Weston & Sampson

Resilient Stormwater Action and Implementation Plan

PROJECT SUMMARY REPORT

June 2021

According to the City of Waltham's Hazard Mitigation Plan – Municipal Vulnerability Preparedness Plan 2019 (HMP-MVP Plan), flooding is the most prevalent and serious natural hazard. Flooding in Waltham occurs both inland/riverine and as urban stormwater flooding. Both types of flooding are expected to worsen with the more intense precipitation projected to occur under climate change. To address this vulnerability, the City of Waltham applied for and was awarded grant funding from the Executive Office of Environmental Affairs' Municipal Vulnerability Preparedness Action Grant Program to create a Resilient Stormwater Action and Implementation Plan (RSAIP) to address flooding and water quality in Waltham. The objectives of this project were to:

- develop a comprehensive and resilient management and implementation plan for the stormwater system;
- identify priority stormwater projects and key areas to equitably incorporate green infrastructure;
- evaluate projects to more efficiently direct future resources;
- better maintain, protect, and improve the assets and natural resources of the City through proactive stormwater management.

The RSAIP focused on approximately 26 miles of stream across six subbasins for evaluation based on several criteria, including their proximity to localized flooding areas, their known health issues, and their lack of assessment in recent years. The following methodology was employed to assess existing conditions, develop actions and prioritize interventions. The results of these steps are available as attachments to this report. As part of this process the project team also conducted public engagement throughout the process and developed a maintenance tracking system for catch basin cleaning that could be expanded to other assets in future phases of work. All of the assessments listed in the table below helped to inform the development of an action and implementation plan. An Executive Summary is also available highlighting the key takeaways from the project.

Table 1. The Steps of the RSAIP

Method	Results	Deliverable
Review existing information	The project team reviewed available historical information to understand the condition of the City's drainage infrastructure.	Attachment A. Literature Review of Existing Plans
Stream and culvert field assessment	The results of the assessment were translated into improvement projects, which included 4 culvert replacements, maintenance on 33 culverts, 2,474 linear feet of bank stabilization, 6,224 linear feet of overgrowth removal, 40,748 cubic yards of sediment removal, and debris removal projects.	Attachment B. Stream and Culvert Assessment
Urban heat island analysis	An urban heat island model was developed to identify heat island mitigation projects, which included a city-wide tree survey, work with the Tree Warden to identify forests and canopies of concern, identify replacement tree species resistant to drought and warmer weather, coordinate with the Parks Department to replace dead and dying trees and increase tree canopy, and develop a maintenance approach and schedule for improving and extending existing tree canopy.	Attachment C. UHI Memo

Table 1. The Steps of the RSAIP

Method	Results	Deliverable
Regional coordination with Cambridge Water Department	The City of Waltham developed action items to protect Cambridge's water supply. These action items focus on the categories of water quality, stormwater, site monitoring, land acquisition, emergency response, invasive species, private/public partnerships program, natural resource restoration, and MassDOT Partnership Program.	Attachment D. Regional Coordination Memo
Initial identification of green infrastructure and upland flood storage	Over three hundred green infrastructure and flood storage opportunities were identified throughout Waltham, and include bioretention, floodable parks and fields, floodplain restoration, permeable paving, reforestation, stream restoration, storage, swales, and urban heat reduction structures.	Attachment E. Green Infrastructure and Flood Storage Opportunities
H&H modeling of existing conditions and proposed interventions. Prioritization of results through co-benefits	A PC-SWMM stormwater model was developed and calibrated to assess benefits and co-benefits from twenty-seven green infrastructure improvement scenarios, upstream flood storage opportunities, and grey infrastructure projects.	Attachment F. H&H Analysis and Prioritization of Actions
Review of regulations and development of recommendations on how to incorporate resilience	The project team reviewed the following for opportunities to incorporate climate resilience and green infrastructure: • Sewers Drains and Sewage Disposal • Part II, Chapter 25 Stormwater Ordinance • Site Plan Permit Application and Review • Part III, Chapter Z Zoning Code • Draft Stormwater Management Rules and Regulations	Attachment G. Regulatory Review Recommendations
Capital improvement plan, cash flow diagram, and operational analysis	A multi-year implementation memo will guide the City's efforts to modernize its stormwater collection system and to proactively build climate resiliency throughout the City. The memo includes a 10-year implementation plan. Yearly costs range from approximately $3.1 million to $7.6 million. The actions listed in Table 2 are currently planned for the next three fiscal years and will rely upon securing several funding sources.	Attachment H. Implementation Plan

Table 2. Projected Stormwater Infrastructure Improvements for the Next Three Years

Year	Projects	Cost
Base Year	Scenario 20 - Trapelo Road Beaver Brook Culvert Replacement Scenario 23 - Fernald Wetland Pond and Stream Daylighting *Base Year Total*	$1,000,000 $2,500,000 ***$3,500,000***
Year 1	Scenario 4 - Rehabilition of Storm Drain - Cabot and Fiske Avenue Scenario 5 - Floodable Field Design at Nipper Maher Park Scenario 15 - Culvert Replacement under 260 Lexington Street Improvements at Lower Chester Brook/Stanley Road to Beaver Brook Green Infrastructure Projects from Relevant Scenarios H/H Modeling Studies and Inspection of Infrastructure Major Operation and Maintenance of the Collection System *Year 1 Total*	$450,000 $200,000 $950,000 $900,000 $250,000 $250,000 $50,000 ***$3,050,000***
Year 2	Scenario 20 - Outlet Control Structure Mallard Way Scenario 26 - Waverley Oaks and Linden Street Culverts Improvements from Stony Brook - Second Avenue Improvements at Lower Beaver Brook to Main Street Green Infrastructure Projects from Relevant Scenarios H/H Modeling Studies and Inspection of Infrastructure Major Operation and Maintenance of the Collection System *Year 2 Total*	$175,000 $5,500,000 $250,000 $325,000 $250,000 $50,000 $1,000,000 ***$7,550,000***

Attachment A. Literature Review of Existing Plans

Waltham Literature Review

City of Waltham Hazard Mitigation Plan and Municipal Vulnerability Preparedness Plan 2019. The hazard mitigation plan notes that the stormwater management systems are undersized and poorly designed, often resulting in localized flooding, depleted groundwater supply, drain resource areas, and cause localized flooding. There is also limited area in the City for stormwater retention. The hazard mitigation plan lists the areas of flooding to include Trapelo Road, Linden Street, Beaver Brook, and Lexington Street. There are several actions in the plan related to stormwater infrastructure that should be considered in the upcoming planning process. More specifically, they have prioritized the Trapelo Road culvert, Beaver Brook, and the Lexington Street culvert.

Signed NOI. This is the signed notice of intent from the City of Waltham seeking coverage under the Massachusetts NPDES Phase II MS4 Permit dated September 2018. This includes information on the Charles River impairments and the control measures required (described in greater detail I the SWMP).

Stormwater Management Plan 2019 and appendices. The Stormwater Management Plan (SWMP) was developed to satisfy the requirements of the US EPA Phase II stormwater permit that went into effect July 1, 2018. The report identifies the Charles River as impaired for The plan describes and details the activities and measures that will be implemented to meet the terms and conditions of the permit. The objectives of the MS4 Permit are accomplished through the implementation of BMPs for each of the following six minimum control measures, which are described in detail in the report:

1. Public education and outreach
2. Public involvement/participation
3. Illicit discharge detection and elimination (IDDE)
4. Constriction site stormwater runoff control
5. Post-construction stormwater management in new development or redevelopment
6. Pollution prevention/good housekeeping

The SWMP includes future work as well as timelines. Further detail and specifics for each of the control measures are included in the appendices.

MS4 Stormwater Management Program 2019 Annual Report. The Annual Report reviews the goals and requirements set in place for the City and tracks the completions of these goals. These include the six minimum control measures described in the Stormwater Management Plan.

Waltham IDDE Plan 2019. The Illicit Discharge Detection and Elimination (IDDE) Plan assessed the requirements of the United States Environmental Protection Agency's (USEPA's) 2016 National Pollutant Discharge Elimination System (NPDES) General Permit for Stormwater discharges from MS4s in Massachusetts. As described in the Stormwater Management Plan, control measure 3 requires that the City must implement an IDDE project. This plan outlines assessment and priority ranking of outfalls to reduce illicit discharges and describes sampling procedures.

Stormwater Outfall Map. This is a map showing the drainage system in Waltham.

Stormwater Business Brochure. This brochure was created to inform businesses on stormwater pollution and how they can help to keep their stormwater clean. This was created as part of control measures 1 and 2 of the Stormwater Management Plan.

Land Rules and Regulations. This document contains zoning and development rules for the City of Waltham, including Flood Plain Districts, subdivision plan requirements, open space requirements, and protection of natural resources.

Stormwater Ordinance. This ordinance was created to implement the requirements of the NPDES general permit for stormwater discharges from MS4s. The ordinance established stormwater management standards.

Waltham Stormwater Drainage System Dataset. The current stormwater drainage system dataset was provided by the city. The feature layers include manholes, catch basins, inlets, outfalls, water quality improvement structures, control structures, drainage pipes, culverts, swales, and detention basins. The dataset is visually complete in regard to connections, flow direction, and outfall location. There are few instances of disjointed or disconnected segments of pipes. The metadata includes sizing, shape, material, age, inverts, and slopes. One third of the drainage pipe features' metadata is complete in terms of full information. The remaining features are primarily missing invert data. Conditions of the drainage system and inspections dates are not included in the datasets. As noted from the MVP 2019 Plan, the current system is undersized, poorly designed, or outdated. The oldest pipes in the current system are iron or brick and date back to the early 1880's.

Fernald Center Rehabilitation Wetland Study

This report ("Wetland Study") documents the results of a hydrologic and hydraulic study to evaluate the potential flood mitigation benefits in Beaver Brook as a result of pond/wetland restoration on the Fernald Center property. The City of Waltham purchased the Fernald Center property in 2014 with the intention of redeveloping the campus – approximately ¾ for open space (including recreation) and ¼ for redeveloping residential/commercial/institutional. The pond/wetland restoration considered by the study related to a series of ponds, wetlands, and streams through the Fernald Center that existed prior to 1947. Model simulations, conducted using HydroCAD, examined three scenarios in which one, two, and three storage ponds were recreated, respectively. Three different land use patterns were also considered: pre-1947 conditions, 2015 conditions, and assumed full build-out post-2025 conditions. The Benefits were evaluated by considering peak discharge from the Fernald Center site into Clematis Brook, a tributary to Beaver Brook. Model results indicated 34-48% reductions in peak discharge during the 2-year design storm, 12-24% during the 25-year event, and 2-13% during the 100-year flood event.

Ultimately, the authors of the Wetland Study recommended Phase I improvements that included the daylighting of two existing roadway crossings, restoration of riparian forests and bordering floodplain wetlands, and enhancing existing open water habitat. Engineering, construction, and post-construction monitoring for the proposed improvements are expected to cost on the order for $1.2-1.5 million.

Attachment B. Stream and Culvert Assessment

M E M O R A N D U M

TO: Catherine Cagle, Planning Director, City of Waltham

FROM: Amanda Kohn and Steve Roy, Weston & Sampson

DATE: March 18, 2021

SUBJECT: Stream Maintenance Assessment

Stormwater is rain or snowmelt that soaks into the soil and recharges groundwater, drains into a waterbody, or is channeled through a series of pipes until being released into a nearby waterbody. Urbanization and the associated increase in impervious surfaces and piped drainage systems over time have led to less groundwater recharge and a greater volume of stormwater directed through drainage pipes to nearby waterbodies. Climate change adds to the stressors on grey infrastructure. It is projected that the frequency and intensity of precipitation events will continue to increase, thus increasing stormwater runoff. Streams and other water bodies receiving stormwater from grey infrastructure may become overwhelmed with flow and experience sediment and nutrient loading, habitat degradation, and erosion. Sediment and nutrient loading occurs when there is no pre-treatment of stormwater runoff that would have naturally been treated by percolating through the soil. Stormwater collected from impervious surfaces, like parking lots, is also more likely to pick up contaminants before being discharged. Damage from erosion may occur as stream flow rates increase after a rain event and erode stream embankments. The functionality of the stream also relies on well-maintained retaining walls and culverts. Sediment buildup, debris, vegetative overgrowth, and deteriorating retaining walls and culverts can be problematic and contribute to localized flooding. Much of the water that flows through Waltham consists of a combination of daylighted streams and underground, culverted sections of streams. There are also many ponds and wetland systems that aid in stormwater storage and water quality treatment. All of these systems combined are an integral part of the City's drainage system.

Figure 1. Overview of Data Collected

The City identified and prioritized 25.7 miles of stream for evaluation based on several criteria, including their proximity to localized flooding areas, their known health issues, and their lack of assessment in recent years. Over four weeks, Weston & Sampson conducted a stream assessment covering 25.7 miles of stream within six subbasins in Waltham including Lower Beaver Brook, Clematis Brook, Chester Brook, West Chester Brook, Master Brook, and Stoney Brook. See Attachment A for an overview map of the stream sections broken up by field day. Table 1 provides a summary of characteristics in each subbasin.

Table 1. Subbasin Statistics and Land Use

Subbasin Name	Size (acres)	Stream Length Assessed (miles)	High Residential Land Use (%)	Low Residential Land Use (%)	Commercial/ Industrial/ Mixed Land Use (%)	Institutional Land Use (%)	Open Space (%)	Water (%)
Beaver Brook	2,471	7	1.8	47.6	10.4	8.4	25.3	6.4
Clematis Brook	572	1.5	20	7.7	0.7	32.8	33.2	5.6
Chester Brook	1,722	9.4	8.7	35.8	5.1	12	29.9	8.6
West Chester Brook	684	1.4	7.8	36.1	17.4	4.4	33.2	1.1
Masters Brook	483	5.15	7	54.8	11	6.5	20.5	0.3
Stoney Brook	318	1.25	0	0	81.4	0.2	14.5	3.8

The stream assessment team walked the centerline of the stream and documented the following conditions, also shown in Figure 2: sediment buildup, debris in the stream, culvert condition, outfall condition, bank erosion, overgrowth, retaining wall condition, and channel cross-section. The team collected data using Trimble GPS units, marking each defect in the stream as a separate GPS point with photos attached. The team took an upstream and a downstream photo at various stream points to provide a future frame of reference. When the team took a stream point at the center of the channel, they also took a GPS point on the adjacent bank. Generally, the bank on one side of a stream is lower than the other and is known as the low bank. An elevation point was taken at the top of the low bank adjacent to a stream point to create a representative cross-section.

All data is available in GIS to serve as a future resource for the City in prioritizing needs and conducting stream maintenance, in addition to assessing opportunities for stormwater detention and flood mitigation. In total, the field crew assessed 68 culverts and 140 outfalls. The City had previously mapped eighteen additional outfalls that could not be located, likely due either to sediment build up which buried the outfalls or old mapping that has not been updated since an outfall was removed. Many of the mapped locations showed signs of an outfall, such as sediment buildup, scouring, and flow, but none of the structures could be located. Others were next to recent developments that likely altered stormwater drainage. The field team located additional outfalls that were not included in the City's outfall mapping system. They were inspected and a new naming system was given to differentiate from previously identified outfalls. The new system followed the format of WSE-##. Individual subbasin maps showing all GPS points can be found in Attachment B.

Figure 2. Stream Data Collected

Subbasin Summaries

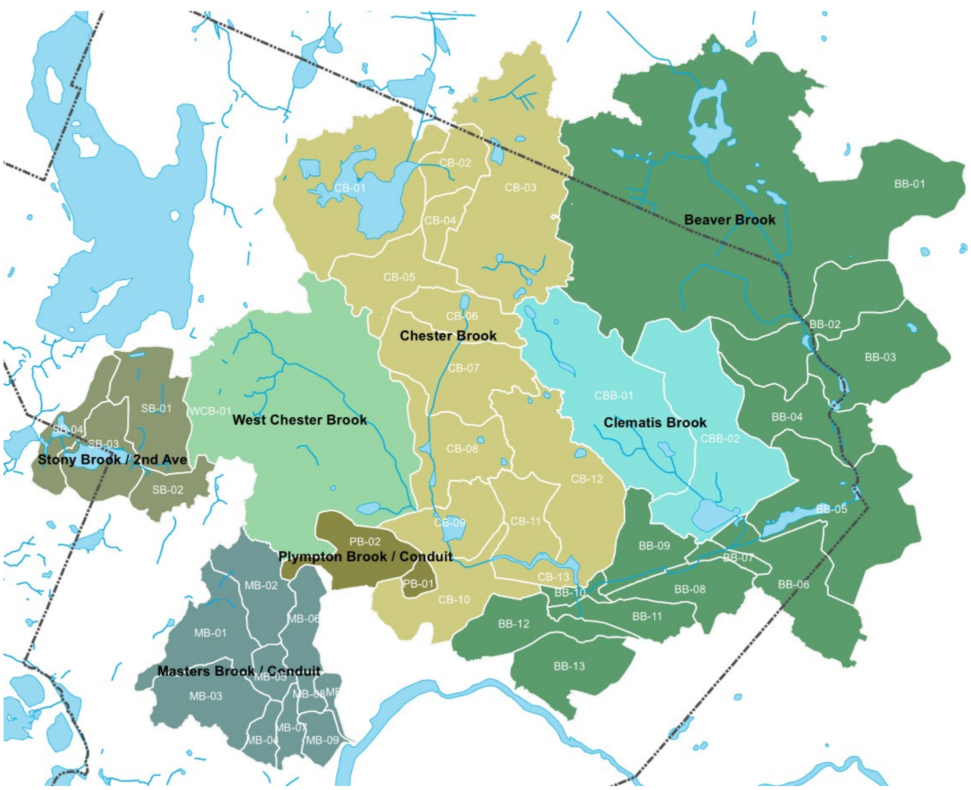


Figure 3. Subbasins of Interest

The stream assessment team walked the length of stream within each of the subbasins shown in Figure 3. Plympton Brook/Conduit, while shown in the figure below, was not included in this assessment since the entirety of the brook was underground and access was limited. The remaining six subbasins were assessed in the methods described above, and the following section provides details of the findings in each subbasin.

Beaver Brook flows south along Belmont and Waltham's border, turning west into Belmont near the Watertown border. The field crew assessed seven miles of Beaver Brook. The Brook primarily runs through wooded areas and at times along roadways and commercial parking lots. There is an extensive wetland system near the Waltham-Belmont border that is thick with sedimentation and vegetation. Approximately half a mile of Beaver Brook flows through an underground culvert, and outlets at River Street and Newton Street's intersection before flowing into the Charles River.

The field team inspected the culverted section of the Brook through utility access holes. They measured the culvert and took an elevation point at these locations. The team could not access the wetland system near the Waltham-Belmont border because of the muck and thick vegetation, resulting in difficultly locating the Brook. Fourteen culverts within the stream assessment area were inspected and three additional culverts upstream of the site were inspected for future modeling purposes. The culverts were generally in fair condition, with only a few requiring repairs, although sediment and debris was observed in seven of the 17 culverts. The team inspected a total of 40 outfalls, with no flow observed at any of these outfalls.

The brook's largest impediment is the number of large fallen trees and several areas of moderate to severe overgrowth. Varying degrees of erosion were observed at nine sections along the stream bank. These sections of bank erosion ranged from 160 feet long to 720 feet long.

Clematis Brook begins at Forest Street and flows southeast into an extensive wetland system before connecting with Beaver Brook. While the entire Brook is over a mile long, the City chose to include the section below the wetland system, and the wetland system itself, in the assessment. The length of this section is just under 1.5 miles. The wetland outlets into a culverted brook before then daylighting in a forested corridor between commercial lots.

Three culverts in Clematis Brook were assessed. Two of the three culverts needed work, while the third was in fair condition. Of the 11 outfalls in this section of Clematis Brook, only one had observed flow following a rain event. However, no evidence of an illicit discharge was detected based on visual observation.

The section of Clematis Brook inspected was surrounded by a bordering vegetated wetland system where there was either no defined stream channel or the vegetation was too thick to perform an inspection. The team inspected approximately 500 feet of Clematis Brook upstream of the wetland system. The crew observed moderate to severe overgrowth, both upstream and within the wetland.

Chester Brook begins at the outlet of Hardys Pond, a 45-acre impoundment in the northern section of Waltham. Chester Brook then flows south for 9.4 miles, primarily along Lexington Street, through multiple wetland systems and a 3 acre impoundment named Lyman Pond, where it ultimately converges with Beaver Brook at the outlet of Lyman Pond. A portion of the Brook is culverted, beginning at Ridge Lane and ending just north of Bishop Forest Drive. The brook flows adjacent to private properties and commercial lots.

The team inspected three dams along Chester Brook. Seventeen culverts were assessed, and all were found to be in either fair or good condition. Sediment observed at culvert inlets and outlets varied in depths, with the most significant sediment depth being 30 inches. A total of 45 outfalls were assessed. Flow was observed at two outfalls following a rain event, but the flow was clear and no evidence of an illicit discharge was observed. The team did not conduct stream assessments on all wetland systems and ponds, as there was no defined stream channel through the wetland systems and ponds.

Much of the area of interest was moderately or severely overgrown, especially near the wetland systems. The team identified debris consisting of fallen trees, garbage, tires, and shopping carts along the Brook. Forty-eight fallen trees were observed on the 9.4 mile stretch of Chester Brook. The fallen trees hindered smaller trees, branches, garbage, and other vegetative debris, creating small impoundments along the Brook.

West Chester Brook enters Chester Brook just south of the Bacon Street and Lexington Street intersection. The portion of the Brook that was inspected included a wetland system, and the Brook ran along the north side of Totten Pond Road, through the front yards and under driveways of multiple private residences. The upper section of the Brook consisted of multiple meandering channels in Prospect Hill Park. A stream assessment was conducted on approximately 1.4 miles of West Chester Brook.

The team assessed 28 culverts, ranging in condition from good to in need of repair. A total of 28 outfalls were inspected. Clear, odorless flow was observed discharging from two outfalls, one of which had a noticeable odor.

Forty-nine fallen trees of varying sizes, from six inches to 24 inches in diameter, interrupted flow in the brook and created impoundments. Severe overgrowth was also observed in multiple locations, restricting flows especially during high flow events.

Masters Brook begins south of Main Street on the west side of Waltham. It consists of two individual brooks converging and eventually discharging to the Charles River in an area adjacent to the Prospect Street bridge. The entire brook is culverted and receives flow from street drainage. In order to inspect the brook, access manholes were opened, and the culvert dimensions and material were recorded. Thirteen manholes along 5.15 miles of brook were inspected in the assessment area. Masters Brook is in good condition and no maintenance is needed at this time.

Stoney Brook is located west of Second Avenue as well as Route 95. The brook receives runoff from nearby roadways and parking lots, where the stormwater runoff is then retained in a large wetland system. The wetland system outlets in the Town of Weston. The team inspected approximately 1.25 miles of Stoney Brook, including the outlet end of the large wetland system.

Three culverts along Stoney Brook were assessed, one located in Waltham, one in Waltham and one in Weston. Eleven outfalls were inspected within the drainage area, and flow was not observed at any of the outfalls. There was an excessive amount of sand and sediment at the initial outlet that began the daylighted system, likely due to winter road treatment. The team inspected the length of the brook, although much of the brook passed through a large wetland system where a defined stream channel could not be located. The wetland system was overgrown and difficult to access.

Potential Projects

Information in Table 2 was gathered while conducting steam assessments. This data was compiled to identify some of the types of maintenance projects required in each subbasin. These projects include bank stabilization, culvert repair, debris removal, overgrowth removal, retaining wall repair, or sediment removal. Each project type could improve stormwater conveyance and storage capacity in the subbasin, thereby reducing flooding in adjacent areas. These projects may also reduce contaminants and sediment entering downstream receiving waters.

Table 2. Potential Flood Mitigation Projects						
Brook	Bank Stabilization	Culvert Maintenance[1] or Replacement	Debris Removal	Overgrowth Removal	Retaining Wall Repair	Sediment Removal
Beaver Brook	1,233 linear feet	Maintenance required on six culverts	34 tree dams, 17 piles of garbage/other debris, 3 locations of rock, brick, or concrete dumped	1,902 linear feet	-	14,167 cubic yards
Clematis Brook	-	Maintenance required on three culverts	4 fallen trees	808 linear feet	-	2,833 cubic yards
Chester Brook	188 linear feet	Maintenance required on ten culverts, replace one culvert	47 debris points: 41 fallen trees, 6 piles of garbage/other debris	1,980 linear feet	Repairs required on one section of retaining wall	16,331 cubic yards
West Chester Brook	1,053 linear feet	Maintenance required on sixteen culverts, replace three culverts	49 fallen trees	1,458 linear feet	Repairs required on one section of retaining wall	4,167 cubic feet
Masters Brook	-	-	-	-	-	-
Stoney Brook	-	Maintenance required on two culvert	3 fallen trees, 3 piles of garbage/other debris	76 linear feet	-	3,250 cubic feet

[1]Maintenance includes structural maintenance on the culvert and/or headwall

Cost Assessment

The team performed a cost assessment for potential projects utilizing preliminary data collected in the field and estimated unit costs for each project type. The following graph (Figure 4) displays the total project cost for each subbasin assessed in Waltham. Attachment C provides additional detail on the cost assessment broken out into stream sections.

