CITY OF LYNN

EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS

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STRAWBERRY BROOK RESILIENT STORMWATER MANAGEMENT AND IMPLEMENTATION PLAN

June 2020

STRAWBERRY BROOK RESILIENT MANAGEMENT AND IMPLEMENTATION PLAN

PREPARED FOR

City of Lynn, MA

PREPARED BY

Weston & Sampson

FUNDING

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PROJECT OVERVIEW

The Strawberry Brook area has a long history of riverine and urban stormwater flooding that is exacerbated by high tides and tidal flooding downstream. These types of flooding are only expected to worsen with the more intense precipitation and sea level rise projected to occur under climate change.

Historically, much of Lynn was a tidal marshland with an open, winding Strawberry Brook flowing through the open space. As the City began to grow, marshland was filled in and Strawberry Brook was developed into a system of drains and pipes. Today, all of Strawberry Brook is hidden underground flowing from Flax Pond to Saugus River.

The Strawberry Brook watershed covers 2,411 acres or 28% of Lynn's total area. Much of this land area is made of impervious surface, or material that does not infiltrate stormwater (or rainfall and melting snow once it hits the Earth's surface). Therefore, much of the stormwater must be carried way through stormwater drainage to protect streets, residents, and businesses from flooding.

The current drainage system built around Strawberry Brook consists of nature-based or gray infrastructures. Nature-based and green infrastructure examples include wetlands along Cedar Brook and Cedar, Sluice, and Flax Ponds. Gray infrastructure within the watershed includes stormwater pipes, culverts, conduits, and combined sewer/stormwater pipes. In many cases, rain will drain directly into the combined sewer/stormwater system. Commonly built in the past, gray infrastructure systems are becoming undersized due to increases in impervious surfaces and more frequently occurring, intense storm events. New nature-based solutions and green infrastructure can complement gray infrastructure systems in the face or future climate change.

MAP OF LYNN AND STRAWBERRY BROOK,1829. LIBRARY OF CONGRESS, GEOGRAPHY AND MAP DIVISION

The Strawberry Brook Resilient Stormwater Management and Implementation Plan set out to:

- Determine the climate factors that will impact Lynn today and in the future
- Identifying opportunities for nature-based solutions and green infrastructure within the watershed
- Provide a prioritized list of evaluated and implementable projects

The result is a comprehensive plan that will help the City become more resilient to future flooding and urban heat. The implementation of the plan will require both municipal leadership, private partnership, and resident support.

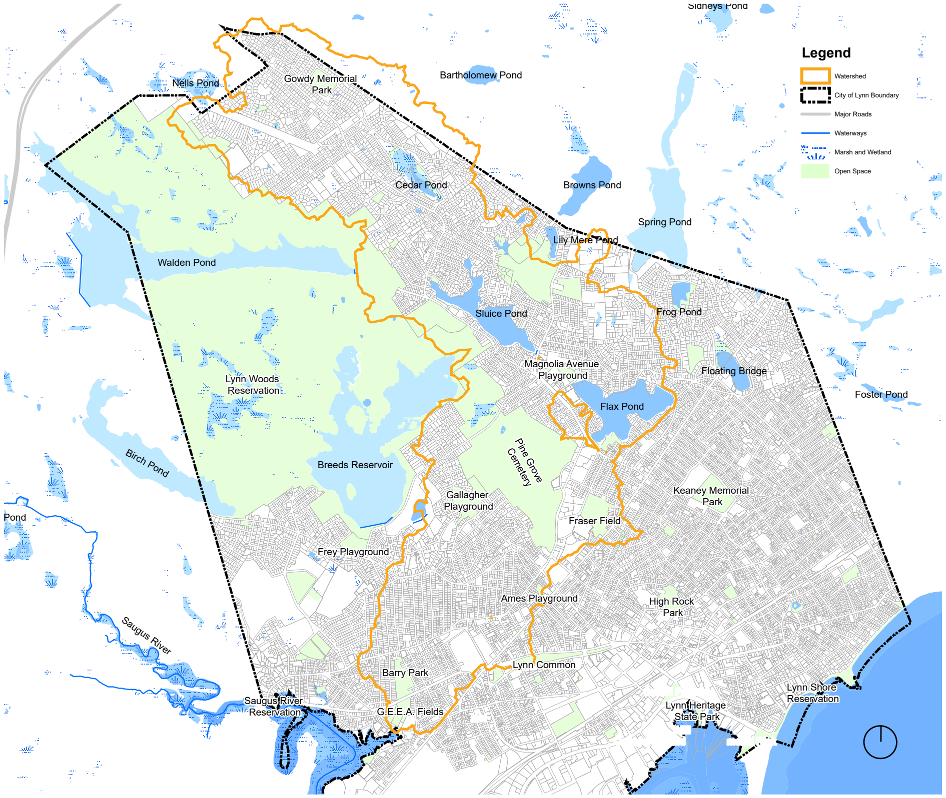

FIGURE 1. STRAWBERRY BROOK WATERSHED

Green Infrastructure and Low Impact Development

Green infrastructure is a stormwater management approach which is designed to slow down, collect, and treat stormwater where it falls. It complements and in some cases replaces the need for gray infrastructure. Green infrastructure offers a feasible and valuable solution for urban areas facing the challenges of climate change. It connects urban hydrological functions with vegetation systems in urban landscape design, providing overall socioeconomic benefits that are greater than the sum of its individual components. Taken together as a comprehensive system, components of green infrastructure projects strengthen urban ecosystems by employing natural processes in man-made environments. Systems of Green Infrastructure can include components like rain gardens, sunken street tree planters, permeable paving, daylighting streams, widening river flood plains, and conveyance swales.

Implemented together forming full, green streets and green areas, they can augment the stresses on existing, over-inundated, or undersized stormwater drainage in urban area by reducing and flattening the peak flow during storm events. As surface solutions, green infrastructure components can also help to reshape our urban environment by reclaiming and redesigning spaces for pedestrians. They combine the demand for sustainable water and stormwater management with the demands of adaptive urban life and planning.


HANS TAVSENS PARK VISUALIZATIONS EVERYDAY (LEFT) AND AFTER STORM (RIGHT) BY SLA

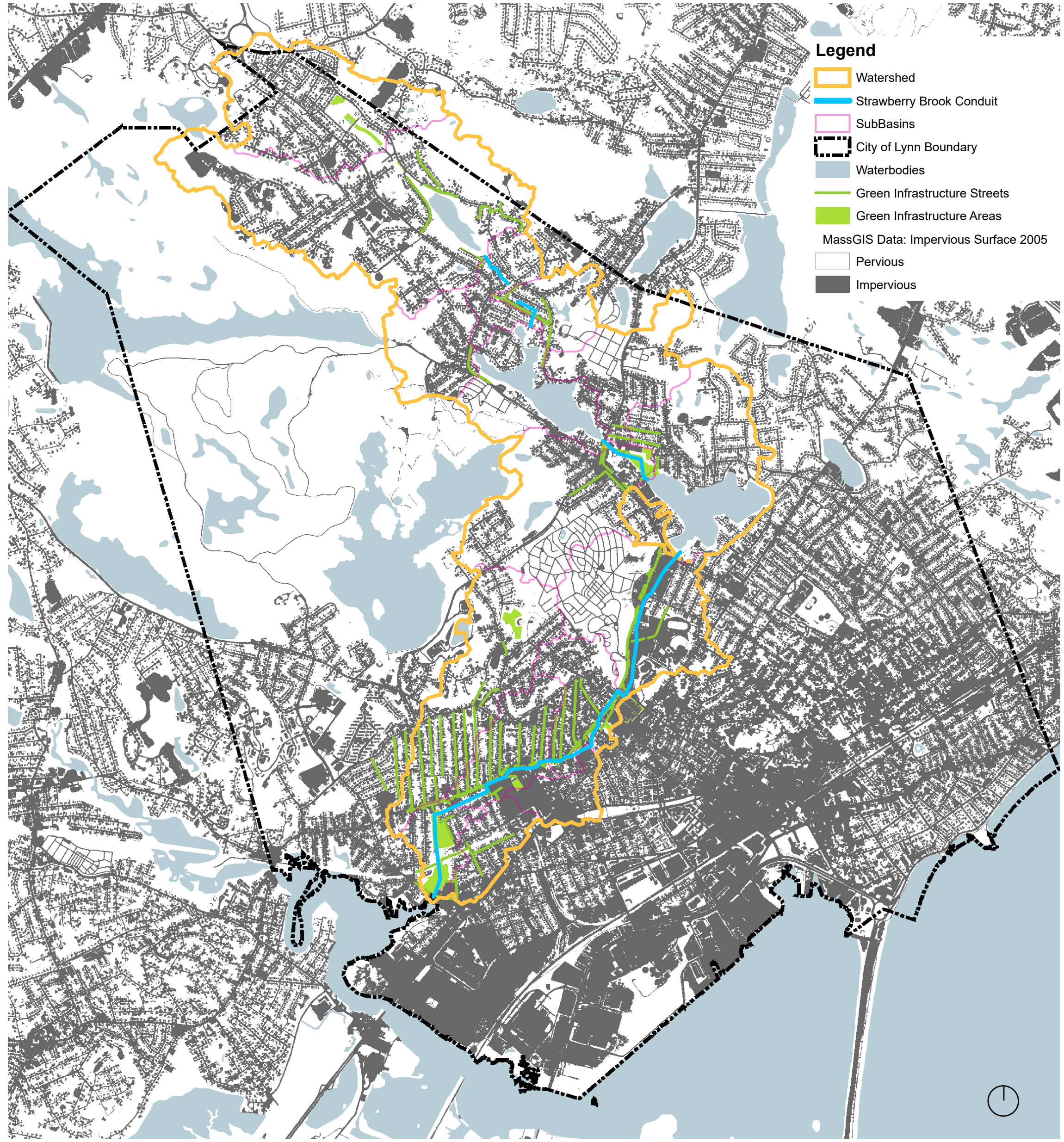

FIGURE 2. STRAWBERRY BROOK WATERSHED, IMPERVIOUS AREAS, AND PROPOSED GREEN INFRASTRUCTURE

FIELD DATA COLLECTION

Historical information was gathered and reviewed regarding the condition of the City's drainage system, including:

- Drainage system data and overview;
- Data from illicit discharge detection and elimination (IDDE) studies;
- Sampling data, including in-system sampling data, and water quality data;
- Locations of prior drainage system improvements and proposed stormwater conveyance projects;
- Implemented and proposed BMP's for regulatory compliance; and
- Information regarding reoccurring maintenance issues

The data review task also included collecting and reviewing data and reports available on the three significant waterbodies in the Strawberry Brook watershed, namely Flax Pond, Sluice Pond, and Cedar Pond. Sources of information on those waterbodies included:

- Dam inspection reports for Sluice Pond Dam (MA00236);
- Dredging or other reports on maintenance activities; and
- Available water quality testing through the MS4 permit program.

Initial Field Investigation

The purpose of the field investigation was to minimize data gaps found in the initial data review and to validate the City's current GIS information. Weston & Sampson (W&S) stormwater professionals spent several days assessing stormwater drainage connectivity, as well as accuracy and completeness of the GIS datasets, and investigating drain manholes, catch basins, outfalls and numerous other physical features such as roadways and waterways. Condition information collected has been compiled in GIS and used to understand the "big picture;" create a list of potential projects; develop rating criteria to prioritize the projects; identify gaps in the available data; and ultimately, present the Strawberry Brook Resilient Stormwater Management and Implementation Plan.

In conjunction with historical information, field reconnaissance enhanced the planning process. In the upper watershed, there are three primary waterbodies along Strawberry Brook; from upstream to downstream, they are Cedar, Sluice, and Flax Ponds, and they are connected in series by culverts. Since the entire length of Strawberry Brook, from the outlet of Flax Pond to the Little River is culverted, visual inspection of the Strawberry Brook conduit required manhole and TV inspections

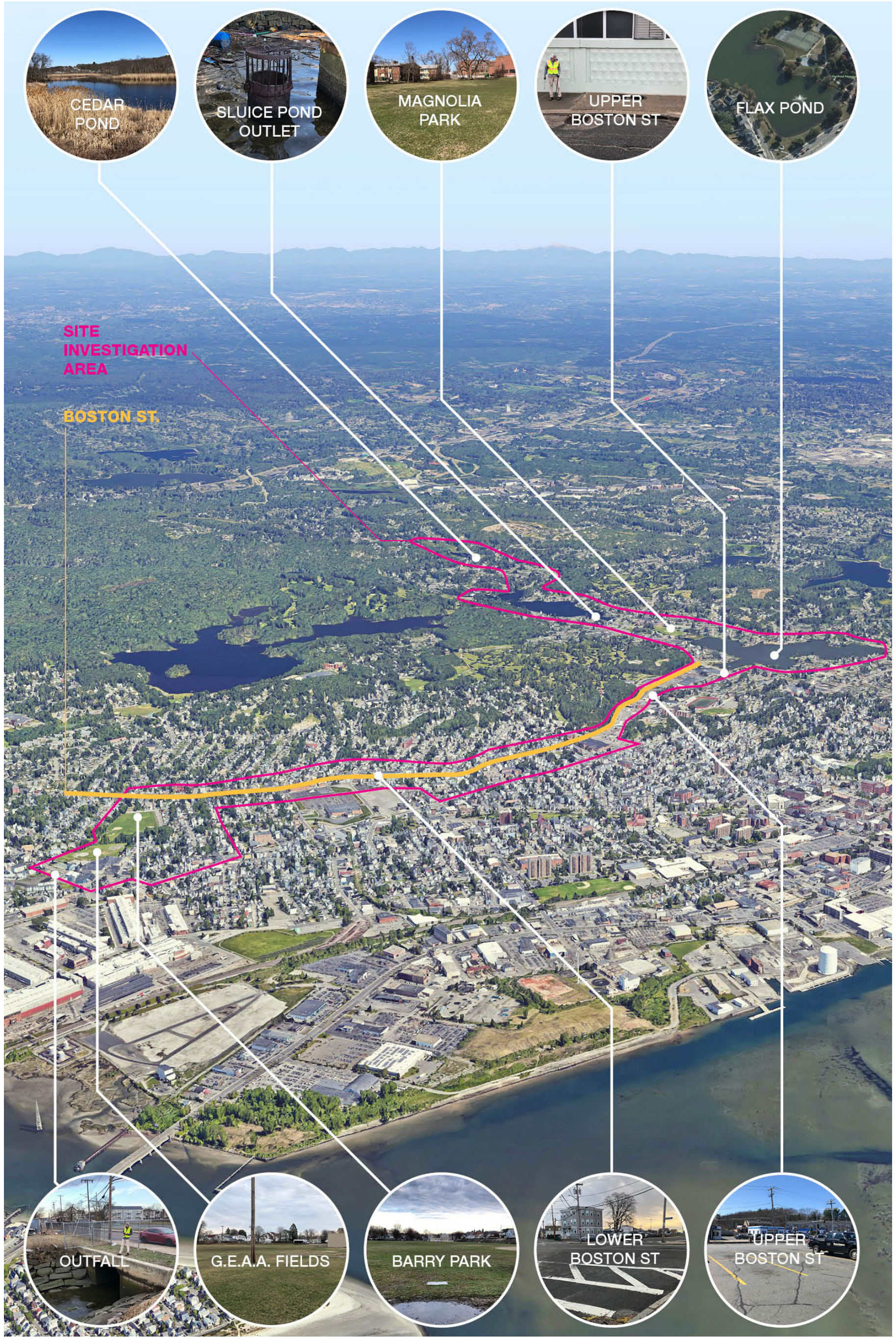

FIGURE 3. OVERVIEW OF THE SITE INVESTIGATION AREA AND CONDITIONS WITHIN THE WATERSHED

for verify depths, dimensions, and connectivity. The City's GIS data contained gaps between Cedar and Sluice Ponds and further site investigations were required to confirm the hydrological connections. In addition, a cursory inspection of the portions of the outlet and inlet structures visible from the waterline at each of the three ponds included a review of potential maintenance issues such as fallen trees or accumulated debris, erosion or other sediment deposition patterns that are restricting flow, and any structural deficiencies at the inlet/outlet works.

Areas of known flooding or prone to flooding, as identified by municipal staff and residents, were evaluated to gain a better understanding of potential improvements required to mitigate flooding issues. Site visits focusing on localized flooding around the intersection of Ford Street and Boston Street and along Marion Street were conducted to document existing conditions and identify potential green infrastructure and LID solutions.

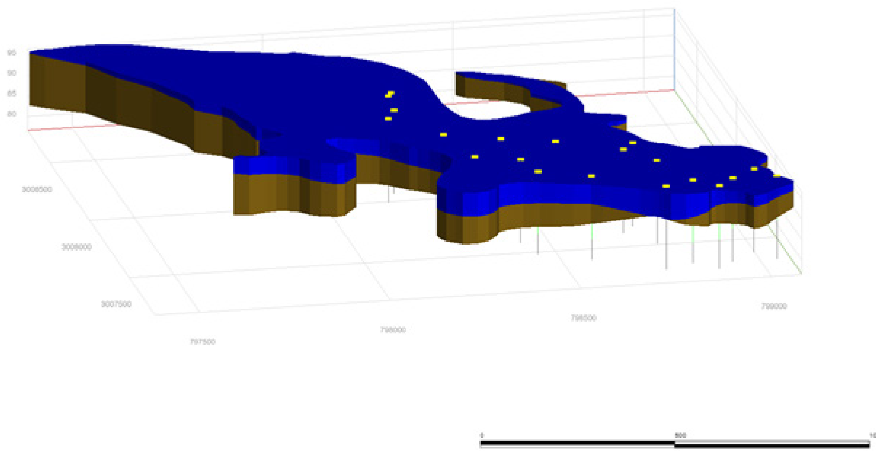

FIGURE 4: LEAPFROG MODEL OF CEDAR POND. SOFT SEDIMENT IS SHOWN IN BROWN AND WATER IS SHOWN IN BLUE

Bathymetric Survey

The project team conducted a bathymetric survey of Cedar, Sluice, and Flax Ponds to support development of stage-storage curves of those ponds in a hydrologic and hydraulic model and to inform potential flood mitigation projects that include increasing the storage capacity of a pond or ponds through dredging or alteration of its outlet controls or normal pond level. Data was collected at 20 locations using a graduated staff that was driven through the sediment layer until refusal was encountered. At each location, the depth to the top of soft sediment and the depth to hard sediment (taken as the point of refusal) was recorded. This data was incorporated into Leapfrog 3D Bathymetry Software to model the bathymetry and thickness of soft sediment in all three ponds (Figure 4).

The upstream side of the pond has the thickest measured sediment layer, nearing 13 feet. This is a significant amount of accumulated sediment. Sedimentation of ponds is a natural process from leaf debris and other detritus. However, some sedimentation in Cedar Pond is also from road runoff and erosion upstream. Dredging of specific areas in the pond or removal of the first several feet of sediment can drastically improve the total storage volume of Cedar Pond. Green infrastructure can help reduce additional sediment build-up by intercepting runoff before it reaches the pond improving water clarity and creating conditions that are more difficult for invasive species to take hold.

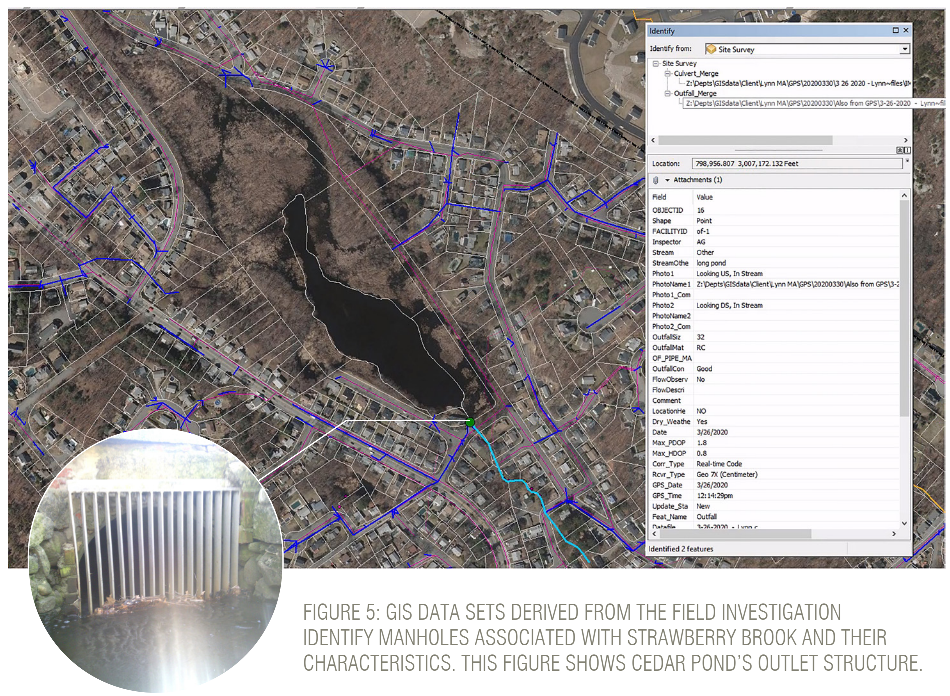

FIGURE 5: GIS DATA SETS DERIVED FROM THE FIELD INVESTIGATION IDENTIFY MANHOLES ASSOCIATED WITH STRAWBERRY BROOK AND THEIR CHARACTERISTICS. THIS FIGURE SHOWS CEDAR POND'S OUTLET STRUCTURE.

