SLR	11.406	11.372	-0.034	-0.3
100 year 2070 Storm, 1 year 2070 SLR	13.142	13.111	-0.031	-0.2

Table 7. Simulated flood volume (MG) removal within Area 10

Storm	Existing	With SMPs	Difference	% Difference
1 year 2030 Storm, 1 year 2030 SLR	0.043	0.033	-0.009	-21.7
1 year 2070 Storm, 1 year 2070 SLR	0.050	0.041	-0.009	-17.4
10 year 2030 Storm, 1 year 2030 SLR	0.075	0.064	-0.011	-14.2
10 year 2070 Storm, 1 year 2070 SLR	0.088	0.076	-0.012	-13.8
100 year 2030 Storm, 1 year 2030 SLR	0.134	0.116	-0.018	-13.7
100 year 2070 Storm, 1 year 2070 SLR	0.149	0.130	-0.019	-12.5

Table 8. Simulated flood volume (MG) removal within Area 11

Storm	Existing	With SMPs	Difference	% Difference
1 year 2030 Storm, 1 year 2030 SLR	0.014	0.013	-0.001	-6.5
1 year 2070 Storm, 1 year 2070 SLR	0.028	0.027	-0.002	-6.6
10 year 2030 Storm, 1 year 2030 SLR	0.318	0.298	-0.020	-6.2
10 year 2070 Storm, 1 year 2070 SLR	0.577	0.549	-0.027	-4.7
100 year 2030 Storm, 1 year 2030 SLR	3.489	3.397	-0.092	-2.6
100 year 2070 Storm, 1 year 2070 SLR	4.843	4.735	-0.108	-2.2

Table 9. Simulated flood volume (MG) removal within Area 12

Storm	Existing	With SMPs	Difference	% Difference
1 year 2030 Storm, 1 year 2030 SLR	2.882	2.863	-0.019	-0.67
1 year 2070 Storm, 1 year 2070 SLR	3.205	3.186	-0.019	-0.58
10 year 2030 Storm, 1 year 2030 SLR	4.391	4.364	-0.027	-0.61
10 year 2070 Storm, 1 year 2070 SLR	4.733	4.705	-0.028	-0.60
100 year 2030 Storm, 1 year 2030 SLR	6.480	6.440	-0.040	-0.62
100 year 2070 Storm, 1 year 2070 SLR	7.238	7.192	-0.047	-0.65

Because areas differ in size and total SMP storage capacity, the impact of SMPs varies across the study areas. For example, flood volume reduction within Study Area 2 varies between 0.082 MG and 0.226 MG, under the 1-year 2070 storm, 1-year 2070 SLR and the 100-year 2070 storm, 1-year 2070 SLR, respectively. Likewise, flood volume reduction within Study Area 10 varies between 0.009 MG and 0.019 MG, under the 1-year 2070 storm, 1-year 2070 SLR and the 100-year 2070 storm, 1-year 2070 SLR, respectively.

Tables 4 through 9 show that net flood volume reduction (i.e., difference in Tables 4-9) increases from smaller to larger storm events. As storm size increases, so do corresponding flooding extents. The larger the flood extent, the larger its likelihood to overlap with SMP impervious tributary area, and consequently the larger the amount of flooding conveyed to, stored, and infiltrated by the SMP.

The effectiveness of the SMP implementation is not only reflected by the reduction in flood volume, but also by the reduction in surface flood depth within study areas. To exemplify this, figures in Appendix D display maximum simulated flood depth hydrographs at selected locations (green stars in accompanying flood maps). For example, there is marginal reduction in peak flood depth at the selected location within Area 12 since the two flood depth hydrographs are indistinguishable, with only 0.001-ft difference from each other; this minimal difference in flood reduction is also reflected in Table 9, which shows only a 0.027 MG flood volume reduction for a 10-year 2030, 1-year 2030 SLR. On the other hand, implementation of SMPs within Area 3 induces a peak flood depth reduction of about 0.15 ft at the selected location. Note that during the 10-year 2030 storm the simulated peak flood depth is smaller under SMP conditions.

4.0 Quantification of Public SMP Implementation Water Quality Benefits

This section describes the methodology adopted for quantifying annual removal of total suspended solids (TSS) and total phosphorous (TP) loadings induced by SMP implementation in the six selected study areas (Ref. 1). SMP types implemented are rain gardens, bumpouts, green roofs, porous pavement, planter boxes, and subsurface trenches. It should be noted that SMP sites were limited on their implementation based on existing site conditions, including slopes and clearances.