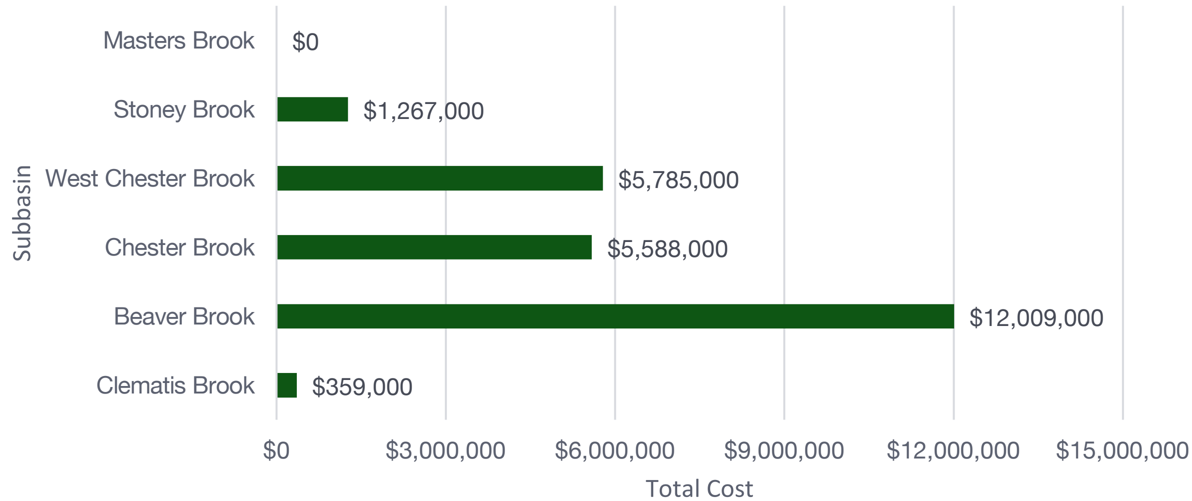


Figure 4.Summary of Estimated Maintenance and Rehabilitation Costs by Subbasin

The City of Waltham is currently prioritizing sediment removal. During the stream assessment, the field team measured sediment depths approximately every 100 feet along the length of the stream channels. Sediment depths varied from two inches to greater than two feet. Three parameters were collected to calculate an approximate volume of sediment for removal: width of stream (calculated as an average width for each stream), depth of sediment at each point (max depth of sediment used for this calculation was 6 inches), and length of stream segment with sediment deposition for removal (100 feet was used as a standard length). A unit cost of $125 per cubic yard was used to calculate a sediment removal project cost for each subbasin, as seen in Figure 5.

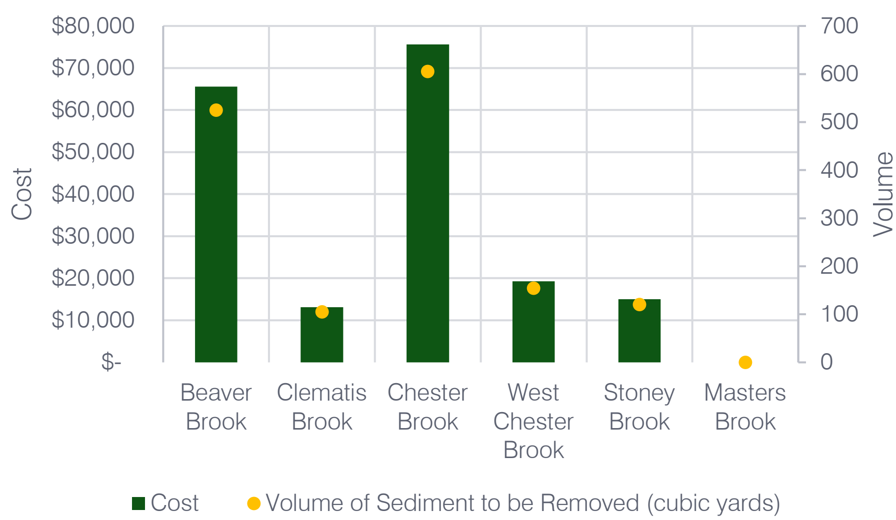


Figure 5. Volume and Cost of Sediment Removal

The field team identified 68 culverts to assess within five out of the six subbasins areas. There were no culverts identified in the Masters Brook project area. The culvert assessment geolocated the structure, measured the dimensions of the culvert, recorded high level structural deficiencies through notes and photos, and notated debris and sedimentation. Attachment D contains a spreadsheet with the detailed documentation, recommendations for improvements, and estimated costs. The costs are represented as a range in the spreadsheet, but the upper limit was used to provide a summary of costs per subbasin and project type in Table 3. The spreadsheet also includes details on how the projects relate to other ongoing efforts in the City.

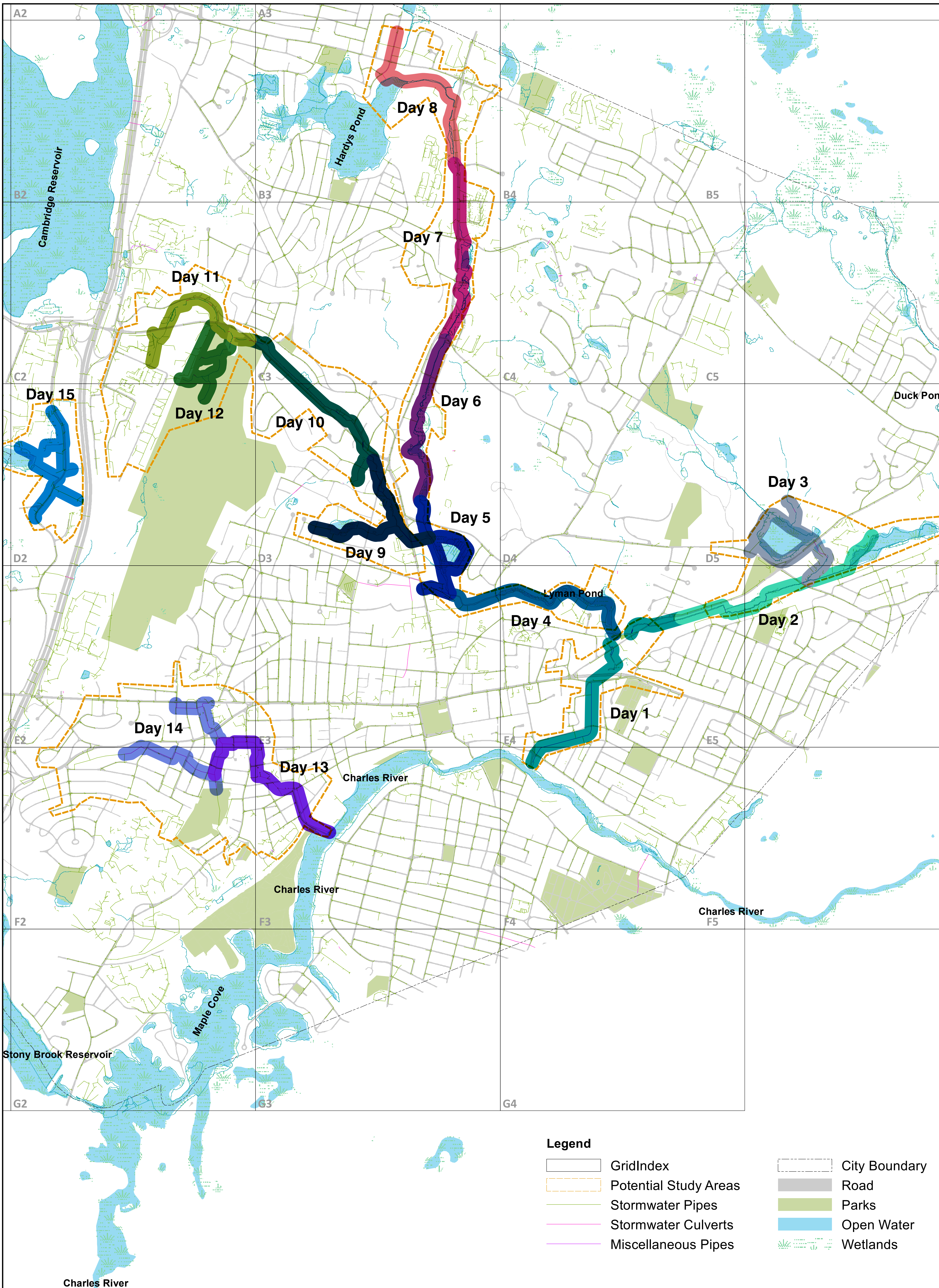
The total cost of maintenance, repair, and replacement of culverts in project area is $21,240,000. The culvert related projects in Beaver Brook watershed account for over half of the estimated costs followed by Chester and West Chester Brook. The most prominent projects need across subbasins are culvert cleaning of debris and sedimentation (12) and culvert replacements (11). Twenty-four culverts do not require any action. Several culverts will need further evaluation, repaired, or should be removed entirely.

Table 3. Project Costs per Subbasin

	Beaver Brook		Clematis Brook		Chester Brook		West Chester Brook		Stoney Brook		Total	
	#	Cost	#	Cost	#	Cost	#	Cost	#	Cost	#	Cost
Headwall Repair or Replace	1	$50,000	0	-	1	$40,000	1	$50,000	0	-	3	$140,000
Culvert Removal	2	$450,000	2	$275,000	1	$250,000	0	$0	0	-	5	$975,000
Further Assessment	2	$500,000	0	-	0	$0	5	$2,750,000	0	-	7	$3,250,000
Culvert Repair	1	$3,500,000	0	-	4	$1,900,000	1	$40,000	0	-	6	$5,440,000
Culvert Replacement	3	$6,500,000	0	-	2	$3,000,000	6	$1,200,000	1	$1,250,000	12	$11,950,000
Culvert Cleaning	0	$0	1	$50,000	3	$60,000	7	$625,000	0	-	11	$735,000
No Action Required	7	-	0	-	7	-	8	$0	2	-	24	-
Total	16	$ 11,000,000	3	$ 325,000	18	$ 5,250,000	28	$ 4,665,000	3	$ 1,250,000	68	$22,490,000

Next Steps

With the projects and cost estimates in hand, the project team will work with the City of Waltham to determine the prioritization of the projects. The prioritization will be informed by the hydrologic and hydraulic analysis, benefits to environmental justice communities, and input from town staff on available funds.



CITY OF WALTHAM
MASSACHUSETTS

Resilient Stormwater Management and Implementation Plan

Site Investigation

1-mile Stretches | Day Breakdown

SEPTEMBER 2020

1 inch = 2,500 feet

0 0.25 0.5 1

Miles

N

Weston & Sampson


City of Waltham, Massachusetts
West Chester Brook - Stream Assessment
Weeks 1-4
DECEMBER 2020
Legend
Outfall
Sediment Buildup Depth (inches)
Debris
RetainingWall
Overgrowth
BankErosion
Culvert
Retaining Walls
Overgrowth
Bank Erosion
Culverts
Structure Conditon - Needs Work
Parcels
Buildings
Hydrologic Connection
Marsh/Bog
Wooded marsh
Open Water
Reservoir (with PWSID)
MAP SHEET 1 of 7
300 0 300 600 900 Feet
Weston & Sampson

City of Waltham, Massachusetts

Upper Beaver Brook - Stream Assessment
Weeks 1-4

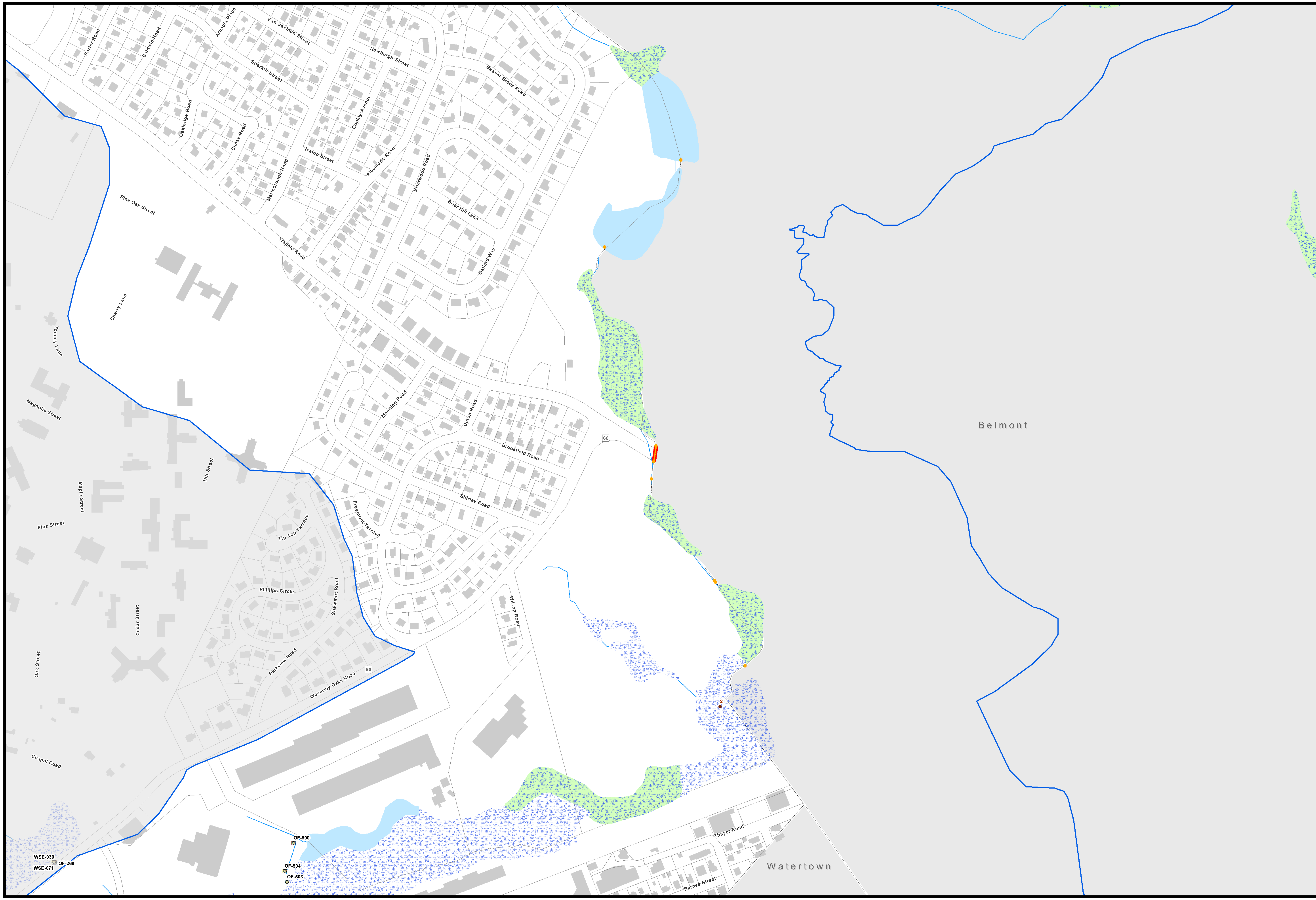
DECEMBER 2020

Data Sources:

Client: datasource 1 name, datasource 2 name
Weston & Sampson Engineers: derived datasource 1, derived datasource2...

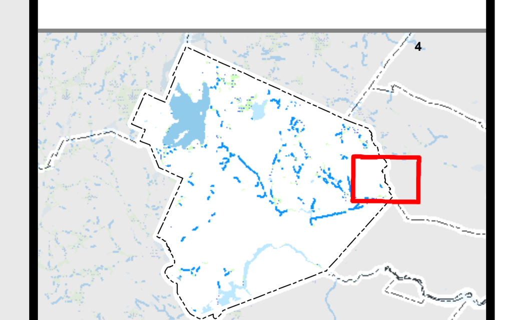
Disclaimer:

This information is for planning purposes only and should not be considered exact. Field inspection and verification is required. This data was created from schematic maps.



Legend

- Outfall
- Sediment Buildup Depth (inches)
- Debris
- RetainingWall
- Overgrowth
- BankErosion
- Culvert
- Retaining Walls
- Overgrowth
- Bank Erosion
- Culverts
- Structure Conditon - Needs Work
- Parcels
- Buildings
- Hydrologic Connection
- Marsh/Bog
- Wooded marsh
- Open Water

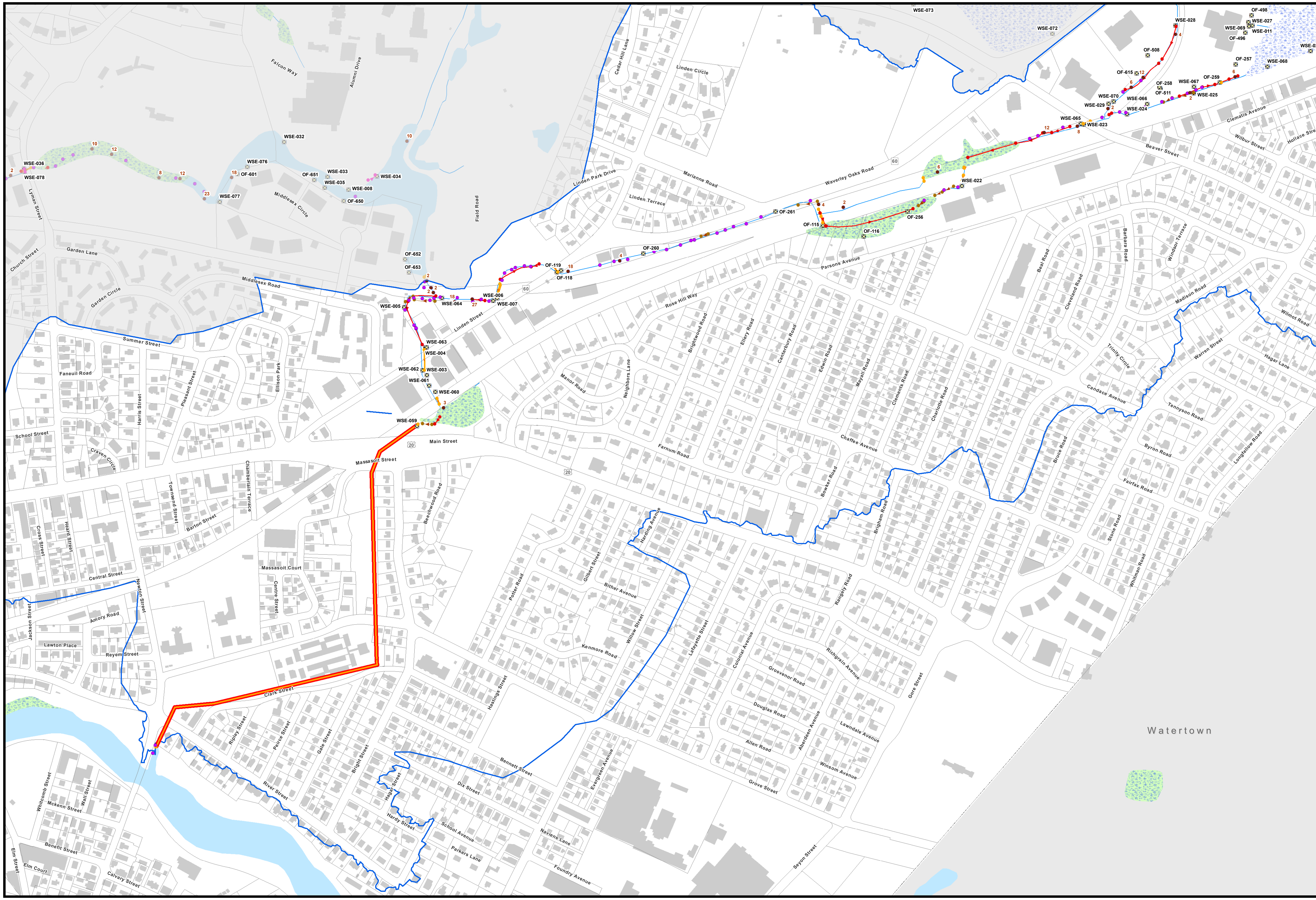


2

MAP SHEET 2 of 7

200 0 200 400 600 Feet

Weston & Sampson



City of Waltham, Massachusetts

Lower Beaver Brook - Stream Assessment
Weeks 1-4

DECEMBER 2020

Data Sources:

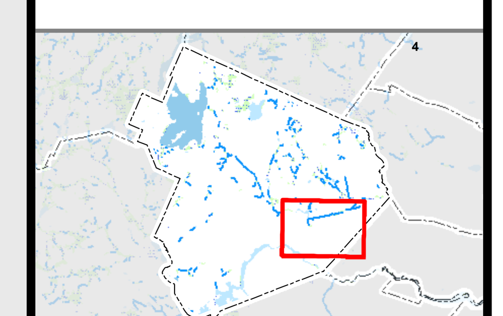
Client
datasource 1 name, datasource 2 name
Weston & Sampson Engineers:
derived datasource 1, derived datasource2...

Disclaimer:

This information is for planning purposes only and should not be considered exact. Field inspection and verification is required. This data was created from schematic maps.

Legend

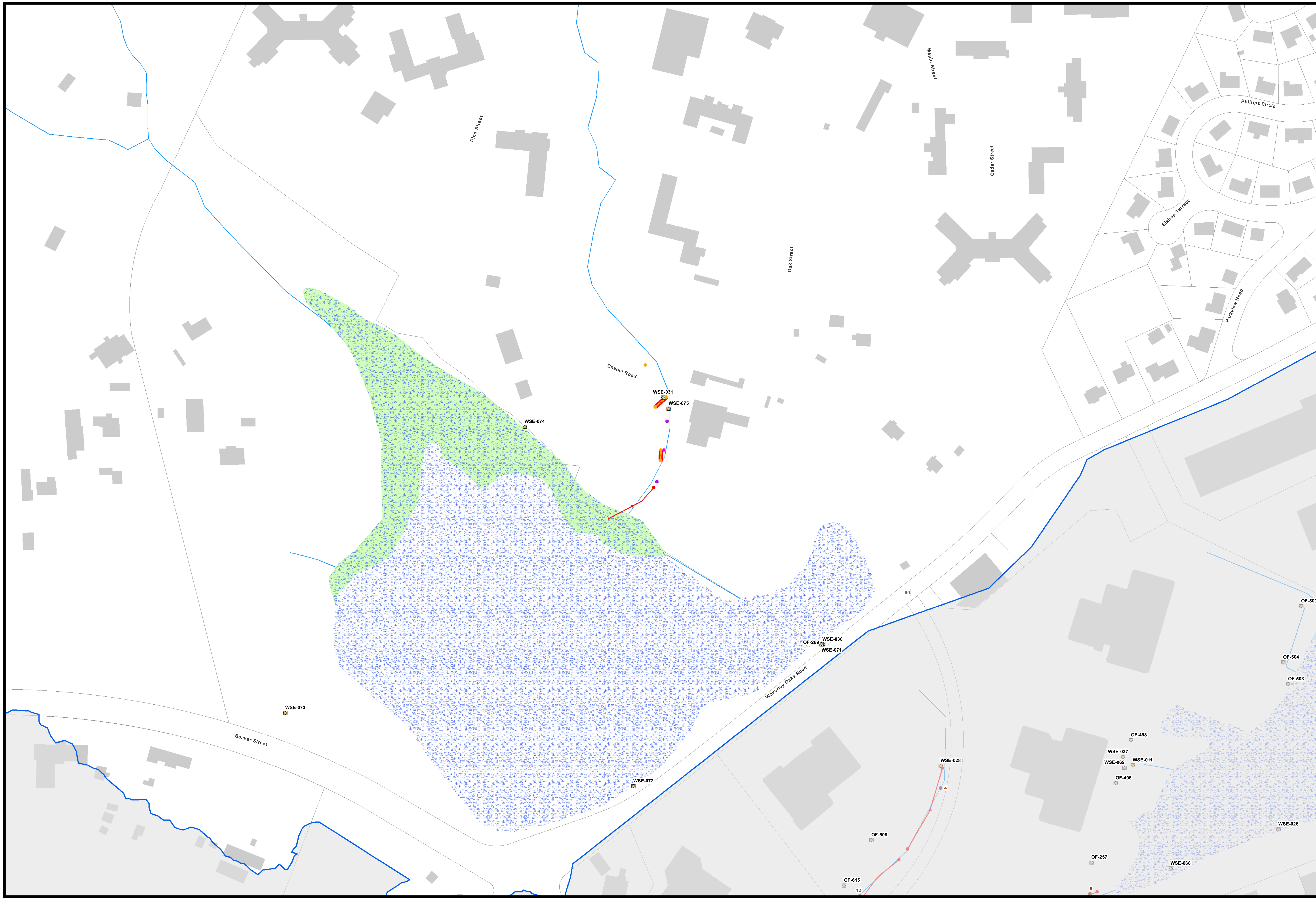
- Outfall
- Sediment Buildup Depth (inches)
- Debris
- RetainingWall
- Overgrowth
- BankErosion
- Culvert
- Retaining Walls
- Overgrowth
- Bank Erosion
- Culverts
- Structure Conditon - Needs Work
- Parcels
- Buildings
- Hydrologic Connection
- Marsh/Bog
- Wooded marsh
- Open Water



3

MAP SHEET 3 of 7

Weston & Sampson



City of Waltham, Massachusetts

Clematis Brook - Stream Assessment
Weeks 1-4

DECEMBER 2020

Data Sources:

Client
datasource 1 name, datasource 2 name
Weston & Sampson Engineers:
derived datasource 1, derived datasource2...