Early review of the bathymetric model of Cedar Pond reveals that a significant amount of stormwater volume could be stored through a new outlet control design and sediment removal reducing downstream flooding impacts.

Manhole Inspection & Survey

The project team conducted an inspection and survey of manholes associated with the Strawberry Brook conduit and tributary culverts in order to verify the accuracy of the City's GIS database and evaluate the condition of the existing infrastructure. We conducted a topside physical survey of sewer/drain manholes associated with Strawberry Brook for defects and infiltration/inflow (I/I). An electronic log was furnished for each manhole inspected. The manhole survey documented location, rim elevation, structural defects, I/I sources, size, depth, materials of construction, deposition of solids, photos, and other pertinent information. Areas of additional focus included the connections between Cedar and Sluice Ponds and the conduit transitions downstream of Flax Pond along Boston St.

TV Inspection

The project team also conducted partial TV inspections of the existing Strawberry Brook conduit, focusing on areas where information gained from manhole inspections was limited and in areas that have historically experienced nuisance flooding or are suspected to have blockages or breaks. A closed-circuit television "pan-and-tilt" camera was used to record the interior condition of drain segments and locate and identify any defects

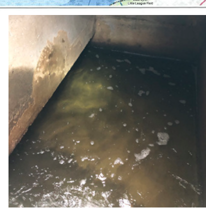

FIGURE 6: PHOTOGRAPHS AND FIELD INVESTIGATION MAPS WITH NOTES/ FINDINGS FROM TV INSPECTION INCLUDING CONDUIT DIMENSIONS AND FLOW.

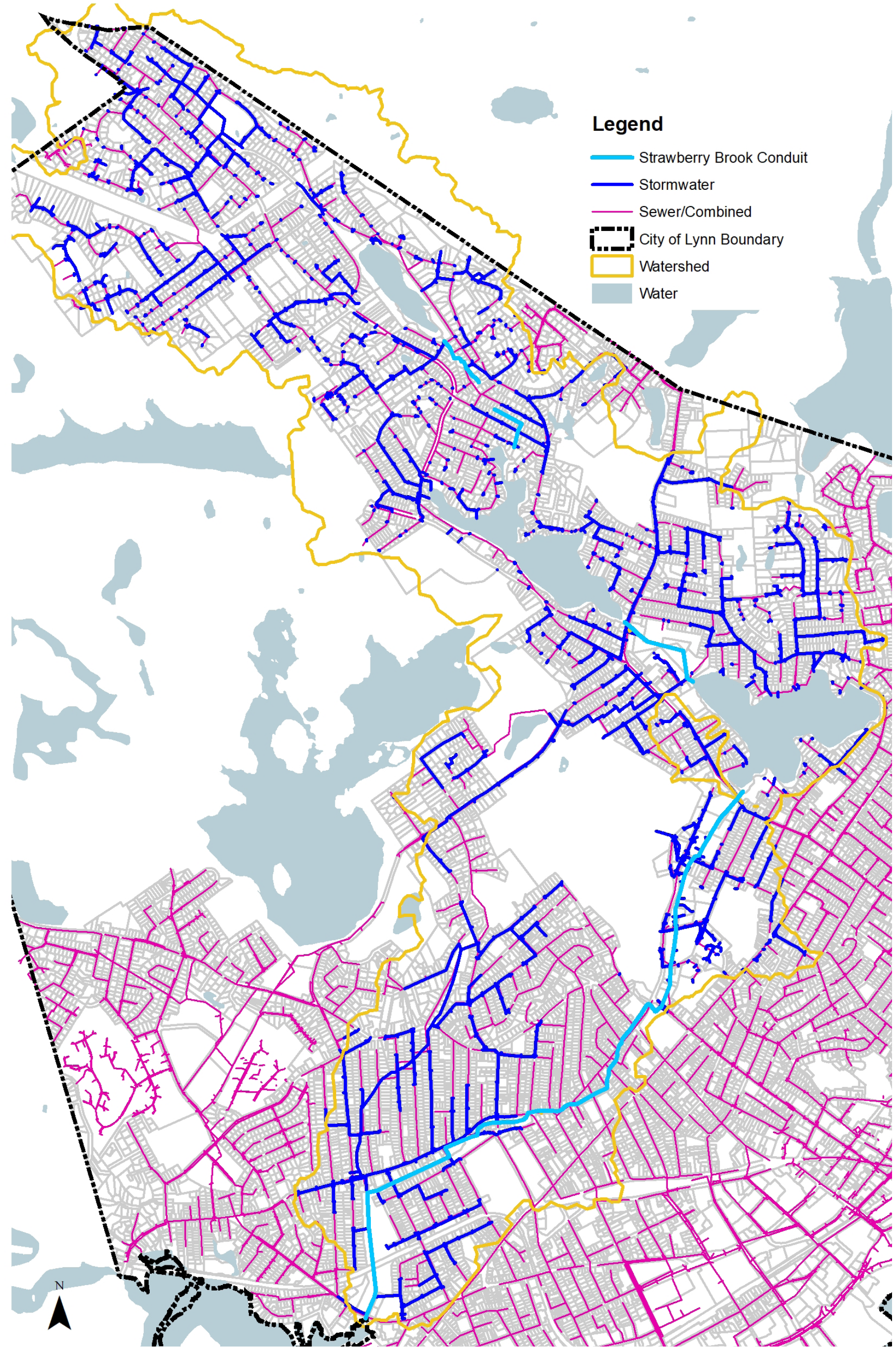

FIGURE 7: THE CITY OF LYNN'S DRAINAGE SYSTEM HIGHLIGHTING THE STRAWBERRY BROOK CONDUIT AND ASSOCIATED DRAINAGE SYSTEM

CLIMATE RESILIENCE ASSESSMENT

Climate Projection Modeling

Baseline and Future Climate Rainfall

Design rainfall depths under present climate conditions for the project area in Lynn are derived from the NOAA Atlas 14: Precipitation-Frequency Atlas of the United States for Stormwater Management (NOAA, 2015). NOAA Atlas 14 provides design rainfall depths for events with durations ranging from 5 minutes to 60 days and with recurrence intervals ranging from 1 year to 1000 years. Given the size of the project area, W&S elected to analyze how the rainfall depths and intensities are likely to change in the future for Lynn for the 24-hour duration storms, as well as for the shorter-duration storms of 2- and 6-hr duration. The design storms are analyzed for the 5-,10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals. NOAA Atlas 14 design rainfall depths associated with these events are presented in Table 1 (second column) centered on the City of Lynn. These NOAA Atlas 14 values represent the industry-standard design rainfall depths for events under a late-1900s/early 2000s (baseline) climate conditions.

Next, the total rainfall depths associated with these design storm events are calculated for future climate conditions using the 2070 planning horizon. To determine the future design storm depths for Lynn, the latest available downscaled climate change projections were used from the Localized Constructed Analogs (LOCA) dataset, which is the same dataset that has been used for ResilientMA.org and the State's Hazard Mitigation and Climate Adaptation Plan(MA SHMCAP, 2018). The emissions scenarios chosen for the climate assessment include RCP8.5, a high emissions scenario, and RCP4.5, a medium emissions scenario. Downscaled precipitation projections were downloaded for 1950-2099 using 14 global climate models (GCMs) based on NCHRP Report 1561(Kilgore et al. 2019) for a grid centered on the City of Lynn. A 30-year averaging period was chosen around two planning horizons: historic 1990s (1986-2015) and future 2070s (2056-2085). Annual maximum rainfall was calculated for each year in the 30-yr averaging period, and these maxima were fit to a statistical extreme value distribution (using Generalized Extreme Value GEV distribution) to determine the rainfall depths for each of the 5-, 10-, 25, 50- 100-, 200- and 500-year recurrence intervals per GCM per emission scenario for each planning horizon. Next, the median values of all GCMs were calculated for each recurrence interval per emission scenario for each planning horizon. Finally, the average between the medium and higher emission scenarios (RCP 4.5 and 8.5) were taken and appropriate conversion factor was used to convert daily rainfall depths to 24-hour rainfall depths for each recurrence interval for each planning horizon.

For locational bias correction, the percent increase in rainfall depths were calculated between the modeled historical baseline (1990s) and modeled 2070 values and this calculated percent increase was applied to present NOAA Atlas 14 values for Lynn to estimate the future design storm depths for each recurrence interval by 2070. The present and projected 24-hour design storm depths are presented in Table 1 and Figure 1. Based on the analyzed data, it appears that today's 100-yr storm (1% annual chance of occurrence) is likely to be between a 25-yr (4% annual chance of occurrence) and 50-yr storm (1% annual chance of occurrence) by 2070. Similarly, today's 500-yr storm (0.2% annual chance of occurrence) is likely to be between a 100-yr and 200-yr storm (0.5% annual chance of occurrence) by 2070. Therefore, it is suggested that new and major retrofits for infrastructure improvements and development projects (both public and private) in the City should consider these future design storm parameters in the planning and design phases.

TABLE 1: PRESENT AND PROJECTED 24-HOUR DESIGN RAINFALL DEPTHS BY 2070 FOR LYNN

Recurrence Interval (Years)	NOAA Atlas 14 Present Baseline (in.)	Estimated 2070 Values (in.)	Percent Increase (%)
5-yr	4.2	4.8	12
10-yr	5.1	5.7	12
25-yr	6.2	7.5	21
50-yr	7.1	8.8	25
100-yr	8.0	10.3	28
200-yr	9.2	12.2	32
500-yr	11.0	15.0	36

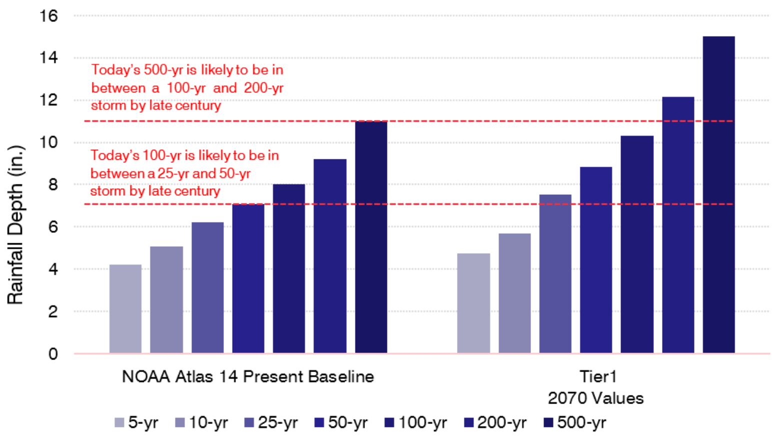

FIGURE 8: STORMWATER FLOODING IMPACTS DUE TO CHANGES IN EXTREME RAINFALL EVENTS

In addition to, 24-hour duration storms, design storm depths were also calculated for shorter-duration storms of 2- and 6-hour. For the purpose of the analysis, the percent increase between the present and 2070 24-hour rainfall depths for each recurrence interval was applied to the present 2-hr and 6-hr storm depths for each recurrence interval to estimate the future 2070 storm depths for these 2-hr and 6-hr storms. The resulting values are presented in Table 2. Similar to the 24-hour storms, the 2- and 6-hr storms are also likely to increase in intensity and frequency by late century.

TABLE 2. PRESENT AND PROJECTED 2-HOUR AND 6-HOUR DESIGN RAINFALL DEPTHS BY 2070 FOR LYNN

Recurrence Interval (Years)	NOAA Atlas 14 Present Baseline -2hr (in.)	2070s (2056-2085) -2hr (in.)	NOAA Atlas 14 Present Baseline - 6hr (in.)	2070s (2056-2085) -6hr (in.)
2-yr	1.4	1.5	2.1	2.3
5-yr	1.8	2.0	2.7	3.1
10-yr	2.2	2.4	3.3	3.7
25-yr	2.7	3.2	4.0	4.9
50-yr	3.1	3.8	4.6	5.7
100-yr	3.5	4.4	5.2	6.6
200-yr	4.0	5.2	5.9	7.8
500-yr	4.7	6.4	7.1	9.7

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Hydrologic & Hydraulic Assessment

W&S developed a stormwater model to identify potential flood-prone areas and to evaluate the potential benefit of various green and gray BMPs under existing conditions and projected future climate conditions. The model was developed with the latest version of the PC Storm Water Management Model (PCSWMM) software. Model simulation results allowed us to evaluate the peak rate, total volume, and duration of flooding throughout the project area under a variety of rainfall events and climate conditions. This section summarizes the development and results of that stormwater model.

Existing Infrastructure

To represent the City's existing stormwater infrastructure, W&S reviewed the Lynn Water & Sewer Commission's (LWSC) GIS database of stormwater and wastewater infrastructure. To fill data gaps in the GIS database, we conducted field investigations on March 26, April 10 and April 30, 2020 to gather additional measurements and elevations of the Strawberry Brook conduit and other storm drains between Cedar Pond and Flax Pond. Based on those measurements on the LWSC's GIS, Weston & Sampson developed a schematic-level representation of the Strawberry Brook conduit and the primary storm drains between Cedar and Flax Ponds.

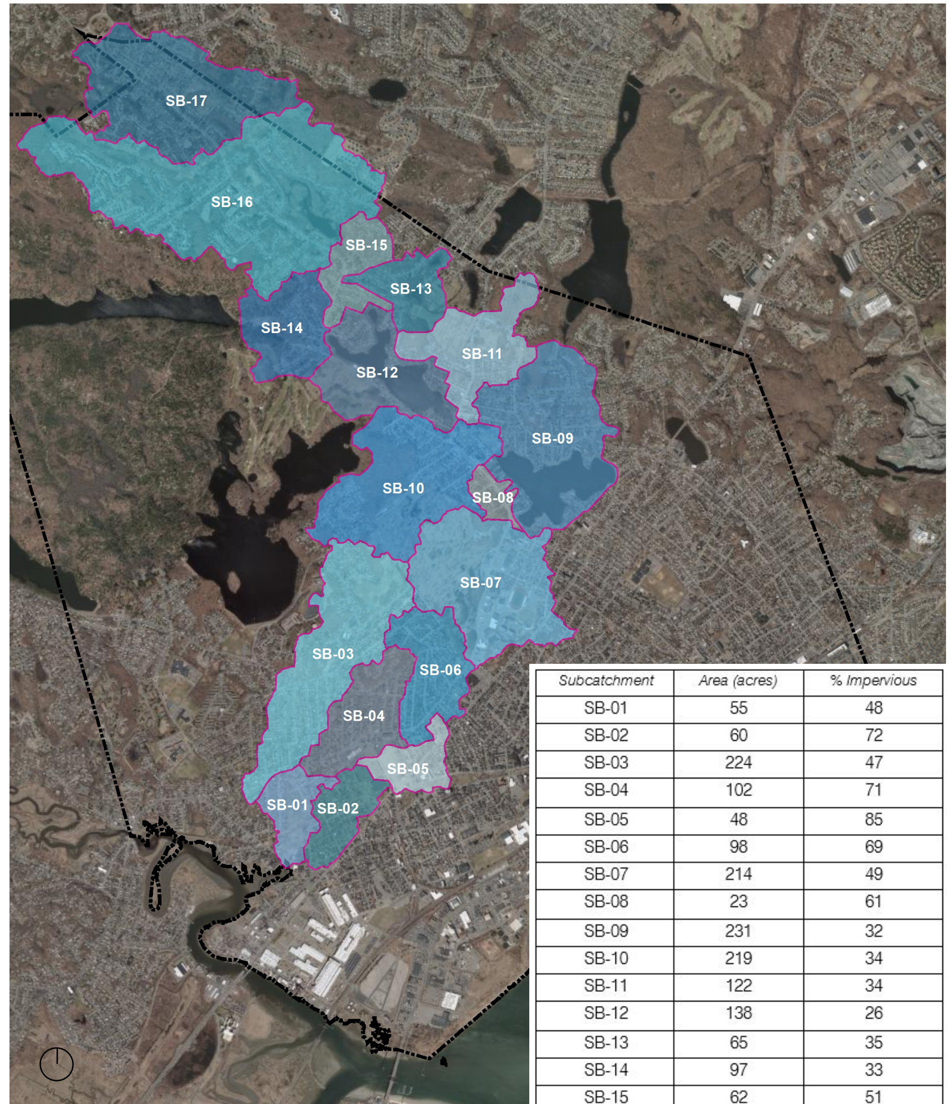
Cedar, Sluice, and Flax Ponds

Cedar, Sluice, and Flax Ponds were also incorporated into the model as storage nodes based on bathymetric surveys of the ponds that were conducted on April 9th and 10th, 2020 to gather measurements of water depth and soft sediment thickness, as described previously.

Subcatchments

The Strawberry Brook watershed was represented by a series of 17 subcatchments as shown in Figure 9. The entire study watershed is approximately 2,464 acres (3.85 mi2), approximately 42% (MassGIS Data) of which consists of impervious surfaces like roofs, roadways, and parking lots. The area and percent impervious cover for each of the 17 subcatchments basins is provided in Figure 9 in the table.

Subcatchment SB-17 represents the Cedar Pond headwaters while SB-16 includes Cedar Pond itself and several neighborhoods to the west and northwest of the pond. Subcatchments SB-13, -14, and -15 discharge to Sluice Pond, draining much of the area between Cedar and Sluice Ponds. SB-12 represents Sluice Pond itself and much of the immediate shoreline. SB-11 captures runoff from Broadway and several side streets to the east of Sluice Pond. Stormwater from SB-11 appears to merge with outflow from Sluice Pond beneath Broadway. Subcatchments SB-10 and -9 drain to Flax Pond. SB-10 represents neighborhoods off Lynnfield St. and Parkland Ave. to the west of the pond while SB-9 includes the pond itself and several neighborhoods due north of the pond.



Subcatchment	Area (acres)	% Impervious
SB-01	55	48
SB-02	60	72
SB-03	224	47
SB-04	102	71
SB-05	48	85
SB-06	98	69
SB-07	214	49
SB-08	23	61
SB-09	231	32
SB-10	219	34
SB-11	122	34
SB-12	138	26
SB-13	65	35
SB-14	97	33
SB-15	62	51
SB-16	469	31
SB-17	237	39

FIGURE 9: STORMWATER CATCHMENTS AND SUMMARY OF AREAS AND IMPERVIOUSNESS

SB-8 encompasses a small area of approximately 23 acres west of Flax Pond along Broadway; stormwater runoff in that area appears to be captured by storm drains/sewer mains that traverse southeast down Chestnut Street, out of the Strawberry Brook watershed. These stormwater flows were assumed not to reach the Strawberry Brook conduit.

SB-7 represents much of the Pine Grove cemetery and developed areas along Upper Boston Street, which runs generally from Flax Pond to Washington Street. Subcatchments SB-6 and -5 contribute runoff to the Middle Boston Street segment of the Strawberry Brook conduit, with SB-6 draining neighborhoods off North Franklin and New Park Streets and SB-5 draining an area near the intersection of Western Ave. and Common St. Subcatchments SB-1, -2, -3, and -4 contribute runoff to the Lower Boston Street Segment of the Strawberry Brook conduit. SB-4 is located primarily north of Boston Street, capturing runoff from neighborhoods between Walnut and Boston Streets. SB-3 is a rather long and thin subcatchment that extends from up near Gallagher playground, down along Linwood Street and then across Walnut Street where it includes several neighborhoods between Myrtle and Flint Streets. SB-2 drains the area between Rte. 107 and Woodman Street. And SB-1 consists of Barry Park, the G.E.A.A. Fields and surrounding neighborhoods.