4.1 Methodology Overview

To quantify annual TSS removal, the Massachusetts Stormwater Handbook (Standard 4) and its TSS removal calculation tool were utilized. Likewise, methodology described in the General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4) in Massachusetts was utilized to quantify Annual TP loading reductions. These methods are discussed in detail in the sections below.

4.2 TSS Water Quality Benefits

To determine the TSS water quality benefits, existing TSS loadings were quantified for each SMP tributary area, as well as for the total impervious area within each of the six study areas. The SMP footprint areas and treated impervious tributary areas were taken directly from Ref. 1. In this analysis, it was assumed that SMP tributary areas were impervious. TSS loadings were determined based on TSS concentrations associated with underlaying land use, and runoff generated during the 1992 typical year, which had a total rainfall of 46.83 inches. This rainfall correlates well with the average rainfall recorded for Boston by the Northeast Regional Climate Center from 2008 through 2018, which is 48.7 inches. Land use associated TSS concentrations were based on stormwater data collected in New England for part of the Merrimack River Watershed Study by CDM (Ref. 2) and are presented in Table 10. If multiple land uses were present in a drainage or study area, then a weighted average of the corresponding TSS concentrations was utilized in the TSS loading calculation. See Appendix E for a table summarizing the land uses and TSS concentrations for each SMP tributary area.

Table 10. TSS Concentrations based on Land Use

	Commercial	Industrial	Residential
TSS, mg/L	41	42	58

TSS loading reductions for SMP implementation scenario conditions were calculated by applying the TSS removal efficiency using the Massachusetts Stormwater Handbook (Standard 4)'s TSS Removal Calculation Tool (Ref. 3). The TSS Removal Calculation Tool requires SMPs to be designed, constructed, operated, and maintained in accordance with the specifications and procedures dictated in Volumes 2 and 3 of the Massachusetts Stormwater Handbook. It is assumed that the SMPs will be installed accordingly. However, as stated in Ref. 2, the SMPs were selected based on a high-level feasibility evaluation, and therefore are only conceptual at this time. Table 11 lists the potential TSS removal efficiencies and reductions for each SMP tributary area.

Table 11. Annual TSS Loading Reduction for SMP Tributary Areas

Drainage Area	Location	SMP Type	Existing TSS Loading within SMP Tributary Areas (kg/year)	TSS Removal Efficiency	Exit TSS Loading from SMP (kg/year)	TSS Load Reduction (kg/yr)
Study Area 2 (Impervious Area = 67 acres)			14,834			
A	Kent St and Somerville Ave	Subsurface Trench	160	80%	32	128
B	Bleachery Ct and Somerville Ave	Subsurface Trench	92	80%	18	74
C	Park St and Somerville Ave	Subsurface Trench	43	80%	9	34
D	Washington St and Hanson St	Bumpout	169	90%	17	152
E	Properzi Way and Hanson St	Subsurface Trench	57	80%	11	46
F	Palmacci Playground	Bumpout	112	90%	11	101
G	Church St and Somerville Ave	Subsurface Trench	23	80%	5	18
Total TSS Reduction for Study Area 2 (kg/year)						**553**
Study Area 3 (Impervious Area = 48 acres)			11,770			
A	Holland St and Elmwood St	Planter	67	90%	7	61
B	Holland St Gorham to Jay	Bumpout	29	90%	3	26
C	Holland Street at Jay St	Subsurface Trench	17	80%	3	14
D	Holland St and Paulina St	Planter	24	90%	2	22
E	Holland St and Elmwood St	Subsurface Trench	92	80%	18	74
F	Thorndike St and Howard St	Bumpout	160	90%	16	144
G	Herbert St Parking Lot*	Rain Garden	108	90%	11	97
H	Orchard St and Day St	Bumpout	161	90%	16	145
I	Davis Square Parking Lot*	Rain Garden	45	90%	4	41
J	City Traffic & Parking Dept*	Green Roof	28	0%	28	0
Total TSS Reduction for Study Area 3 (kg/year)						**624**
Study Area 8 (Impervious Area = 66 acres)			16,892			
A	Sydney St and Taylor St	Bumpout	86	90%	9	77
B	Grant St and Mystic Ave	Subsurface Trench	45	80%	9	36