Disclaimer:

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Legend

- Outfall
- Sediment Buildup Depth (inches)
- Debris
- RetainingWall
- Overgrowth
- BankErosion
- Culvert
- Retaining Walls
- Overgrowth
- Bank Erosion
- Culverts
- Structure Conditon - Needs Work
- Parcels
- Buildings
- Hydrologic Connection
- Marsh/Bog
- Wooded marsh
- Open Water

4

MAP SHEET 4 of 7

100 0 100 200 300 Feet

Weston & Sampson

City of Waltham, Massachusetts

Stony Brook - Stream Assessment Weeks 1-4

DECEMBER 2020

300 0 300 600 900 Feet

Data Sources:

Client
datasource 1 name, datasource 2 name
Weston & Sampson Engineers:
derived datasource 1, derived datasource2...

Disclaimer:

This information is for planning purposes only and should not be considered exact. Field inspection and verification is required. This data was created from schematic maps.

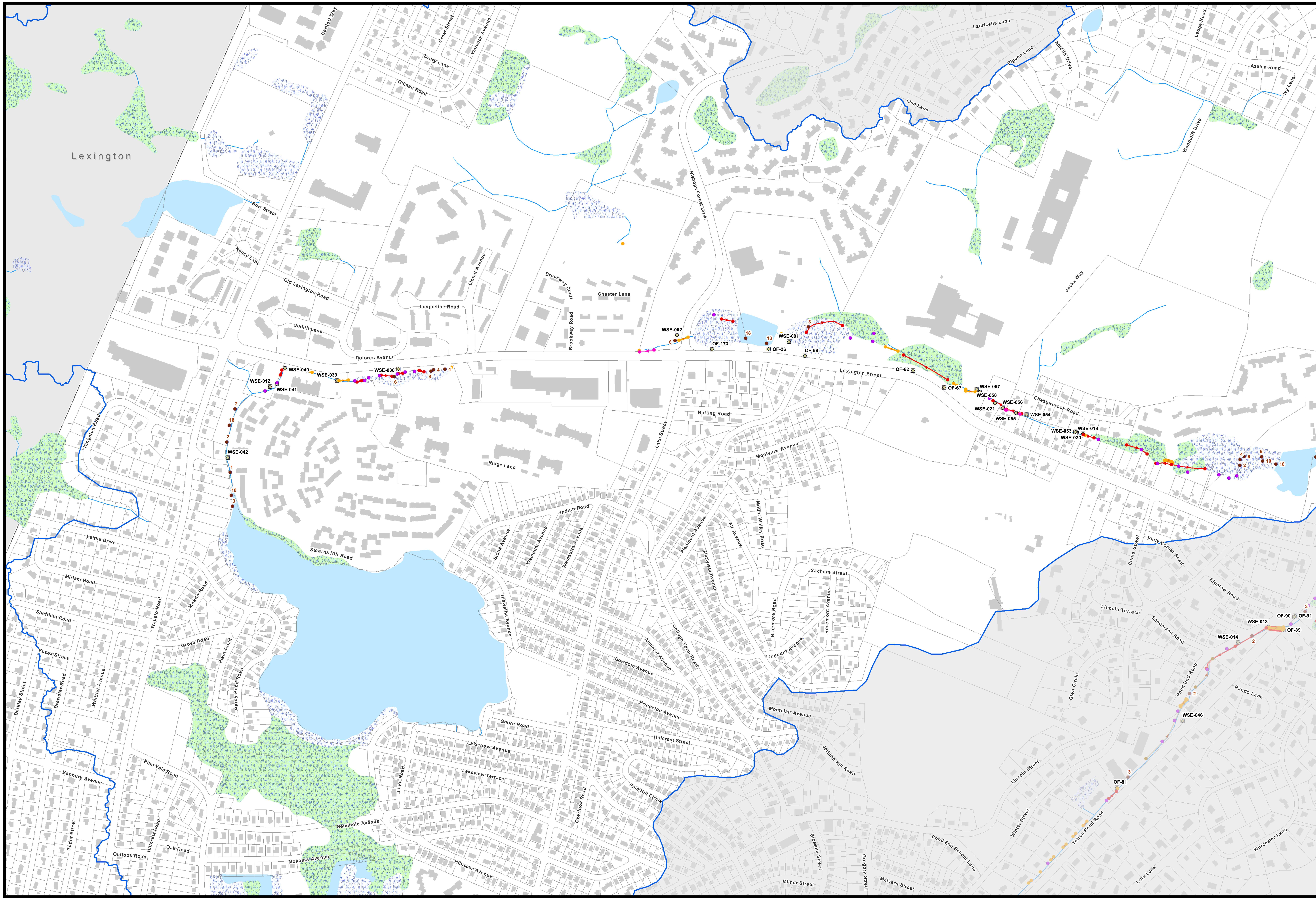
Legend

- Outfall
- Sediment Buildup Depth (inches)
- Debris
- RetainingWall
- Overgrowth
- BankErosion
- Culvert
- Retaining Walls
- Overgrowth
- Bank Erosion
- Culverts
- Structure Conditon - Needs Work
- Parcels
- Buildings
- Hydrologic Connection
- Marsh/Bog
- Wooded marsh
- Open Water
- Reservoir (with PWSID)

5

MAP SHEET 5 of 7

Weston & Sampson



City of Waltham, Massachusetts

Upper Chester Brook - Stream Assessment Weeks 1-4

DECEMBER 2020

Data Sources:

Client: datasource 1 name, datasource 2 name

Weston & Sampson Engineers: derived datasource 1, derived datasource2...

Disclaimer:

This information is for planning purposes only and should not be considered exact. Field inspection and verification is required. This data was created from schematic maps.

Legend

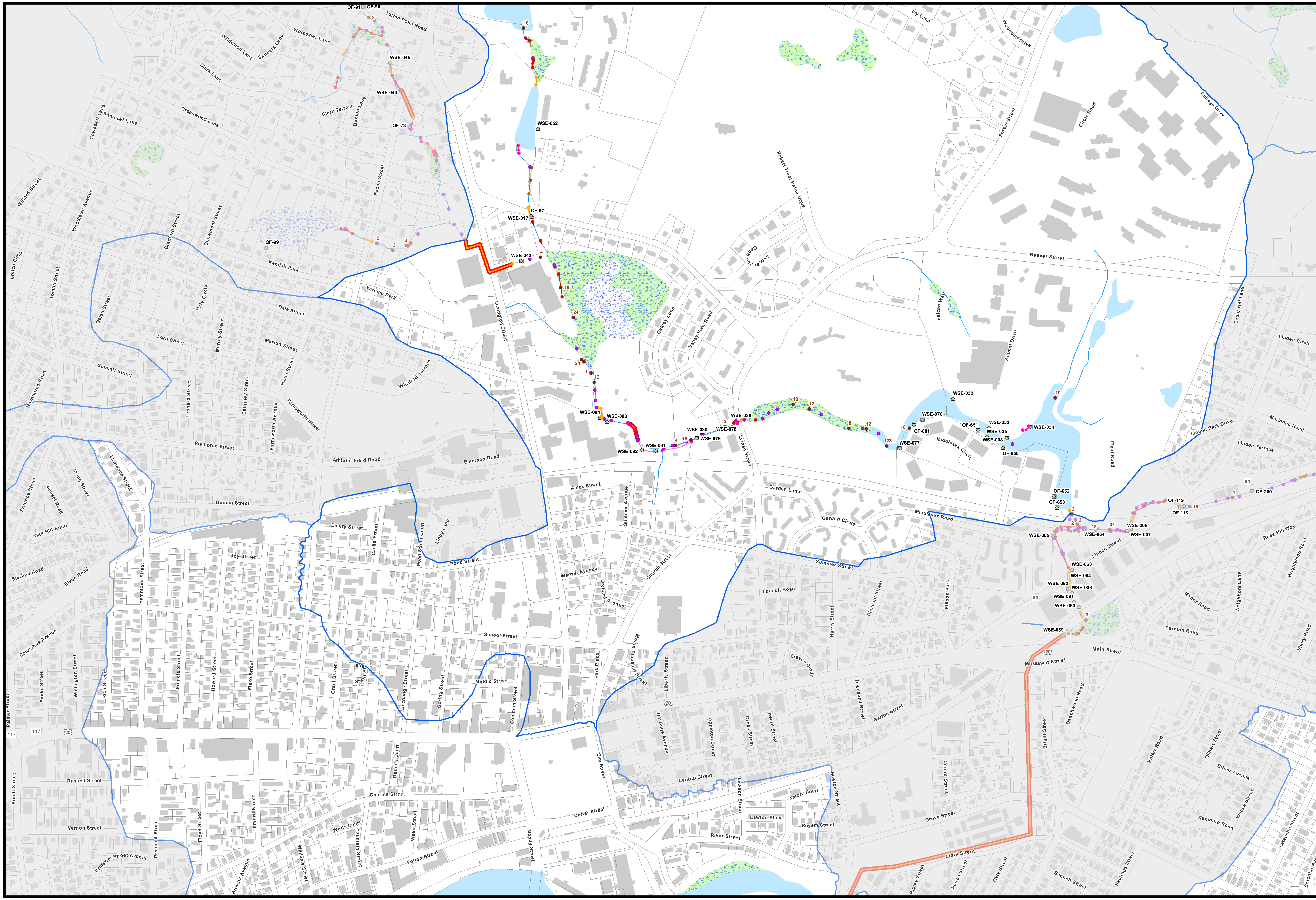
- Outfall
- Sediment Buildup Depth (inches)
- Debris
- RetainingWall
- Overgrowth
- BankErosion
- Culvert
- Retaining Walls
- Overgrowth
- Bank Erosion
- Culverts
- Structure Conditon - Needs Work
- Parcels
- Buildings
- Hydrologic Connection
- Marsh/Bog
- Wooded marsh
- Open Water

6

MAP SHEET 6 of 7

300 0 300 600 900 Feet

Weston & Sampson



City of Waltham, Massachusetts

Lower Chester Brook - Stream Assessment Weeks 1-4

DECEMBER 2020

Data Sources:

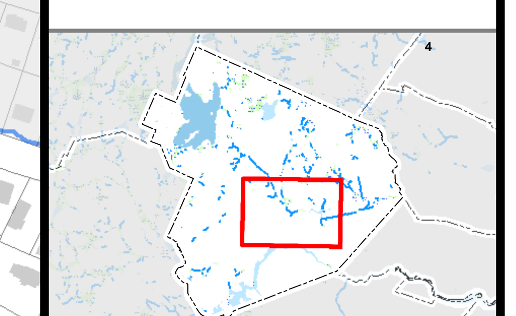
Client
datasource 1 name, datasource 2 name
Weston & Sampson Engineers:
derived datasource 1, derived datasource2...

Disclaimer:

This information is for planning purposes only and should not be considered exact. Field inspection and verification is required. This data was created from schematic maps.

Legend

- Outfall
- Sediment Buildup Depth (inches)
- Debris
- RetainingWall
- Overgrowth
- BankErosion
- Culvert
- Retaining Walls
- Overgrowth
- Bank Erosion
- Culverts
- Structure Conditon - Needs Work
- Parcels
- Buildings
- Hydrologic Connection
- Marsh/Bog
- Wooded marsh
- Open Water



7

MAP SHEET 7 of 7

300 0 300 600 900 Feet

Weston & Sampson

Path: \\wse03.local\WSE\Depts\GIS\data\Client\Waltham MA\Project\ENG20-0648.B.01\Subbasins.mxd User: LaVackC Saved: 12/17/2020 11:37:28 AM Opened: 12/17/2020 11:49:02 AM

Stream Improvements - Cost Assessment for Recommended Improvements

Stream	Cost Assessment				Notes
	Quantity	Unit Cost	Repair Cost	Total Cost	
Clematis Brook (Chapel Road - Lower Beaver Brook)				$21,396	
Sediment Removal (cy)	49	$125	$6,171		4" depth, 12" depth, 6" depth
Debris Removal (trees, leaves, etc) (lf)	10	$25	$250		1 fallen tree <6", 1 tree 6"-12", 1 tree 12"-24", pallets
Cut Back Overgrowth (lf)	599	$25	$14,975		209' moderate, 390' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Clematis Brook (Waverly Oaks Road - Lower Beaver Brook)				$12,619	
Sediment Removal (cy)	56	$125	$6,944		4" depth, 12" depth, 6" depth, 2" depth
Debris Removal (trees, leaves, etc) (lf)	18	$25	$450		1 fallen trees <6", 1 trees 12"-24"
Cut Back Overgrowth (lf)	209	$25	$5,225		209' moderate, 466' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Beaver Brook (Marlborough Road - Beaver Brook wetland)				$11,574	
Sediment Removal (cy)	93	$125	$11,574		6" depth, 3" depth, 3" depth
Debris Removal (trees, leaves, etc) (lf)	0	$25	$0		
Cut Back Overgrowth (lf)	0	$25	$0		
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Beaver Brook (Beaver Brook Wetland - Beaver Street)				$187,768	
Sediment Removal (cy)	62	$125	$7,718		6" depth , 2" depth
Debris Removal (trees, leaves, etc) (lf)	20	$25	$500		3 fallen trees <6", 2 trees 6"-12", trees 12"-24", pipe, tire, rail road tracks
Cut Back Overgrowth (lf)	382	$25	$9,550		382' moderate
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	170	$1,000	$170,000		170' moderate
Beaver Brook (Beaver St - Railroad Crossing)				$27,524	
Sediment Removal (cy)	93	$125	$11,574		8" depth, 12" depth,
Debris Removal (trees, leaves, etc) (lf)	5	$25	$125		3 fallen trees <6"
Cut Back Overgrowth (lf)	633	$25	$15,825		340' moderate, 293' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Beaver Brook (Railroad Crossing - Railroad Crossing)				$730,843	
Sediment Removal (cy)	62	$125	$7,718		2" depth, 6" depth
Debris Removal (trees, leaves, etc) (lf)	5	$25	$125		1 fallen trees 6"-12", tire, wood
Cut Back Overgrowth (lf)	0	$25	$0		
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	723	$1,000	$723,000		82' moderate, 641' severe
Beaver Brook (Railroad Crossing - Linden Street)				$20,037	
Sediment Removal (cy)	154	$125	$19,287		4 " depth, 6" depth, 4" depth, 18" depth
Debris Removal (trees, leaves, etc) (lf)	30	$25	$750		4 fallen tree <6", 5 trees 6"-12", 1 tree 12"-24", 1 tree 24"-36", 2 shopping carts, bricks
Cut Back Overgrowth (lf)	0	$25	$0		

Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	160	$1,000	$160,000		160' moderate
Beaver Brook (Linden Street - Main Street)					
Sediment Removal (cy)	62	$125	$7,718		18" depth, 2" depth
Debris Removal (trees, leaves, etc) (lf)	30	$25	$750	$30,643	10 fallen tree <6", 4 trees 6"-12", trash, garbage, concrete, 3 tires, shopping cart
Cut Back Overgrowth (lf)	887	$25	$22,175		837' moderate, 50' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	180	$1,000	$180,000		180' moderate
Beaver Brook (River Street - Charles River)					
Sediment Removal (cy)	0	$125	$0		
Debris Removal (trees, leaves, etc) (lf)	5	$25	$125	$125	3 fallen tree <6"
Cut Back Overgrowth (lf)	0	$25	$0		
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Chester Brook (Lower Beaver Brook - Lyman Street)					
Sediment Removal (cy)	198	$125	$24,782		2" depth, 10" depth, 18" depth, 23" depth, 12" depth, 8" depth, 12" depth, 10" depth
Debris Removal (trees, leaves, etc) (lf)	30	$25	$750	$27,497	1 fallen tree <6", 6 trees 6"-12", 2 trees 12"-24", trash, shopping cart, brush
Cut Back Overgrowth (lf)	15	$25	$375		15' minor
Repair Retaining Walls (sf)	53	$30	$1,590		53' fair
Bank Stabilization	0	$1,000	$0		
Chester Brook (Lyman Street - Beaver Street)					
Sediment Removal (cy)	50	$125	$6,264		2" depth, 18" depth, 4" depth
Debris Removal (trees, leaves, etc) (lf)	20	$25	$500		6 fallen trees <6", 8 trees 6"-12"
Cut Back Overgrowth (lf)	272	$25	$6,800	$26,674	30' fair, 242' moderate
Repair Retaining Walls (sf)	437	$30	$13,110		437' fair
Bank Stabilization (lf)	0	$1,000	$0		
Chester Brook (Beaver Street - Stanley Road)					
Sediment Removal (cy)	134	$125	$16,782		18" depth, 10" depth, 5" depth, 6" depth, 4" depth, 2" depth
Debris Removal (trees, leaves, etc) (lf)	20	$25	$500	$220,107	1 fallen trees <6", 3 trees 6"-12", 2 trees 12"-24", concrete, bricks
Cut Back Overgrowth (lf)	527	$25	$13,175		178' minor, 316' moderate, 33' severe
Repair Retaining Walls (sf)	55	$30	$1,650		55' fair
Bank Stabilization (lf)	188	$1,000	$188,000		188' moderate
Chester Brook (Stanley Road - Lexington Street)					
Sediment Removal (cy)	69	$125	$8,681		3" depth, 18" depth, 6" depth
Debris Removal (trees, leaves, etc) (lf)	12	$25	$300	$39,056	3 fallen trees <6", 1 trees 6"-12", 1 tree 12"-24", trash
Cut Back Overgrowth (lf)	951	$25	$23,775		357' minor, 224' moderate, 370' severe
Repair Retaining Walls (sf)	210	$30	$6,300		104' good, 106' fair
Bank Stabilization (lf)	0	$1,000	$0		
Chester Brook (Lexington Street - Hardy Pond)					

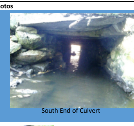
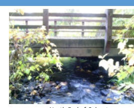
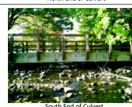
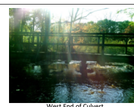
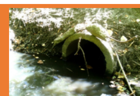
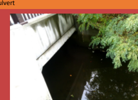
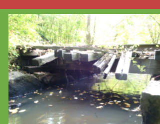
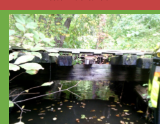
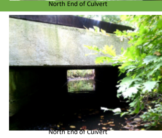
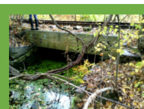
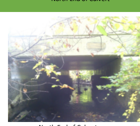
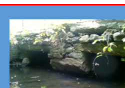
Sediment Removal (cy)	153	$125	$19,097	$24,972	4" depth, 8" depth, 6" depth, 2" depth, 18"depth, 2" depth, 1" depth, 18" depth
Debris Removal (trees, leaves, etc) (lf)	20	$25	$500		2 fallen trees <6", 3 trees 6"-12", 2 trees 12"-24", trash, tire
Cut Back Overgrowth (lf)	215	$25	$5,375		140' moderate, 75' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
West Chester Brook (Chester Brook - wetland/pond near Greenwood Lane)					
Sediment Removal (cy)	12	$125	$1,542	$4,867	4" depth
Debris Removal (trees, leaves, etc) (lf)	10	$25	$250		2 fallen trees <6", 3 trees 6"-12"
Cut Back Overgrowth (lf)	123	$25	$3,075		93' minor, 30' moderate
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
West Chester Brook (West Chester Brook split - Totten Pond Road)					
Sediment Removal (cy)	9	$125	$1,157	$17,187	3" depth
Debris Removal (trees, leaves, etc) (lf)	25	$25	$625		2 fallen trees <6", 3 trees 6"-12", 3 trees 12"-24", 2 trees 24"-36"
Cut Back Overgrowth (lf)	285	$25	$7,125		145' minor, 212' moderate, 69' severe
Repair Retaining Walls (sf)	276	$30	$8,280		224' fair, 52' needs work
Bank Stabilization (lf)	0	$1,000	$0		
West Chester Brook (Totten Pond Road - Winter Street and Prospect Hill Stream)					
Sediment Removal (cy)	49	$125	$6,176	$1,077,251	2" depth, 2" depth, 3" depth, 4" depth, 2" depth, 3" depth
Debris Removal (trees, leaves, etc) (lf)	65	$25	$1,625		4 fallen trees <6", 15 trees 6"-12", 8 trees 12"-24", tire, shopping cart
Cut Back Overgrowth (lf)	658	$25	$16,450		253' minor, 405' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	1053	$1,000	$1,053,000		296' moderate, 557' severe
West Chester Brook (Winter Street - inlet by Totten Pond Rd)					
Sediment Removal (cy)	83	$125	$10,417	$20,517	3" depth, 18" depth, 10" depth, 15" depth, 12" depth
Debris Removal (trees, leaves, etc) (lf)	12	$25	$300		1 fallen trees <6", 2 trees 6"-12", 1 trees 12"-24"
Cut Back Overgrowth (lf)	392	$25	$9,800		119' moderate, 273' severe
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Stoney Brook (Second Avenue - Weston)					
Sediment Removal (cy)	120	$125	$15,046	$17,146	6" depth, 6" depth, 3" depth, 3" depth, 6" depth, 12" depth, 3" depth, 12" depth
Debris Removal (trees, leaves, etc) (lf)	8	$25	$200		2 fallen trees <6", 1 trees 6"-12"
Cut Back Overgrowth (lf)	76	$25	$1,900		76' moderate
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		
Masters Brook					
Sediment Removal (cy)	0	$125	$0	$0	
Debris Removal (trees, leaves, etc) (lf)	0	$25	$0		
Cut Back Overgrowth (lf)	0	$25	$0		
Repair Retaining Walls (sf)	0	$30	$0		
Bank Stabilization (lf)	0	$1,000	$0		

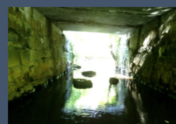
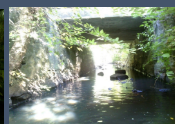
CULVERT SUMMARY

Summary of Data

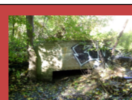
	number of culverts	cost
Total culverts	68	
Further assessment required	6	
remove culvert for stream restoration	5	
headwall repair/replace	3	
culvert repair	6	
culvert replacement	12	
stream maintenance	12	
no maintenance required	24	

Beaver Brook

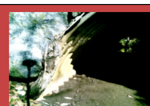
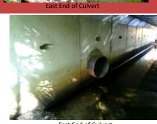
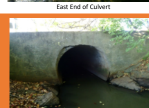
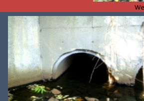
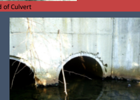
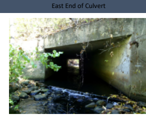
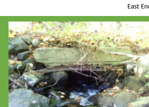
ObjectID	Street	Culvert Description	Culvert Length	Photos	Deficiencies	Recommendations	Comments	Inspection Cost	Repair/Replacement Cost
13	Trapelo Road	6.5' wide by 5.5' high concrete and stone box culvert beneath road crossing. Road is 9.5' above stream bottom.	75 ft +/-	 North End of Culvert  South End of Culvert	The center of the culvert roof is caving in and there is exposed rebar	replace culvert			$1.5-$2.0 Million Costs include culvert replacement only. The City plans for installation of a flood wall and new sidewalk. Additional cost $0.7-$1.0 Million
No line ID (Pt ID 51)	Beaver Brook Reservation Pedestrian Bridge	22' wide by 2' high beneath walking bridge. 3.75' to bridge platform.	15 +/-	 North End of Culvert	-	None			
12	Beaver Brook Reservation Pedestrian Bridge	28' wide by 1.75' high beneath walking bridge, 3.75' to bridge platform	10 +/-	 South End of Culvert	-	None			
No Line ID (Pt ID 47)	Beaver Brook Reservation Pedestrian Bridge	35' wide by 2' high	6 ft +/-	 West End of Culvert	-	None			
No Line ID (Point ID 110)	Warrendale Appliances Driveway	24" diameter reinforced concrete culvert under driveway	unknown	 North End of Culvert	Exposed rebar and concrete on top of culvert pipe. 4" of sediment in outlet.	Replace headwall			$50,000
5	Beaver Street	14' wide by 5' high reinforced concrete box culvert	40 ft +/-	 North End of Culvert  South End of Culvert	Metal section of culvert blocking part of the opening on the North End. 4" of sediment inside Culvert.	Remove Sediment			Need more info on the metal blocking the cuvlert. When the new culvert was built it had three sides and no bottom. There may not be a need to remove sediment.
4	Inactive Railroad Bridge	8' wide by 3' high inactive railroad bridge	6 ft +/-	 North End of Culvert  South End of Culvert	Old railroad ties are rotting	Repair crossing if considering a rail trail; otherwise, remove crossing for stream restoration			$75,000 assuming that the crossing is removed with minor stream restoration. $200,000 for removing and installation of a trail bridge.
3	Active Railroad Bridge	10' wide by 4' high reinforced concrete	30 ft +/-	 North End of Culvert  South End of Culvert	-	none			
2	Inactive Railroad Bridge	8' wide x 3' high reinforced concrete box culvert	20 ft +/-	 North End of Culvert  South End of Culvert	cracks are forming in concrete	Repair crossing if considering a rail trail; otherwise, remove crossing for stream restoration			$100,000 assuming that the crossing is removed with minor stream restoration. $250,000 for removing and installation of a trail bridge.
7	Active Railroad Bridge	8' wide by 5' high railroad bridge	40 ft +/-	 North End of Culvert  South End of Culvert	-	None			
6	Inactive Railroad Bridge	8' wide by 10' high box culvert	28 ft +/-	 North End of Culvert  South End of Culvert	-	None			
8	Linden Street	Two 5' stone box culverts	50 ft +/-	 East End of Culvert  West End of Culvert	Exposed rebar in headwall	Further assessment is required			Replace Culvert per Bob Winn. $1.25 - $1.5 Million
9, 32	Inactive Railroad Bridge	Two 4' stone box culverts	80 ft +/-	 West End of Culvert  East End of Culvert	-	None	These culverts will be addressed under the Wayside Trail Project		Could be part of the Beaver Brook Phase II Flood Mitigation Project - Brook Cleaning and Culvert Inspection - This was propsoed on the segment of Beaver Brook along Linden Street. Total project cost $500,000