Tidal Data

Strawberry Brook discharges into the Little River / Saugus River, which is tidally influenced. Tide levels can affect the hydraulic capacity and therefore water levels in the Strawberry Brook conduit. To account for this influence, Weston & Sampson modeled the confluence of Strawberry Brook with the Saugus River using dynamic tidal data, which allowed us to evaluate the impact of diurnal tide cycles, projected future sea level rise, and storm surge.

Dynamic normal tidal elevations under both baseline and 2070 climate scenarios were obtained from MC-FRM developed by the Woods Hole Group. The MC-FRM is a hydrodynamic coastal flood model based on ADCIRC, which simulated tens of thousands of historical and hypothetical storms to generate probability of flooding, flood elevations, flood extents, and dynamic flood elevations under regular tide at different points along the model domain. The dataset consisted of 30 days' worth of 15-minute tide level estimates in Salem Harbor . Weston & Sampson selected a 48-hour period within that 30-day tidal dataset so that the highest high tide roughly coincided with the peak runoff resulting from the 6-hour design events under a baseline climate scenario. Simulations of the 2-, 5-, and 10-year events under a baseline climate were modeled in this way. A fourth baseline climate simulation was also developed to evaluate the impact of storm surge. For that design event, the 10-year rainfall event was assumed to peak at roughly the same time peak tidal elevations for the 1% (100-year) storm event, as obtained from MC-FRM developed by the Woods Hole Group.

Tidal data for four corresponding design events under a 2070 climate (i.e. 2-year, 5-year, 10-year, and 10-year with storm surge) were developed similarly, with non-surge simulations again based on median tide cycles and the storm surge simulation based on the 1% tide event, both derived from MC-FRM data

Model Output Locations

The model includes 30 nodes where flood levels, volumes, peak rates, and durations are identified. Those 30 nodes and their approximate locations are identified in Table 2.

TABLE 3: LIST AND DESCRIPTION OF MODEL OUTPUT LOCATIONS/JUNCTIONS

Junction ID	Location Description
Outfall of Strawberry Brook into the Little River / Saugus River	
J002	G.E.A.A. Field
J003	Tennis courts in Barry Park
J004	Cottage St near Boston St
J006	Federal St between Marion St and Boston St
J009	Boston St between Moulton St and Cedar St
J011	Park St near Boston St
J012	Mansfield Place (end of street)
J015	Boston St, 110 feet southwest of Washington St
J017	Stop & Shop parking lot along Washington St
J019	Washington St
J020	Off Boston St in parking lot of Ferrari Landscaping
J022	Granite St
J025	Parking Lot northeast of Boston St and Stetson St
J026	Parking Lot northeast of Boston St and Stetson St
J028	Dunkin' Donuts drive-thru along Boston St near Ford St
J030	Back lot of Performance Auto Brokers near Ford St
J033	Ford St sidewalk (south side)
J034	Dollar Zone parking lot off Boston St
J037	Planet Fitness Parking Lot off Boston St
J039	South side of Chestnut St near Allerton St
J042	North side of Chestnut St near Allerton St
Flax Pond	
J045	Outfall into Flax Pond along Magnolia Ave
J046	In roadway behind Charlie Reinfuss Field backstop
J049	Eastern edge of Broadway
Sluice Pond	
J053	Outfall into Sluice Pond south of Sutcliffe Rd
J055	Millard Ave between Durgin Rd and Jenness St
J056	Backyards between Millard Ave and Edge Hill Rd
J057	Backyards between Den Quarry Rd and Range Ave
J059	Eastern edge of culvert under Den Quarry Rd
J061	Western edge of culvert under Den Quarry Rd
J063	Beginning of open channel at the end of Woodrow Terrace
Cedar Pond	

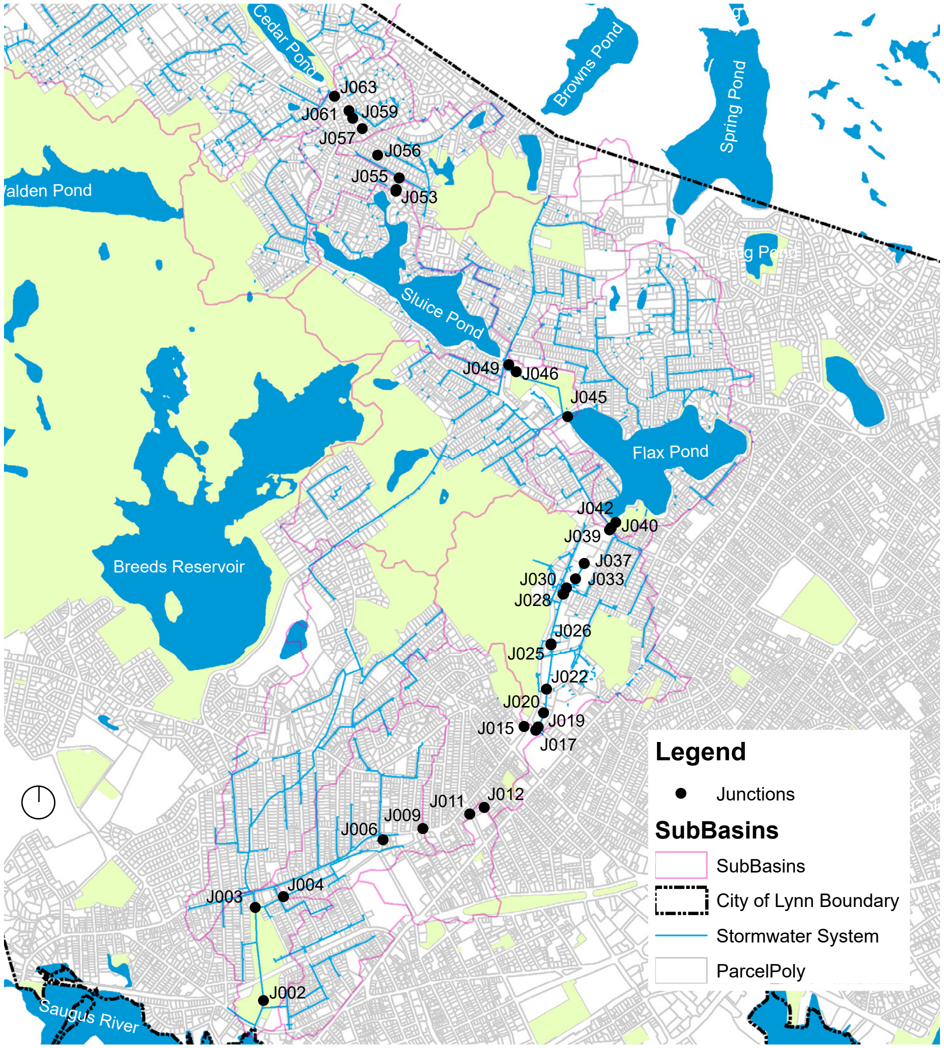


FIGURE 10: LOCATION OF MODEL OUTPUT LOCATIONS/JUNCTIONS WITHIN STRAWBERRY BROOK WATERSHED

Existing Conditions

As detailed in the sections above, W&S developed a stormwater model of the Strawberry Brook conduit in its existing condition. Based on simulations of the eight design events described above, Weston & Sampson identified several floodprone areas that are generally consistent with previous flood studies of the Strawberry Brook watershed and with historical/anecdotal observations. Total flood volumes for the four baseline and four 2070 climate simulations are summarized in Table 3.

TABLE 4: TOTAL FLOOD VOLUMES FOR BASELINE AND 2070 CLIMATE SIMULATIONS UNDER EXISTING CONDITIONS

ID	Total Flood Volume (MG)							
	Base 2-yr	Base 5-yr	Base 10-yr	Base 10-yr with Surge	2070 2-yr	2070 5-yr	2070 10-yr	2070 10-yr with Surge
J002	0	0	0	0	141.394	144.274	147.024	496.388
J003	0	0	0	0	0	0	0.003	0.002
J004	0	0.005	0.009	0.010	0.007	0.031	0.277	0.308
J006	2.624	3.969	5.508	5.488	3.786	5.700	7.547	8.015
J009	0.379	0.588	0.667	0.667	0.455	0.644	0.718	0.721
J011	2.198	3.604	4.532	4.531	2.614	4.225	5.307	5.308
J012	2.796	4.401	6.014	6.014	3.278	5.481	7.370	7.369
J015	0	0	0	0	0	0	0	0
J017	0	0	0	0	0	0	0	0
J019	0	0	0	0	0	0	0	0
J020	0	0.069	0.100	0.100	0.051	0.088	0.133	0.133
J022	0	0	0	0	0	0	0	0
J025	0	0	0	0	0	0	0	0
J026	0	0	0	0	0	0	0	0
J028	0.001	0	0.001	0.001	0	0	0	0
J030	0	0	0.001	0.001	0	0	0	0
J033	2.743	4.835	7.387	7.387	3.365	6.513	9.775	9.779
J034	0	0	0	0	0	0	0	0
J037	0	0	0	0	0	0	0	0
J039	0	0	0.003	0.004	0	0.001	0.016	0.015
J042	0	0	0.006	0.006	0	0	0.025	0.026
J046	0	0	0	0	0	0	0	0
J049	1.024	2.514	4.481	4.481	1.485	3.800	6.417	6.417
J053	0	0.000	0	0	0	0	0	0
J055	0	0.067	0.361	0.361	0	0.245	0.697	0.697
J056	0	0	0.001	0.001	0	0	0.046	0.046
J057	0	0	0	0	0	0	0	0
J059	0	0	0	0	0	0	0	0
J061	0	0	0	0	0	0	0	0
J063	0	0	0	0	0	0	0	0
Total	11.805	20.052	29.071	29.052	156.435	171.002	185.355	535.224

BASED ON THE MODEL OUTPUT SUMMARIZED IN THE TABLE ABOVE, THERE ARE SIX GENERAL FLOODPRONE AREAS:

G.E.A.A. Fields

The area at the downstream end of Strawberry Brook, near the Barry Park and the G.E.A.A. Fields (J002) may experience tidal-driven flooding by the second half of the 21st century. While the area is not shown to flood under a baseline climate, flooding occurs under all four 2070 climate simulations. Based on the LWSC's GIS database, rim elevations of stormwater manholes at the edge of the G.E.A.A. Fields are at approximately El. 9.65 ft. NAVD88. Typical tide cycles for 2070, derived from MC-FRM indicate that spring tides may regularly reach approximately El. 10.87 ft. NAVD88, suggesting high tide will inundate the area to a depth of about a foot.

Lower and Middle Boston Street

Significant flooding is expected in the Lower Boston Street area and parts of the Middle Boston Street area (J004, 006, 009, 011, and 012), extending up from near Cottage Street, past Federal, Marion, Myrtle, and Cedar Streets up to Mansfield Place. For the design events considered, flooding in this area ranges from a total of 8 MG during the baseline climate, 2-year event up to 21.7 MG during the 2070 climate, 10-year event with storm surge. Flooding is nearly entirely rainfall driven as the flood volumes for 10-year and 10-year simulations with storm surge are very similar, indicating that tide levels are not causing significant backwatering up into this segment of the Strawberry Brook conduit.

Boston Street and Washington Street

Modest flooding is expected in the parking lot northeast of the intersection of Boston and Washington Streets (J020) under a wide range of design events. Of the eight design events modeled, only the 2-year storm under a baseline climate resulted in no flooding at this location. Of the seven events that did indicate flooding here, flood volumes were modest, ranging from 51,000 to 131,000 gallons. Flooding also appears to be rather localized as several other nearby nodes in and around the Boston-Washington Street intersection (J015, 017, and 019) indicated no flooding.

Boston Street and Ford Street

Significant flooding is expected in the Ford Street area near its intersection with Boston Street (J033). All eight design events modeled indicated significant flooding in this area, with flood volumes ranging from 2.7 to 9.8 MG. This is an area that has a history of flooding, likely because it is at the base of a long steady slope that carries Boston Street down from Chestnut Street and Flax Pond, and the hydraulic grade line of the Strawberry Brook conduit rises above ground elevations relatively easily here.

Broadway

Significant flooding is expected at Broadway, immediately downstream of the outlet from Sluice Pond (J049). All eight design events modeled indicated significant flooding in this area, with flood volumes ranging from 1.0 to 6.4 MG. While J049 experiences significant flooding, no flooding is expected at nodes immediately upstream (Sluice Pond) or downstream (J046). Flooding is so localized here because of significant lateral inflows coming down Broadway from subcatchment SB-11. Flooding here is a direct result of significant runoff generated in the streets and neighborhoods in this area, including Broadway, Mayfair Street, Warwick Street, Pendexter Street, Conomo Avenue, and others.

Between Edge Hill Road and Millard Avenue

Moderate flooding may occur in the backyard areas of Edge Hill Road and Millard Avenue (J055 and 056). Model simulations indicate flooding may occur in this area during events larger than or equal to the 5-year storm although none is shown to occur during the 2-year event. Of the six events that did indicate flooding here, flood volumes were moderate, ranging from 0.7 to 2.5 MG. However, it should be noted that this is an area of the City's stormwater and wastewater GIS databases that has relatively little elevation data. Weston & Sampson did visit the area during field investigations, but due to tree cover, private property access, and difficulty finding manholes, little additional elevation data was gathered. Consequently, assumptions were made in the modeling of the invert and rim elevations in this area, which may be responsible for the flood volumes predicted by the model. Further field measurements and survey may be necessary to confirm the validity of flooding predictions in this area.

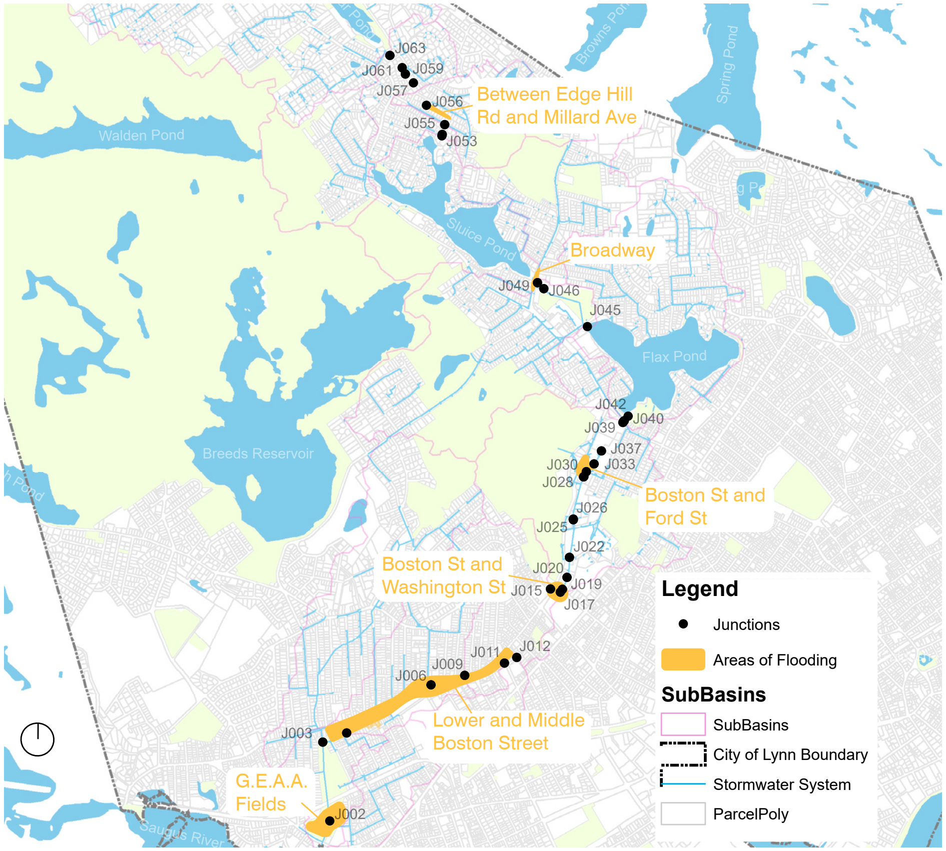


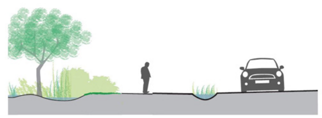
FIGURE 11: IDENTIFIED LOCATIONS OF FLOODING BASED ON MODELING EXISTING INFRASTRUCTURE AND DESIGN STORM SCENARIOS

Stormwater Infrastructure Toolbox

Green infrastructure and low impact development are considered climate resilience best management practices. They use surface features including native vegetation, soils, and other natural processes to reduce flooding and improve water quality. These systems collect and store runoff, aiding in infiltration and treatment of the stormwater. Green infrastructure opportunities considered in the evaluation of the Strawberry Brook Watershed are summarized below.

Bioswales / Sunken Planters

Bioswales or sunken planters capture and hold stormwater runoff and allow it to slowly infiltrate through soil media, thus reducing flooding. Roots uptake water as well as nutrients in the runoff. These systems provide water quality benefits by removing pollutants. They can be installed along sidewalks, in medians, and parking lot edges to directly treat runoff from surrounding impervious surfaces. These components can retain stormwater for future use or detain it before it flows back into the drainage system after the storm event.



Floodable Parks

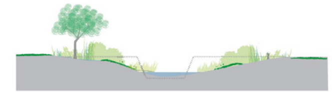
Floodable parks and recreation spaces represent the greatest opportunity for large retention spaces within urban areas. They can be located throughout the watershed and receive stormwater via conveyance systems or adjacent water bodies. They can provide a combination of hydrological services including water quality improvements via retention, detention, and infiltration.

Wet Plazas

Wet plazas or floodable public spaces are another great opportunity for large retention capacity within denser urban environments. Typically hardscapes with some potential vegetation, these spaces collect, detain and retain stormwater to reduce flooding. Additionally, they can incorporate drainage connections to allow the plaza, courtyard, and other spaces to return to normal use quickly.

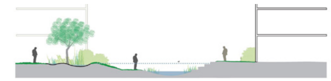
Pond Restoration

Pond restoration and targeted dredging can help build capacity for stormwater through retention and detention. Restoration can occur through edge transformations, dredging, or outlet structure design. Additionally, redesign of pond or waterfront parks to allow for seasonal and stormwater flooding can reduce downstream flooding in unwanted ares.



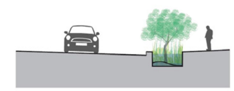
Stream Daylighting

Daylighting pipes can involve reopening historic streams, formalizing existing streams, or creating new streams as conveyance connections between other cloudburst elements. Typically smaller in scale, urban creeks can re-establish or create new neighborhood character, increase biodiversity, and social spaces.



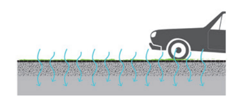
Street Tree Planters

Tree planters can be installed on their own, or in conjunction with bioswales. These systems have the potential to contribute significantly to stormwater management, with large capacity to transpire water, intercept rainfall, and treat water quality. They also aid in reducing the urban heat island effect and add character and value to the neighborhood.



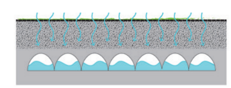
Permeable Pavement

Roadways and sidewalks are big contributors to stormwater runoff. Replacing impervious surfaces with permeable pavement allows for reduced runoff and slower infiltration back into the ground or stormwater system. Permeable pavement can be used where stable, hard surfaces are needed along streets, sidewalks and in parking areas and can be used in conjunction with underground storage.



Underground Storage

Designed to store large volumes of stormwater underground, storage chambers can be used for reuse, retention, detention, or controlling the flow of on-site stormwater runoff. They can be implemented with various depths and forms, i.e. chambers, vaults.



Stormwater Improvement Opportunities

Stormwater BMP Evaluation

Flooding has historically been the most significant natural hazard in Lynn. As a city with high amounts of impervious cover in many areas, there is little opportunity for stormwater infiltration or diversion. This frequently results in urban stormwater flooding when runoff exceeds infrastructure capacity, inland flooding along water bodies, and coastal flooding in tidally influenced areas.

In order to choose the areas within the Strawberry Brook watershed that will have the greatest impact on flood reduction, the City first looked at locations prone to flooding. Site investigations were conducted to evaluate existing drainage infrastructure and water bodies. Information gathered during this initial investigation included size and condition of existing drainage infrastructure. Information was gathered from knowledgeable residents and stakeholders about existing flooding in Lynn. They also provided feedback to the City about green infrastructure designs and locations. The City focused on identified areas prone to flooding as locations for on-site treatment, including bioretention and infiltration chambers, as well as large, impervious areas with storage potential. There are opportunities to hold stormwater on site in areas with large impervious surfaces, instead of directing runoff immediately into the drainage system.