Drainage Area	Location	SMP Type	Existing TSS Loading within SMP Tributary Areas (kg/year)	TSS Removal Efficiency	Exit TSS Loading from SMP (kg/year)	TSS Load Reduction (kg/yr)
C	Grant St and Sydney St	Bumpout	148	90%	15	133
D	Grant St and Sydney St	Bumpout	47	90%	5	42
E	Grant St and Sewall St	Bumpout	52	90%	5	47
F	Jaques St and Temple St	Bumpout	100	90%	10	90
G	Edgar Ave and Heath St	Bumpout	110	90%	11	99
Total TSS Reduction for Study Area 8 (kg/year)						**524**
Study Area 10 (Impervious Area = 23 acres)			6,405			
A	North St and Bailey St	Bumpout	448	90%	45	403
B	W Adams St and Chetwynd Rd	Bumpout	78	90%	8	70
C	Hillsdale Rd and Upland Rd	Bumpout	46	90%	5	39
D	Hillsdale Rd and Sunset Rd	Subsurface Trench	44	80%	9	35
E	Conwell Ave and College Hill Rd	Subsurface Trench	120	80%	24	96
F	Conwell Ave and College Hill Rd	Subsurface Trench	179	80%	36	143
G	Hillsdale Rd and Conwell Ave	Subsurface Trench	51	80%	10	41
H	W Adams St and Conwell Ave	Subsurface Trench	314	80%	63	251
I	W Adams St and Conwell Ave	Subsurface Trench	51	80%	10	41
J	Chetwynd Rd and Curtis St	Subsurface Trench	86	80%	17	69
K	Chetwynd Rd and Curtis St	Subsurface Trench	49	80%	10	39
Total TSS Reduction for Study Area 10 (kg/year)						**1,227**
Study Area 11 (Impervious Area = 28 acres)			7,320			
A	Medford St and School St	Bumpout	196	90%	20	176
B	Central St and Willoughby St	Subsurface Trench	261	80%	52	209
C	Waldo and Hudson	Bumpout	84	90%	8	76
D	Waldo and Hudson	Bumpout	125	90%	13	112
Total TSS Reduction for Study Area 11 (kg/year)						**573**
Study Area 12 (Impervious Area = 39 acres)			10,284			
A	Auburn and Cross	Subsurface Trench	90	80%	18	72
B	Auburn and Cross	Bumpout	374	90%	37	337

Drainage Area	Location	SMP Type	Existing TSS Loading within SMP Tributary Areas (kg/year)	TSS Removal Efficiency	Exit TSS Loading from SMP (kg/year)	TSS Load Reduction (kg/yr)
C	Flint and Rush	Subsurface Trench	181	80%	36	145
D	Glen St and Fountain	Bumpout	50	90%	5	45
E	Tufts St and Glen St	Bumpout	78	90%	8	70
F	Tufts St and Knowlton St	Bumpout	234	90%	23	211
G	Glen St and Fountain	Bumpout	65	90%	7	58
H	Glen St and Morton St	Bumpout	245	90%	24	221
I	Tufts St and Glen Parking Lot*	Rain Garden	65	90%	7	58
J	Fountain Ave and Glen St Parking Lot*	Porous Paving	21	80%	4	17
K	Capuano School Vacant Lot*	Porous Paving	21	80%	4	17
Total TSS Reduction for Study Area 12 (kg/year)						**1,251**
Total Overall TSS Reduction for all Study Areas (kg/year)						**4,752**

Table 12 summarizes the TSS reduction for the SMP drainage areas within each SMP study area. TSS generated within the tributary area to the SMPs can be reduced by 86 percent due to SMP implementation. As can be observed in the table, Area 8 exhibits the largest TSS percent reduction due to the fact that the majority of its proposed SMP types are bumpouts, which can reduce TSS up to 90 percent for their tributary areas. However, Study Area 12 exhibits the greatest net reduction in TSS loading due to it containing the largest amount of individual SMPs, i.e., 11. Likewise, Area 10 exhibits the second greatest reduction of TSS loading while having the same number of proposed SMP sites as Area 12. For percentage of TSS treated for the total impervious area in the entire study area, see Table 16 in Section 4.4.

Table 12. Annual TSS Loading Percent Reduction within SMP Tributary Areas due to SMP Implementation

SMP Study Area	SMP (footprint + impervious treated) Area, Ac	Existing TSS Loading within SMP Tributary Areas (kg/year)	Exit TSS Loading from SMP (kg/year)	Net TSS Reduction (kg/year)	% Reduction
2	3.21	656	103	553	84
3	3.94	731	109	622	85
8	2.34	588	63	525	89
10	5.50	1,468	236	1,232	84
11	1.78	666	93	573	86
12	4.98	1,424	174	1,250	88
Total	**21.75**	**5,533**	**779**	**4,754**	**86**