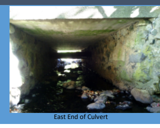
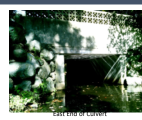
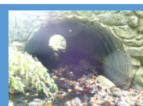
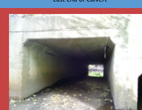
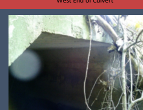
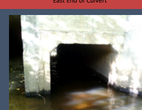
10	Linden Street	inlet: 8' box culvert outlet: 24' wide x 6' high at center corrugated metal pipe culvert	120 ft +/-	 East End of Culvert  West End of Culvert	-	None			Priority 1 culvert replacement. This is a major bottleneck just downstream of confluence of Beaver Brook with Chester and Wester Chester Brooks. This culvert was designed to be replaced in 1993 by the then MDC (DCR) but never built. The downstream end was built as planned. Cost of cuvlert repalcement $3.0 Million. Managing brook flow and existing utility crossing will be a significant portion of the cost.
11	Active Railroad Bridge	10' high x 6'wide stone masonry culvert	45 ft +/-	 West End of Culvert  East End of Culvert	Some masonry blocks have fallen from walls inside of culvert	Repair culvert walls			This is under the commjuer rail bridge and not City-owned. If the Linden Street culvert is replaced (above) this will need to be at least rehabilitated /or repalced based on the H/H that is being completed. Anticipated repalcement cost $3.5 Million.
40	Inlet at Main Street, outlet at Charles River	Inlet: 13' high x 8.5' w concrete culvert outlet: two 4' high x 12' wide concrete culverts	3,015 ft +/-	 Upstream End of Culvert  Downstream End of Culvert	-	None			

Clematis Brook

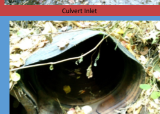
Culvert Line Object iD	Street	Culvert Description	Culvert Length	Photos	Deficiencies	Recommendations		Inspection Cost	Repair Cost
38	driveway	4' wide x 2' high concrete box culvert	25 ft +/-	 East End of Culvert  West End of Culvert	height of culvert was uncertain due to excessive sedimentation	Remove sediment and debris			$50,000
39	driveway	5' wide x 3' high concrete culvert	90 ft +/-	 East End of Culvert	Culvert is filled with sediement and headwall is open	replace culvert if access road is necessary; otherwise, remove culvert and road for stream restoration			$75,000 assuming that the crossing is removed with minor stream restoration. $200,000 for culvert replacement
No line ID (Pt ID 169)	Chapel Road	3' diameter concrete culvert flows into downstream driveway culvert	50 ft +/-	 North End of Culvert	debris in inlet, headwall and culvert are cracking	repair culvert headwall if access road is necessary; otherwise, remove culvert and road for stream restoration			$75,000

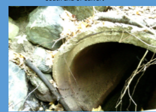
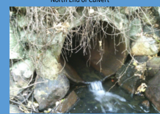
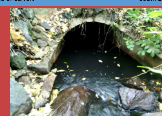
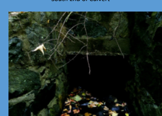
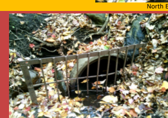
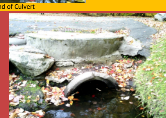
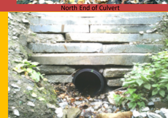
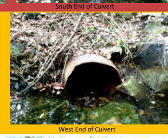
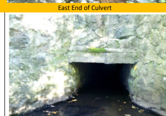
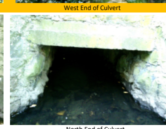
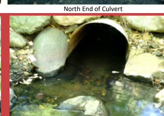
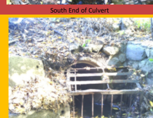
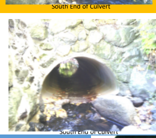
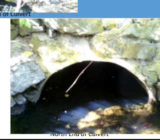
Chester Brook

Culvert Line Object ID	Street	Culvert Description	Culvert Length	Photos	Deficiencies	Recommendations		Inspection Cost	Repair Cost
37	Driveway off of Lexington Street	10' wide x 6' high corrugated metal pipe culvert	65 ft +/-	 West End of Culvert  East End of Culvert	some overgrowth around culvert and a few inches of sediment in pipe	cut back overgrowth			**$25,000**
36	Driveway off of Lexington Street	10' wide x 5' high concrete box culvert. Outfall in culvert 15' from east end	70 ft +/-	 West End of Culvert  East End of Culvert	-	None			
No line ID (Pt ID 3 at inlet, 119 at outlet)	Lexington Street	64" concrete pipe culvert	1,325 ft +/-	 East End of Culvert  West End of Culvert	scouring at outlet, culvert and headwall is cracking	Repair outlet headwall			$40,000 Repair headwall and stabilize with riprap
23	Bishops Forest Drive	Two 48" Reinforced Concrete Pipe Culverts	85 ft +/-	 West End of Culvert	Debris blocking culvert inlet. Couldn't access outlet for thorough inspection	Clear debris			$10,000 part of group of cleaning debris from culvert. If this is the only one City crews can do it.
No Object ID (Pt ID 110)	YMCA Driveway	Two 36" concrete pipe culverts	90 ft +/-	  East End of Culvert	headwall and wings undermined at culvert outlet. Inlet is located behind a dam	repair culvert			The dam is a flow control structure and is in poor structural condition. Replace flow control structure and repair the headwalls and stabilize channel with rip-rap. Ownership between City and YMCA will need to be resolved and has been an issue. Anticipated construction cost $750,000. A modified flow control structure can provide additional flood storage.
35	John F. Kennedy Middle School Exit Driveway	8' wide x 5' high concrete box culvert	75 ft +/-	 East End of Culvert	-	None			
24	Overgrown Dirt Road (No longer used)	30" stone masonry box culvert	25 ft +/-	 West End of Culvert  West End of Culvert	Root growing through roof, stones falling out of culvert walls	Remove crossing for stream restoration			**This currently acts as a flow control structure creating flood storage upstream. Removal of this may not be permittable. Replacing it in combination with an extended berm to further enhance flood storage could be an option. $250,000**

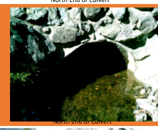
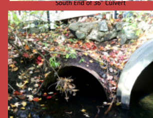
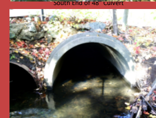
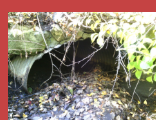
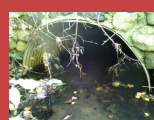
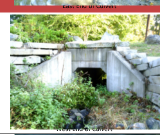
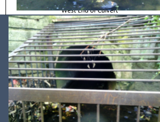
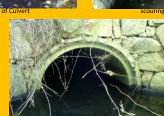
22	John F. Kennedy Middle School Entrance Driveway	8' wide x 5' high concrete box culvert	70 ft +/-	 West End of Culvert  East End of Culvert	Concrete is falling off of roof and rebar is exposed	Repair culvert roof			$100,000
No Line ID (Point ID 96)	Stanley Road	10' wide x 5' high concrete box culvert	50 ft +/-	 East End of Culvert	Concrete is cracking inside of culvert and stones have come loose and fallen into culvert	Replace culvert			$1.5 Million
19, 20 21	501 Lexington Street Driveway	Three 10' wide x 3.5' high concrete box culverts	60 ft +/-	 West End - left culvert  West End - right culvert  East End - center culvert  East End - right culvert	-	None			
No Line ID (Pt ID 70)	Chapel Hill - Chauncy Hall School Back Driveway	6' wide x 4' high box culvert	20 ft +/-	 West End of Culvert	Concrete is cracking inside of culvert and on headwall	Repair culvert and headwall			$1.0 Million
17	Driveway crossing	10' wide x 6' high concrete box culvert	50 ft +/-	 West End of Culvert  East End of Culvert	-	None			
No Line ID (Pt ID 29)	Pedestrian Bridge	15' wide x 7' high culvert arch with stone walls	10 ft +/-	 West End of Culvert  West End of Culvert	-	None			
18	Beaver Street	8' corrugated metal pipe culvert	65 ft +/-	 West End of Culvert  East End of Culvert	metal pipe is rotting	replace or reline culvert			Repalce culvert. $1.5 Million
16	DPW Bridge	8' wide x 4' high concrete box culvert	80 ft +/-	 West End of Culvert  East End of Culvert	sediment build up at outlet	Remove sediment			$25,000
15	DPW Bridge	4' wide x 5' high concrete box culvert	65 ft +/-	 West End of Culvert  East End of Culvert	Overgrowth and sediment blocking culvert. Headwall is cracking	remove sediment and overgrowth, repair culvert			$50,000
No Line ID (Pt ID 264)	DPW Bridge	5' box culvert; could not locate inlet	unknown	 South End of Culvert - Left	-	None			
14	Lyman Street	Two 8' x 8' stone box culverts	50 ft +/-	 South End of Culvert - Left  South End of Culvert - Right  North End of Culvert - Right  North End of Culvert - Left	-	None			

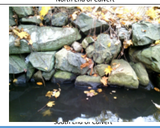
West Chester Brook

Culvert Line Object ID	Street	Culvert Description	Culvert Length	Photos	Deficiencies	Recommendations		Inspection Cost	Repair Cost
No Line ID (Pt ID 165)	Parking Lot	24" cast iron pipe with grate cover	unknown	 Culvert Inlet	debris blocking inlet	Remove Debris			City
52	Driveway off Winter Street	18" corrugated plastic pipe	75 ft +/-	 South end of culvert	Culvert is crushed	Replace Culvert			$150,000

No line ID (Pt ID 151)	Driveway off Winter Street	18" cast iron pipe	75 ft +/-	 South End of Culvert  North End of Culvert	pipe is rusted and outlet is perched. Sediment at outlet	replace culvert to meet stream crossing standards			$200,000
51	Driveway off Winter Street	30" reinforced concrete pipe	80 ft +/-	 South End of Culvert  South End of Culvert	Rebar Exposed in Culvert on South End, Overgrowth at north end	replace culvert to meet stream crossing standards			$200,000
No line ID (Pt ID 144)	Driveway off Winter Street	30" reinforced concrete pipe	45 ft +/-	 South End of Culvert	Couldn't access North End of Culvert due to overgrowth and fence blocking access	Clear overgrowth			$50,000
55	Totten Pond Road	36" corrugated metal pipe (inlet), 36" reinforced concrete pipe (outlet) culvert with stone headwall	100 ft +/-	 West End of Culvert  East End of Culvert	culvert is partially collapsed under road	Further assessment is required			Assume replacement. $500,000
1	Prospect Hill Park Road	24" stone box culvert	50 ft +/-	 South End of Culvert  North End of Culvert	Debris completely blocking culvert inlet. Stones and large rocks immediately downstream of culvert	Replace to meet stream crossing standards			$250,000
53	Prospect Hill Park Road	30" x 30" stone box culvert	60 ft +/-	 South End of Culvert  North End of Culvert	Logs placed at outlet	Replace to meet stream crossing standards			$300,000
No line ID (Pt ID 168)	Prospect Hill Park Road	24" corrugated metal pipe culvert. Couldn't access inlet	unknown	 North End of Culvert	bottom of pipe is rusted out	Further investigation required			Assume replacement. $250,000
50	Prospect Hill Park Road	30" reinforced concrete pipe culvert	40 ft +/-	 North End of Culvert  South End of Culvert	8" of sediment at trash trap	Remove sediment			Ian has a better idea of this and can ask for his input.
49	Prospect Hill Park Road	inlet: 18" corrugate plastic pipe culvert outlet: 24" metal pipe	40 ft +/-	 East End of Culvert  West End of Culvert	outlet pipe is corroded	further investigation, increase size to meet stream crossing standards			Ian has a better idea of this and can ask for his input.
48	Prospect Hill Park Road	3' x 3' stone box culvert	60 ft +/-	 South End of Culvert  North End of Culvert	-	None			
47	Prospect Hill Park Road	30" corrugated metal pipe culvert	40 ft +/-	 South End of Culvert  North End of Culvert	pipe is rusted and outlet is blocked by debris	Clear debris and replace culvert			Replace culvert. $350,000
46	Totten Pond Road	36" reinforced concrete pipe with trash trap at inlet 36" corrugate plastic pipe culver (outlet)	285 ft +/-	 South End of Culvert  North End of Culvert	-	Further investigation			Needs new headwalls and may be culvert replacement. $500,000
45	245 Totten Pond Road Driveway	48" diameter corrugated metal pipe culvert	25 ft +/-	 South End of Culvert  North End of Culvert	-	None			
No line ID (Pt ID 111)	237 Totten Pond Road Driveway	Two 30" Diameter Corrugate Plastic Pipe Culverts with Concrete Headwalls	25 ft +/-	 South End of Culvert	bottom of culvert is rusted out	reline or replace culvert			Reline culverts under the driveways. $100,000
44	231 Totten Pond Road Driveway	48" corrugated metal pipe culvert	30 ft +/-	 South End of Culvert  North End of Culvert	-	None			

Stoney Brook

Culvert Line Object iD	Street	Culvert Description	Culvert Length	Photos	Deficiencies	Recommendations		Inspection Cost	Repair Cost
43	221 Totten Pond Road Driveway	48" corrugated metal pipe culvert	30 ft +/-	 South End of Culvert  North End of Culvert	-	None			
42	211 Totten Pond Road Driveway	48" corrugated metal pipe	30 ft +/-	 South End of Culvert  North End of Culvert	Headwall is cracking	Repair headwall			$50,000
41	203 Totten Pond Road Driveway	48" corrugated metal pipe culvert	40 ft +/-	 South End of Culvert  North End of Culvert	-	None			
No line ID (Pt ID 100)	Pond End Road Driveway	Three 30" reinforced concrete pipe culverts	115 ft +/-	 West End of Culvert	-	None			
25, 26	Pond End Road Driveway	Two culvert pipes: 36" diameter (RCP at inlet, CMP at outlet) and 48" diameter (RCP)	65 ft +/-	 South End of 36" Culvert  South End of 48" Culvert  North End of 36" Culvert  North End of 48" Culvert	Sediement buildup at outlet	remove sediment			Combined project with 25, 26, 27, 28 and 29 to include sediment removal from culverts and stream, remove overgrowth and stream stabilization. Toal cost $200,000
27, 28, 29	Totten Pond Road	Three 48" diameter reinforced concrete pipe culverts	110 ft +/-	 West End of Culvert  West End of Culvert  East End of Culvert  East End of Culvert	Sediment and overgrowth at inlet and outlet	Remove sediment and overgrowth			
58	Worcester Lane	42" wide x 48" high concrete box culvert with concrete headwall and wings	40 ft +/-	 East End of Culvert  West End of Culvert	-	None			
33, 34	Worcester Lane	Two 42" diameter reinforced concrete pipe culverts	60 ft +/-	 West End of Culvert  East End of Culvert	-	None			
30	Bacon Street	48" diameter reinforced concrete pipe with trash rack at inlet	215 ft +/-	 Southeast End of Culvert  Northwest End of Culvert	Undermined around culvert, scour upstream, debrus in trashrack	clear trashrack and repair culvert at inlet			$40,000
57	Bacon Street	24" stone box culvert with trash rack at inlet	55 ft +/-	 North End of Culvert  South End of Culvert	Debris in trashrack, sediment upstream	Remove debris in trashrack and sediment			$25,000
56	Lexington Street	36" diameter reinforced concrete pipe with trashrack at inlet	545 ft +/-	 South End of Culvert  scouring around culvert inlet  North End of Culvert	culvert is undermined and water is flowing into bank adjacent to culvert inlet. Scour hole downstream.	Further assessment is required			Priority 1 culvert replacement. The storage place replaced and rehabilitated portion of the drain and culvert through their property and the City was going to replace the portion of culvert under Lexington Street. $1.5 Million

No Line ID (Pt ID 74, 75)	Driveway in Weston	6' wide x 9" high box culvert	18 ft +/-	 North End of Culvert  South End of Culvert	Homeowner would like to replace culvert due to safety concerns (ownership is uncertain)	None			
31	West Street	unknown	40 ft +/-	 South End of Culvert  North End of Culvert	culvert is fully submerged and buried in sediment.	Located in Weston.			Minimal
No line ID (Pt ID 76)	153 Second Ave Driveway	5.5' corrugated metal pipe. Couldn't locate outlet	unknown	 Culvert Inlet	culvert is crushed, debris in inlet	Further assessment is required			$1.0 - $1.25 Million for culvert replacement in drainage easement

Attachment C. UHI Memo

55 Walkers Brook Drive, Suite 100, Reading, MA 01867
Tel: 978.532.1900

MEMORANDUM

TO: Catherine Cagle, Planning Director, City of Waltham

FROM: Amanda Kohn and John Frey, Weston & Sampson

DATE: December 2020

SUBJECT: Urban Heat Island Assessment

Waltham is projected to experience both warmer average temperatures, as well as intensification of extreme temperatures in summer as a result of climate change. Based on temperature projections published on resilientMA.org, the number of days per year in Waltham 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 Waltham, 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 Waltham are exposed to heat regularly through walking, biking, and public transit use.

Assessment Approach

Urban Heat Island (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 Waltham 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 Waltham 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 r^2 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 90ºF, 95ºF and 100ºF 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 Waltham when average temperatures in the City correspond to 90ºF, 95ºF and 100ºF are illustrated in Figure 1. 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 4 – 6ºF more** than the average air temperatures over greener or more pervious spaces.

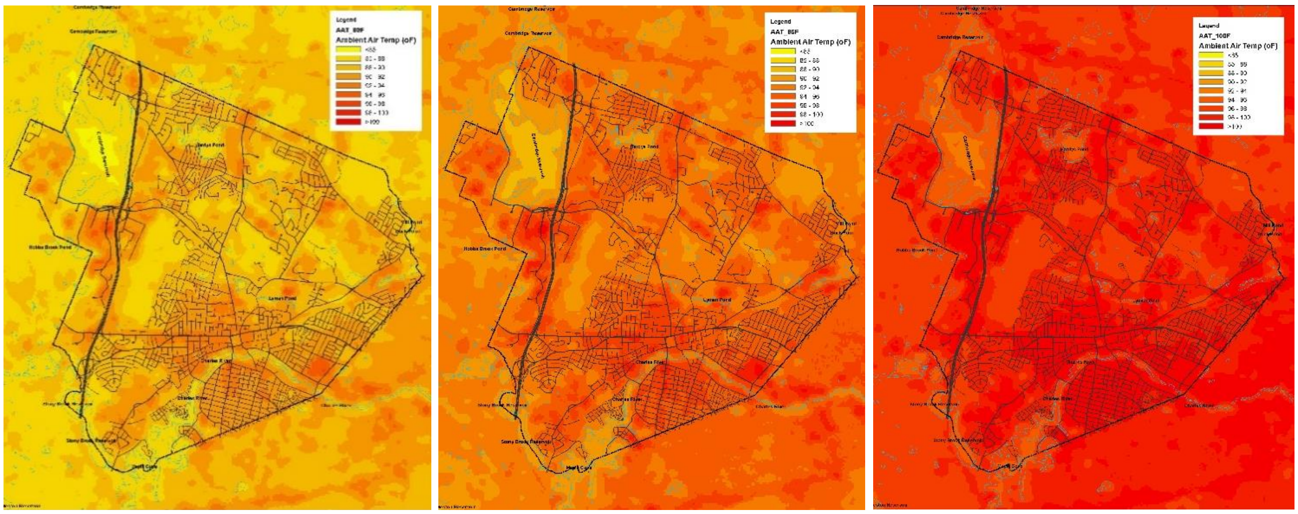


Figure 1: Urban Heat Island (UHI) effect based on estimated ambient air temperature in Waltham on an average 90ºF, 95ºF, and 100ºF day (left to right)

The ambient air temperature UHI map for Waltham was then used to evaluate the cooling benefits of green infrastructure implementation in Beaver, Clematis, Chester, West Chester, Masters, Plympton, and Hobbs Brook watersheds. 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**.

A second comparison was completed to determine the cooling impact of tree canopy cover on urban heat island effect by comparing the change in ambient air temperature as a function of change in tree canopy cover in the City. Tree locations and tree canopy from ongoing City surveys were combined with state forest canopy data to create a city-wide tree canopy feature. As the surveys are ongoing, the comparison is based on best data available. Gaps in tree canopy data include additional street tree locations and trees on private properties / backyards. However, with the best data available a statistically averaged, positive slope confirmed that the UHI corresponding to ambient air temperature is expected to decrease as non-canopy covered areas are reduced by green infrastructure projects like reforestation. **The resulting relationship demonstrates that for every 10% increase tree canopy cover, approximately 0.2°F of cooling can be achieved**.

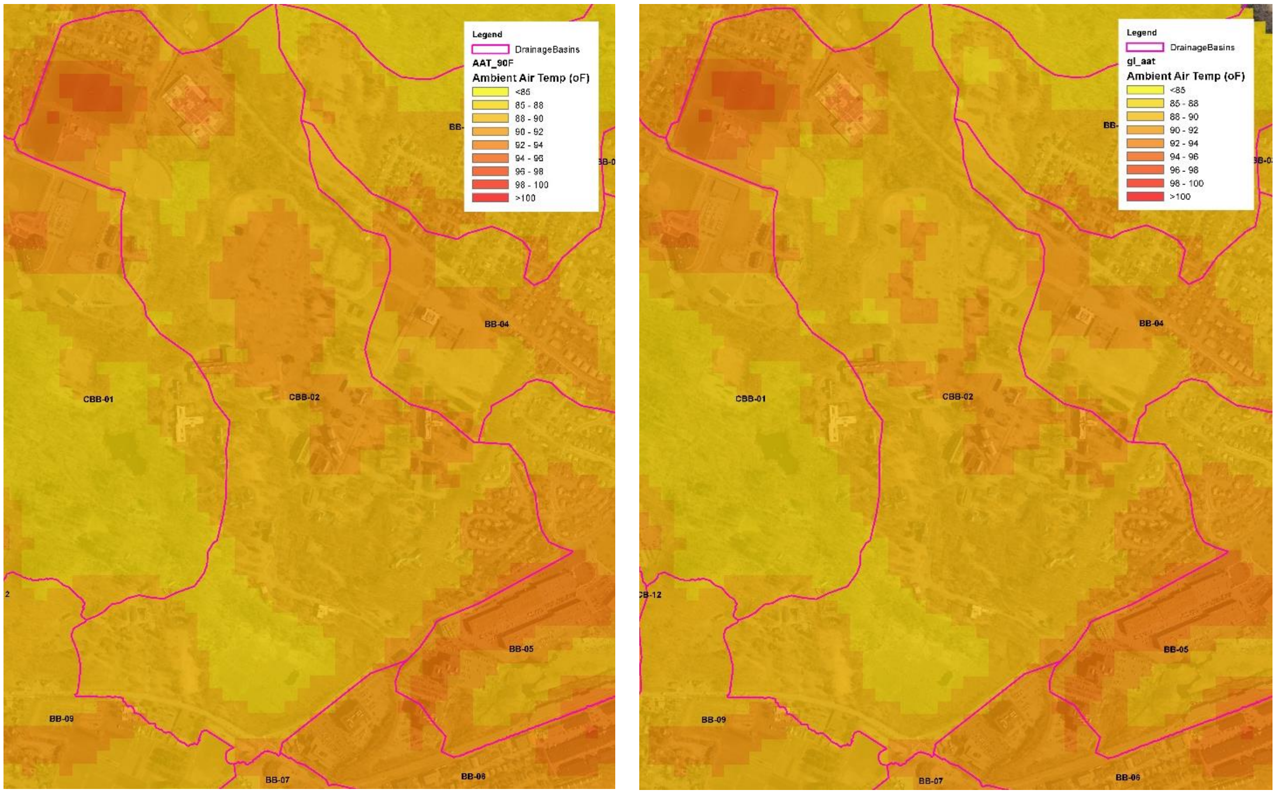


Figure 2: Estimated change in ambient air temperature for the Fernald School Campus, part of Clematis Brook subbasin CBB-02, under existing conditions (left) and proposed conditions with green infrastructure implementation (right).