The City of Lynn also took the opportunity to examine areas to hold back stormwater in the upstream portion of the watershed. By increasing the storage volume in existing ponds within the watershed, a greater volume of water could be held back during a rain event. This process would reduce runoff going into the drainage system. The water could then be slowly released at a rate that would not overwhelm the system.

This plan intends to incorporate climate resiliency into the Strawberry Brook Watershed stormwater infrastructure by looking for opportunities to implement the green infrastructure methods described above. The City is also looking at stormwater controls that reduce heat island effects. A few areas of Lynn within the Strawberry Brook Watershed are especially susceptible to flooding. Known flooding locations include the neighborhoods of West Lynn, Boston Street, and Barry Park. While some of the focus on flood reduction in centered in this area, it is important to see the system as a whole. By retaining water upstream and slowing down the stormwater entering the drainage system, the system is able to function at or below its designed volume, thus reducing flooding in all areas of the watershed. Table XX presents a range of green infrastructure approaches in multiple locations across the watershed that are being considered by the City.

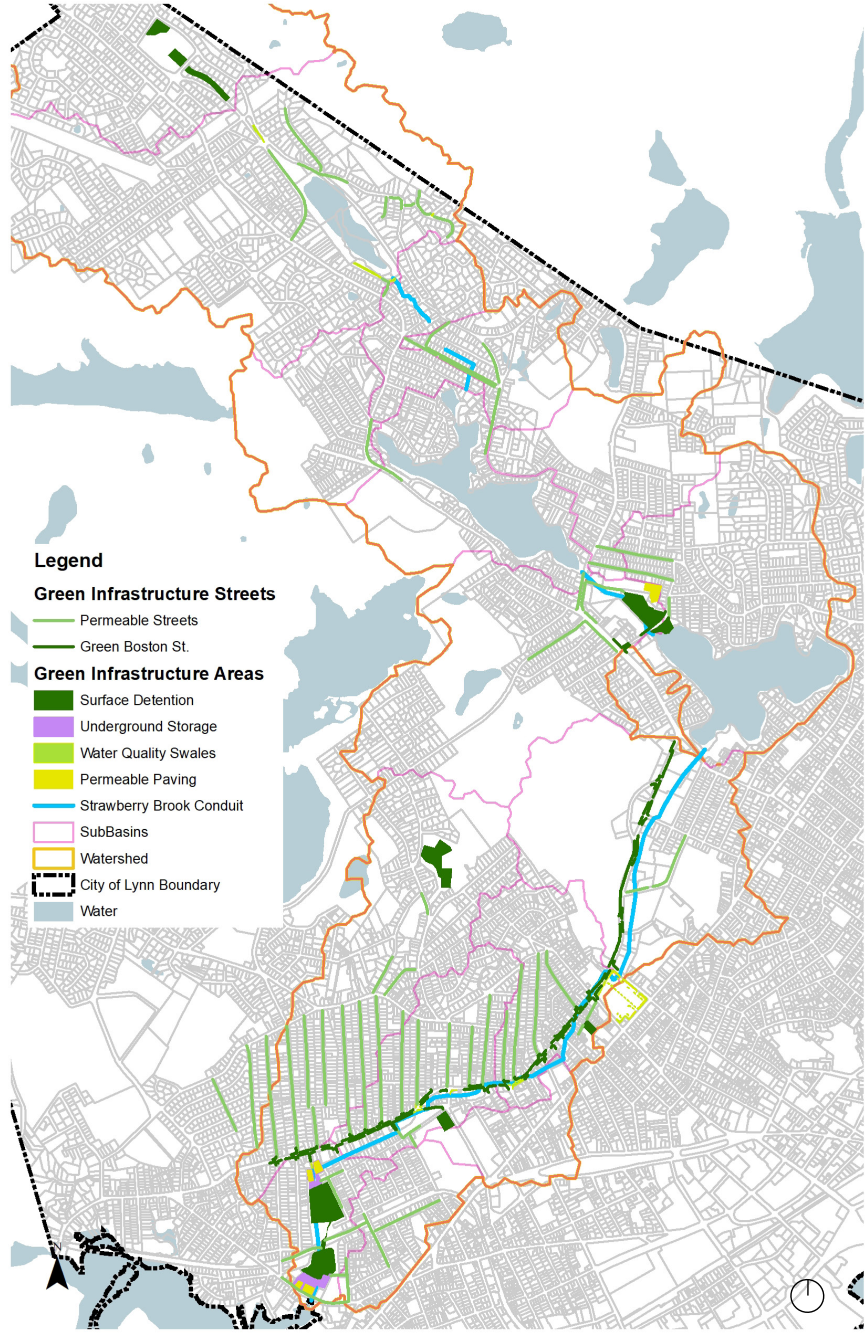


FIGURE 12: OVERVIEW OF PROPOSED GREEN INFRASTRUCTURE OPPORTUNITIES WITHIN THE STRAWBERRY BROOK WATERSHED

Modeling Green Infrastructure Improvements

A TOTAL OF 24 SCENARIOS WERE MODELED TO ILLUSTRATE THE EFFECTIVENESS OF GREEN INFRASTRUCTURE WITHIN THE WATERSHED:

Scenario 1 – Existing Conditions

Existing conditions were modeled during a 2-, 5-, and 10-year storm event under baseline and 2070 climate scenarios. These simulations were conducted with a typical dynamic tide cycle in the Saugus River at the downstream limit of the Strawberry Brook model. A second pair (baseline and 2070 climates) of 10-year storm event simulations were also run while incorporating storm surge in the Saugus River. That storm surge was modeled with a dynamic tide cycle that has a 1% chance of occurring in a given year. These 8 design events were used as the basis of evaluating 23 potential gray and green improvement projects to the Strawberry Brook stormwater conduit and its upgradient watershed.

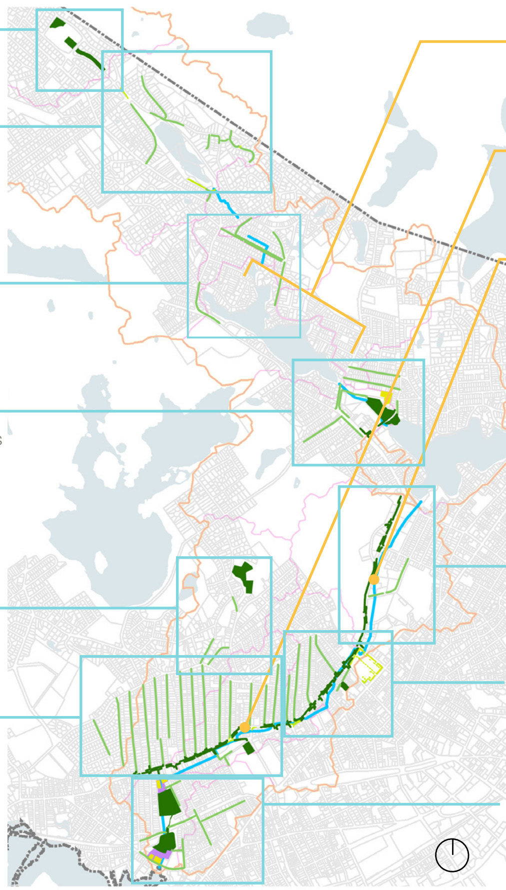


FIGURE 13: OVERVIEW OF MODELING SCENARIOS AND LOCATIONS

Scenario 2 – Eliminate Restrictions Near Sluice Pond

Stormwater conduits upstream and downstream of Sluice Pond tend to be 4 feet in diameter. However, a review of the City's GIS and our own field investigations revealed an approximately 30-foot stretch immediately upstream of the pond near Sutcliff Road and an approximately 300-foot stretch immediately downstream of the pond near Broadway that are only 3 feet in diameter. These segments restrict stormwater runoff being conveyed into and out of Sluice Pond.

Model simulations indicate that expanding the upstream segment would provide a significant benefit in the Millard Ave. area. The table below summarizes the duration of flooding that would be expected to occur in that area under for both existing and proposed conditions.

Events	Hours Flooded (hrs)			
	Existing	Proposed	Δ	% Δ
Baseline 2-year	0.00	0.00	0.00	0%
Baseline 5-year	0.09	0.04	-0.05	-56%
Baseline 10-year	0.20	0.14	-0.06	-30%
2070 2-year	0.00	0.00	0.00	0%
2070 5-year	0.17	0.11	-0.06	-35%
2070 10-year	0.30	0.23	-0.07	-23%

As the summary table shows, flooding of Millard Ave. is expected to occur under existing conditions for the 5-year and 10-year storm events under both baseline and 2070 climate scenarios. Flooding is expected only at the peak of those events, lasting between 6 and 20 minutes generally. Expanding the 30-foot length of pipe that is currently restricting flow upstream of Sluice Pond will reduce those flooding durations by 20 to 60%.

In contrast, expanding the 300-foot-long segment downstream of the Pond actually worsens flooding conditions in the area between Sluice and Flax Ponds. The conduit under Broadway Ave. currently throttles flow, keeping more water back in Sluice Pond and less flooding downstream. Eliminating that restriction would produce slight decreases in the Sluice Pond level, generally less than 0.03 feet, at the cost of increasing the duration of stormwater main flooding in the Broadway-Sisson Elementary School-Magnolia Ave. Playground area considerably.

Scenario 3 – Eliminate Restriction in Strawberry Brook Conduit by Boston & Stetson

A review of the City's GIS and our own field investigations revealed that an approximately 14-foot-long segment of Strawberry Brook near the intersection of Boston St. and Stetson St. is currently restricted. The segment in question has a diameter of 3 feet. Upgradient of that segment, the conduit has a diameter of 4 feet, and downstream of that segment, Strawberry Brook is carried by a 5-foot-wide by 3-foot-tall box conduit. This scenario consists of enlarging the restriction to a 4-foot diameter.

Model simulations indicate that expanding this short segment of restrictive conduit will have a negative impact to flooding rates and volumes downstream, particularly in the area of Boston St. just north of Washington St. as shown in the table below:

Event	Max Flood Rate (cfs)				Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change	Existing	Proposed	Change	% Change
Baseline 2-year	6.02	8.25	2.23	37%	0.04	0.078	0.038	95%
Baseline 5-year	3.44	7.51	4.07	118%	0.069	0.132	0.063	91%
Baseline 10-year	2.31	4.03	1.72	74%	0.1	0.189	0.089	89%
2070 2-year	4.04	8.11	4.07	101%	0.051	0.097	0.046	90%
2070 5-year	1.57	4.8	3.23	206%	0.088	0.168	0.08	91%
2070 10-year	1.92	3.07	1.15	60%	0.133	0.25	0.117	88%

Flood volumes in that downstream area are expected to nearly double during most design events. Flooding rates at the peak of storm events are also expected to increase with increases ranging from roughly 40 to 200%. These increases are significant but make sense as elimination of the restriction allows greater flows to downstream areas.

Benefits in upstream areas are generally more modest and are experienced primarily near the intersection of Boston St. and Ford St. The total flood volumes experienced in that area are generally quite small and the proposed project does relatively little to reduce total flood volumes. However, it does make a significant impact on the maximum flooding rates. The table below summarizes those changes to maximum flooding rates in the vicinity of the Dunkin Donuts drive-thru lane:

Event	Max Flood Rate (cfs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	7.95	4.19	-3.76	-47%
Baseline 5-year	8.17	3.49	-4.68	-57%
Baseline 10-year	2.24	3.13	0.89	40%
2070 2-year	8.9	3.91	-4.99	-56%
2070 5-year	3.19	3.04	-0.15	-5%
2070 10-year	1.21	2.44	1.23	102%

As the table shows, for smaller storms, like the 2-year and 5-year events under both Baseline and 2070 climate scenarios, reductions in peak flooding rates were on the order of 40-60%. Maximum flooding rates in this area are actually expected to increase during the larger 10-year events, likely due to increased backwatering from downgradient of the proposed project. By eliminating the restriction, that backwater condition is able to extend further upstream than it does under existing conditions.

Scenario 4 – Eliminate Restriction in Lower and Middle Boston St.

The Strawberry Brook conduit from Flax Pond to the Saugus River was built over many years and so the age, material, shape, and cross-sectional area of the conduit varies considerably along its length. Much of the conduit in the Lower and Upper segments of Boston St. has a cross-sectional area of at least 12 ft2 with pipes that are 4 feet in diameter or 4x3-foot box conduits or larger. However, an approximately 3,800-foot long segment of the Strawberry Brook conduit along Boston St., located between Washington St. and Marion St., is of a smaller size despite being further downstream and expected to receive greater stormwater runoff. Much of this segment is comprised of 3x3-foot box conduit with a cross-sectional area of less than 10 ft2. This scenario examines the potential benefit of eliminating this restriction and replacing this 3,800-foot length of conduit with new 4x3' box conduit.

This scenario is extensive in scope and would be expensive to design and construct. It is useful to consider the benefits of the project in their own right but also as point of comparison for the many other cheaper gray and green alternatives considered in this study. The benefits of this project are felt in reduced flooding durations and volumes along Boston St. from Federal Street to Ford St. The table below presents the potential benefits to the Boston St.-Park St. area:

Event	Hours Flooded (hrs)				Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change	Existing	Proposed	Change	% Change
Baseline 2-year	2.32	1.34	-0.98	-42%	2.198	1.752	-0.446	-20%
Baseline 5-year	3.92	2.1	-1.82	-46%	3.604	2.636	-0.968	-27%
Baseline 10-year	4.43	3.17	-1.26	-28%	4.532	3.656	-0.876	-19%
Baseline 10-year with Storm Surge	4.42	3.17	-1.25	-28%	4.531	3.658	-0.873	-19%
2070 2-year	2.94	1.54	-1.4	-48%	2.614	2.032	-0.582	-22%
2070 5-year	4.28	2.94	-1.34	-31%	4.225	3.318	-0.907	-21%
2070 10-year	4.75	3.84	-0.91	-19%	5.307	4.613	-0.694	-13%
2070 10-year with Storm Surge	4.76	3.84	-0.92	-19%	5.308	4.611	-0.697	-13%

Under existing conditions, that area is expected to flood between 2 and 5 hours of a 6-hour design event. Model simulations showed a reduction in flooding durations for all eight design events, with reductions ranging from roughly 20 to 50%. The proposed project may also reduce the total volume of overflows from the Strawberry Brook conduit with reductions ranging from 10 to 30%.

Benefits in the lower end of the Strawberry Brook conduit, as far upstream as Federal St., where water levels are influenced by tide levels in the Saugus River, are more mixed. These lower areas may experience reductions in flooding durations and volumes during smaller events like the 2- and 5-year storms, but actually experience more flooding during larger events like the 10-year storm or during events with storm surge.

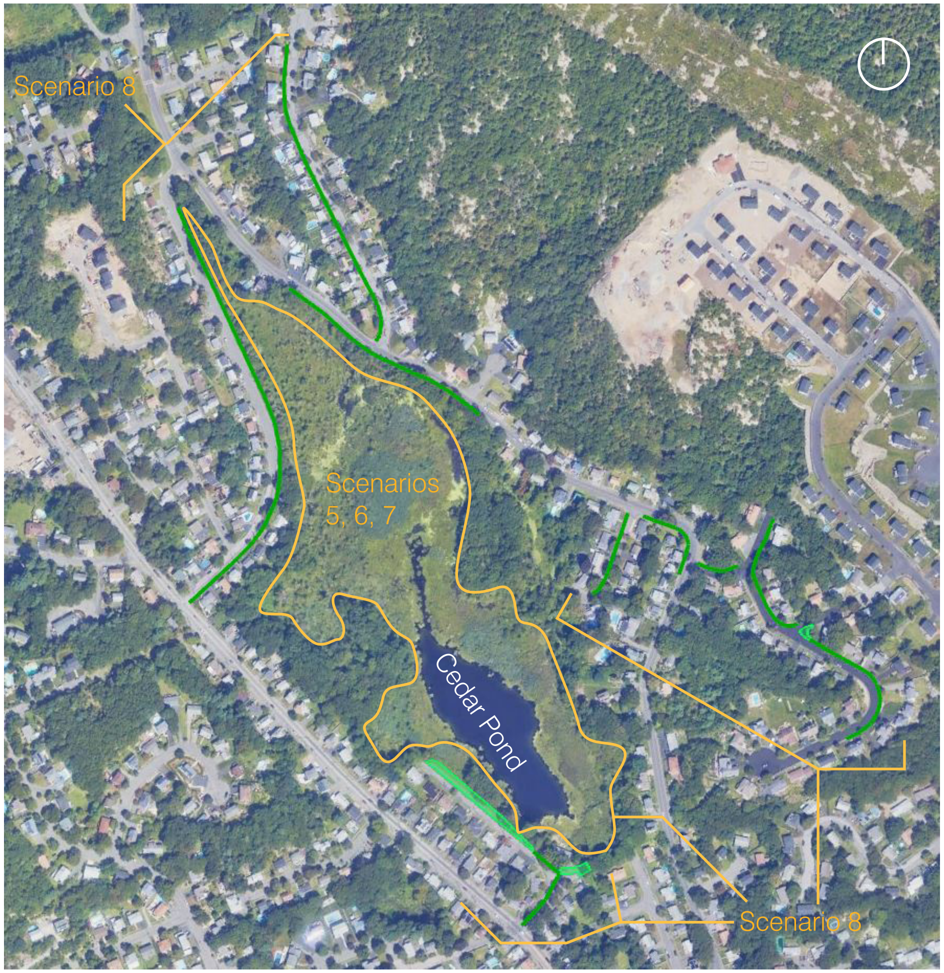


FIGURE 14: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIOS 5-8 BASED AROUND CEDAR POND.

Scenario 5 – Lower Cedar Pond 6" Ahead of Storm Events

Cedar Pond is the furthest upstream waterbody in Lynn's Strawberry Brook Watershed. It is fed by two perennial streams and has several stormwater drain inlets from the surrounding residential neighborhoods. Its pond edges are steep-sloped and vegetated. Our bathymetric model of Cedar Pond reveals that a 6-inch drawdown in advance of a rainfall event would result in the detention storage of 486,400 cubic ft or 3.6 million gallons. A 12-inch drawdown would capture 929,000 cubic ft or 7 million gallons. This is a significant amount of stormwater volume that could reduce downstream flooding impacts

This scenario included modifications to the outlet of Cedar Pond and downstream conduit grades, as necessary, to support the ability to draw the pond down 6" prior to a significant storm event. While the starting pond level was effectively lowered 6" in this way, the invert of the outlet was left at the same elevation as it is presently. Based on that geometry, the table below summarizes outflow volumes from Cedar Pond.

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	18.9	9.83	-9.07	-48%
Baseline 5-year	26.5	19.1	-7.4	-28%
Baseline 10-year	34.6	29.1	-5.5	-16%
2070 2-year	31.9	25.7	-6.2	-19%
2070 5-year	21.4	12.8	-8.6	-40%
2070 10-year	31.9	25.7	-6.2	-19%

As the table shows, outflow volumes from Cedar Pond may drop significantly, generally 20 to 50% based on the proposed modifications to the pond outlet. Significant reductions in runoff volumes are expected to propagate as far downstream as Sluice Pond. Peak pond levels were also shown to drop as a result of the proposed modifications:

Lowering the starting water level in Cedar Pond by 0.5 feet ahead of a significant storm event may lower peak water levels by 0.4 to 0.45 feet for all six design events that were evaluated. The fact that outflow from the pond is shown to be reduced and peak pond levels are expected to be lower than existing conditions, indicates that even further benefits could be achieved by raising the invert of the pond's outlet structure above its current elevation.

Event	Existing	Proposed	Change
Baseline 2-year	10.82	10.42	-0.40
Baseline 5-year	11.30	10.88	-0.42
Baseline 10-year	11.77	11.33	-0.44
2070 2-year	10.98	10.58	-0.40
2070 5-year	11.61	11.18	-0.43
2070 10-year	12.15	11.70	-0.45

Scenario 6 – Lower Cedar Pond 12" Ahead of Storm Events

This scenario is very similar to Scenario 5. A gated outlet is envisioned that would support lowering the pond level by 12" ahead of significant storm events and then raising the invert 12" above the normal water level, effectively creating 24" of storage. Based on that configuration, the table below summarizes outflow volumes from Cedar Pond.