4.3 TP Water Quality Benefits

To quantify TP water quality benefits, phosphorus removal was determined per procedures described in Attachment 3 to Appendix F of the MA MS4 General Permit (Ref.4), which provides methods to calculate phosphorus load reductions for structural SMPs. In this analysis, it was assumed that the SMP tributary areas, provided in Ref.1, were impervious. Therefore, the method selected for this analysis was based on having a structural SMP with a known design volume when the contributing drainage area is 100% impervious (see Flow Chart 2 in Ref 4). Structural SMP design storage volumes were based on the SMP footprint areas provided in Ref. 1 and the SMP parameters depicted in the design schematics presented in Appendix A. Once available storage volumes were calculated, the volumes were converted into inches of runoff from the SMP impervious tributary areas. Performance curves, based on infiltration rates listed in Table 2, were then analyzed and interpolated to determine the corresponding percent TP load reduction for the depth of runoff. Figure 2 shows one of the performance curves from Ref. 4 that was referenced. Appendix F provides the interpolated curve values that were used to determine the percent TP load reduction. It should be noted that some runoff depths exceeded the upper interpolation range, and therefore extrapolated values were used. As stated in Ref. 4, only surface infiltration and infiltration trench performance curves were simulated for infiltration. Therefore, if SMP storage capacity was provided through surface-ponding, then infiltration basin performance curves were referenced. Likewise, if SMP storage capacity was provided only in void spaces, then infiltration trench performance curves were referenced. Table 13 states which one of these curves was referenced for each of the selected SMPs, along with the soil infiltration rate. No performance curve was provided for green roofs because green roofs do not treat runoff.

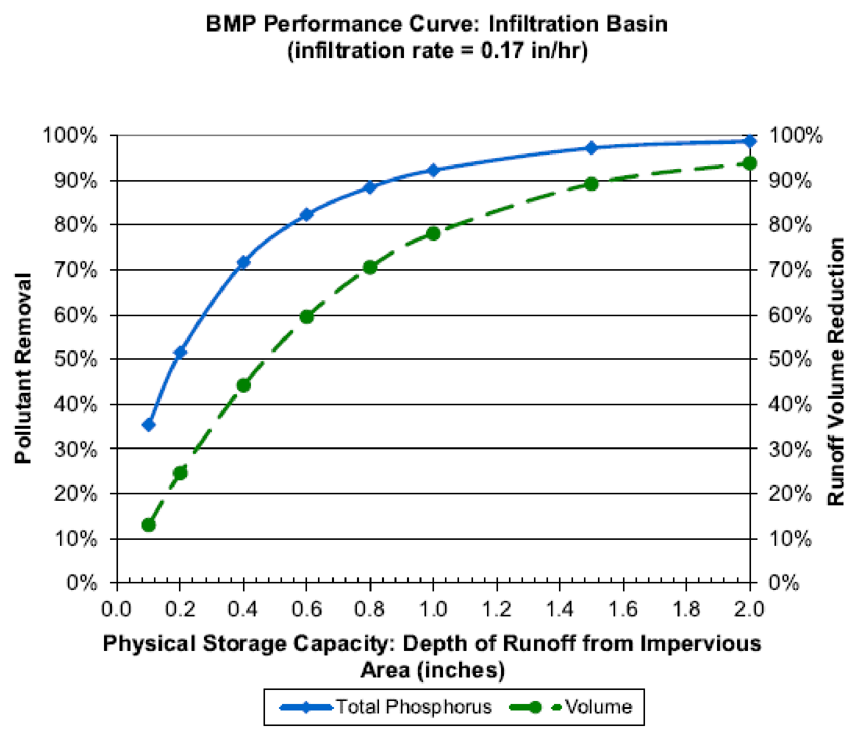

Figure 2. Performance Curve

Table 13. SMP Performance Curves for TP Removal

SMP Type	Performance Curve
Bumpout	Infiltration Basin (rate = 0.4 in/hr)
Planter Box	Infiltration Basin (rate = 0.4 in/hr)
Subsurface Trench	Infiltration Trench (rate = 2 in/hr)
Rain Garden	Infiltration Basin (rate = 0.4 in/hr)
Green Roof	N/A
Porous Pavement	Infiltration Trench (rate=0.4 in/hr)

TP loads were calculated for each SMP based on annual TP load export rates (PLERs) by land use category, provided in Table 3-1 of Attachment 3 to Appendix F (Ref. 4). As performed for the TSS loading calculation, if multiple land uses were present in a drainage area, then a weighted average for TP was calculated. Appendix E tabulates land uses and TP concentrations for each SMP tributary area. The percent TP load reduction was then applied to the TP load to determine the phosphorus load reduction. Table 14 lists the potential TP load reductions for each drainage and study area. Note that TP reduction may appear off by one decimal due to rounding.