Tree Benefits

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 Waltham. 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 Waltham was done for existing impervious cover (buildings, roads and other), trees and shrubs, grass and herbaceous cover, soil and bare ground, and waterbodies as cover classes. Over 1500 points were processed in the Tool to realize a high-resolution analysis (recommended to use minimum of 500 points or more at a City scale) (Fig. 3). Based on these 1500 points sampled using the Tool, the City has approximately 39% impervious cover, and 56% vegetated cover (Fig. 4).

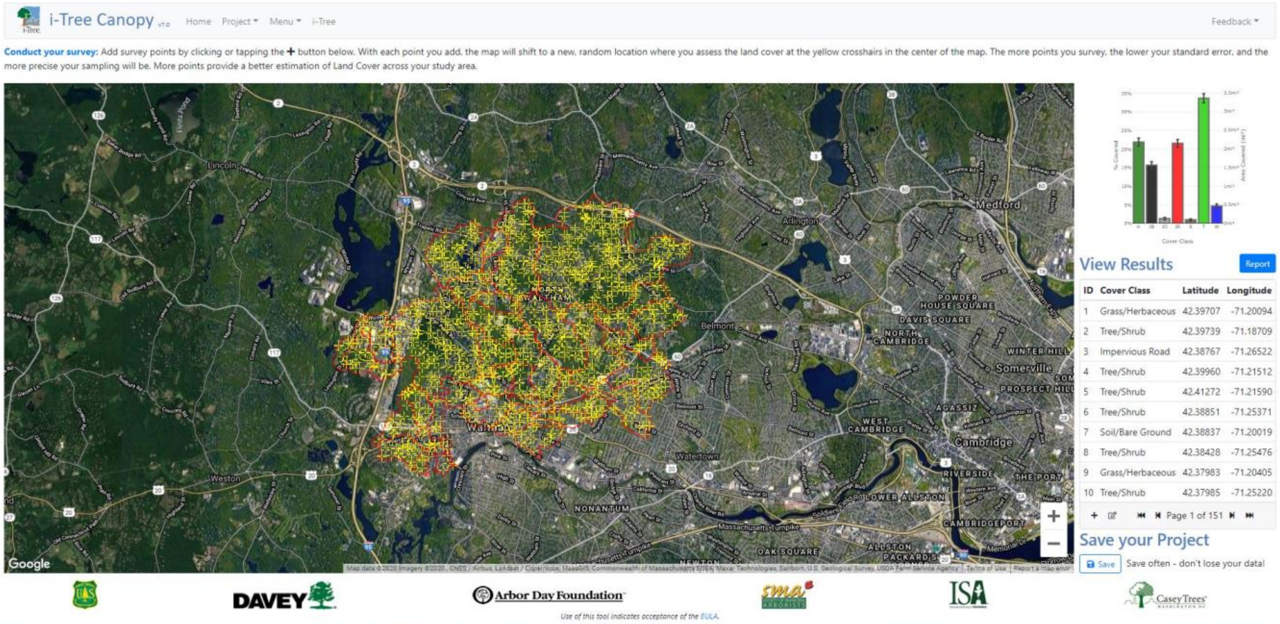


Figure 3. In process screen shot of i-Tree Canopy Tool using selected major watersheds.

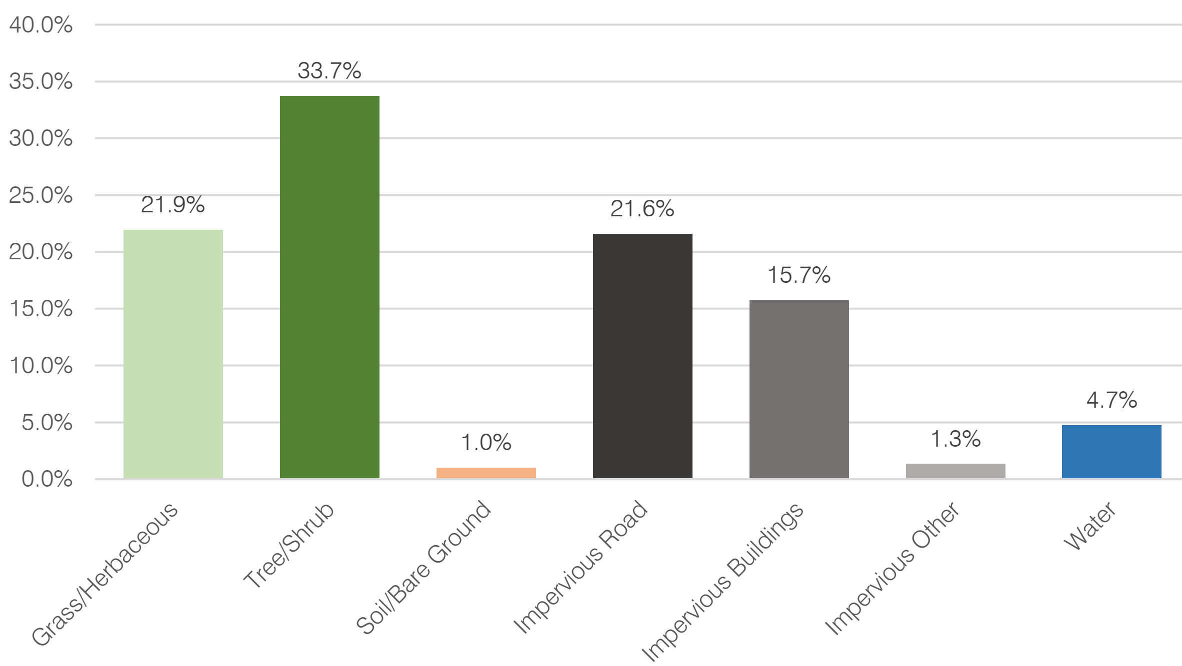


Figure 4. Waltham i-Tree Landcover

The ecosystem benefits of tree canopy in Waltham estimated using the i-Tree Tool are presented in Tables 1a and 1b. It is estimated that the existing tree canopy in Waltham can sequester carbon up to 2.93 kilotons (kT) annually, which is comparable to 10.73 kT of CO_2 equivalents (Table 1a). In addition, the City's existing canopy is also proposed to remove over 1,933 lbs. of Carbon Monoxide, and over 35,171 lbs. of particulate matter annually (Table 1b).

The hydrological benefits of tree canopy estimated from the i-Tree Tool are presented in Table 2. Existing tree canopy cover in Waltham saves the City over 1.5 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 1a. Tree Benefit Estimates for Carbon Sequestration and Storage

Description	Carbon kT* (±SE**)	CO_2 Equiv. kT* (±SE**)	Value (±SE**)
Sequestered annually in trees	2.93 (± 0.11)	10.73 (±0.39)	$499,199 (±18,068)
Stored in trees (Note: this benefit is not an annual rate)	73.51 (±2.66)	269.53 (±9.76)	$12,536,772 (±453,766)

Table 1b. Tree Benefit Estimates for Air Pollution

Description	Amount in lbs (±SE)	Value (±SE)
Carbon Monoxide removed annually	1,933.46 (±69.98)	$82 (±3)
Nitrogen Dioxide removed annually	10,542.71 (±381.59)	$142 (±5)
Ozone removed annually	105,000.72 (±3,800.48)	$7,374 (±267)
Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	35,171.33 (±1,273.02)	$5,354 (±194)
Particulate Matter less than 2.5 microns removed annually	5,102.16 (±184.67)	$15,244 (±552)
Sulfur Dioxide removed annually	6,643.75 (±240.47)	$25 (±1)
Total	**164,394.14**	**$28,221**

Table 2. Tree Benefit Estimates for Hydrological Parameters

Benefit	Amount gallon (±SE)
Avoided Runoff	1110(±40.0)
Evaporation	91,550 (±3,310)
Interception	92,060 (±3,330)
Transpiration	123,880 (±4,480)
Potential Evaporation	693,690 (±25,110)
Potential Evapotranspiration	565,990 (±20,490)
Total	**1,568,280**

Recommendations

As climate change increasingly causes risk and stress to the City in the form of extreme storm events and heat, planting trees and increasing canopy is a great, nature-based solution that can mitigate the effects of climate change through carbon sequestration and help our urban areas adapt by creating shade and respite within the pedestrian realm. When planting and reforestation is combined with reduction in impervious surfaces, like with street-side swales or daylighting streams, the potential for urban heat reduction and co-benefits of water quality and public space improvements are readily apparent. The following recommendations identify projects and strategies to help Waltham improve its tree canopy.

Assessments and Monitoring

1. Complete city-wide tree survey (street tree points with diameter measurements, or tree canopy polygons for smaller, inaccessible massing of trees and shrubs).
2. Work with Tree Warden to identify forests and canopies of concern (fire-susceptible, tree die-off, invasive species, overgrown understory preventing typical plant succession, in need of maintenance).
3. Identify replacement tree species that include drought tolerant and warmer weather species (Mid-Atlantic Hardiness Zones) considering future climate.
4. Coordinate with Parks Department to replace dead / dying trees and find open park space for increasing canopy, i.e. between baseball fields.
5. Develop maintenance approach and schedule for improving and extending existing tree canopy.

Potential Projects

The green infrastructure opportunities projects identified in this study include typologies, like bioretention, swales, floodplain restoration, stream restoration, reforestation, and structural canopies, that provide opportunities for increasing tree canopy throughout the City. The list below focuses on a few of the larger tree canopy projects as well as urban heat reduction strategies.

Table 3. Tree Canopy and Urban Heat Reduction Strategies

Location	Description	Tree Canopy Improvement (sq.ft.)
Fernald Campus	Removal of concrete foundations (former buildings/dorms), daylighting of stream, and reforestation within the Clematis Brook and Beaver Brook Watersheds.	1,053,930
Mackerel Hill	Removal of abandoned parking area off of Trapelo Road and reforestation	827,080
National Archives	Planting new trees in open grass areas and removal of unused paved area behind building resulting	119,000
Prospect Hill Park	Potential for stream restoration and realignment, removal of wide parking area, park design, and new tree plantings	122,340
McDevitt Middle School Field	Create potential for floodable field or underground stormwater storage surrounded with new tree canopy	182,245
Urban Wild near Meadow Green Nursing Home	Potential for stream restoration, clearing debris, and replanting new trees.	
Square Pond Restoration	Predominately a forested wetland, potential for increased storage and need for flood tolerant species, clearing debris, and replanting canopy	995,410
Waltham High School Parking Lot	Reduction of pavement, realignment of parking spaces and inclusion of tree planters throughout the lot	
YMCA Parking Lot	Reduction of pavement, realignment of parking spaces and inclusion of tree planters throughout the lot	
City Parking Garage in Downtown	Install a new green roof of solar roof on the parking garage to reduce impervious surface within City center	

Additional Strategies

1. Within denser, narrower, downtown areas of Waltham, consider more built structures to increase shade and improve pedestrian experiences.
2. Consider seasonal street closures where covered outdoor areas can be created for markets, dining, and events.
3. Public engagement and outreach to show the impacts of tree planting on urban heat
4. Work with community groups to help with mapping trees and tree planting initiatives

References

United States Environmental Protection Agency. “Green Infrastructure: Reduce Urban Heat Island Effect”. https://www.epa.gov/green-infrastructure/reduce-urban-heat-island-effect

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Attachment D. Regional Coordination Memo

55 Walkers Brook Drive, Suite 100, Reading, MA 01867
Tel: 978.532.1900

M E M O R A N D U M

TO: Catherine Cagle, Planning Director, City of Waltham

FROM: Amanda Kohn and Steve Roy, Weston & Sampson

DATE: December 2020

SUBJECT: Regional Resilience

The City of Waltham, located 11 miles west of Boston and 7 miles west of Cambridge, is bound and intersected by the Charles River and several major tributaries. Most notably, Hobbs Brook and Stony Brook framing Waltham's western edge have drainage areas that account for 29.7% of Waltham's total area (Fig.1.) These two water systems include reservoirs, the Cambridge / Hobbs Brook Reservoir and Stony Brook Reservoir, that are owned by the City of Cambridge and used for drinking water supply. Lexington, Lincoln, Weston, and Waltham account for 9%, 38%, 36%, and 17% of the City of Cambridge Drinking Water Supply watershed lands respectively, which are designated for protection under state regulations. The purpose of this document is to provide an overview of the drainage areas and stormwater management practices in Waltham that contribute to the Cambridge Drinking Water System, including surface water protections, increases in development and impervious surfaces, climate change impacts, and on-going planning initiatives culminating in a list of action items.

Surface Water Protection

The State of Massachusetts Drinking Water Regulations (310 CMR 22.00) establishes Surface Water Supply Protections Areas (SWPA) for public drinking water supplies delineated into 4 zones: Zone A, Zone B, Zone C, and Zone R. Zone A is the closest to the water source representing the land area from the water surface and upper boundary of the bank to a 400-foot lateral distance. Zone A protection zones also include a 200-foot buffer from the upper boundary of the bank for tributaries. Zone B represents the lesser of the land area within one-half mile of the upper boundary of the bank or the edge of the watershed. Zone C represents the remaining watershed areas not included in Zones A and B. Zone R includes the reservoir or surface water body to its boundary.

The same state regulations include protection areas for public water supply groundwater resources. Wellhead protection areas are separated into 3 types: Zone I, Zone II, and Interim Wellhead Protection Areas (IWPA). Zone I areas have radii defined by gallon per day (gpd) yields with a maximum protective radius of 400 feet for 100,000 gpd or greater and 250 feet for tubular wellfields. Zone II areas are determined by hydro-geologic modeling and must be approved by Mass Department of Environmental Protection's (DEP) Drinking Water Program. IWPA's are established when Zone II's have not been approved or have not been studied. The radii for IWPA's are dependent on pumping rates and have a range of 400 feet to 2,640 feet (one-half mile).

The total area of SWPA Zones (A, B, and C) within Waltham for the Cambridge Reservoir, Stony Brook Reservoir and Hobbs Brook is 2,618.28 acres. Additionally, the Kendall Green Tubular Wells located in Weston, MA have an IWPA that extends into the western edge of Waltham accounting for 39.4 acres (Fig. 3).

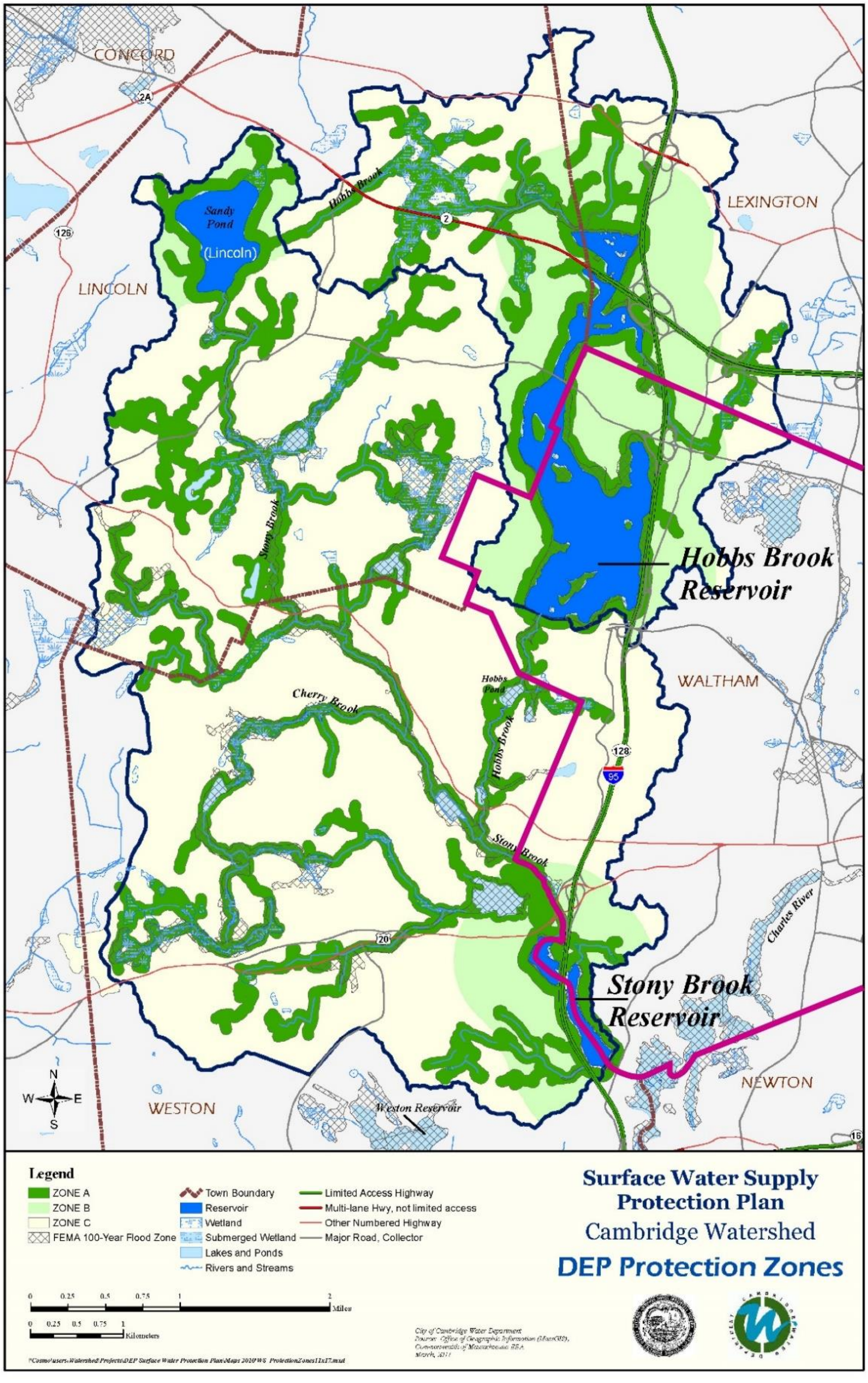
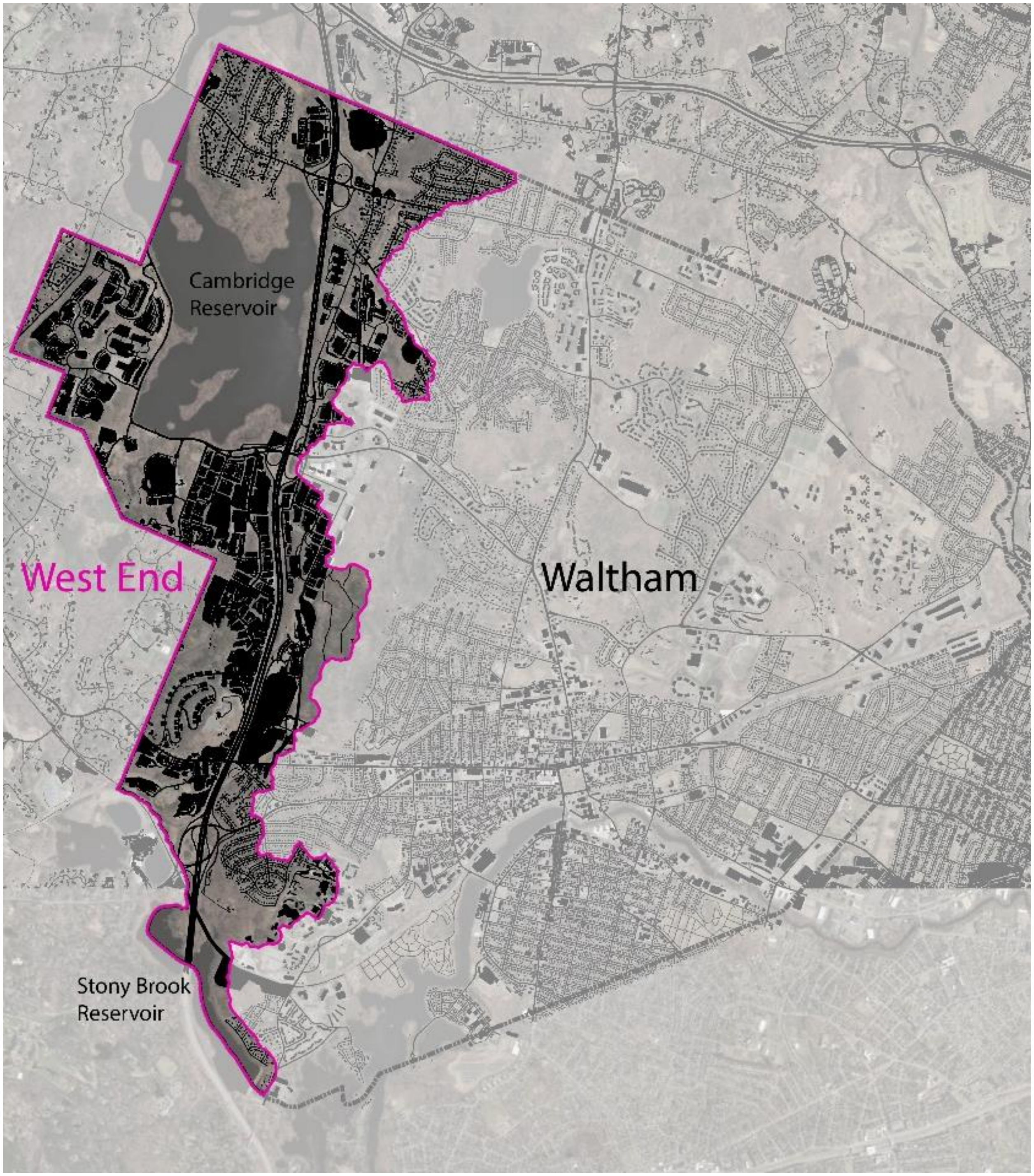


Figure 1. Cambridge Drinking Water Supply Watershed. Surface Water Supply Protection Plan. October 2011

Imperviousness

Commercial landuse and development is redifining the West End in Waltham, spurred by accessibilty from Interstate 95. Car-centric offices, warehouses and retail spaces have been built along Border Ave, 5th Ave, 4th Ave, 3rd Ave, Tower Rd, Bear Hill Rd, and 2nd Ave. Several newer developments include green infrastructure or low-impact development to account for stormwater runoff from the current 1–year, 24–hour storm event (Figure 3a & 3b). But new roads, boxstore and strip mall roofprints, and large parking areas are increasingly impacting storm runoff volumes and water quality.



Within Waltham's SWPA, impervious surfaces account for over 830 acres or 33.6% of the total area with some subbasins recording 65% imperviousness. This represents significant challenges to maintaining water quality now and into the future. Highly impervious areas adversely affect water quality due to faster rates of runoff, lower groundwater recharge rates, and increased erosion which can compromise green infrastructure and natural systems built to mitigate stormwater runoff. Vehicular associated pollutants, like exhaust, metals, oil, and dirt, are deposited on impervious surfaces and picked up by runoff. In the winter, threats of ice and snow result in salting of roads and parking areas which cause higher chloride levels in water and groundwater and plant death for less salt tolerant species.

Figure 3a & 3b. Green Infrastructure BMP's incorporated into new Reservoir Woods Development

Climate Change Impacts

Magnifying the challenges for Waltham's SWPAs is the threat of climate change. Rainfall and Drought represent a spectrum of increasingly extreme conditions projected for Greater Boston area. Both in near- and long-term modeling projections, storm intensities and frequencies will increase resulting in more flooding in areas known to flood as well as flooding in areas beyond FEMA's 100-year floodplain. Low-lying pervious areas can become water-logged during storm events and start to sheet runoff similar to impervious areas. Additionally, some vegetation and plant death can occur if root systems are inundated for long periods of time.

Drought and heat will adversely impact water quality. Waltham is projected to experience both warmer average temperatures, as well as intensification of extreme temperatures in summer as a result of climate change. Through evaporation and higher usage, water supplies will be stressed. Warming temperatures can deplete lakes and ponds of oxygen creating more favorable conditions for harmfal algal blooms. Stressed vegeatation and plant death can occur resulting in bare and loose soils that erode and increase sediments in public water resoureces. Green infrastructure designed to filter or improve water quality can lose efficacy if drought intolerant species die off impacting soil biochemistry and removing another line of defense for drinking water supplies.