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	18.9	0.02	-18.885	-100%
Baseline 5-year	26.5	0.06	-26.444	-100%
Baseline 10-year	34.6	5.35	-29.25	-85%
2070 2-year	21.4	0.02	-21.384	-100%
2070 5-year	31.9	2.90	-29	-91%
2070 10-year	41.7	12.70	-29	-70%

As the table shows, outflow volumes from Cedar Pond may drop significantly. For smaller events such as the 2-year and even the 5-year event under a Baseline climate and the 2-year event under a 2070 climate, outflows from Cedar Pond may be eliminated. Outflow volume reductions during larger events like the 10-year are also expected to be significantly reduced, on the order of 70 to 90%. While the greatest reductions in runoff volumes are expected to occur in the area between Cedar Pond and Sluice Pond, noteworthy reductions are expected in the Strawberry Brook conduit as well, with reductions of generally at least 10% propagating as far downstream as Ford Street.

At the same time, peak water levels in Cedar Pond were also shown to drop when compared to existing conditions.

As shown in the table, lowering the starting water level in Cedar Pond by 12" ahead of a significant storm event may lower peak water levels by 0.6 to 0.7 feet for a wide range of storm events. As this scenario and Scenario 5 indicate, being able to lower Cedar Pond ahead of large storms can significantly reduce the volume of stormwater discharge downstream to Sluice Pond and ultimately to the Strawberry Brook conduit, while simultaneously lowering peak pond levels.

Event	Existing	Proposed	Change
Baseline 2-year	10.82	10.05	-0.77
Baseline 5-year	11.30	10.59	-0.71
Baseline 10-year	11.77	11.11	-0.66
2070 2-year	10.98	10.23	-0.75
2070 5-year	11.61	10.94	-0.67
2070 10-year	12.15	11.51	-0.64

Additional reductions to flooding in Strawberry Brook might be possible with similar outlet and operational improvements to Sluice and Flax Pond.

Scenario 7 - Lower Cedar Pond 12" Ahead of Storm Events and Dredge

This scenario is very similar to Scenario 6. A gated outlet is envisioned that would support lowering the pond level by 12" ahead of significant storm events and then raising the invert 12" above the normal water level, effectively creating 24" of storage. In addition, fine sediments that have accumulated in the pond over the years would be dredged to create additional storage capacity. The total dredged volume is estimated at approximately 2,664 cubic yards in the top two feet below the pond's normal water level. Based on that configuration and the proposed dredging, the table below summarizes outflow volumes from Cedar Pond.

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	18.9	0.02	-18.885	-100%
Baseline 5-year	26.5	0.02	-26.483	-100%
Baseline 10-year	34.6	3.69	-30.91	-89%
2070 2-year	21.4	0.02	-21.384	-100%
2070 5-year	31.9	1.58	-30.32	-95%
2070 10-year	41.7	10.70	-31	-74%

As with Scenario 6, outflow volumes from Cedar Pond may drop significantly. For smaller events such as the 2-year and even the 5-year event under a Baseline climate and the 2-year event under a 2070 climate, outflows from Cedar Pond may be eliminated. Outflow volume reductions during larger events like the 10-year are also expected to be significantly reduced, on the order of 75 to 95%. At the same time, peak pond levels were also shown to drop when compared to existing conditions.

Event	Existing	Proposed	Change
Baseline 2-year	10.82	9.95	-0.87
Baseline 5-year	11.30	10.48	-0.82
Baseline 10-year	11.77	11.00	-0.77
2070 2-year	10.98	10.12	-0.86
2070 5-year	11.61	10.83	-0.78
2070 10-year	12.15	11.40	-0.75

As with Scenario 6, model results for this scenario indicate significant benefits to downstream stormwater flows may be significant. However, the cost of dredging fine sediments in the top two feet of the water column will be significant as well, and very well may not be worth the incremental benefit over Scenario 6. For instance, for the Baseline climate 10-year storm event, dredging will only increase the percent reduction in total discharge from the pond by 89%, rather similar to the 85% reduction expected of Scenario 6 where the pond is lowered but not dredged. Similar trends were observed for several other design events.

Scenario 8 – Lower Cedar Pond 12” Ahead of Storm Events and Construct New Stormwater Swales and Permeable Streets

This scenario is very similar to Scenario 6. A gated outlet is envisioned that would support lowering the pond level by 12” ahead of significant storm events and then raising the invert 12” above the normal water level, effectively creating 24” of storage. Additionally, 3 stormwater swales intercept and treat runoff before it enters Cedar Pond. Two of the swales are located at the edge of the pond. The third swale is located along Canon Rock Road. Nine permeable streets collect, detain and convey stormwater runoff from roads surrounding Cedar Pond, including Canon Rock Road, Harris Road, Cedar Brook Road, Elsie Road,Betty Trace, Den Quarry Road, and Cedardale Road.

Model simulations of this combination of gray and green improvements are compared against model results for Scenario 6 (gray improvements only):

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	0.015	0.015	0.000	0%
Baseline 5-year	0.056	0.033	-0.023	-41%
Baseline 10-year	5.350	5.070	-0.280	-5%
2070 2-year	0.016	0.016	0.000	0%
2070 5-year	2.900	2.670	-0.230	-8%
2070 10-year	12.700	12.400	-0.300	-2%

Construction of swales and a combination of pervious and green streets is shown to have a modest impact on total stormwater outflow from Cedar Pond. Reductions range from 0% during events that already have negligible outflow already due to lowering the pond ahead of significant storm events. For larger design events, like the 10-year, which continue to result in significant discharge from Cedar Pond, discharge volumes are reduced on the order of 5 to 10%.

It is also possible that reducing runoff rates and volumes from the upgradient watershed through green streets and other green infrastructure projects would lower peak water levels in Cedar Pond. Peak pond levels for this scenario are compared against Scenario 6:

Event	Existing	Proposed	Change
Baseline 2-year	10.05	10.04	-0.01
Baseline 5-year	10.59	10.57	-0.02
Baseline 10-year	11.11	11.09	-0.02
2070 2-year	10.23	10.22	-0.01
2070 5-year	10.94	10.92	-0.02
2070 10-year	11.51	11.49	-0.02

As shown in the table above, reductions in pond level over Scenario 6 are minimal, generally not more than 0.02 feet. In short, while the benefits of the proposed green infrastructure in this scenario are modest in and downstream of Cedar Pond, they have potential to make a significant impact on stormwater conditions in localized streets and neighborhoods upgradient of the pond.

FIGURE 15: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIOS 9-11 UPSTREAM OF CEDAR POND NEAR GOWDY MEMORIAL PARK.

Scenario 9 – Stormwater Detention at Gowdy Memorial Playground near Hilda Road

Part of the northern portion of Gowdy Memorial Park, a playground and several hard court sports can be converted to permeable surfaces and regrading can occur to build up detention capacity in the area. With potential 2 feet of storage across the area, this space could detain around 88,096 cu.ft. of stormwater runoff from surrounding streets.

Model simulations of the potential impact of the proposed detention basin on runoff volumes being discharged from Cedar Pond and the reduction in peak pond levels in Cedar Pond are summarized in the tables below:

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	18.9	18.80	-0.1	-1%
Baseline 5-year	26.5	26.40	-0.1	0%
Baseline 10-year	34.6	34.40	-0.2	-1%
2070 2-year	21.4	21.30	-0.1	0%
2070 5-year	31.9	31.70	-0.2	-1%
2070 10-year	41.7	41.50	-0.2	0%

Event	Existing	Proposed	Change
Baseline 2-year	10.82	10.80	-0.02
Baseline 5-year	11.30	11.28	-0.02
Baseline 10-year	11.77	11.75	-0.02
2070 2-year	10.98	10.96	-0.02
2070 5-year	11.61	11.59	-0.02
2070 10-year	12.15	12.14	-0.01

As shown in the tables above, reductions in runoff volumes discharged from Cedar Pond are minimal, generally not more than 1% over existing conditions. The impact of the proposed project on peak pond levels are also minimal, with reductions not exceeding 0.03 feet. In short, while the benefits of the proposed project in this scenario are modest in and downstream of Cedar Pond, they have potential to make a significant impact on stormwater conditions in the playground, ball courts, and roadway of Hilda Road.

Scenario 10 – Stormwater Detention at Gowdy Memorial Playground near Tuscan Road Ballfields

Part of the southern portion of Gowdy Memorial Park, two ball fields share an extended outfield that is a naturally occurring perennial wetland. Through redesign new grading, and an outlet control structure, the area can detain larger stormwater runoff from the adjacent roads while maintaining playable sports surfaces. The total area of the wetland is 36,910 sq.ft. with the potential of 2 feet of storage totaling 70,715cu.ft. of stormwater runoff.

Model simulations of the potential impact of the proposed detention basin on runoff volumes being discharged from Cedar Pond and the reduction in peak pond levels in Cedar Pond are summarized in the tables below:

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	18.9	18.90	0	0%
Baseline 5-year	26.5	26.40	-0.1	0%
Baseline 10-year	34.6	34.50	-0.1	0%
2070 2-year	21.4	21.30	-0.1	0%
2070 5-year	31.9	31.80	-0.1	0%
2070 10-year	41.7	41.60	-0.1	0%

Event	Existing	Proposed	Change
Baseline 2-year	10.82	10.80	-0.02
Baseline 5-year	11.30	11.28	-0.02
Baseline 10-year	11.77	11.75	-0.02
2070 2-year	10.98	10.96	-0.02
2070 5-year	11.61	11.59	-0.02
2070 10-year	12.15	12.14	-0.01

As shown in the tables above, reductions in runoff volumes discharged from Cedar Pond are negligible. The impact of the proposed project on peak pond levels are also minimal, with reductions not exceeding 0.03 feet. In short, while the benefits of the proposed project in this scenario are minimal in and downstream of Cedar Pond, they may have potential to make a modest impact on stormwater conditions in the ballfield area of Gowdy Memorial Park and the Tuscan Road surface.

Scenario 11 – Stormwater Detention along Cedar Brook

Downstream of Gowdy Memorial Park and Upstream of Cedar Pond, Cedar Brook is a perennial stream that flows through a ravine. The ravine divides properties along Cedar Brook Road and Longhill Road. The land is preserved by the Cedar Brook Trust. The ravine is 773 feet long with a vertical drop of 3 feet. Stormwater detention can be created by constructing 3 cross veins or check dams, each approximately 1 foot tall, designed to pass baseflow but attenuate more significant runoff events. The check dams effectively create three wedges of stored runoff, each 250 feet long, 1 foot tall, and 20 feet wide for a total storage volume of 15,000 cubic feet.

Model simulations of the potential impact of the proposed check dams on runoff volumes being discharged from Cedar Pond and the reduction in peak pond levels in Cedar Pond are summarized in the tables below:

Event	Total Inflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	18.9	18.90	0	0%
Baseline 5-year	26.5	26.50	0	0%
Baseline 10-year	34.6	34.60	0	0%
2070 2-year	21.4	21.30	-0.1	0%
2070 5-year	31.9	31.90	0	0%
2070 10-year	41.7	41.70	0	0%

Event	Existing	Proposed	Change
Baseline 2-year	10.82	10.82	0.00
Baseline 5-year	11.30	11.29	-0.01
Baseline 10-year	11.77	11.77	0.00
2070 2-year	10.98	10.98	0.00
2070 5-year	11.61	11.61	0.00
2070 10-year	12.15	12.15	0.00

As shown in the tables above, reductions in runoff volumes discharged from Cedar Pond are negligible. The impact of the proposed project on peak pond levels is also negligible. In short, this concept of creating check dams along Cedar Brook downstream of Tuscan Road is unlikely to have a significant impact on stormwater runoff anywhere in the Strawberry Brook watershed.

WATTS BRANCH STREAM RESTORATION PROJECT IN WASHINGTON, DC SHOWS CROSS VEINS DESIGNED TO SLOW STREAM VELOCITY AND BUILD UP VOLUME WITH THE INTENTION OF CREATING MORE DIVERSE HABITATS.
PHOTO: J.FREY 2018

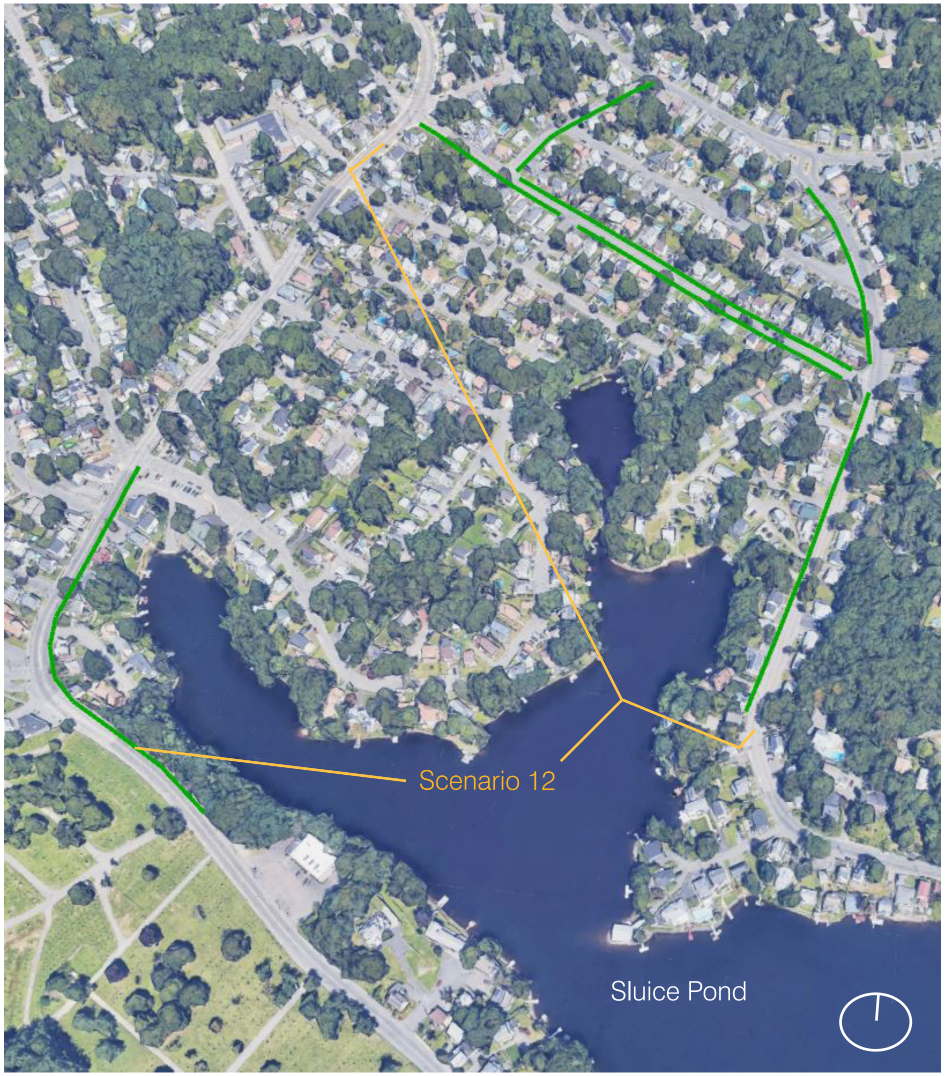


FIGURE 16: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIO 12 UPSTREAM OF SLUICE POND

Scenario 12 – Sluice Pond Green and Permeable Streets

Sluice Pond is fed by Cedar Pond upstream and numerous surrounding streets. The pond edges are generally steep and predominately, privately owned. There are limited open spaces upstream of Sluice and the best strategies consider transformation of the surrounding streets from impervious surfaces to green infrastructure. There are seven permeable streets that can intercept, detain and retain stormwater runoff, reducing volume loads on existing infrastructure and improving water quality by trapping sediments and metals. Model simulations of the potential impact of the proposed green streets and permeable streets in the catchments that drain to Sluice Pond are summarized in the tables below in terms of runoff volumes leaving Sluice Pond and peak pond levels:

Event	Total Outflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	19.2	19.10	-0.1	-1%
Baseline 5-year	28.6	28.50	-0.1	0%
Baseline 10-year	39.1	38.90	-0.2	-1%
2070 2-year	22.2	22.10	-0.1	0%
2070 5-year	35.5	35.30	-0.2	-1%
2070 10-year	48.6	48.40	-0.2	0%

Event	Existing	Proposed	Change
Baseline 2-year	65.59	65.59	0.00
Baseline 5-year	65.69	65.68	-0.01
Baseline 10-year	65.77	65.77	0.00
2070 2-year	65.62	65.62	0.00
2070 5-year	65.74	65.74	0.00
2070 10-year	65.84	65.84	0.00

As shown in the tables above, reductions in runoff volumes discharged from Sluice Pond are minimal, generally not more than 1% over existing conditions. The impact of the proposed project on peak pond levels are also minimal, with reductions not exceeding 0.01 feet. The minimal impact to Sluice Pond and downstream areas is a function of the fact that Sluice Pond is much larger and has a much greater storage volume at normal water levels than the additional storage created with green streets. However, green and permeable streets in the Sluice Pond sub-catchments have the potential to make significant impacts on local flooding of those roadways, sidewalks, and parking lots. Streets with existing runoff ponding issues should be targeted for these types of green infrastructure improvements.

FIGURE 17: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIOS 13-14 UPSTREAM OF FLAX POND

Scenario 13 – Flax Pond Permeable Streets

Between Sluice and Flax Ponds, the natural topography rises on each side creating steeper slopes that form a ravine with stormwater runoff converging at low points along Broadway and withing Magnolia Park before outfalling into Flax Pond. The slopes and increase in impervious surfaces creates fast moving, erosive runoff. Permeable Streets are located along steeper roads and at low points between the two ponds to intercept stormwater runoff. Stormwater can be collected and conveyed from street to street as it moves downstream and finally into Magnolia Park or Flax Pond. In addition to potential water quality improvements, the permeable streets create a healthier urban environment with increase shade.

Model simulations of the potential impact of the proposed green streets and permeable streets in the catchments that drain to Flax Pond are summarized in the tables below in terms of runoff volumes leaving Flax Pond and peak pond levels:

Event	Total Outflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	22.3	22.30	0	0%
Baseline 5-year	32.4	32.40	0	0%
Baseline 10-year	43	42.90	-0.1	0%
2070 2-year	25.5	25.50	0	0%
2070 5-year	39.3	39.30	0	0%
2070 10-year	52.1	52.00	-0.1	0%

Event	Existing	Proposed	Change
Baseline 2-year	19.77	19.77	0.00
Baseline 5-year	19.94	19.94	0.00
Baseline 10-year	20.12	20.11	-0.01
2070 2-year	19.83	19.83	0.00
2070 5-year	20.06	20.06	0.00
2070 10-year	20.26	20.26	0.00

As shown in the tables above, reductions in runoff volumes discharged from Flax Pond are negligible. The impact of the proposed project on peak pond levels is also minimal, with reductions not exceeding 0.01 feet. The minimal impact to Flax Pond and downstream areas is a function of the fact that Flax Pond is much larger and has a much greater storage volume at normal water levels than the additional storage created with green streets and the permeable parking lot at Pickering Middle School. However, green and permeable streets in the Flax Pond sub-catchments have the potential to make significant impacts on local flooding of those roadways, sidewalks, and parking lots. Streets with existing runoff ponding issues should be targeted for these types of green infrastructure improvements.

Scenario 14 – Magnolia Park Daylighting and Surface Storage

Magnolia Park is located directly between Sluice and Flax Ponds and historically Strawberry Brook flowed openly through the area. Currently, the ponds are connected via conduits. This project considers daylighting the current conduit and creating a wide floodable park space adjacent to the reestablished Strawberry Brook. Additionally, a large school parking area can be converted to permeable parking with underground storage beneath it. The storage and stream will be fed by Sluice Pond overflow and stormwater runoff from surrounding streets. In addition to potential storage, daylighting the stream can reduce the need to replace undersized, contributing gray infrastructure in the future. It also provides an opportunity to redesign a single serving space (recreation) into a multifunctional landscape with a potential storage area of 357,454 cu.ft of runoff.