Table 14. Annual TP Loading Reduction for SMP Tributary Areas

Drainage Area	Location	SMP Type	Existing TP Loading within SMP Tributary Areas (kg/yr)	Percent TP Load Reduction (%)	Exit TP Loading from SMP (kg/yr)	TP Load Reduction (kg/yr)
Study Area 2 (Impervious Area = 67 acres)			58.9			
A	Kent St and Somerville Ave	Subsurface Trench	0.7	89.5%	0.1	0.6
B	Bleachery Ct and Somerville Ave	Subsurface Trench	0.4	99.8%	0.0	0.4
C	Park St and Somerville Ave	Subsurface Trench	0.2	98.3%	0.0	0.2
D	Washington St and Hanson St	Bumpout	0.7	60.2%	0.3	0.4
E	Properzi Way and Hanson St	Subsurface Trench	0.2	99.8%	0.0	0.2
F	Palmacci Playground	Bumpout	0.4	89.5%	0.0	0.4
G	Church St and Somerville Ave	Subsurface Trench	0.1	98.5%	0.0	0.1
Total TP Reduction for Study Area 2 (kg/year)						**2.2**
Study Area 3 (Impervious Area = 48 acres)			45.4			
A	Holland St and Elmwood St	Planter	0.3	99.0%	0.0	0.3

Drainage Area	Location	SMP Type	Existing TP Loading within SMP Tributary Areas (kg/yr)	Percent TP Load Reduction (%)	Exit TP Loading from SMP (kg/yr)	TP Load Reduction (kg/yr)
B	Holland St Gorham to Jay	Bumpout	0.1	96.0%	0.0	0.1
C	Holland Street at Jay St	Subsurface Trench	0.1	100.0%	0.0	0.1
D	Holland St and Paulina St	Planter	0.1	99.0%	0.0	0.1
E	Holland St and Elmwood St	Subsurface Trench	0.3	91.1%	0.0	0.3
F	Thorndike St and Howard St	Bumpout	0.7	72.5%	0.2	0.5
G	Herbert St Parking Lot*	Rain Garden	0.4	97.0%	0.0	0.4
H	Orchard St and Day St	Bumpout	0.7	91.8%	0.1	0.6
I	Davis Square Parking Lot*	Rain Garden	0.2	97.1%	0.0	0.2
J	City Traffic & Parking Dept*	Green Roof	0.1	0.0%	0.1	0.0
Total TP Reduction for Study Area 3 (kg/year)						**2.6**
Study Area 8 (Impervious Area = 66 acres)			65.2			
A	Sydney St and Taylor St	Bumpout	0.3	98.5%	0.0	0.3
B	Grant St and Mystic Ave	Subsurface Trench	0.2	98.5%	0.0	0.2
C	Grant St and Sydney St	Bumpout	0.6	79.8%	0.1	0.4
D	Grant St and Sydney St	Bumpout	0.2	96.0%	0.0	0.2
E	Grant St and Sewall St	Bumpout	0.2	98.2%	0.0	0.2
F	Jaques St and Temple St	Bumpout	0.4	94.4%	0.0	0.4
G	Edgar Ave and Heath St	Bumpout	0.4	85.5%	0.1	0.4
Total TP Reduction for Study Area 8 (kg/year)						**2.0**
Study Area 10 (Impervious Area = 23 acres)			24.4			
A	North St and Bailey St	Bumpout	1.7	81.9%	0.3	1.4
B	W Adams St and Chetwynd Rd	Bumpout	0.3	96.0%	0.0	0.3
C	Hillsdale Rd and Upland Rd	Bumpout	0.2	97.0%	0.0	0.2
D	Hillsdale Rd and Sunset Rd	Subsurface Trench	0.2	100.0%	0.0	0.2
E	Conwell Ave and College Hill Rd	Subsurface Trench	0.5	95.5%	0.0	0.4
F	Conwell Ave and College Hill Rd	Subsurface Trench	0.7	65.6%	0.2	0.4