Figure 2. Impervious areas within Waltham's SWPA

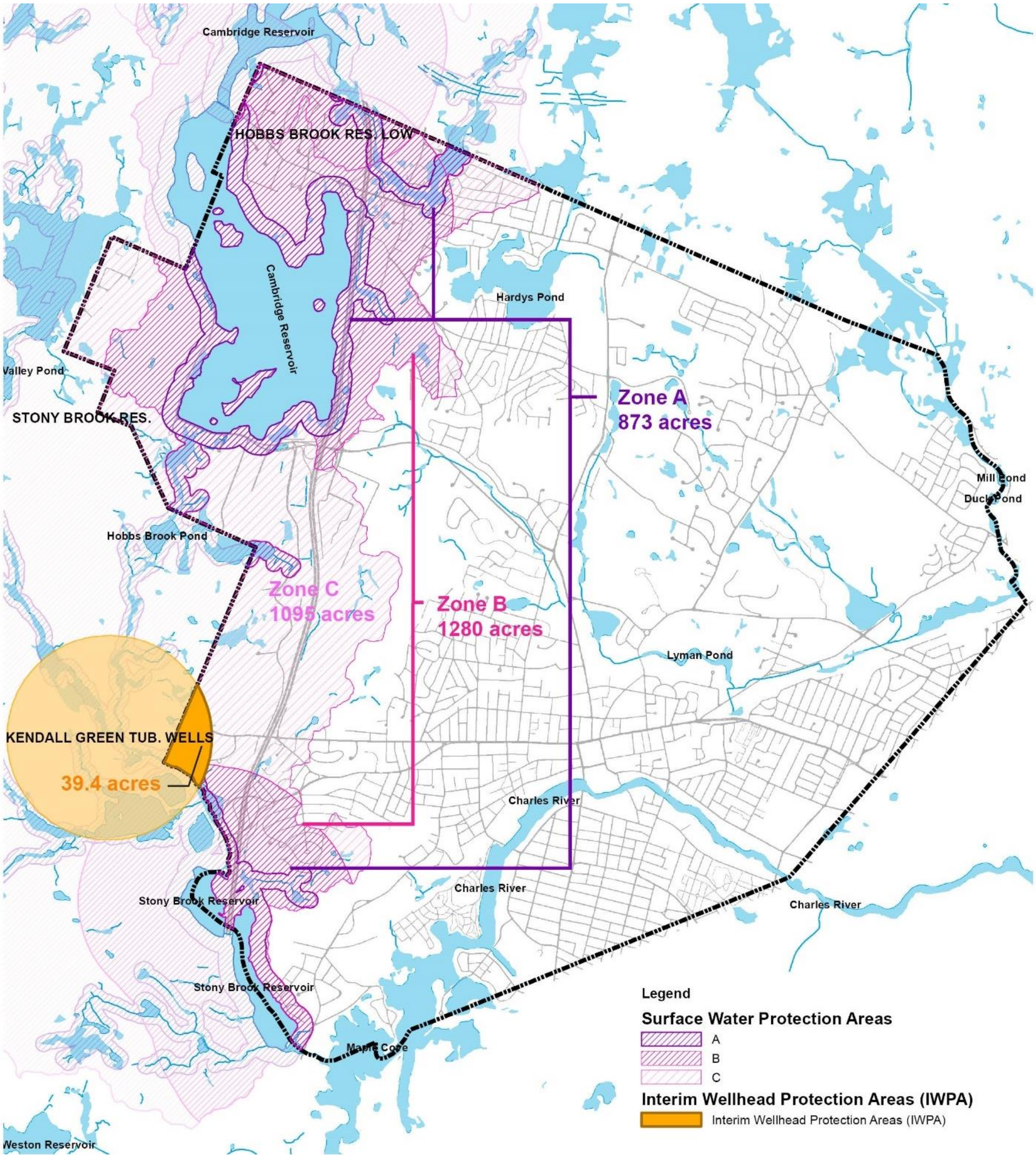
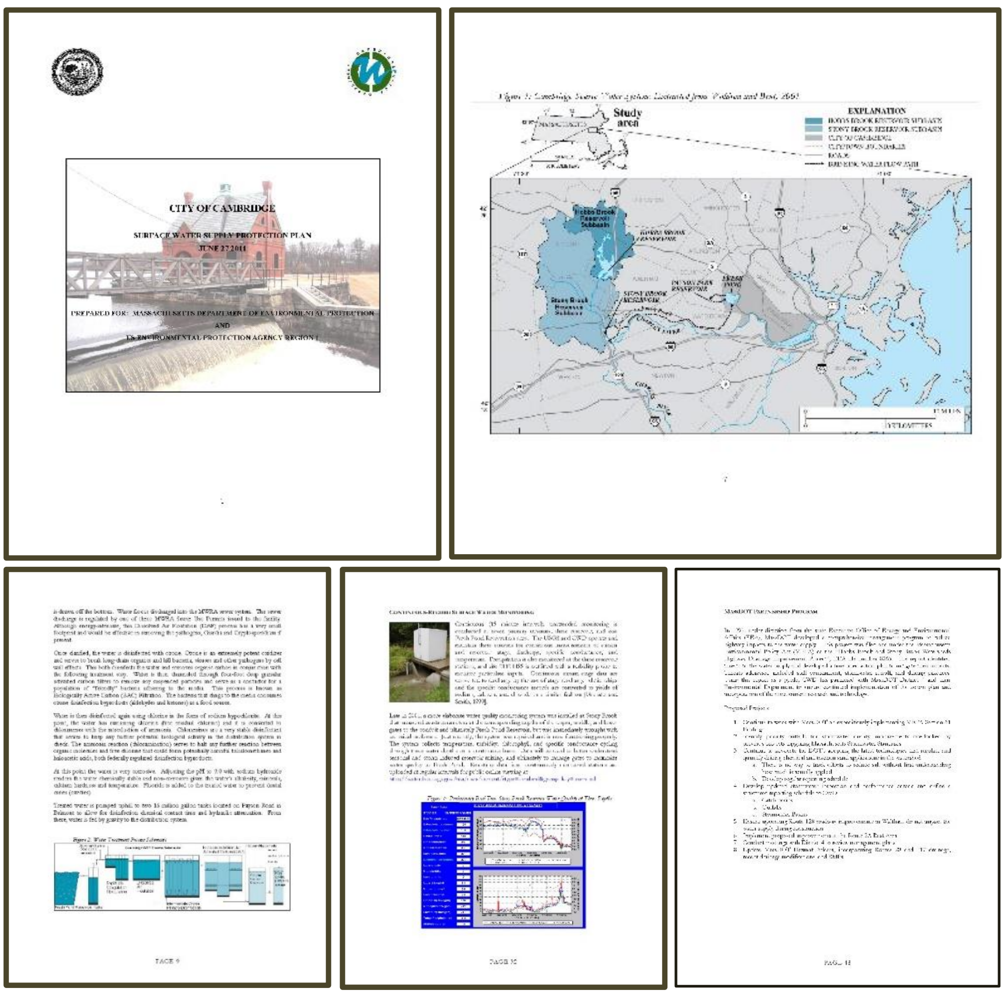


Figure 3. City of Waltham and State-regulated Surface Water and Drinking Water Protection Areas

Planning Initiatives

Developed in June 2011, The City of Cambridge's Surface Water Supply Protection Plan (SWSPP) serves as a guiding document for identifying and addressing susceptibilities and management of the City's drinking water supply. Acknowleding the intensity of development and its limited control of the surrounding watershed located in other towns, the SWSPP is set up to help the City of Cambridge effectively and efficiently protect the watershed through assessments, water quality monitoring, site monitoring, land acquisition, emergency response planning, restoration programs, public outreach, and key partnership programs with local and state agencies.

Climate change was not incorporated into the water supply plan though the City of Cambridge completed its Climate Change Vulnerability Assessment (CCVA) in 2015 and subsequent Climate Change Preparedeness and Resilience (CCPR) Plan in 2019. However, the extents of those studies were limited to the city boundaries excluding assessment of the vulnerabilities and risks associated with precipitation, flooding and urban heat to the water supply and distribution system. The CCVA does acknowledge that *"[t]here are upstream failure points in the water supply and distribution system…",* but stops short of identifying those points. An important output of Cambridge's SWSPP was a list of action items under an Umbrella Program that stressed project development and strategic alliances to address watershed issues.



Action Items

Recent intensification of development within the watershed and the risks to water security presented by climate change requires reevaluating and inclusion of proposed projects. Building upon the SWSPP proposed projects, the action items listed below reemphasize the process of monitoring and assessing through a filter of climate resiliency.

Water Quality

1. Perform targeted stormwater monitoring to support proposed Stormwater Program
2. Include sampling for pollutants of emerging concern (PFAS, Chlorine)

Stormwater

3. Work with the City of Waltham to review 2019 Stormwater Management Plan strategies and planning and development initiatives in within Cambridge watershed.
4. Conduct climate resiliency study for watershed with future projected rainfalls
5. Assess and monitor recently built BMP's to determine capacity / designed storm level
6. Develop a preferred BMP list for the Cambridge watershed

Site Monitoring

7. Continue to develop a private property stormwater assets spatial database
8. Work with Waltham to define limits on deicing chemicals, fertilizers, turf management chemicals, and street sweeping.

Land Acquisition

9. Continue to work with watershed communities to look for land acquisition opportunities and funding as they become available

Emergency Response

10. Update the Hazmat Emergency Response Plan, Emergency Action Plan for Dams, and Atlas to include future climate planning for more frequent emergencies like flooding and drought

Invasive Species

11. Review and coordinate holistic management strategies (from Mid-Atlantic states) for flora and fauna that are migrating north with warming temperatures.

Private/Public Partnerships Program

12. Encourage partners to use future climate projections for planning and management programs.

Natural Resource Restoration

13. Work with municipalities to Identify degraded streams, wetlands beyond Cambridge-owned parcels and rank on restoration potential
14. Identify opportunities to daylight streams and incorporate water quality BMP's between outfalls and waterbodies.

MassDOT Partnership Program

15. Continue to advocate for DOT's adopting the latest technologies that regulate and quantify deicing chemical and traction sand applications in the watershed
16. Update MassDOT Hazmat Atlases, incorporating Routes 20 and 117 drainage, recent drainage modifications, and BMPs to include future climate projections for planning and management.

References

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https://www.cambridgema.gov/CDD/Projects/Climate/~/media/E7D8EF710F77449A906B29556BE2BB25.ashx

City of Cambridge, MA, Surface Water Supply Protection Plan (SWSPP) June 27, 2011
https://www.cambridgema.gov/~/media/Files/waterdepartment/Watershed/SWSPP_2011_06_27_all.pdf

Attachment E. Green Infrastructure and Flood Storage Opportunities

TO: Catherine Cagle, Planning Director, City of Waltham

FROM: Amanda Kohn and John Frey, Weston & Sampson

DATE: February 2021

SUBJECT: Green Infrastructure Opportunities Analysis

Cities and their decision-makers today face many complex challenges that are associated with balancing urban development and its impact on the environment. Around the world, including New England, enormous investments are required to upgrade and maintain aging infrastructure stock as well as constructing new infrastructure to accommodate population growth. There is growing recognition that the traditional, "gray" approach to infrastructure will be insufficient to meet the growing pressures of urbanization and stresses associated with climate change.

The Waltham Stormwater Management and Implementation Plan promotes nature-based solutions and green infrastructure helping to mitigate the impacts of climate change and develop a more resilient city. As part of the plan, green infrastructure opportunities were identified throughout the City of Waltham within 7 major watersheds. Developing a green infrastructure toolbox was the first step in identifying the typologies of

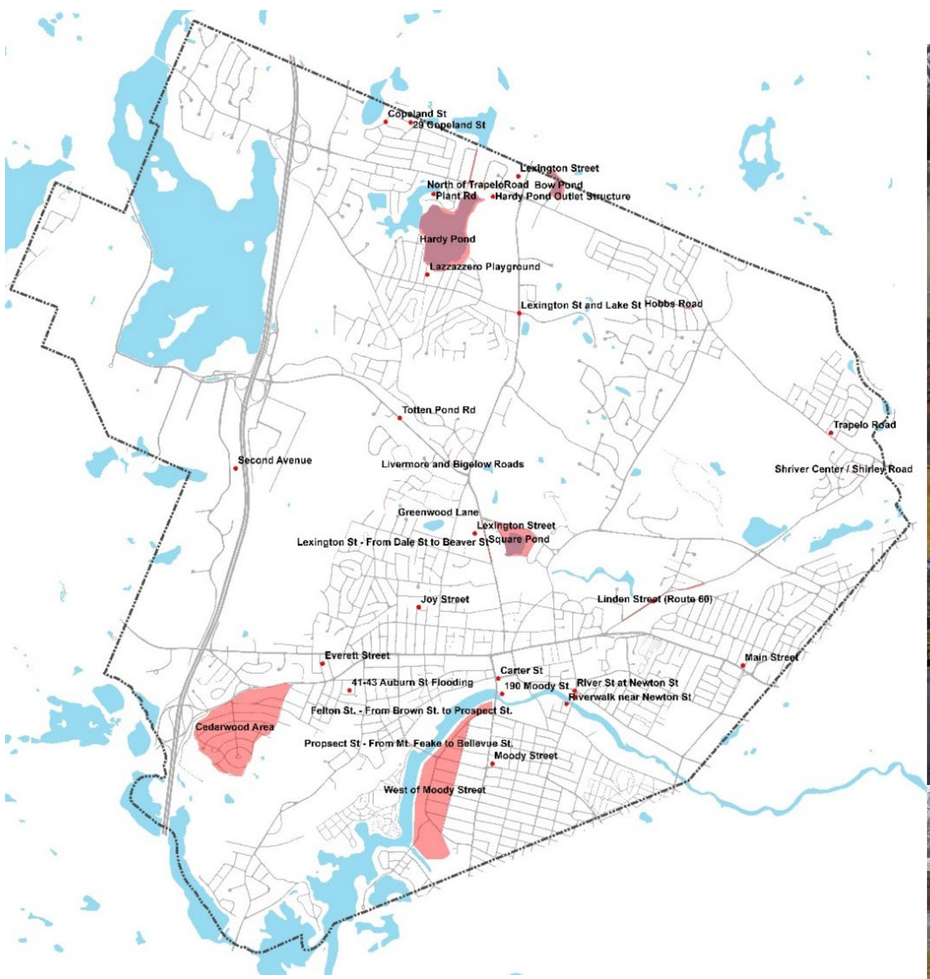

Figure 1. Known Areas of Flooding within Waltham

Weston & Sampson

stormwater solutions that are best suited for the diverse physical and built context of Waltham. But the main objective is to find ways to store and convey stormwater in a way that can also create inspiring urban areas with added value for the citizens, local businesses, and the city. With limited resources to fund flood risk reduction projects and public projects in general, it is more important than ever to build projects that are not just single purpose but can deliver on multiple goals for the city.

The following document outlines green infrastructure options that have been evaluated for Waltham.

GI Toolbox for Waltham

The City of Waltham has a collection of rich natural resources, preserved land, and open space. It also has a dense urban center at the lowest lying elevation in the town, with numerous urban streams that outfall into the Charles River. The following Green Infrastructure Toolbox for Waltham outlines strategies that work across urban and suburban areas, upstream and downstream, and are flexible in their scale and implementation.

Bioretention

These systems capture and hold stormwater runoff and allow it to slowly infiltrate through soil media, thus reducing flooding. Planting will uptake water as well as nutrients in the runoff. Bioretention systems provide water quality benefits by removing pollutants. Bioretention systems can be installed along sidewalks, in medians, and parking lot edges to directly treat runoff from surrounding impervious surfaces. There is the option to install a bioretention cell as a shallow, topographic depression which accepts and treats runoff through vegetation and engineered soils. The other option is a pre-cast bioretention unit, which is a prefabricated box below engineered soils which treats and temporarily treats runoff.

Floodable Parks and Fields

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

Floodplain Restoration

Focused on ponds, wetland areas and other larger waterbodies (non-stream), floodplain restoration is the process of fully or partially restoring the hydrologic, vegetative, or ecological function of a waterbody's floodable area. With numerous upland wetlands and ponds along its streams, Waltham has opportunities to restore and maintain naturally occurring surface water storage areas that will help reduce stresses from flooding downstream.

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Permeable Paving

Roadways and sidewalks are big contributors to stormwater runoff. By infiltrating the runoff through impervious surface, it will allow for reduced runoff and slower infiltration back into the ground or stormwater system. Porous pavement can be used in conjunction with stormwater curb extensions on side streets, and in parking spaces along edges of large parking lots.

Reforestation

Included to limit runoff and erosion from bare and low-cover areas, reforestation provides numerous benefits from carbon sequestration, rebuilding ecosystems, and reduction in air pollution and urban heat. The scale of reforestation can vary from restocking existing forests and woodlands to planting clear cut fields.

Stream Restoration

Stream Restoration and re-profiling existing urban water edges can help build capacity for stormwater through retention and detention. Additionally, redesign of stream or riverfront parks to allow for seasonal and cloudburst flooding can reduce downstream flooding in unwanted areas.

Storage

Existing ponds and wetlands are used to detain stormwater during a rain event. Ponds may be dredged to increase storage volume. Additionally, outlet structures on existing ponds can be retrofitted for control structures to adjust the water level in the pond prior to a rain event. The stormwater would be held back and then slowly released back into the stormwater system following the completion of the rain event. This would allow for an increase in flood storage.

Swales

Used primarily as interceptors of stormwater runoff and conveyance, swales are proposed as upstream solutions and along road corridors with limited spacing. They are often established with a combination of small-scale channels and stormwater planters or permeable paving. Through swales, stormwater can be collected, delayed, and then channeled toward bioretention and natural areas.

Urban Heat Reduction – Structures

Included as an option for the densest parts of the Waltham where space and city properties are limited, buildings structures that can reduce urban heat while also incorporating rainfall capture are critical. Urban design examples include green roofs, covered roofs with solar panels in public garages, spanning canopies along sidewalks or bus stops. The scale of these strategies can vary, but the focus is improving the pedestrian experience at the sidewalk level.

Figure 2. Waltham Study Area Watersheds

Waltham Streams and Subbasins

Waltham is surrounded and intersected by surface water systems that also interact with the City's stormwater drainage system. Based on data and known flooding areas flooding throughout the city, the following major streams were included in this study. (Fig. 2)

1. Stony Brook / 2nd Ave - Downstream of Hobbs Brook and Cambridge Reservoir (SB)
2. Master Brook / Conduit (MB)
3. Chester Brook (CB)
   Plympton Brook / Conduit (PB)
4. West Chester Brook (WCB)
5. Beaver Brook (BB)
   Clematis Brook (CBB)

The watersheds of these streams account for nearly 60% of the total area of the City. Each watershed was delineated into smaller subbasins based on LiDAR derived elevation, surface flow analysis, and the City's existing stormwater drainage system. There are 45 subbasins in total. The delineation of subbasins allow for focused modeling for proposed green infrastructure. Clematis Brook is a tributary of Beaver Brook. West Chester and Plympton Brooks are tributaries of Chester Brook which is a tributary of Beaver Brook as well forming a confluence after Lyman Pond. The last stretch of Beaver Brook is in a conduit and outfalls into the Charles River near the Newton Street Bridge.

Masters Brook is system of storm drainage pipes that form a major conduit that outlets into the Charles River near the Prospect St Bridge. In its upper watershed, there are some surface water bodies and streams, mainly within the southern end of Prospect Hill Park. The historic flow of the stream is reflected by the current surface flow analysis and elevation, but now is intersected by dense road networks, utilities, and neighborhoods. Green infrastructure strategies within this watershed.

The 2nd Ave Watershed area is upstream of the Stony Brook Reservoir, part of the City of Cambridge drinking water supply. Waltham's West End is one of the most impervious areas of the city due to its industrial and commercial land use. The drainage area includes runoff from I-95, large parking areas, and large commercial rooftops. Storm drainage is collected through a collection of pipes and detention areas before outfalling into a series of forested wetlands. This drainage area is located fully within the Massachusetts Surface Water Protection Areas Zone B and C. (See Regional Resilience Fig. 3)

Green Infrastructure Overview

Within the focus watershed areas, 325 Green Infrastructure projects have been identified utilizing the GI toolbox with City drainage data, GIS analyses, and known areas of flooding. Focus was placed on feasibility of implementing projects by identifying city owned properties or right-of-way (ROWs) aligned with surface flow paths and known flooding areas. In addition to stormwater volume reduction and water quality improvement, these projects were calculated to reduce impervious surfaces in Waltham by 1,716,680 sq.ft (39.4 acres) helping to reduce Urban Heat. The GI projects are listed below according to stream network are provide a breakdown of the types of projects by area. The square footage indicates the area of the feature. Future analysis will determine the impact, such as the amount of drainage area, storage, and phosphorus treatment.

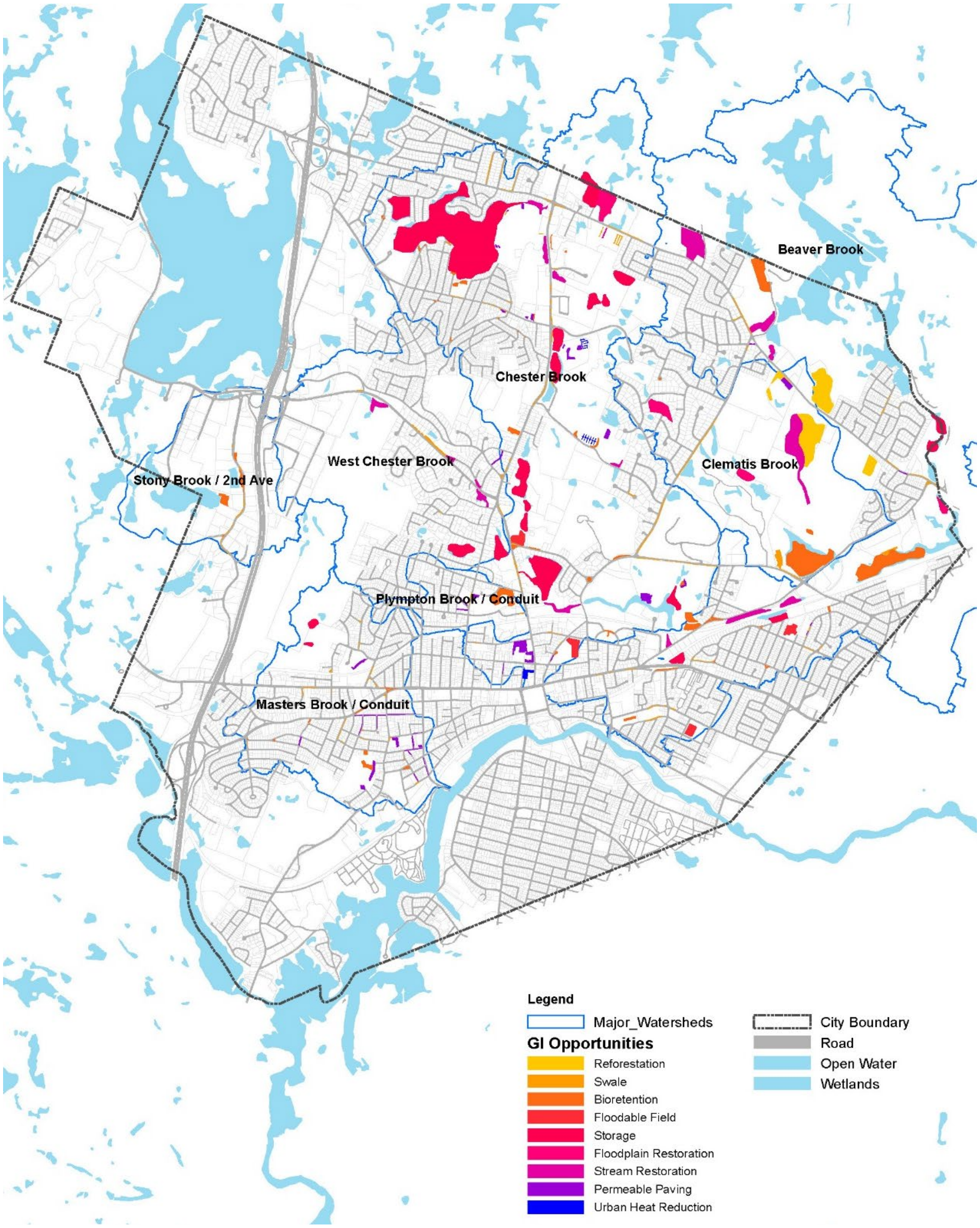
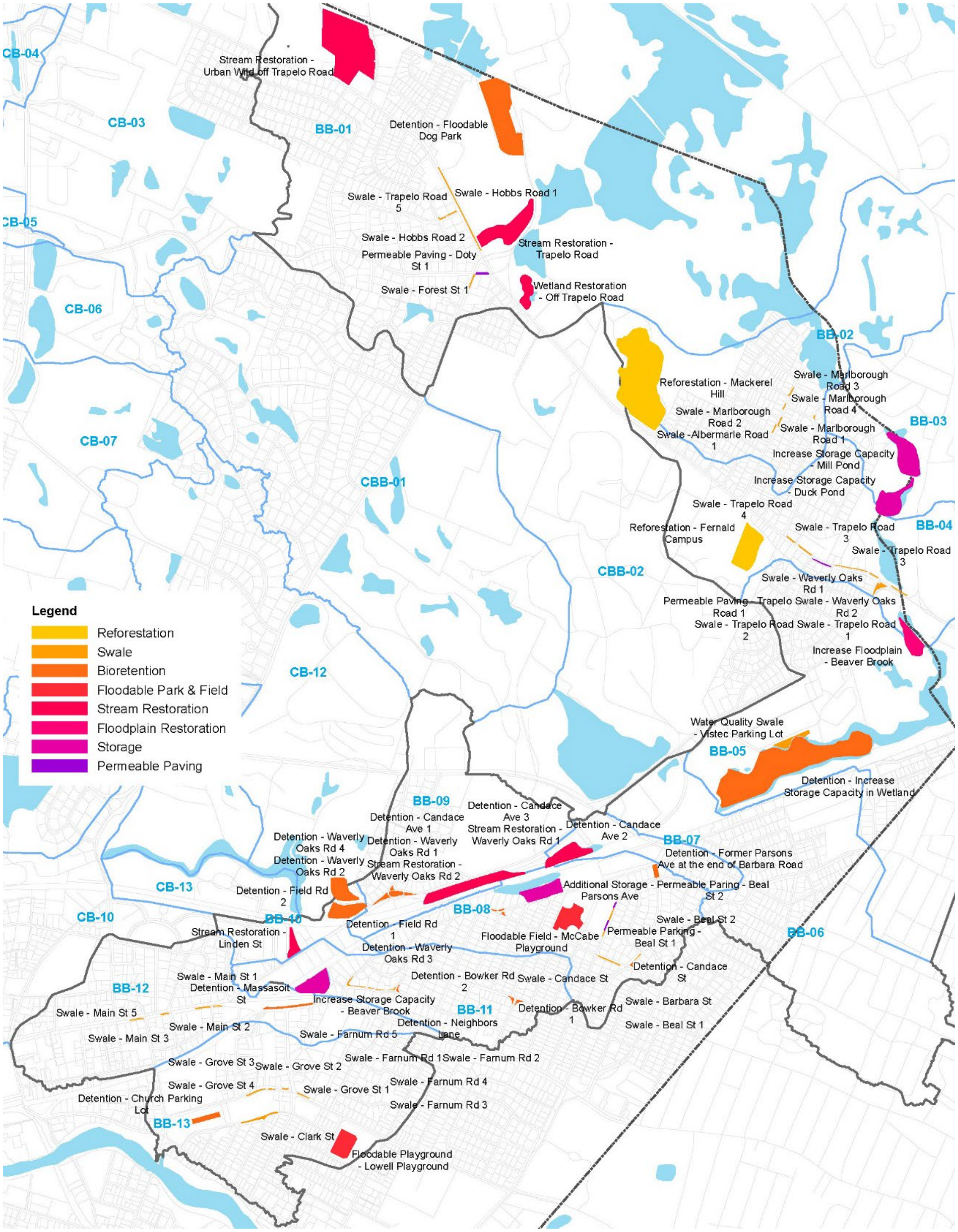
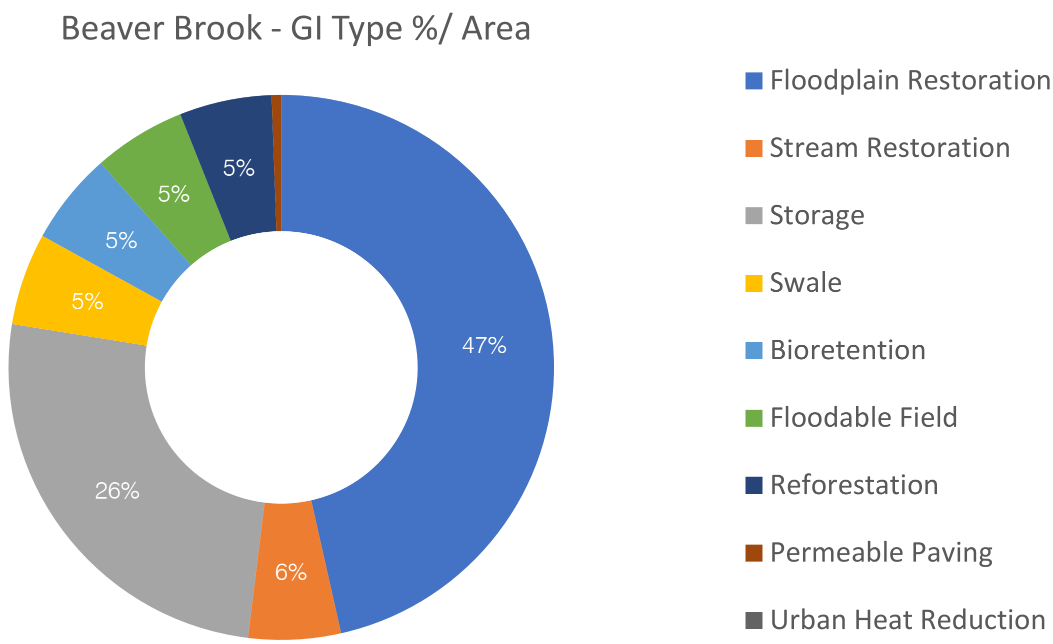