Model simulations of the potential impact of the proposed surface storage at Magnolia Park during significant storm events are summarized in the tables below in terms of runoff volumes leaving Flax Pond and peak pond levels:

Event	Total Outflow (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	22.3	22.40	0.1	0%
Baseline 5-year	32.4	32.80	0.4	1%
Baseline 10-year	43	43.30	0.3	1%
2070 2-year	25.5	25.80	0.3	1%
2070 5-year	39.3	39.70	0.4	1%
2070 10-year	52.1	52.60	0.5	1%

Event	Existing	Proposed	Change
Baseline 2-year	19.77	19.76	-0.01
Baseline 5-year	19.94	19.94	0.00
Baseline 10-year	20.12	20.10	-0.02
2070 2-year	19.83	19.82	-0.01
2070 5-year	20.06	20.05	-0.01
2070 10-year	20.26	20.23	-0.03

As shown in the tables above, reductions in runoff volumes discharged from Flax Pond are small, generally not more than 1%. The impact of the proposed project on peak pond levels is also minimal, with reductions not exceeding 0.03 feet. The minimal impact to Flax Pond and downstream areas is a function of the fact that Flax Pond is much larger and has a much greater storage volume at normal water levels than the additional surface storage created in Magnolia Park. However, that additional surface storage does have the potential to make significant impacts on local flooding of the roadways, sidewalks, and parking lots of the low-lying neighborhoods surrounding Magnolia Park. This project should be coordinated with the construction of green or permeable streets and permeable parking at the middle school to maximize the benefit of both projects (Scenarios 13 and 14).

HANS TAVSENS PARK IN COPENHAGEN IS A REDESIGNED OPEN SPACE SHARED BY SEVERAL SCHOOLS THAT FUNCTIONS AS A STORMWATER COLLECTION BASIN DURING LARGE STORM EVENTS AND COVEYS CLEANER STORMWATER TO THE COPENHAGEN LAKES. IMAGE: SLA

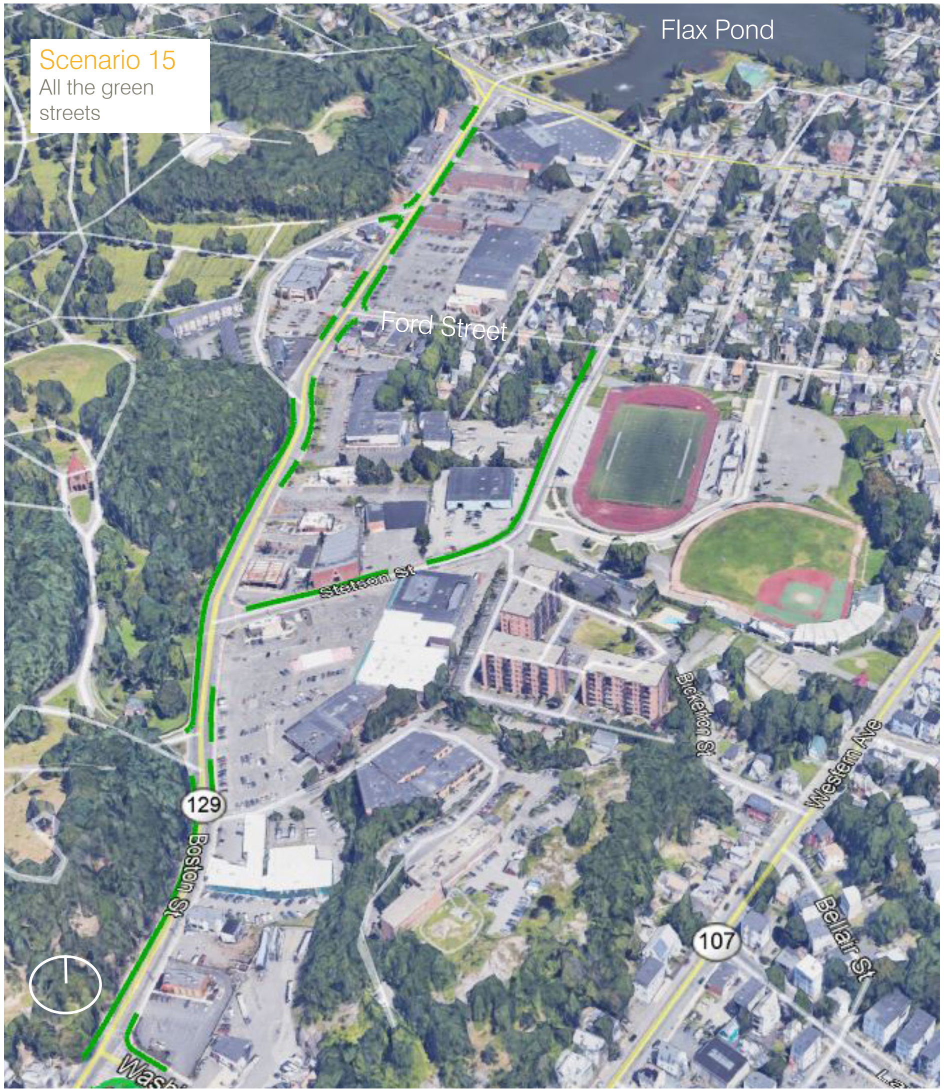


FIGURE 18: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIO 15 ALONG THE UPPER SECTION OF BOSTON ST

Scenario 15 – Upper Boston Street Green Streets

Downstream of Flax Pond, Strawberry Brook pours into a conduit that follows along Boston Street between Chestnut and Washington St. Naturally occurring shelf and rock cliff creates a narrowing ravine as the Boston St moves south and downstream. Additionally, the area is largely, commercially developed and represents the beginning of high percentages of imperviousness with the watershed. Given the lack of public spaces, increasing heat index, and two areas of known flooding, the most effective green infrastructure strategy is to convert stretches of Boston and Stetson St into Green Streets. Green Streets are similar to permeable streets but focus on creating retention and conveyance via bioswales / sunken planters with permeable paving, street tree planters, underground storage, and wet plazas. The physical transformation of these street improvements create a healthier and safer urban environment particularly for pedestrians.

The proposed construction of green streets along Upper Boston Street and permeable pavement along several side streets might be expected to reduce stormwater runoff downstream due to reduced impervious cover and the creation of a small amount of storage. Those impacts are highlighted by the effect on total flood volumes that might be expected to occur near Washington Street, the downstream limit of the Upper Boston Street segment of the Strawberry Brook Conduit:

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	0.040	0.038	-0.002	-5%
Baseline 5-year	0.069	0.061	-0.008	-12%
Baseline 10-year	0.100	0.090	-0.010	-10%
2070 2-year	0.051	0.051	0.000	0%
2070 5-year	0.088	0.078	-0.010	-11%
2070 10-year	0.133	0.126	-0.007	-5%

As shown in the table above, flood volumes are generally modest, ranging from 40,000 to 133,000 gallons under existing conditions. The proposed construction of green streets in the Upper Boston Streets area may reduce those total flood volumes by up to 10-15% depending on the design event.

The creation of additional storage and reductions to downstream flooding might also be expected to lower water levels upstream along Boston Street, however, model results did not confirm that potential benefit for the design events considered. In general, the benefits of this project are not expected to propagate downstream to the lower reaches of Strawberry Brook, but modest benefits may be experienced locally in the roadways, sidewalks, and parking lots of the Upper Boston Street area.

FIGURE 19: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIOS 16-18 ALONG THE MIDDLE SECTION OF BOSTON ST

Scenario 16 – Middle Boston Street Green Streets, Permeable Streets and Barrett Court Swales

The middle section of Boston Street transitions from heavy commercial land use to mixed, dense residential and commercial spaces. Arterial permeable streets feed runoff south toward Boston St. before reaching the Strawberry Brook Conduit. Green Street designs along Boston St intercept stormwater and convey it toward large swales near Barrett Court. A mix of retention and detention provide more pervious surfaces, better pedestrian spaces, and greater opportunities for shade.

The proposed construction of green streets along the Middle segment of Boston Street and construction of conveyance swales along Barrett Court might be expected to reduce stormwater runoff downstream due to reduced impervious cover and the creation of additional storage. Those impacts are highlighted by the effect on total flood volumes and duration of flooding that might be expected to occur near Park Street, as shown in the tables below:

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.198	2.054	-0.144	-7%
Baseline 5-year	3.604	3.456	-0.148	-4%
Baseline 10-year	4.532	4.387	-0.145	-3%
2070 2-year	2.614	2.478	-0.136	-5%
2070 5-year	4.225	4.082	-0.143	-3%
2070 10-year	5.307	5.163	-0.144	-3%

Event	Hours Flooded (hrs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.320	2.120	-0.200	-9%
Baseline 5-year	3.920	3.670	-0.250	-6%
Baseline 10-year	4.430	4.160	-0.270	-6%
2070 2-year	2.940	2.750	-0.190	-6%
2070 5-year	4.280	4.020	-0.260	-6%
2070 10-year	4.750	4.490	-0.260	-5%

The Strawberry Brook conduit is expected to flood near Park Street under all six design events considered, with flood volumes ranging from 2.198 MG during the 2-year event under a baseline climate to 4.750 MG during the 10-year event under a 2070 climate. The proposed green streets may reduce total flood volumes by 3 to 7% during those events. The duration of flooding may also be reduced. Flooding durations during those 6-hour design events ranged from 2.32 to 4.75 hours. The proposed green streets may reduce the duration of flooding by 5 to 10%.

Scenario 17 – Stop & Shop Swales and Permeable Pavement

As one of the larger impervious areas along middle Boston St. and at a key point above the Strawberry Brook conduit and known flooding, the Stop & Shop Parking lot can be utilized as a stormwater detention basin through the implementation of permeable paving, underground storage, and swales. The total lot size is 304,000sq.ft. Overflow stormwater from surrounding streets, the roof of the grocery store, and the conduit can be stored for later use, or simply detained while the peak flow volumes recede.

The proposed replacement of the existing Stop & Shop parking lot with permeable pavement and the creation of stormwater swales along several edges of the parking lot might be expected to reduce stormwater runoff downstream due to reduced impervious cover and the creation of additional storage. Those impacts are highlighted by the effect on total flood volumes and duration of flooding that might be expected to occur near Mansfield Place, as shown in the tables below:

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.796	2.769	-0.027	-1%
Baseline 5-year	4.401	4.387	-0.014	0%
Baseline 10-year	6.014	6.002	-0.012	0%
2070 2-year	3.278	3.256	-0.022	-1%
2070 5-year	5.481	5.468	-0.013	0%
2070 10-year	7.37	7.358	-0.012	0%

Event	Hours Flooded (hrs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	1.820	1.710	-0.110	-6%
Baseline 5-year	3.530	3.430	-0.100	-3%
Baseline 10-year	4.020	3.920	-0.100	-2%
2070 2-year	2.180	2.060	-0.120	-6%
2070 5-year	3.910	3.800	-0.110	-3%
2070 10-year	4.320	4.220	-0.100	-2%

The Strawberry Brook conduit is expected to flood near Mansfield Place under all six design events considered, with flood volumes ranging from 2.796 MG during the 2-year event under a baseline climate to 7.370 MG during the 10-year event under a 2070 climate. The proposed project is, in fact, not expected to have a significant impact on flood volumes in that area, with reductions less than 1%. The duration of flooding, however, may experience more significant reductions, up to 6% for some design events. In addition, significant benefits to localized flooding in and around the Stop & Shop parking area would be expected.

Scenario 18 – Floodable Ames Street Park

Ames Street Park is south of Boston St on the opposite side of the Strawberry Brook Conduit. It is a smaller neighborhood park with a playground, two tennis courts and a basketball court in need of repair. Creating a park with floodable recreation spaces and plazas can alleviate inundation stresses to the conduit by detaining and storing stormwater runoff from surrounding streets while providing an improved community asset.

The proposed development of the Ames Street Park to create additional surface storage during large storm events might be expected to reduce stormwater runoff downstream due to reduced impervious cover and the creation of additional storage. Those impacts are highlighted by the effect on total flood volumes and duration of flooding that might be expected to occur near Mansfield Place, as shown in the tables below:

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.796	2.582	-0.214	-8%
Baseline 5-year	4.401	4.242	-0.159	-4%
Baseline 10-year	6.014	5.882	-0.132	-2%
2070 2-year	3.278	3.083	-0.195	-6%
2070 5-year	5.481	5.342	-0.139	-3%
2070 10-year	7.37	7.247	-0.123	-2%

Event	Hours Flooded (hrs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	1.820	1.540	-0.280	-15%
Baseline 5-year	3.530	3.230	-0.300	-8%
Baseline 10-year	4.020	3.680	-0.340	-8%
2070 2-year	2.180	1.890	-0.290	-13%
2070 5-year	3.910	3.570	-0.340	-9%
2070 10-year	4.320	3.960	-0.360	-8%

The Strawberry Brook conduit is expected to flood near Mansfield Place under all six design events considered, with flood volumes ranging from 2.796 MG during the 2-year event under a baseline climate to 7.370 MG during the 10-year event under a 2070 climate. The proposed project may reduce those total flood volumes by up to 10% with greater benefits experienced during smaller storms. The duration of flooding may also be reduced. Flooding durations during the six 6-hour design events ranged from 1.82 to 4.32 hours. The proposed surface storage project at the Ames Street park may reduce the duration of flooding by up to 15%, again with smaller events experiencing the greater benefits. In addition, significant benefits to localized flooding in and around the park and surrounding neighborhood may be expected.

Scenario 19 – Gallagher Park Surface Storage and Green Streets

Gallagher Park is a large recreational park upstream near Lynn Reservoir. It features 4 ball fields, 4 basketball courts and a playground in a naturally occurring bowl-shaped landform. Designing an intentionally floodable, storage area between the flex fields and converting the courts to permeable surfaces with underground storage will create a system of detention that is conveyed slowly via 3 connected permeable streets downstream toward Strawberry Brook Conduit.

The proposed development of surface storage in Gallagher Park during large storm events and the creation of green streets near the park might be expected to reduce stormwater runoff downstream due to reduced impervious cover and the creation of additional storage. Gallagher Park is located in an area of West Lynn incorporated into the stormwater model as subcatchments SB-03. Runoff from subcatchment SB-03 is conveyed downgradient by a series of storm drains, converging with the Strawberry Brook conduit near the intersection of Boston Street and Barry Park. The potential benefit of the proposed surface storage Gallagher Park and the creation of green streets near the park can be evaluated by the total runoff and peak runoff rates entering the Strawberry Brook conduit from subcatchment SB-03, as shown in the tables below:

Event	Lateral Inflow Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	13.7	11.8	-1.9	-14%
Baseline 5-year	18.3	16.3	-2.0	-11%
Baseline 10-year	22.8	20.8	-2.0	-9%
Baseline 10-year with Surge	22.8	20.8	-2.0	-9%
2070 2-year	15.2	13.3	-1.9	-13%
2070 5-year	21.3	19.3	-2.0	-9%
2070 10-year	26.6	24.6	-2.0	-8%
2070 10-year with Surge	26.6	24.6	-2.0	-8%

Event	Max Lateral Inflow (cfs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	621	572	-48.9	-8%
Baseline 5-year	834	804	-30.1	-4%
Baseline 10-year	1058	1039	-19.2	-2%
Baseline 10-year with Surge	1058	1039	-19.2	-2%
2070 2-year	695	653	-42.4	-6%
2070 5-year	986	964	-22.2	-2%
2070 10-year	1253	1239	-14.1	-1%
2070 10-year with Surge	1253	1239	-14.1	-1%

Inflows to the Strawberry Brook conduit at Boston Street and Barry Park are expected to range from approximately 13.7 MG, during the 2-year event under baseline climate conditions, up to approximately 26.6 MG, during the 10-year event under 2070 climate conditions. The proposed project would reduce the total runoff by up to about 15% with greater benefits experienced during smaller storms. Peak inflow rates to the Strawberry Brook conduit may also be reduced as a result of the proposed project. Reductions vary, with minimal benefits, on the order of 1-2% during large events like the 10-year event up to 8% during the 2-year storm. In addition, significant benefits to localized flooding in and around the park and surrounding neighborhood may be expected.

FIGURE 20: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIO 19 NEAR GALLAGHER PARK

Scenario 20 – Lower Boston Street Green Streets and Swales

Lower Boston St. is characterized by mixed-use, industrial and dense residential spaces. Boston St varies in width along this stretch and is on average 46 feet wide reaching nearly 50 feet near Barry Park. The amount of extra space along the road and high percentage of impervious surfaces makes street transformations a clear option for reducing flooding. Boston Green Streets are comprised of components like bioswales / sunken planters, tree planters, permeable paving, and large swales. Taking space from the road and converting it to public spaces will improved walkability, provide a stronger corridor aesthetic, and greatly reduce heat associated with large paved areas. The Green Streets will collect, detain, and convey stormwater runoff from surrounding into storage areas downstream.

The proposed construction of green streets along the Lower segment of Boston Street might be expected to reduce stormwater runoff in this area due to reduced impervious cover and the creation of additional storage. Those potential impacts were estimated by evaluating the effect of the proposed project on total flood volumes and duration of flooding at the intersection of Boston Street at Federal Street as well as further downstream near the intersection of Boston Street and Barry Park and at the G.E.A.A. Fields. In addition to providing a sense of potential benefits throughout the Lower Boston Street area, these three locations are also the approximate locations where runoff from the three affected subcatchments converge with the Strawberry Brook conduit.

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.624	2.306	-0.318	-12%
Baseline 5-year	3.969	3.690	-0.279	-7%
Baseline 10-year	5.508	5.238	-0.270	-5%
Baseline 10-year with Surge	5.488	5.223	-0.265	-5%
2070 2-year	3.786	3.454	-0.332	-9%
2070 5-year	5.700	5.416	-0.284	-5%
2070 10-year	7.547	7.279	-0.268	-4%
2070 10-year with Surge	8.015	7.664	-0.351	-4%

Event	Hours Flooded (hrs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.35	1.91	-0.44	-19%
Baseline 5-year	3.47	2.91	-0.56	-16%
Baseline 10-year	4.37	3.74	-0.63	-14%
Baseline 10-year with Surge	4.36	3.73	-0.63	-14%
2070 2-year	2.77	2.29	-0.48	-17%
2070 5-year	4.14	3.55	-0.59	-14%
2070 10-year	4.69	4.03	-0.66	-14%
2070 10-year with Surge	4.88	4.32	-0.56	-11%

As shown in the tables above, the proposed project may provide significant benefits to total flooding volumes in the Federal Street area. The Strawberry Brook conduit is expected to flood there under all eight design events considered, with flood volumes ranging from 2.624 MG during the 2-year event, under a baseline climate, to 8.015 MG during the 10-year event with storm surge, under a 2070 climate. The proposed project was shown to reduce total flood volumes by 4 to 12% during those events, with greater benefits occurring during smaller storms. The duration of flooding may also be reduced. Flooding durations during those 6-hour design events ranged from 2.35 to 4.88 hours. The proposed improvements were shown to reduce the duration of flooding by 11 to 19%.

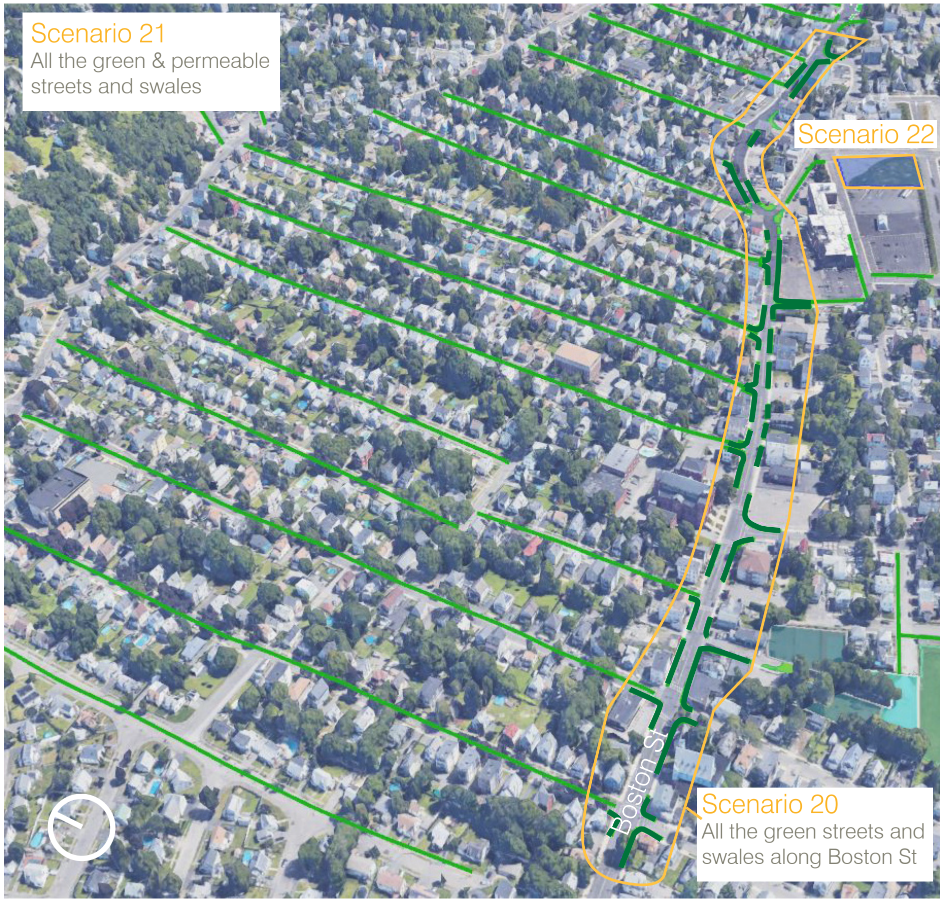


FIGURE 21: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIOS 20-22 ALONG THE LOWER END OF BOSTON ST

Similar comparisons were made for areas near the intersection of Boston Street with Barry Park and the G.E.A.A Fields. However, in both locations, model results indicated that the proposed improvements made no meaningful benefit to either flood volumes or durations due to either a lack of flooding under existing conditions or the mitigating tidal influence of the Saugus River.