Drainage Area	Location	SMP Type	Existing TP Loading within SMP Tributary Areas (kg/yr)	Percent TP Load Reduction (%)	Exit TP Loading from SMP (kg/yr)	TP Load Reduction (kg/yr)
G	Hillsdale Rd and Conwell Ave	Subsurface Trench	0.2	100.0%	0.0	0.2
H	W Adams St and Conwell Ave	Subsurface Trench	1.2	53.9%	0.5	0.6
I	W Adams St and Conwell Ave	Subsurface Trench	0.2	100.0%	0.0	0.2
J	Chetwynd Rd and Curtis St	Subsurface Trench	0.3	98.5%	0.0	0.3
K	Chetwynd Rd and Curtis St	Subsurface Trench	0.2	98.6%	0.0	0.2
Total TP Reduction for Study Area 10 (kg/year)						**4.4**
Study Area 11 (Impervious Area = 28 acres)			28.0			
A	Medford St and School St	Bumpout	0.7	92.2%	0.1	0.7
B	Central St and Willoughby St	Subsurface Trench	1.0	90.6%	0.1	0.9
C	Waldo and Hudson	Bumpout	0.3	95.5%	0.0	0.3
D	Waldo and Hudson	Bumpout	0.5	89.5%	0.0	0.4
Total TP Reduction for Study Area 11 (kg/year)						**2.3**
Study Area 12 (Impervious Area = 39 acres)			38.9			
A	Auburn and Cross	Subsurface Trench	0.3	95.7%	0.0	0.3
B	Auburn and Cross	Bumpout	1.4	76.6%	0.3	1.1
C	Flint and Rush	Subsurface Trench	0.7	92.5%	0.1	0.6
D	Glen St and Fountain	Bumpout	0.2	96.4%	0.0	0.2
E	Tufts St and Glen St	Bumpout	0.3	86.6%	0.0	0.3
F	Tufts St and Knowlton St	Bumpout	0.9	68.4%	0.3	0.6
G	Glen St and Fountain	Bumpout	0.3	98.2%	0.0	0.3
H	Glen St and Morton St	Bumpout	0.9	70.4%	0.3	0.6
I	Tufts St and Glen Parking Lot*	Rain Garden	0.3	98.2%	0.0	0.3
J	Fountain Ave and Glen St Parking Lot*	Porous Paving	0.1	99.0%	0.0	0.1
K	Capuano School Vacant Lot*	Porous Paving	0.1	99.0%	0.0	0.1
Total TP Reduction for Study Area 12 (kg/year)						**4.5**
Total Overall TP Reduction for all Study Areas (kg/year)						**18.0**

Table 15 summarizes the TP reduction for the SMP drainage areas within each study area. TP generated within all SMP tributary areas is reduced by 84.5% due to SMP implementation. Table 15 shows that Areas

10 and 12 exhibit the largest TP reduction namely 4.4 kg/year and 4.5 kg/year, respectively, as each contains the largest number of SMPs (i.e., 11 SMPs each) and the largest combined SMP footprint and treated impervious areas, namely 5.50 acres and 4.98 acres, respectively. For percentage of TP treated for the total impervious area in the entire study area, see Table 16 in Section 4.4.

Table 15. TP Percent Reduction within SMP Tributary Areas due to SMP Implementation

Study Area with SMPs	SMP (footprint + impervious treated) Area, Ac	Existing TP Load within SMP Tributary Area (kg/year)	Exit TP Load from SMP (kg/year)	TP Reduction (kg/year)	% Reduction
2	3.21	2.6	0.4	2.2	84.6
3	3.94	3.0	0.4	2.6	86.7
8	2.34	2.2	0.2	2.0	90.9
10	5.50	5.5	1.1	4.4	80.0
11	1.78	2.5	0.2	2.3	92.0
12	4.98	5.5	1.0	4.5	81.8
Total	**21.75**	**21.3**	**3.3**	**18.0**	**84.5**

4.4 TSS and TP Results per Study Area

Table 16 shows TSS and TP loading reductions due to SMP implementation, as a percent of total loadings generated from impervious surfaces within study areas. Table 16 shows that from a total TSS loading of 67,505 kg/year generated within all study areas, only a small fraction totaling 4,752 kg/year, i.e., 7%, are removed due to SMP implementation. Likewise, regarding TP loadings, only 18.5 kg/year out of 260.8 kg/year, i.e., 7% are removed due to SMP implementation in all study areas. TSS and TP load reductions are highest in Areas 10 and 12 on both counts, net load and percent load reductions. Based on this, SMP implementation in Areas 10 and 12 may prove most effective in terms of water quality benefits.

Table 16. TSS and TP Treated as Percent of Loadings from Total Impervious Area

SMP Study Area	TSS Load from Impervious Area* (kg/yr)	TSS Loading Reduction (kg/year)	TSS Treated as % of Total Load from Total Impervious Area	TP Load from Impervious Area* (kg/yr)	TP Loading Reduction (kg/year)	TP Treated as % of Total Load from Total Impervious Area
2	14,834	553	4%	58.9	2.2	4%
3	11,770	624	5%	45.4	2.6	6%
8	16,892	524	3%	65.2	2.0	3%
10	6,405	1,227	19%	24.4	4.4	18%

SMP Study Area	TSS Load from Impervious Area* (kg/yr)	TSS Loading Reduction (kg/year)	TSS Treated as % of Total Load from Total Impervious Area	TP Load from Impervious Area* (kg/yr)	TP Loading Reduction (kg/year)	TP Treated as % of Total Load from Total Impervious Area
11	7,320	573	8%	28.0	2.3	8%
12	10,284	1,251	12%	38.9	4.5	11%
Total	**67,505**	**4,752**	**7%**	**260.8**	**18.5**	**7%**
(*) Total Impervious area within Study Area.						