Figure 3. Green Infrastructure Opportunities in Waltham

Beaver Brook

Total Area: 107,646,341 sq.ft (2,471.22 acres) including areas in Lexington and Belmont
Total Subbasins: 13
Number of Green Infrastructure Projects: 72

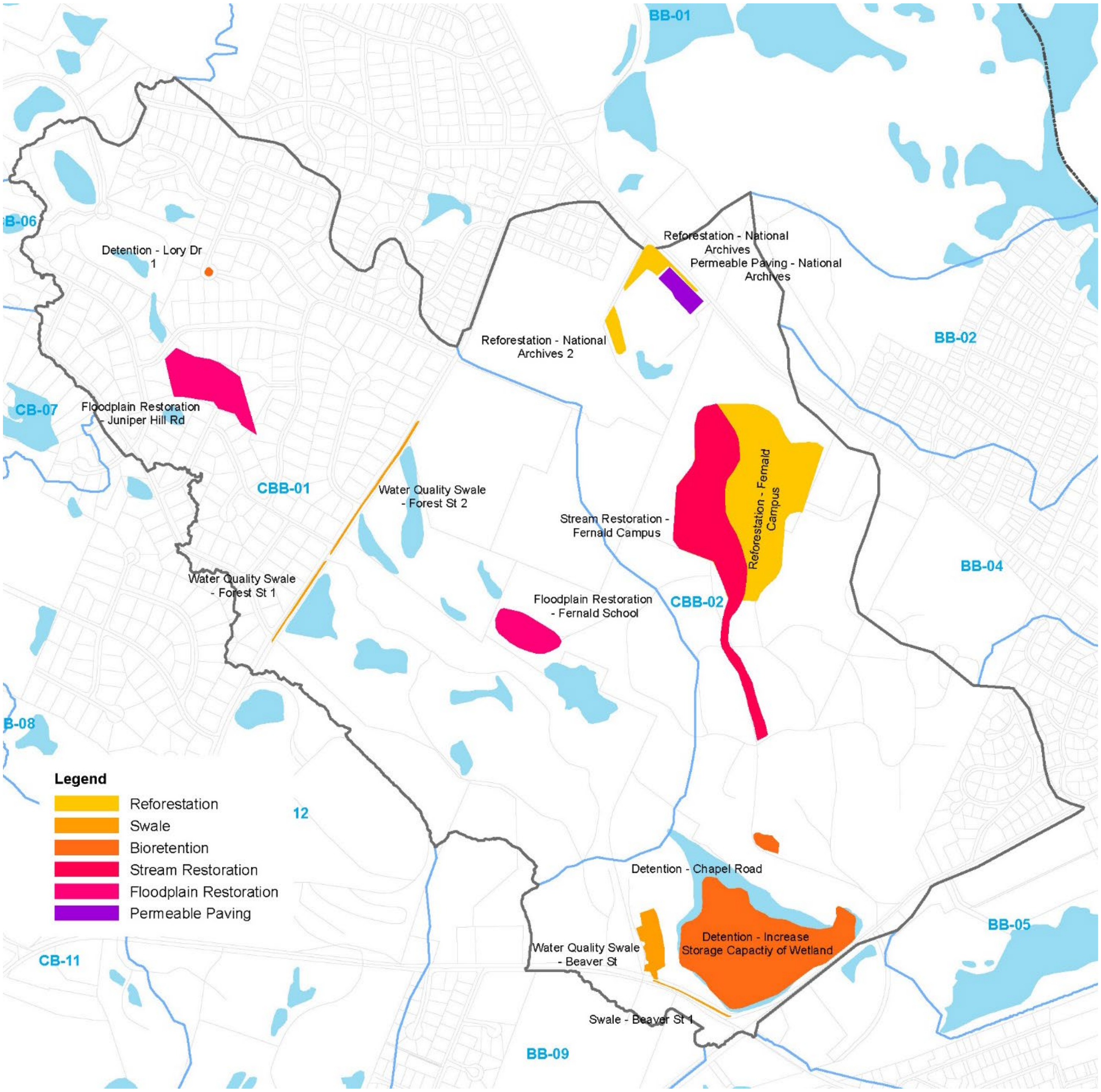


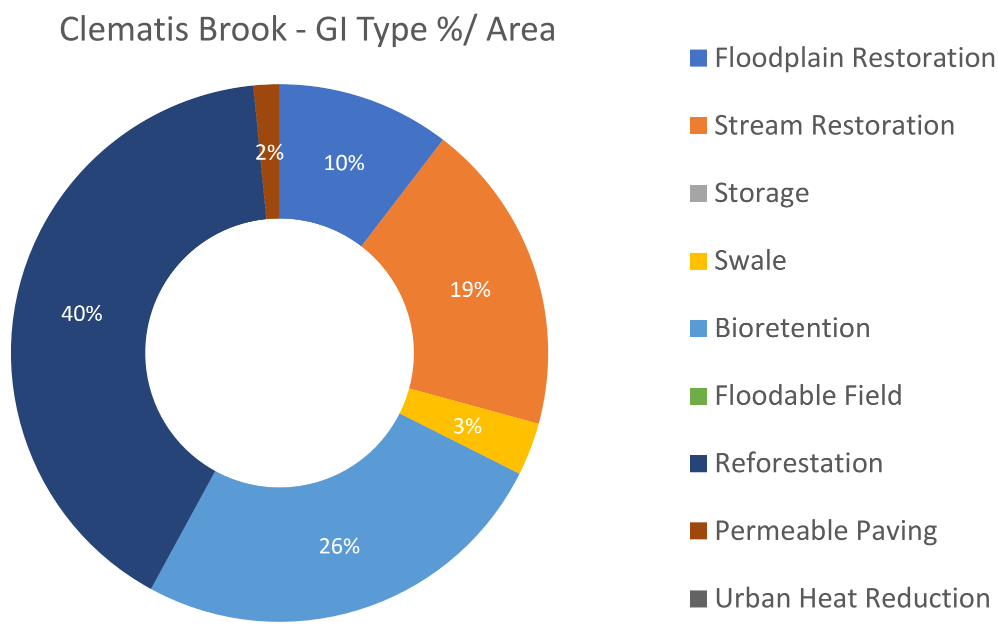


Beaver Brook Projects	Area (sqft.)	Type	Subbasin
Detention - Floodable Dog Park	426988.03	Bioretention	BB-01
Permeable Paving - Doty St 1	5328.24	Permeable Paving	BB-01
Wetland Restoration - Off Trapelo Road	75576.58	Stream Restoration	BB-01
Stream Restoration - Trapelo Road	233262.04	Stream Restoration	BB-01
Stream Restoration - Urban Wild Trapelo Road	645840.86	Stream Restoration	BB-01
Swale - Hobbs Road 1	1622.44	Swale	BB-01
Swale - Hobbs Road 2	1726.32	Swale	BB-01
Swale - Trapelo Road 5	14067.77	Swale	BB-01
Swale - Forest St 1	2918.66	Swale	BB-01
Reforestation - Mackerel Hill	827086.43	Reforestation	BB-02
Swale - Marlborough Road 2	1544.49	Swale	BB-02
Swale - Marlborough Road 1	1599.98	Swale	BB-02
Swale - Marlborough Road 3	1007.35	Swale	BB-02
Swale - Marlborough Road 4	1283.17	Swale	BB-02
Swale -Albermarle Road 1	597.34	Swale	BB-02
Increase Storage Capacity - Duck Pond	146616.79	Storage	BB-03
Increase Storage Capacity - Mill Pond	183306.76	Storage	BB-03
Increase Floodplain - Beaver Brook	97966.27	Floodplain Restoration	BB-04
Permeable Paving - Trapelo Road 1	3314.43	Permeable Paving	BB-04
Reforestation - Fernald Campus	204053.42	Reforestation	BB-04
Swale - Waverly Oaks Rd 1	3322.51	Swale	BB-04
Swale - Waverly Oaks Rd 2	5841.34	Swale	BB-04
Swale - Trapelo Road 1	2805.45	Swale	BB-04
Swale - Trapelo Road 2	1398.07	Swale	BB-04
Swale - Trapelo Road 3	3367.14	Swale	BB-04

Swale - Trapelo Road 4	2707.67	Swale	BB-04
Swale - Trapelo Road 5	1601.26	Swale	BB-04
Detention - Increase Storage in Wetland	960580.77	Bioretention	BB-05
Water Quality Swale - Vistec Parking Lot	33309.06	Swale	BB-05
Stream Restoration - Waverly Oaks Rd 1	124560.37	Stream Restoration	BB-07
Detention - Former Parsons Ave at the end of Barbara Road	13017.32	Bioretention	BB-08
Detention - Candace Ave 1	1272.47	Bioretention	BB-08
Detention - Candace Ave 2	981.67	Bioretention	BB-08
Detention - Candace Ave 3	791.49	Bioretention	BB-08
Detention - Candace Ave 4	1100.76	Bioretention	BB-08
Floodable Field - McCabe Playground	121077.62	Floodable Field	BB-08
Permeable Parking - Beal St 1	2533.25	Permeable Paving	BB-08
Permeable Paring - Beal St 2	1388.22	Permeable Paving	BB-08
Additional Storage - Parsons Ave	117142.22	Storage	BB-08
Swale - Candace St	3297.30	Swale	BB-08
Swale - Barbara St	797.27	Swale	BB-08
Swale - Beal St 1	677.15	Swale	BB-08
Swale - Beal St 2	1734.18	Swale	BB-08
Detention - Waverly Oaks Rd 1	8777.62	Bioretention	BB-09
Detention - Waverly Oaks Rd 2	14016.31	Bioretention	BB-09
Detention - Waverly Oaks Rd 3	4003.26	Bioretention	BB-09
Detention - Waverly Oaks Rd 4	2247.42	Bioretention	BB-09
Stream Restoration - Waverly Oaks Rd 2	202098.45	Stream Restoration	BB-09
Detention - Field Rd 2	99338.94	Bioretention	BB-10
Detention - Field Rd 1	99421.05	Bioretention	BB-10
Stream Restoration - Linden St	44229.66	Stream Restoration	BB-10
Detention - Bowker Rd 1	2550.72	Bioretention	BB-11
Detention - Bowker Rd 2	2442.92	Bioretention	BB-11
Detention - Neighbors Lane	1383.02	Bioretention	BB-11
Increase Storage Capacity - Beaver Brook	120796.38	Storage	BB-11
Swale - Farnum Rd 1	1175.93	Swale	BB-11
Swale - Farnum Rd 2	832.61	Swale	BB-11
Swale - Farnum Rd 3	394.13	Swale	BB-11
Swale - Farnum Rd 4	1057.87	Swale	BB-11
Swale - Farnum Rd 5	1826.72	Swale	BB-11
Detention - Massasoit St	18521.59	Bioretention	BB-12
Swale - Main St 1	1688.47	Swale	BB-12
Swale - Main St 2	3244.37	Swale	BB-12
Swale - Main St 3	1550.09	Swale	BB-12
Swale - Main St 4	2296.87	Swale	BB-12
Detention - Church Parking Lot	30018.83	Bioretention	BB-13
Floodable Playground - Lowell Playground	108013.78	Floodable Field	BB-13
Swale - Grove St 1	1757.72	Swale	BB-13
Swale - Grove St 2	1011.30	Swale	BB-13
Swale - Grove St 3	964.03	Swale	BB-13
Swale - Grove St 4	3917.42	Swale	BB-13
Swale - Clark St	12455.91	Swale	BB-13

Clematis Brook
Total Area: 24,912,429.87 sq.ft (571.9 acres)
Total Subbasins: 2
Number of Green Infrastructure Projects: 14





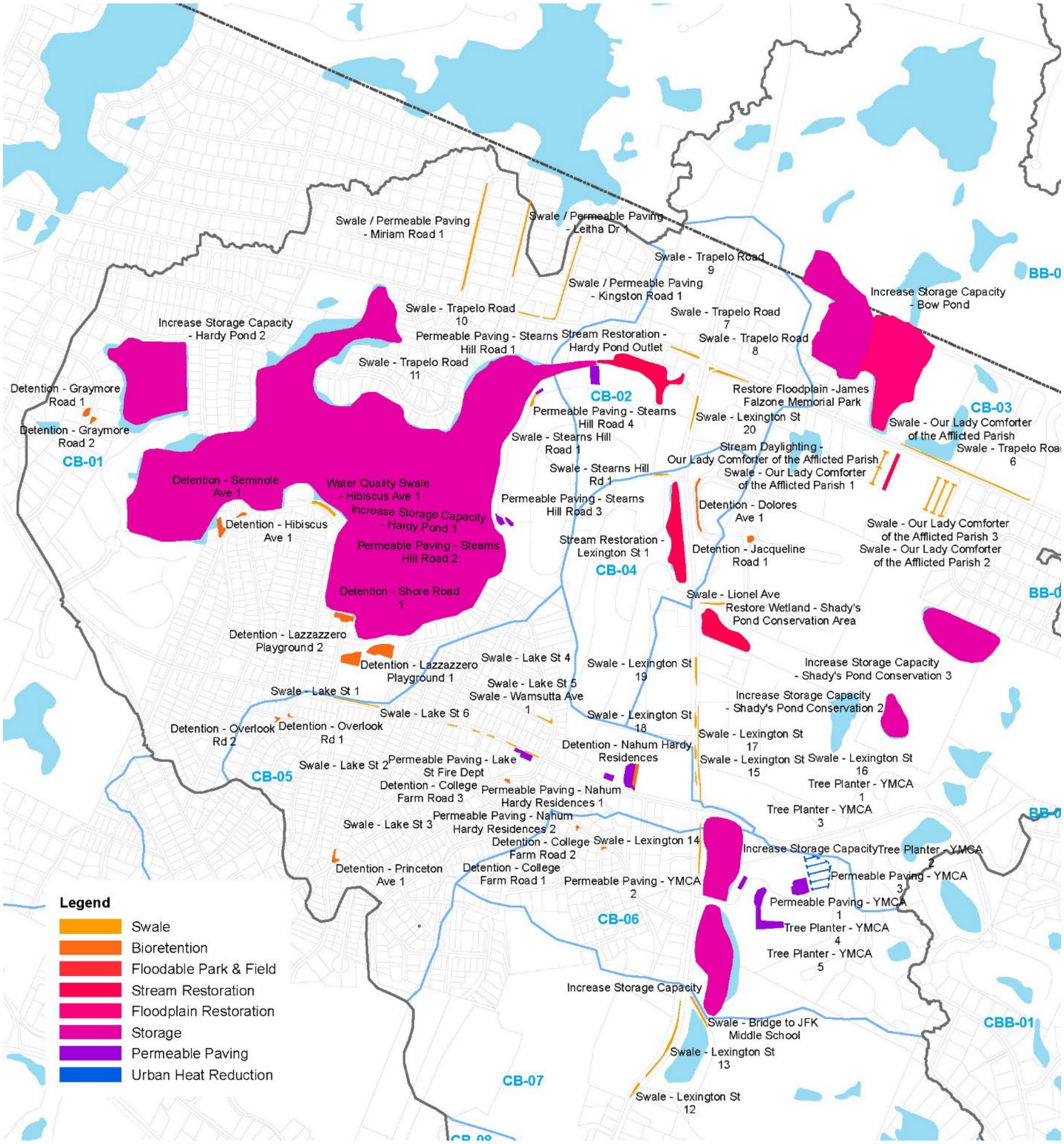
Name	Area	Type	Subbasin
Floodplain Restoration - Fernald School	162302.9	Floodplain Restoration	CBB-01
Water Quality Swale - Forest St 1	11278.03	Swale	CBB-01
Water Quality Swale - Forest St 2	20727.15	Swale	CBB-01
Detention - Lory Dr 1	4399.744	Bioretention	CBB-01
Floodplain Restoration - Juniper Hill Rd	307760.7	Floodplain Restoration	CBB-01
Reforestation - Fernald Campus	1709019	Reforestation	CBB-02
Stream Restoration - Fernald Campus	849875.9	Stream Restoration	CBB-02
Water Quality Swale - Beaver St	104334.4	Swale	CBB-02
Detention - Chapel Road	28684.41	Bioretention	CBB-02
Swale - Beaver St 1	7163.305	Swale	CBB-02
Detention - Increase Storage in Wetland	1119262	Bioretention	CBB-02
Reforestation - National Archives	75300.63	Reforestation	CBB-02
Permeable Paving - National Archives	70420.57	Permeable Paving	CBB-02
Reforestation - National Archives 2	43701.13	Reforestation	CBB-02