Scenario 21 – Lower Boston Street Green Streets and Permeable Side Streets

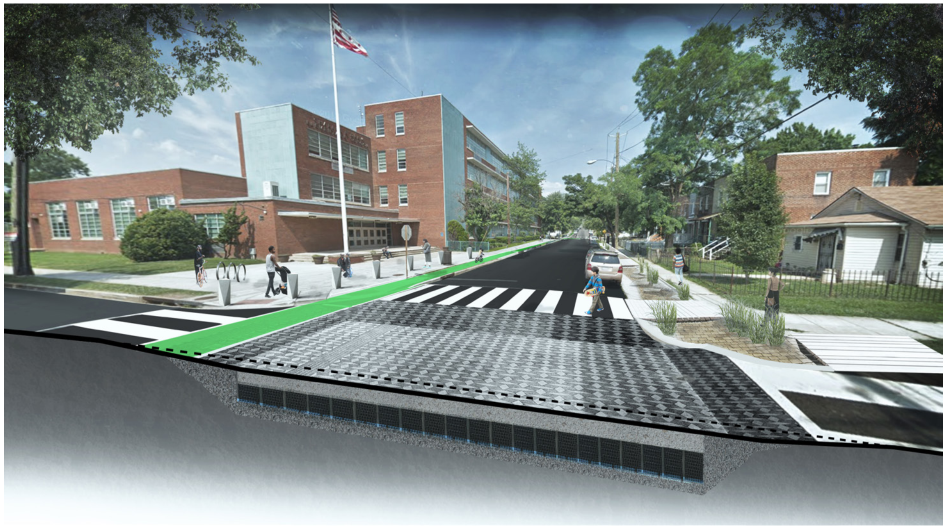
Building on the impact of the Boston Green Streets, arterial permeable streets will intercept and retain stormwater runoff heading toward Boston St. Stretching from Moulton St to Gardiner St, these permeable streets perpendicularly intersect Boston St. They are comprised of green infrastructure components like permeable paving, underground storage and tree planters. Due to needed street parking and driveway access, large areas may be permeable paving.

This scenario assumes that the green streets associated with Scenario 20 are built in an earlier phase and remain in the calculation. This scenario also includes the construction of permeable side streets arterial to Boston Street. The additional permeable pavement is expected to lower the impervious cover of the area, reducing total and peak runoff, which would in turn reduce the total volume and duration of flooding in the Lower Boston Street area. As with Scenario 20, those potential impacts were estimated by evaluating the effect of the proposed project on total flood volumes and duration of flooding at the intersection of Boston Street at Federal Street as well as further downstream near the intersection of Boston Street and Barry Park and at the G.E.A.A. Fields

Event	Hours Flooded (hrs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.624	1.896	-0.728	-28%
Baseline 5-year	3.969	3.325	-0.644	-16%
Baseline 10-year	5.508	4.902	-0.606	-11%
Baseline 10-year with Surge	5.488	4.893	-0.595	-11%
2070 2-year	3.786	3.071	-0.715	-19%
2070 5-year	5.700	5.076	-0.624	-11%
2070 10-year	7.547	6.960	-0.587	-8%
2070 10-year with Surge	8.015	7.301	-0.714	-9%

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.35	1.81	-0.54	-23%
Baseline 5-year	3.47	2.65	-0.82	-24%
Baseline 10-year	4.37	3.39	-0.98	-22%
Baseline 10-year with Surge	4.36	3.38	-0.98	-22%
2070 2-year	2.77	2.08	-0.69	-25%
2070 5-year	4.14	3.24	-0.90	-22%
2070 10-year	4.69	3.68	-1.01	-22%
2070 10-year with Surge	4.88	3.91	-0.97	-20%

As shown in the tables above, the proposed construction of permeable side streets significant reduces total flooding volumes at Franklin Street, reducing flood volumes by 8 to 28% over existing conditions, generally doubling the 4 to 12% reductions in flood volumes achieved by just the green streets along Boston Street in Scenario 20. In addition, flooding durations are shown to decrease by 20 to 25% over existing conditions, compared to a range of 11 to 19% for Scenario 20, a modest but noteworthy improvement. As with Scenario 20, similar comparisons were made for areas near the intersection of Boston Street with Barry Park and the G.E.A.A Fields. However, in both locations, model results indicated that the proposed improvements made no meaningful benefit to either flood volumes or durations due to either a lack of flooding under existing conditions or the mitigating tidal influence of the Saugus River.



EXAMPLE OF PERMEABLE STREETS IN WASHINGTON, DC. INCLUDING STORMWATER CONVEYANCE, UNDERGROUND STORAGE, SLOWER ROADS NEARS SCHOOLS AND SAFER BIKING LANES.

Scenario 22 – Federal Street Parking Lot Surface Storage

The intersection of Marion St and Federal St sits directly above the historic flow of Strawberry Brook. It is a topographic low point that is surrounded by vast, paved parking areas and industrial development. The area is split with half of its surface paved for overflow parking while the other half is grass on a slightly raised plinth with no additional vegetation. The form of the parking area is roughly the same size and location of the historic Mill Pond formed from an offshoot of the brook. The site can be redesigned to create a new park or plaza that can intentionally flood and store runoff during large events. It also has potential be a location for increase tree planting to increase shade and reduce urban heat islands in the denser part of the City.

The proposed development of the Federal Street parking lot to create additional surface storage during large storm events might be expected to reduce stormwater runoff in the Lower Boston Street area due to reduced impervious cover and the creation of additional storage. Those impacts are highlighted by the effect on total flood volumes and duration of flooding that might be expected to occur near Federal Street, as shown in the tables below:

Event	Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.624	1.803	-0.821	-31%
Baseline 5-year	3.969	3.264	-0.705	-18%
Baseline 10-year	5.508	4.842	-0.666	-12%
Baseline 10-year, with Surge	5.488	4.831	-0.657	-12%
2070 2-year	3.786	2.975	-0.811	-21%
2070 5-year	5.700	4.991	-0.709	-12%
2070 10-year	7.547	6.873	-0.674	-9%
2070 10-year, with Surge	8.015	7.192	-0.823	-10%

Event	Hours Flooded (hrs)			
	Existing	Proposed	Change	% Change
Baseline 2-year	2.35	1.79	-0.56	-24%
Baseline 5-year	3.47	2.62	-0.85	-24%
Baseline 10-year	4.37	3.33	-1.04	-24%
Baseline 10-year, with Surge	4.36	3.32	-1.04	-24%
2070 2-year	2.77	2.05	-0.72	-26%
2070 5-year	4.14	3.19	-0.95	-23%
2070 10-year	4.69	3.61	-1.08	-23%
2070 10-year, with Surge	4.88	3.82	-1.06	-22%

As shown in the tables above, the proposed construction of surface storage in the Federal Street Parking Lot during large storm events may have a significant impact on total flood volumes and the duration of flooding in that area. Total flood volumes are reduced by 9 to 31% over existing conditions, with the greatest benefits occurring during smaller, more frequent storms, like the 2-year event. The proposed project is also likely to reduce the duration of flooding by roughly 25%. Model results, however, suggest that these benefits will be localized to the Federal Street area and that no meaningful benefits are experienced downstream in the Cottage Street and Barry Park area or upstream in the Mall Street and Barrett Court area.

FIGURE 22: SCHEMATIC PLAN WITH LOCATIONS OF SCENARIOS 23-24 WITHIN BARRY PARK AND THE G.E.A.A. FIELDS AND NEAR THE OUTFALL OF STRAWBERRY BROOK INTO THE LITTLE RIVER.

Scenario 23 – Barry Park & G.E.A.A. Field Surface Storage and Green Streets

Barry Park and the General Electric Athletic Association (G.E.A.A.) Fields are city-owned properties encompassing more than 650,000 sq.ft. of mixed recreation and parking. The parks are located directly above the last segment of the Strawberry Brook Conduit and were formally wetlands. The parks are comprised of large recreations fields, predominantly baseball, parking areas, tennis courts, basketball courts, and a playground. Utilizing Boston St. Green Streets and surrounding permeable streets to convey stormwater, both Barry Park and the G.E.A.A. fields can be utilized as surface storage and infiltration. Underdrainage beneath the fields and connected to the conduit would fields maintain playability and function.

The proposed development of green streets in subcatchments SB-01 and SB-02 around Barry Park and the G.E.A.A. fields, the creation of surface storage in both fields during large storm events, and the daylighting of the Strawberry Brook conduit between the two fields might be expected to reduce stormwater runoff in those areas due to reduced impervious cover and the creation of additional storage. The impact of the proposed project on total flood volumes for both Barry Park and the G.E.A.A. Fields is summarized in the tables below, respectively:

Event	Barry Park Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	0.000	0.000	0.000	0%
Baseline 5-year	0.000	0.000	0.000	0%
Baseline 10-year	0.000	0.000	0.000	0%
Baseline 10-year, with Surge	0.000	0.000	0.000	0%
2070 2-year	0.000	0.000	0.000	0%
2070 5-year	0.000	0.000	0.000	0%
2070 10-year	0.003	0.000	-0.003	-100%
2070 10-year, with Surge	0.002	0.000	-0.002	-100%

Event	G.E.A.A. Fields Total Flood Volume (MG)			
	Existing	Proposed	Change	% Change
Baseline 2-year	0.000	0.000	0.000	0%
Baseline 5-year	0.000	0.000	0.000	0%
Baseline 10-year	0.000	0.000	0.000	0%
Baseline 10-year, with Surge	0.000	0.000	0.000	0%
2070 2-year	141.394	0.000	-141.394	-100%
2070 5-year	144.274	0.000	-144.274	-100%
2070 10-year	147.024	0.000	-147.024	-100%
2070 10-year, with Surge	496.388	29.956	-466.432	-94%

Barry Park is not shown to flood under any baseline or future climate design event; therefore, the creation of green streets and surface storage in that area is not shown to provide any benefit. However, those projects would likely produce localized benefits in the form of reduced flooding in the immediate vicinity of the proposed Green Streets near Barry Park.

In contrast, while the G.E.A.A. Fields area is not expected to flood during the 2- to 10-year events under a baseline climate, significant flooding is expected under a 2070 climate scenario, with total flood volumes in excess of 100 MG during all four future climate design events. These large flood volumes are caused by tidal intrusion up the Strawberry Brook conduit from the Saugus River. The proposed projects are shown to eliminate or significantly reduce total flood volumes because it is assumed that the elevation threshold when flooding occurs rises due to the fields' ability to store surface water during extreme tides and storm events. The benefits are likely overstated, but the key takeaway remains – that designing the G.E.A.A fields to accommodate tidal intrusions up the Strawberry Brook conduit can reduce flooding impacts to the G.E.A.A Fields and surrounding roadways and neighborhoods. However, those benefits will only be achieved if tidal intrusion over Summer Street and other pathways are prevented.

Scenario 24 – Barry Park & G.E.A.A. Underground Storage

Incorporating underground storage in each park is a great opportunity to capture street runoff and overflow storm volume from Strawberry Brook Conduit and reuse it within the park and elsewhere in the city as a gray water source. Green Streets and permeable streets would convey stormwater into underground storage located under raised sports courts and parking areas in the park. Once filled, overflow from the underground storage could flow via gravity to the surface storage in the park.

This scenario builds on Scenario 23, assuming that surface storage and green streets are already constructed. The proposed development of underground storage beneath Barry Park and the G.E.A.A. fields and the associated replacement of the existing parking lots and walkways with permeable pavement might be expected to reduce stormwater runoff in those areas due to reduced impervious cover and the creation of additional storage.

As with Scenario 23, model simulations indicate that Barry Park is not shown to flood under any baseline or future climate design event; therefore, the creation of additional underground storage in that area is not shown to provide any benefit. However, such a project may produce some modest localized benefits in the form of reduced flooding in the immediate vicinity of the proposed Green Streets near Barry Park. These benefits would be significantly reduced by the late 21st century due to sea level rise extending tidal intrusion up the Strawberry Brook conduit. The benefits of underground storage in the Barry Park area would also be reduced if surface storage and green streets had already been constructed as in Scenario 23.

The impact of the proposed construction of underground storage chambers beneath the G.E.A.A. Fields on total flood volumes in that area are summarized in the tables below. In this case, the proposed conditions (Scenario 24) are compared to model results for Scenario 23 to evaluate the benefits of underground storage only.

Event	G.E.A.A. FieldsTotal Flood Volume (MG)			
	Scenario 23	Scenario 24	Change	% Change
Baseline 2-year	0.000	0.000	0.000	0%
Baseline 5-year	0.000	0.000	0.000	0%
Baseline 10-year	0.000	0.000	0.000	0%
Baseline 10-year, with Surge	0.000	0.000	0.000	0%
2070 2-year	0.000	0.000	0.000	0%
2070 5-year	0.000	0.000	0.000	0%
2070 10-year	0.000	0.000	0.000	0%
2070 10-year, with Surge	29.956	29.711	-0.245	-1%

As shown in the table above, the creation of underground storage chambers beneath the G.E.A.A. Fields is not expected to have a significant impact on flood volumes in that area. Only one of eight design events showed any change, and the reduction over Scenario 23 was approximately 1%. A more discretized analysis of the proposed project area may highlight additional local benefits, but this project is unlikely to be a cost-effective solution.

Urban Heat Island Assessment

Lynn is projected to experience both warmer average temperatures, as well as intensification of extreme temperatures as a result of climate change. Based on temperature projections published on resilientMA.org, the number of days per year in Lynn with temperatures greater than 90°F can be as high as approximately 33 days by 2050, 50 days by 2070, and 62 days by 2090. Urban areas like Lynn, particularly sections of the City that lack vegetation, will experience heat vulnerability exacerbated due to the Urban Heat Island (UHI) effect. According to the EPA definition, "urban heat islands" occur when cities replace natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat. These types of hardscaped surfaces result in increased energy costs (e.g., for air conditioning), higher air pollution levels, increased stormwater runoffs, and heat-related illness and mortality. Many residents in Lynn are exposed to heat regularly through walking, biking, and public transit use.

UHI modeling and mapping is a raster-based approach and uses geographical information system (GIS) software to produce UHI maps for existing and proposed land cover conditions. UHI effect for Lynn was analyzed by first estimating the ambient air temperature data from the land surface temperature data. The temperature of the ground surface, referred to as "land surface temperature" is warmer than the ambient air temperature, which is felt by humans. Therefore, it is important to estimate ambient air temperature from land surface temperature data for the purpose of UHI modeling. The land surface temperature data for Lynn was obtained from the Metropolitan Area Planning Council (MAPC). The land surface temperature data is based on using Landsat satellite imagery of the greater Boston area taken on August 30, 2010 at around 11 am and processed using thermal remote sensing tools. The ambient air temperature data was downloaded for the same time frame (August 30, 2010 at 11:00 am) from nearby weather stations located in the greater Boston area. A linear regression relationship (correlation coefficient r2 was determined to be 0.9) was established between the land surface temperature and measured ambient air temperature for each corresponding weather station location.

Ambient air temperature variability due to UHI effect in the future was estimated based on the ratio between average ambient air temperature for existing conditions and average ambient air temperature for projected future scenarios. For this project, projected future temperature scenarios of 90°F, 95°F and 100°F were selected since these are the extreme temperature scenarios that are being recommended for Massachusetts as part of the State Hazard Mitigation and Climate Adaptation Plan (MEMA, EOEAA, 2018). The ambient air temperature variability in Lynn when average temperatures in the City correspond to 90°F, 95°F and 100°F are illustrated in Figure 23. It can be seen in these figures that downtown areas of the City that have higher impervious surfaces and lack tree canopy cover correspond to the UHI "hot spots" in the City where localized temperatures can be as high as up to 2 – 4°F more than the average air temperatures over greener or more pervious spaces.

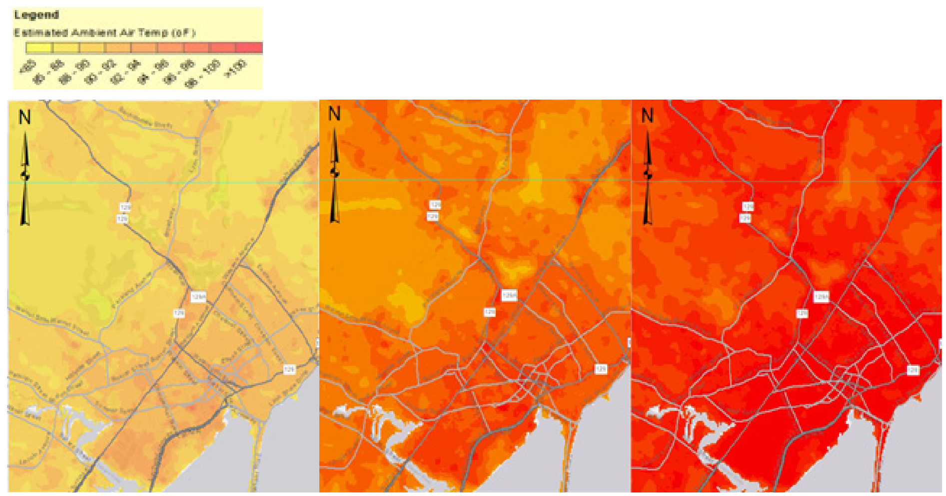


FIGURE 23: URBAN HEAT ISLAND (UHI) EFFECT BASED ON ESTIMATED AMBIENT AIR TEMPERATURE IN LYNN ON AN AVERAGE 90°F, 95°F, AND 100°F DAY (LEFT TO RIGHT)

The ambient air temperature UHI map for Lynn was then used to evaluate the cooling benefits of green infrastructure implementation in the Strawberry Brook watershed. The cooling impact of green infrastructure on urban heat island effect was determined by comparing the change in ambient air temperature as a function of change in impervious cover in the City. A spatial relationship between existing percent impervious surface and ambient air temperature was established at the Citywide scale. The statistically averaged slope derived from this spatial relationship exhibits a positive slope, which confirms that UHI corresponding to ambient air temperature increases with increasing percent impervious surface. This also implies that ambient air temperature is expected to decrease as impervious area is reduced with the implementation of green infrastructure, such as swales, bioretention basins, rain gardens, and light-colored permeable pavers. The resulting relationship demonstrates that for every 10% decrease in impervious surface, approximately 0.4°F of cooling can be achieved.

The cooling relationship established between ambient air temperature and impervious area was then used to quantify the cooling benefits of green infrastructure for one of the drainage sub-basins of the Strawberry Brook watershed (southern sub-basin SB-01). This drainage sub-basin was selected since SB-01 is expected to have the largest decrease of impervious area (up to 6%) with proposed green infrastructure strategies, such as swales, surface detention, permeable courts and playgrounds in parks and open spaces. Figure 24 (left panel) illustrates the UHI ambient air temperature variability in the sub-basin on an average 90°F-day under existing impervious conditions, whereas Figure 24 (right panel) illustrates the UHI ambient air temperature variability on the same average 90°F-day under proposed conditions after implementation of green infrastructure strategies. The result shows that a temperature decrease of up to 3.5°F can be achieved in this sub-basin due to decrease in impervious area from proposed green infrastructure implementation. This clearly demonstrates that green infrastructure strategies can be effective in mitigating UHI effects, which in turn can alleviate significant public health impacts on extreme temperature days.