The Massachusetts Stormwater Handbook (Standard 4) states that the goal is to have SMP sites achieve an 80 percent removal of TSS. Appendix F of the MA MS4 General Permit states that Somerville's required reduction in phosphorus load is 331 kg/year, or 51% per its baseline phosphorus load of 646 kg/year. As previously mentioned, potential SMP sites for this analysis were limited by existing site conditions. Therefore, not all impervious areas can be routed to one of these proposed SMP sites for treatment. Additional measures will need to be taken to achieve MS4 compliance, but exploration of such are beyond the scope of the present analysis.

5.0 Quantification of Private GSI Implementation Flood Benefits

As a standalone exercise, the impact of private GSI on flooding within the six study areas was modeled as a scenario within the model for the 1-year and 10-year 2030 storms. The modeled private GSI combined two components. The first component included disconnecting 50 percent of roof drains from the storm drain system to pervious areas; the second component included converting 50 percent of existing impervious driveways to permeable pavement. Table 17 quantifies the disconnected roof area and permeable pavement (treated driveway area) compared to the total impervious area within the study area.

Table 17. Disconnected Roof Area and Permeable Pavement Relative to Total Impervious Area

SMP Study Area	Total Area (Ac)	Impervious Area (Ac)	Disconnected Building Roof Area (Ac)	% of Impervious Area	Permeable Pavement Area (Ac)	% of Impervious Area
2	91	67	13.8	20.5%	3.3	4.9%
3	67	48	8.4	17.5%	2.8	5.8%
8	71	66	9.4	14.2%	3.1	4.7%
10	35	23	5.1	22.3%	1.7	7.4%
11	38	28	4.7	16.7%	1.6	5.6%
12	43	39	4.8	12.4%	1.6	4.1%

Appendix G shows simulated peak flood depth maps under private GSI implementation conditions for the design storms listed above. Peak flood depths range from 0.5-ft to over 3-ft, correlating with light to dark blue, respectively. Flood depth maps of Study Area 12 in Appendix G shows maximum flood depth under existing and private GSI conditions during the 1-year 2030 storm, 1-year 2030 SLR and the 10-year 2030 storm, 1-year 2030 SLR. Peak flood depths for private GSI conditions correlate with light to dark blue triangles; peak flood depths for existing conditions correlate with light to dark red triangles. The implementation of private GSI induces a slight reduction of flooding extents at several locations, including along Fountain Avenue, Dell Street, and Oliver Street.

Table 18 lists simulated maximum flood volume within each of the six areas under the 1-year and 10-year storms, with and without Private GSI implementation for the 2030 time horizon. The effectiveness of the private GSI implementation is reflected by the *Difference* and *% Difference* columns in Table 18. The negative difference reflects the reduction in flood volume (million gallons (MG), %) induced by private GSI implementation.

Table 18. Simulated flood volume (MG) removal due to Private GSI

Study Area	Storm	Flood Volume (MG)			
		Existing	With Private GSI	Difference	% Difference
2	1 year 2030 Storm, 1 year 2030 SLR	0.852	0.766	-0.086	-10.1
	10 year 2030 Storm, 1 year 2030 SLR	5.212	5.000	-0.212	-4.1
3	1 year 2030 Storm, 1 year 2030 SLR	0.000	0.000	0.000	0.0
	10 year 2030 Storm, 1 year 2030 SLR	0.765	0.686	-0.079	-10.4
8	1 year 2030 Storm, 1 year 2030 SLR	1.982	1.932	-0.049	-2.5
	10 year 2030 Storm, 1 year 2030 SLR	5.286	5.174	-0.112	-2.1
10	1 year 2030 Storm, 1 year 2030 SLR	0.043	0.035	-0.008	-18.4
	10 year 2030 Storm, 1 year 2030 SLR	0.075	0.070	-0.005	-6.7
11	1 year 2030 Storm, 1 year 2030 SLR	0.014	0.009	-0.005	-38.4
	10 year 2030 Storm, 1 year 2030 SLR	0.318	0.294	-0.023	-7.3
12	1 year 2030 Storm, 1 year 2030 SLR	2.882	2.664	-0.217	-7.6
	10 year 2030 Storm, 1 year 2030 SLR	4.391	4.165	-0.226	-5.2

Because areas differ in size and total private GSI storage capacity, the impact of private GSI varies across the study areas. For example, flood volume reduction within Study Area 2 varies between 0.086 MG and 0.212 MG, under the 1-year 2030 storm, 1-year 2030 SLR and the 10-year 2030 storm, 1-year 2030 SLR, respectively. Table 18 shows that net flood volume reduction (i.e., difference) generally increases from smaller to larger storm events.

6.0 Results Summary

Regarding surface flood reduction benefits, implementation of the SMP technologies investigated herein reduces street flooding in the six (6) selected study areas; however, some areas have more substantial reduction than others. Flood volume reduction ranges from 0.000 MG to 0.226 MG within all six SMP study areas under the selected array of design storms and SLR scenarios (ranging from the 1 year 2030 Storm, 1 year 2030 SLR to the 100 year 2070 Storm, 1 year 2070 SLR). For example, flood volume reduction within Study Area 2 varies between 0.082 MG and 0.226 MG under the 1-year 2030 storm, 1-year 2030 SLR and the 100-year 2070 storm, 1 year 2070 SLR, respectively.

Implementation of private GSI investigated herein reduces flooding in the six (6) selected study areas. As observed with public SMP implementation, some areas exhibit larger flood reduction than others. Flood volume reduction ranges from 0.000 MG to 0.226 MG within all six study areas under the selected array of design storms and SLR scenarios (1 year 2030 Storm, 1 year 2030 SLR and 10 year 2030 Storm, 1 year 2030 SLR).

Regarding water quality benefits, implementation of SMP technologies within all six study areas effectively reduce TSS and TP annual loadings by 86% (Table 12) and 84.5% (Table 15), respectively, for the treated impervious SMP tributary areas. On the other hand, TSS and TP annual load reductions account for only 7% and 5% (Table 16) of the loadings generated from entire impervious surfaces within all study areas. In both cases, Areas 10 and 12, each accounting for largest impervious treated areas and number of SMPs, exhibit the largest annual TSS and TP loading reductions.

7.0 Conclusions and Remarks

The implementation of SMP technologies investigated in this work was shown to reduce street flooding in the six (6) selected study areas (i.e., areas 2, 3, 8, 10, 11, and 12). The relative effectiveness of the SMP is less dramatic for larger storm events, e.g., the 10-, or 100-year design events as shown by the trends in % Differences in Tables 4 through 9. Similar trends were observed for private GSI implementation. In some instances, private GSI achieved a greater flood reduction than the public SMP implementation scenarios (e.g., Study Areas 8 and 12, comparing Tables 6 and 9, respectively, to Table 18).

Annual TSS and TP removals results indicate that study areas 10 and 12 are most effective as both exhibit the largest pollutant reduction benefits, both in terms of net reduction and percent reduction. Table 11 indicates that most effective SMPs, in terms of annual TSS % reduction, are bumpouts, planters, and rain gardens. In the case of annual TP % reduction, bumpouts and subsurface trenches exhibit the largest pollutant trapping efficiencies.

Results of this study should be considered with caution as they only serve as an indicator of the overall effectiveness of SMP implementation. Results from this study should be considered as a theoretical maximum benefit that could potentially be achieved with full SMP implementation. Actual feasibility of implementation as well as SMP effectiveness need to be evaluated on a case by case basis or at a parcel scale as outcomes are highly site-specific.

It should be noted that the effectiveness of the SMP types is time dependent, as these can be affected by many environmental conditions, such as antecedent rainfall as well as operational conditions. It is well documented that permeable pavements decay in efficiency over time as particles fill the pavement cavities (clogging) the unit. Therefore, maintenance is a factor that must be carefully considered for all measures.

8.0 References

[Ref. 1] Green Infrastructure Feasibility Study, June 24, 2019. Technical Memorandum, prepared by Stantec for City of Somerville, Municipal Vulnerability Preparedness Grant.

[Ref. 2] Merrimack River Watershed Assessment Study - Screening Level Model, March 2004. Report prepared by CDM Smith for New England District of the Army Corps of Engineers.

[Ref. 3] Massachusetts Stormwater Handbook Vol. 2 (Standard 4)'s and TSS Removal Calculation Tool (TSS.xlsl, https://www.mass.gov/files/documents/2016/08/nn/tss.xls).

[Ref. 4] Massachusetts Small MS4 General Permit, 2016. Attachment 3 to Appendix F 'requirements for Discharges to Impaired Waters with an Approved TMDL'.