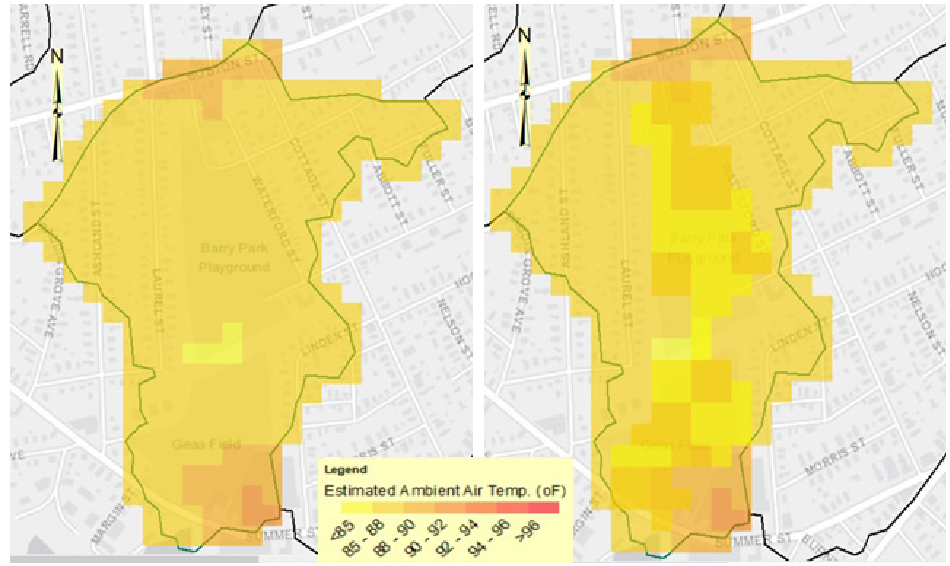


FIGURE 24. ESTIMATED CHANGE IN AMBIENT AIR TEMPERATURE IN DRAINAGE SUBBASIN-01 UNDER EXISTING CONDITIONS (LEFT) AND PROPOSED CONDITIONS WITH GREEN INFRASTRUCTURE IMPLEMENTATION (RIGHT).

In addition to quantifying the cooling benefits of green infrastructure to mitigate UHI, this project used the i-Tree Canopy Tool to estimate the benefits of the existing urban tree canopy coverage in Lynn. The i-Tree Canopy Tool is an analysis software tool developed by the USDA Forest Service that can be used to first calculate tree canopy cover, and other landscape attributes at a Citywide scale. Next, this Tool can also be used to analyze multiple benefits of urban canopy, such as carbon sequestration, air quality improvements, and hydrological benefits.

i-Tree Canopy analysis for Lynn was done for existing groundcover, impervious cover, grass and shrubs, trees, and waterbodies as cover classes. Over 1300 points were classified in the Tool to realize a high-resolution analysis (recommended to use minimum of 500 points or more at a City scale). Based on these 1300 points sampled using the Tool, the City has approximately 41% impervious cover, and 26% covered by trees (Fig. 25).

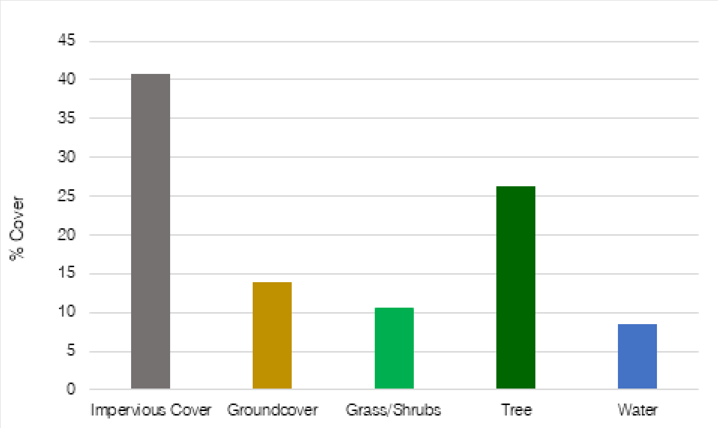


FIGURE 25. PERCENT COVERAGE BY VARIOUS COVER CLASSES IN LYNN, MA BASED ON THE CLASSIFIED POINTS

The ecosystem benefits of tree canopy in Lynn estimated using the i-Tree Tool are presented in Tables 5a and 5b. It is estimated that the existing tree canopy in Lynn can sequester carbon up to 2 kilotons (kT) annually, which is comparable to 7.5 kT of CO2 equivalents (Table 5a). In addition, the City's existing existing canopy is also proposed to remove over 1000 lbs. of Carbon Monoxide, and over 28,000 lbs. of particulate matter annually (Table 5b).

The hydrological benefits of tree canopy estimated from the i-Tree Tool are presented in Table 6. Existing tree canopy cover in Lynn saves the City over 1 million gallon of water loss through avoided runoff, evaporation, interception, transpiration, potential evaporation, and potential evapotranspiration. This has a direct benefit in terms of reducing stormwater runoff and improving water quality.

TABLE 5A. TREE BENEFIT ESTIMATES FOR CARBON SEQUESTRATION AND STORAGE

Description	Carbon kT* (±SE**)	CO_2 Equiv. kT* (±SE**)	Value (±SE**)
Sequestered annually in trees	2 (± 0.07)	7.51 (±0.27)	$349,430 (±12,551)
Stored in trees (Note: this benefit is not an annual rate)	51 (±1.85)	188.66 (±6.78)	$8,775,502 ±315,194

TABLE 5B. TREE BENEFIT ESTIMATES FOR AIR POLLUTION

Description	Amount in lbs (±SE)	Value (±SE)
Carbon Monoxide removed annually	1,353 (±48.61)	$58 (±2)
Nitrogen Dioxide removed annually	7,380 (±265.06)	$99 (±4)
Ozone removed annually	73,498 (±2,639.88)	$5162 (±185)
Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	24,619 (±884.26)	$3747 (±135)
Particulate Matter less than 2.5 microns removed annually	3,571 (±128.28)	$10671 (±383)
Sulfur Dioxide removed annually	4,650 (±167.03)	$17 (±1)
Total	**115,072.79**	**$19,754**

TABLE 6. TREE BENEFIT ESTIMATES FOR HYDROLOGICAL PARAMETERS

Benefit	Amount gallon (±SE)
Avoided Runoff	776 (±27.88)
Evaporation	64,081 (±2,301.62)
Interception	64,439 (±2,314.50)
Transpiration	86,71 (±3,114.44)
Potential Evaporation	485,567 (±17,440.36)
Potential Evapotranspiration	396,182 (±14,229.88)
Total	**1,097,757**

REFERENCES:

- COMMONWEALTH OF MASSACHUSETTS, MASSACHUSETTS EMERGENCY MANAGEMENT AGENCY (MEMA), AND MASSACHUSETTS EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS (EOEEA). "MASSACHUSETTS STATE HAZARD MITIGATION AND CLIMATE ADAPTATION PLAN," SEPTEMBER 2018. HTTPS://WWW.MASS.GOV/SERVICE-DETAILS/MASSACHUSETTS-INTEGRATED-STATE-HAZARD-MITIGATION-AND-CLIMATE-ADAPTATION-PLAN
- I-TREE CANOPY. I-TREE SOFTWARE SUITE V5.X. (N.D.). WEB. ACCESSED JUNE 15, 2020. HTTP://WWW.ITREETOOLS.ORG
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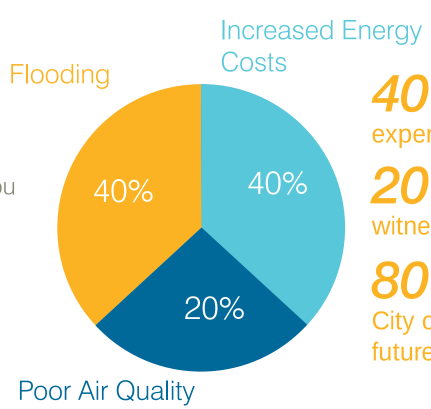
PUBLIC ENGAGEMENT

Stakeholder and Public Engagement

Stormwater management programs are most effective when the community is fully involved. For this reason, the project team coordinated efforts with local organizations to achieve public engagement throughout the City. We worked with local groups, such as the YMCA, My Brother's Table, and the Greater Lynn Chamber of Commerce, to distribute information about climate change, its impact on flooding and urban heat island around Strawberry Brook. Due to COVID-19 pandemic, the City was limited on the format of public engagement that could be used at the time. Educational materials were posted online, passed out to residents, and posted in public areas. Materials were prepared in the form of informational flyers, social media posts, an informative video, and a survey for feedback. All materials were distributed throughout the Town using multiple outlets in order to reach the greatest audience. Additionally, all materials were available in both English and Spanish to accommodate the great diversity in Lynn.

A fact sheet was shared on the City's website and was distributed through the City with the help of YMCA and My Brother's Table prepared meal service. Mayor McGee shared informative posts on social media speaking about climate change and impacts in Lynn and solutions that the City has developed. These posts were shared by stakeholders in order to reach a broader audience. The public engaged with the social media posts by sharing information and giving feedback. A final video was posted on the City's website and on social media which gave a summary of these issues and asked the public for feedback by way of a survey. The City received feedback which was used to inform the recommendations included in this report.

Which Climate Impacts have you experienced in Lynn?



40% of Respondents have experienced Flooding in Lynn

20% of Respondents have witnessed flooding in West Lynn

80% of Respondents feel the City could be more prepared for future Climate Hazard Events

EXAMPLES OF THE PUBLIC ENGAGEMENT STRATEGIES USED BY THE PROJECT TEAM DURING THE PROJECT INCLUDING MULTI-LINGUAL VIDEOS, ONLINE SURVEYS, AND INFORMATION FLYERS.

ACTION IDENTIFICATION

Evaluation of Modeled Opportunities

Our investigation into Strawberry Brook Watershed as well as the City of Lynn's existing infrastructure and physical characteristics have led to over 230 potential green infrastructure components being identified. These components which vary in scale and function were grouped into 23 potential projects according to the junction or part of the watershed they impact most.

These projects were incorporated into the H&H modeling as well as the UHI modeling to illustrate their overall effectiveness at alleviating urban infrastructure stresses and function during various designed storm events. In addition to performance-based metrics, the projects were evaluated on their impact to the urban environment taking into account transformations that benefit the health and quality of pedestrian, public spaces.

Grouping the projects together increases the sizing and estimated costs and maintenance, though generally Green Infrastructure will require more upfront costs and maintenance than traditional gray infrastructure. This can be balanced by the numerous, identified co-benefits Green Infrastructure provides.

TABLE 7: EVALUATION OF IDENTIFIED PROJECTS

	Proposed Projets	Project Type	Maintenance	Flood Risk Mitigation	Water Quality Control	Urban Heat Reduction	Creation of Public Space	Sizing	Costs
1	Enlarge C026, C025, C024 from 3' to 4'	Gray Infrastructure	**Low**	**Moderate**	N/A	N/A	N/A	2 4x4 Conduits 30' and 300' Long	$$
2	Enlarge C013 from 3' to 4'	Gray Infrastructure	**Low**	**Low**	N/A	N/A	N/A	4' Diameter x 14' Long	$
3	Enlarge C010, C009, C008, C007, C006, C005, C004 to 4x3'	Gray Infrastructure	**Low**	**Moderate**	N/A	N/A	x	4'x3' Conduit x 3,800' Long	$$$
4	Lower Cedar 6"	Gray/Green Infrastructure	**Moderate**	**Significant**	N/A	N/A	N/A	Gated Outlet with 6" Drawdown	$
5	Lower Cedar 12"	Gray/Green Infrastructure	**Moderate**	**Significant**	N/A	N/A	N/A	Gated Outlet with 12" Drawdown	$
6	Lower Cedar 12" and dredge	Gray/Green Infrastructure	**Moderate**	**Significant**	N/A	N/A	N/A	Gated Outlet with 12" Drawdown, 2,664cu.yd. of Dredged Volume	$$$
7	Lower Cedar 12", Permeable Streets and Swales	Gray/Green Infrastructure	**High**	**Significant**	**Moderate**	**Low**	**Low**	Gated Outlet with 12" Drawdown, 42,210sq.ft x 2' Detention	$$$
8	Gowdy Memorial Playground Surface Storage	Green Infrastructure	**Moderate**	**Low**	**Moderate**	**Low**	**Moderate**	44,048sq.ft. x 2' Detention	$$
9	Gowdy Memorial Park Outfield Surface Storage	Green Infrastructure	**Moderate**	**Low**	**Moderate**	**Low**	**Moderate**	35,357sq.ft. x 2' Detention	$$
10	Cedar Brook Stream Restoration	Green Infrastructure	**Moderate**	**Low**	**High**	**Low**	**Low**	3 Weirs, 1' tall, 20' Wide, 250' Long, Total 15,000cu.ft Detention	$
11	Sluice Pond Permeable Streets	Green Infrastructure	**High**	**Low**	**Moderate**	**Moderate**	**Low**	23,200sq.ft. x 2' Detention	$$$
12	Flax Pond Permeable Streets and Parking	Green Infrastructure	**High**	**Low**	**High**	**Moderate**	**Moderate**	53,037sq.ft. x 2' Detention	$$$
13	Flax Pond Permeable Streets, Parking and Magnolia Park	Green Infrastructure	**High**	**Low**	**High**	**High**	**High**	178,727sq.ft. x 2' Detention	$$$
14	Upper Boston St Green Streets	Green Infrastructure	**High**	**Low to Moderate**	**High**	**High**	**High**	22,034sq.ft. x 2' Detention	$$$
15	Mid-Boston St Green Streets, Permeable Streets, and Swales	Green Infrastructure	**High**	**Low to Moderate**	**High**	**High**	**High**	36,628sq.ft. x 2' Detention	$$$
16	Stop & Shop Swales / Permeable Pavement	Green Infrastructure	**High**	**Low**	**High**	**Low**	**Moderate**	17,596sq.ft. x 2' Detention	$$$
17	Ames Park Surface Storage	Green Infrastructure	**Moderate**	**Low to Moderate**	**High**	**Moderate**	**Moderate**	21,281sq.ft. x 2' Detention	$$
18	Gallagher Park and Permeable Streets	Green Infrastructure	**High**	**Low to Moderate**	**High**	**Moderate**	**High**	149,564sq.ft. x 2' Detention	$$$
19	Lower Boston St Green Streets and Swales	Green Infrastructure	**High**	**Significant**	**High**	**High**	**High**	17,6804sq.ft. x 2' Detention	$$$
20	Lower Boston St Green Streets and Permeable Side Streets	Green Infrastructure	**High**	**Significant**	**High**	**High**	**High**	45,359sq.ft. x 2' Detention	$$$
21	Federal Street Parking Redesign Surface Detention	Green Infrastructure	**Moderate**	**Significant**	**High**	**High**	**High**	41,618sq.ft. x 2' Detention	$$
22	Barry Park & GEAA Surface Storage and Permeable Streets	Green Infrastructure	**High**	**Significant**	**High**	**High**	**High**	381,422sq.ft. x 2' Detention	$$$
23	Barry Park & GEAA Underground Storage	Gray/Green Infrastructure	**High**	**Low**	**Moderate**	**Moderate**	**High**	249,343cu.ft Storage	$$$

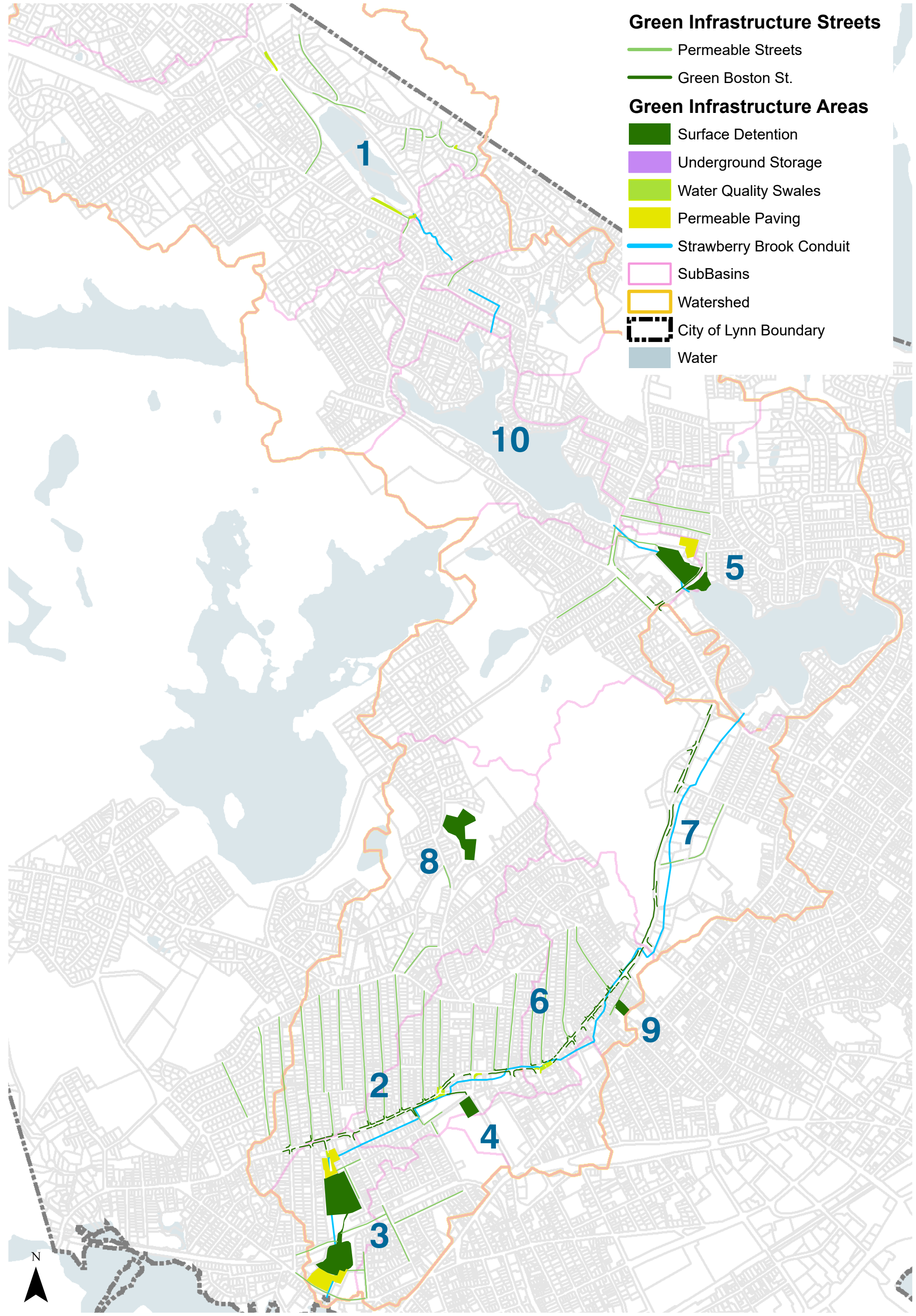
ACTION PRIORITIZATION

Next Steps

This report was developed in order to identify pilot projects that could demonstrate the usefulness of low impact development and green infrastructure to reduce the impacts of urban flooding in Lynn. By identifying the potential projects and developing a reviewing criteria that takes into account impacts to the drainage system, urban heat, the built environment, and costs, the project team has prioritized the following projects for further consideration:

1. Cedar Pond Flood Mitigation and Management
2. Lower Boston Street Green Street Pilot Projects
3. Park Stormwater Detention and Concept Plan for Barry Park and G.E.A.A. Fields
4. Federal Street Parking Redesign Surface Detention
5. Flax Pond Permeable Streets, Parking and Stream Daylighting in Magnolia Park
6. Mid-Boston St Green Streets, Permeable Streets, and Swales
7. Upper Boston St Green Streets
8. Gallagher Park and Permeable Streets
9. Ames Park Surface Storage
10. Eliminate Restrictions Near Sluice

These 10 prioritized actions represent projects that create the greatest impact in terms of flood risk reduction, reducing flooding times, and reducing urban heat. They also prioritize water quality improvements and creation of better, healthier public spaces. The integration of nature-based solutions into the City's existing drainage system will create a more resilient infrastructure that can accommodate future climate, social, and environmental challenges.



ACKNOWLEDGMENTS

The Weston & Sampson Climate Resilience Team wishes to thank the City of Lynn for their involvement, participation, and leadership to bring innovative climate resilience solutions to this project that when fully implemented will reduce flooding, create more green space, and lower the impacts from urban heat island effects. A vibrant community is a liveable community and the Strawberry Brook Watershed in Lynn is an excellent example of responding to climate threats with new approaches that will protect residents and businesses.

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