Chester Brook

Total Area: 74,990,061.4 sq.ft (1,721.5 acres) including areas in Lexington

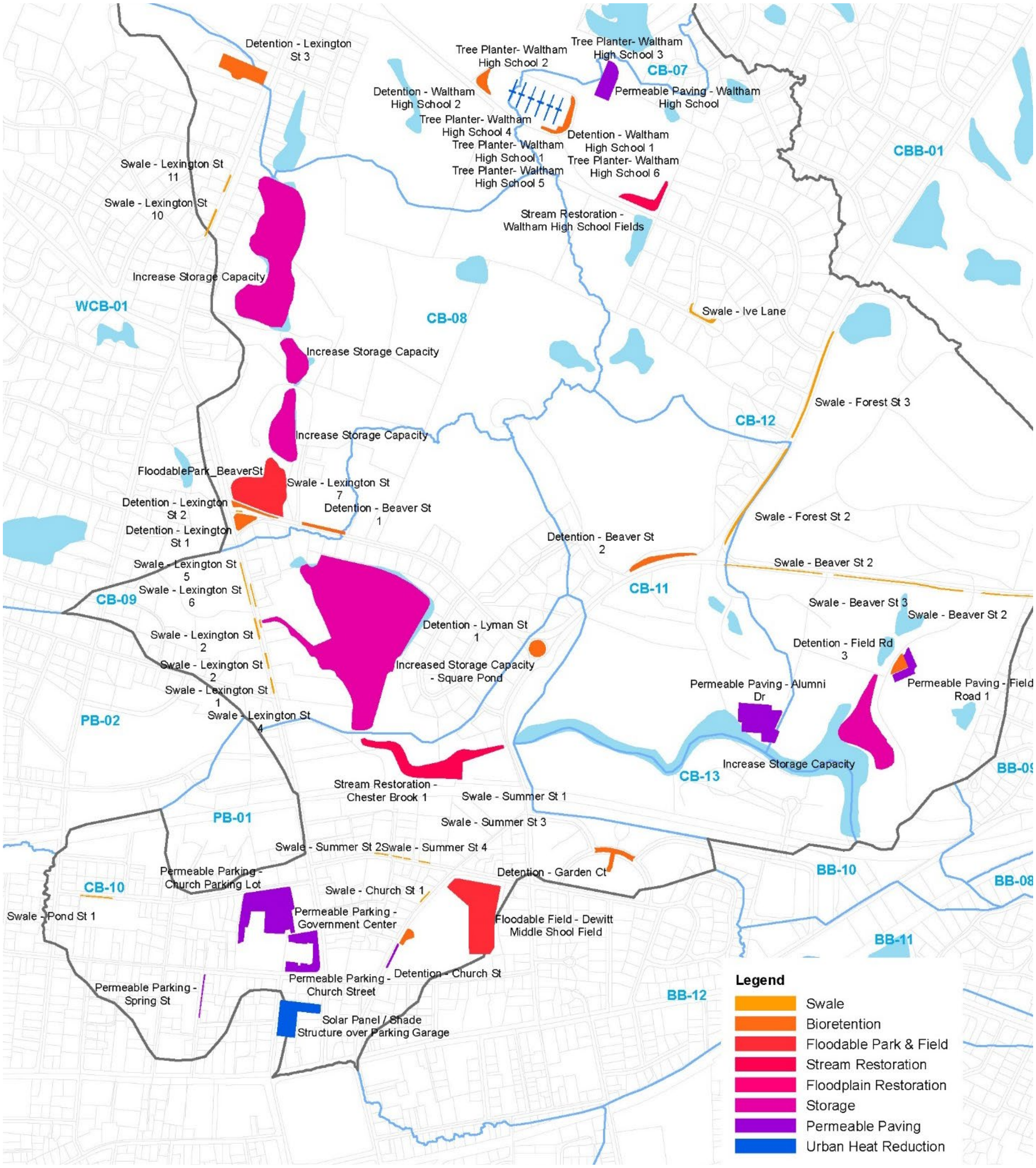
Total Subbasins: 12

Number of Green Infrastructure Projects: 132



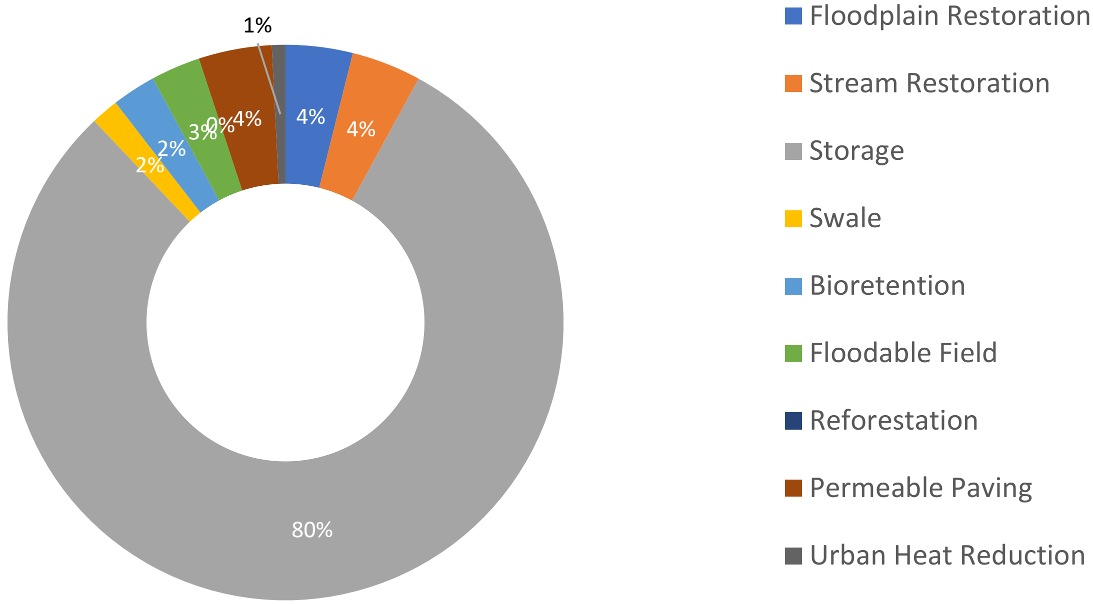
Upper Chester Brook

Weston & Sampson



Lower Chester Brook

Chester Brook - GI Type %/ Area



Name	Area	Type	Subbasin
Detention - Lazzazzero Playground 1	24,022.46	Bioretention	CB-01
Detention - Lazzazzero Playground 2	19,193.35	Bioretention	CB-01
Detention - Shore Road 1	10,082.87	Bioretention	CB-01
Detention - Graymore Road 1	3,584.56	Bioretention	CB-01
Detention - Graymore Road 2	2,038.92	Bioretention	CB-01
Detention - Hibiscus Ave 1	8,234.39	Bioretention	CB-01
Detention - Seminole Ave 1	1,814.53	Bioretention	CB-01
Permeable Paving - Stearns Hill Road 1	1,606.25	Permeable Paving	CB-01
Permeable Paving - Stearns Hill Road 3	4,368.40	Permeable Paving	CB-01
Permeable Paving - Stearns Hill Road 2	2,801.15	Permeable Paving	CB-01
Increase Storage Capacity - Hardy Pond 1	5,787,725.60	Storage	CB-01
Increase Storage Capacity - Hardy Pond 2	474,412.31	Storage	CB-01
Water Quality Swale - Hibiscus Ave 1	6,018.08	Swale	CB-01
Swale - Trapelo Road 10	1,143.23	Swale	CB-01
Swale - Trapelo Road 11	809.98	Swale	CB-01
Swale - Stearns Hill Road 1	2,064.70	Swale	CB-01
Swale / Permeable Paving - Leitha Dr 1	7,682.88	Swale	CB-01
Swale / Permeable Paving - Kingston Road 1	5,000.63	Swale	CB-01
Swale / Permeable Paving - Miriam Road 1	13,278.97	Swale	CB-01
Permeable Paving - Stearns Hill Road 4	14,575.93	Permeable Paving	CB-02
Stream Restoration - Hardy Pond Outlet	104,058.25	Stream Restoration	CB-02
Swale - Lexington St 20	3,550.42	Swale	CB-02
Swale - Trapelo Road 7	3,067.12	Swale	CB-02
Swale - Trapelo Road 8	3,702.71	Swale	CB-02
Swale - Trapelo Road 9	812.23	Swale	CB-02
Detention - Jacqueline Road 1	3,203.65	Bioretention	CB-03
Restore Floodplain -James Falzone Memorial Park	457,845.39	Floodplain Restoration	CB-03
Increase Storage Capacity - Shady's Pond Conservation 2	76,466.32	Storage	CB-03
Increase Storage Capacity - Shady's Pond Conservation 3	235,811.61	Storage	CB-03
Increase Storage Capacity - Bow Pond	498,468.45	Storage	CB-03

Stream Daylighting - Our Lady Parish	11,666.81	Stream Restoration	CB-03
Restore Wetland - Shady's Pond Conservation Area	83,778.93	Stream Restoration	CB-03
Swale - Our Lady Parish 1	4,713.85	Swale	CB-03
Swale - Our Lady Parish 2	4,191.83	Swale	CB-03
Swale - Our Lady Parish 3	4,238.04	Swale	CB-03
Swale - Our Lady Parish	4,021.61	Swale	CB-03
Swale - Trapelo Road 6	10,080.77	Swale	CB-03
Swale - Lexington St 15	5,691.20	Swale	CB-03
Swale - Lexington St 16	1,078.31	Swale	CB-03
Swale - Lexington St 17	1,407.49	Swale	CB-03
Swale - Lexington St 18	1,529.70	Swale	CB-03
Swale - Lexington St 19	3,212.49	Swale	CB-03
Swale - Lionel Ave	2,542.78	Swale	CB-03
Detention - Dolores Ave 1	7,093.29	Bioretention	CB-04
Stream Restoration - Lexington St 1	106,502.42	Stream Restoration	CB-04
Swale - Stearns Hill Rd 1	1,378.01	Swale	CB-04
Detention - Nahum Hardy Residences	6,281.80	Bioretention	CB-05
Detention - College Farm Road 3	1,036.41	Bioretention	CB-05
Detention - Overlook Rd 1	1,049.82	Bioretention	CB-05
Detention - Overlook Rd 2	536.41	Bioretention	CB-05
Detention - Princeton Ave 1	3,114.10	Bioretention	CB-05
Permeable Paving - Nahum Hardy Residences 1	20,219.22	Permeable Paving	CB-05
Permeable Paving - Nahum Hardy Residences 2	4,644.47	Permeable Paving	CB-05
Permeable Paving - Lake St Fire Dept	7,987.47	Permeable Paving	CB-05
Swale - Lake St 1	1,852.56	Swale	CB-05
Swale - Lake St 2	426.92	Swale	CB-05
Swale - Lake St 3	448.68	Swale	CB-05
Swale - Lake St 4	451.23	Swale	CB-05
Swale - Lake St 5	621.55	Swale	CB-05
Swale - Lake St 6	479.13	Swale	CB-05
Swale - Wamsutta Ave 1	1,162.70	Swale	CB-05
Detention - College Farm Road 1	641.47	Bioretention	CB-06
Detention - College Farm Road 2	803.34	Bioretention	CB-06
Permeable Paving - YMCA 1	38,932.74	Permeable Paving	CB-06
Permeable Paving - YMCA 2	4,707.85	Permeable Paving	CB-06
Permeable Paving - YMCA 3	20,993.13	Permeable Paving	CB-06
Increase Storage Capacity	260,434.76	Storage	CB-06
Increase Storage Capacity	246,107.58	Storage	CB-06
Swale - Lexington 14	3,093.05	Swale	CB-06
Tree Planter - YMCA 1	2,297.03	Urban Heat Reduction	CB-06
Tree Planter - YMCA 2	1,857.82	Urban Heat Reduction	CB-06
Tree Planter - YMCA 3	2,740.82	Urban Heat Reduction	CB-06
Tree Planter - YMCA 4	2,031.92	Urban Heat Reduction	CB-06
Tree Planter - YMCA 5	1,561.06	Urban Heat Reduction	CB-06
Detention - Waltham High School 2	14,517.36	Bioretention	CB-07
Swale - Lexington St 12	2,007.99	Swale	CB-07
Swale - Lexington St 13	8,869.40	Swale	CB-07
Swale - Bridge to JFK Middle School	4,645.13	Swale	CB-07
Detention - Lexington St 3	56,876.18	Bioretention	CB-08
Detention - Lexington St 1	17,873.43	Bioretention	CB-08
Detention - Lexington St 2	8,866.41	Bioretention	CB-08

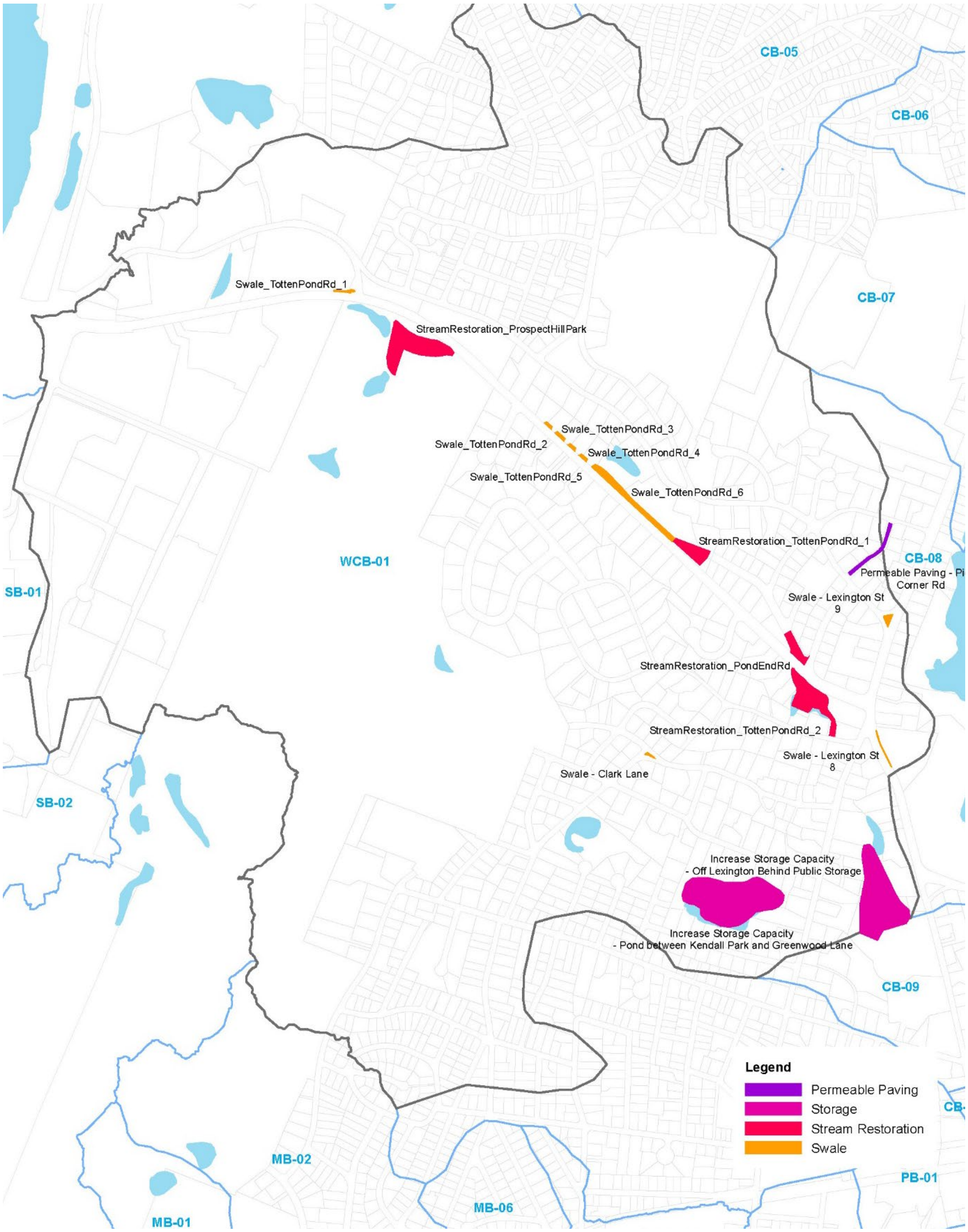
Detention - Beaver St 1	8,869.20	Bioretention	CB-08
FloodablePark_BeaverSt	155,362.88	Floodable Field	CB-08
Increase Storage Capacity	110,804.72	Storage	CB-08
Increase Storage Capacity	63,164.01	Storage	CB-08
Increase Storage Capacity	478,255.88	Storage	CB-08
Swale - Lexington St 7	392.76	Swale	CB-08
Swale - Lexington St 10	2,745.34	Swale	CB-08
Swale - Lexington St 11	1,762.37	Swale	CB-08
Increased Storage Capacity - Square Pond	995,409.67	Storage	CB-09
Swale - Lexington St 6	2,763.79	Swale	CB-09
Swale - Lexington St 1	1,633.56	Swale	CB-09
Swale - Lexington St 2	1,582.10	Swale	CB-09
Swale - Lexington St 2	2,261.12	Swale	CB-09
Swale - Lexington St 5	1,577.87	Swale	CB-09
Swale - Lexington St 4	503.66	Swale	CB-09
Detention - Church St	8,723.50	Bioretention	CB-10
Detention - Garden Ct	19,528.95	Bioretention	CB-10
Detention - Lyman St 1	17,579.20	Bioretention	CB-10
Floodable Field - Dewitt Middle School Field	182,246.59	Floodable Field	CB-10
Permeable Parking - Church Street	2,974.79	Permeable Paving	CB-10
Permeable Parking - Government Center	55,576.13	Permeable Paving	CB-10
Permeable Parking - Church Parking Lot	152,755.60	Permeable Paving	CB-10
Permeable Parking - Spring St	2,628.92	Permeable Paving	CB-10
Stream Restoration - Chester Brook 1	137,678.47	Stream Restoration	CB-10
Swale - Church St 1	780.32	Swale	CB-10
Swale - Summer St 1	398.35	Swale	CB-10
Swale - Summer St 2	565.30	Swale	CB-10
Swale - Summer St 3	667.78	Swale	CB-10
Swale - Summer St 4	715.38	Swale	CB-10
Swale - Pond St 1	2,027.77	Swale	CB-10
Solar Panel / Shade Structure over Parking Garage	68,977.30	Urban Heat Reduction	CB-10
Detention - Beaver St 2	20,914.87	Bioretention	CB-11
Permeable Paving - Alumni Dr	98,095.37	Permeable Paving	CB-11
Swale - Forest St 2	16,173.70	Swale	CB-11
Detention - Waltham High School 1	19,937.75	Bioretention	CB-12
Detention - Field Rd 3	13,002.79	Bioretention	CB-12
Permeable Paving - Waltham High School	41,959.55	Permeable Paving	CB-12
Permeable Paving - Field Road 1	24,640.32	Permeable Paving	CB-12
Increase Storage Capacity	163,550.53	Storage	CB-12
Stream Restoration - Waltham High School Fields	31,899.01	Stream Restoration	CB-12
Swale - Ive Lane	5,128.68	Swale	CB-12
Swale - Forest St 3	14,165.54	Swale	CB-12
Swale - Beaver St 2	5,671.03	Swale	CB-12
Swale - Beaver St 3	8,601.05	Swale	CB-12
Swale - Beaver St 2	3,536.36	Swale	CB-12
Tree Planter- Waltham High School 1	2,215.76	Urban Heat Reduction	CB-12
Tree Planter- Waltham High School 2	2,229.22	Urban Heat Reduction	CB-12
Tree Planter- Waltham High School 3	2,166.51	Urban Heat Reduction	CB-12
Tree Planter- Waltham High School 4	2,283.98	Urban Heat Reduction	CB-12
Tree Planter- Waltham High School 5	1,975.50	Urban Heat Reduction	CB-12
Tree Planter- Waltham High School 6	2,213.71	Urban Heat Reduction	CB-12

West Chester Brook

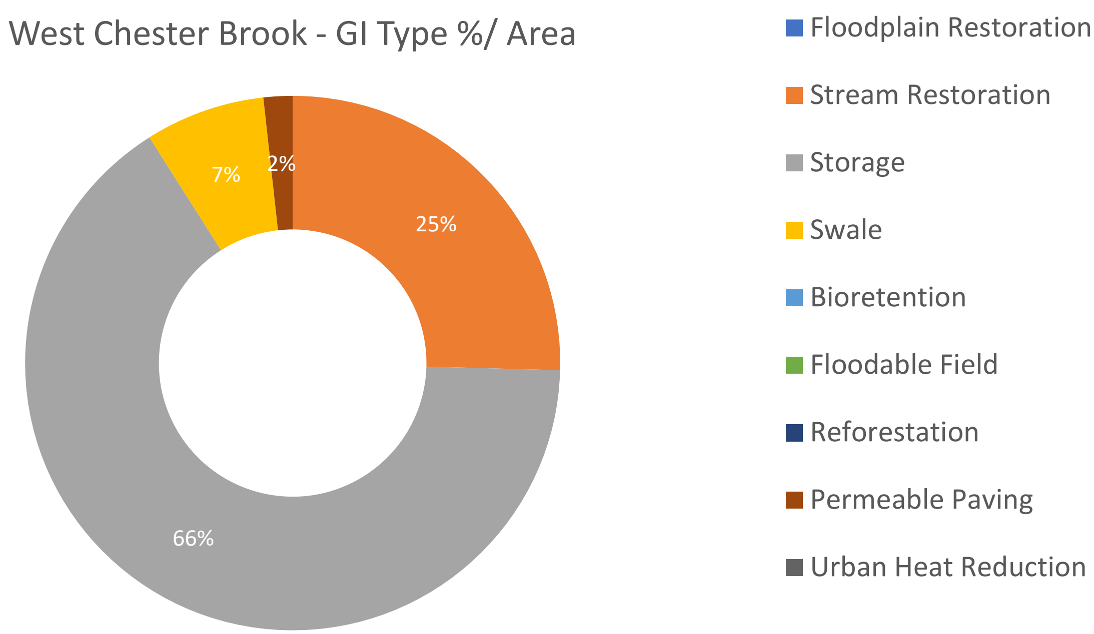
Total Area: 29,780,579.86 sq.ft (683.7 acres)

Total Subbasins: 1

Number of Green Infrastructure Projects: 17

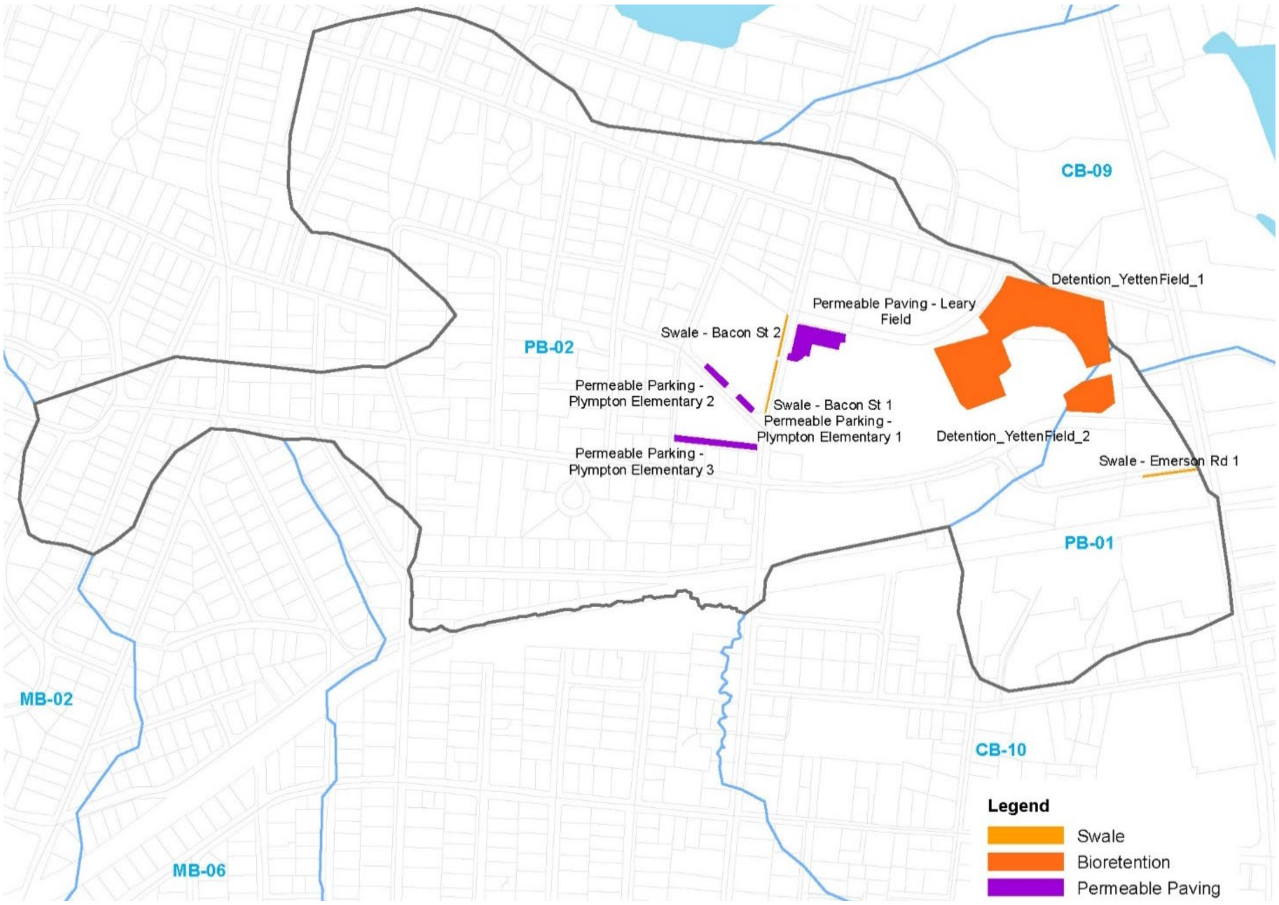


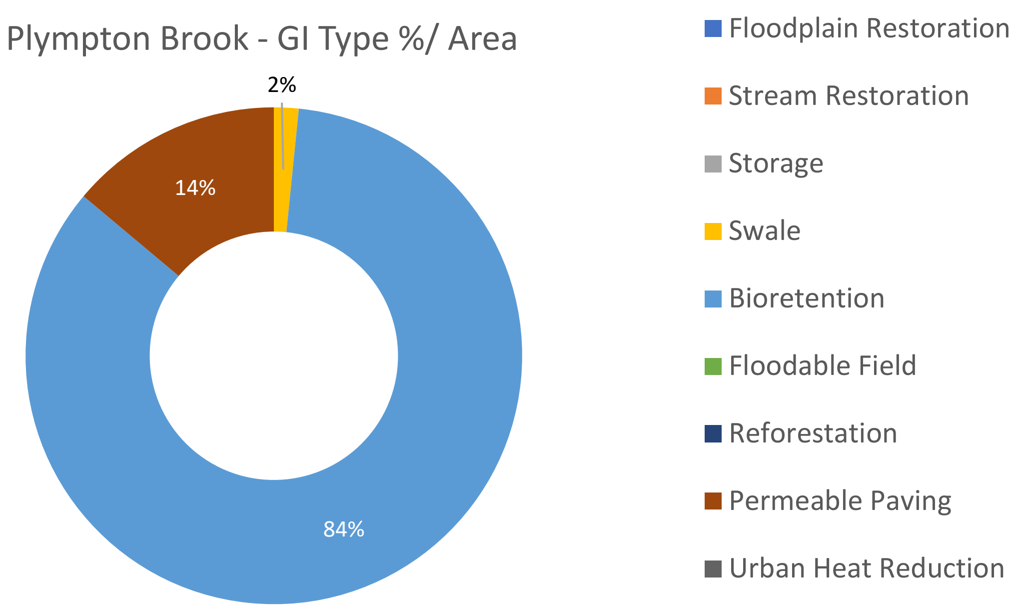
Weston & Sampson



Name	Area	Type	Subbasin
Increase Storage Capacity - Shady's Pond Conservation 1	158,664.20	Storage	WCB-01
Swale - Lexington St 8	4,405.89	Swale	WCB-01
Swale - Lexington St 9	5,685.19	Swale	WCB-01
Permeable Paving - Piety Corner Rd	18,555.43	Permeable Paving	WCB-01
Increase Storage Capacity - Pond between Kendall Park and Greenwood Lane	299,908.68	Storage	WCB-01
Swale_TottenPondRd_1	4,267.85	Swale	WCB-01
Stream Restoration Prospect Hill Park	122,347.59	Stream Restoration	WCB-01
Stream Restoration_Totten Pond Rd_1	34,810.89	Stream Restoration	WCB-01
Stream Restoration Pond End Rd	23,463.12	Stream Restoration	WCB-01
StreamRestoration_TottenPondRd_2	88,918.02	Stream Restoration	WCB-01
Swale_TottenPondRd_2	2,319.63	Swale	WCB-01
Swale_TottenPondRd_3	3,249.46	Swale	WCB-01
Swale_TottenPondRd_4	2,463.76	Swale	WCB-01
Swale_TottenPondRd_5	2,699.29	Swale	WCB-01
Swale_TottenPondRd_6	49,906.51	Swale	WCB-01
Increase Storage Capacity - Off Lexington Behind Public Storage	236,739.11	Storage	WCB-01
Swale - Clark Lane	1,780.07	Swale	WCB-01

Plympton Brook / Conduit
Total Area: 4,710,335.61sq.ft (108.1 acres)
Total Subbasins: 2
Number of Green Infrastructure Projects: 9





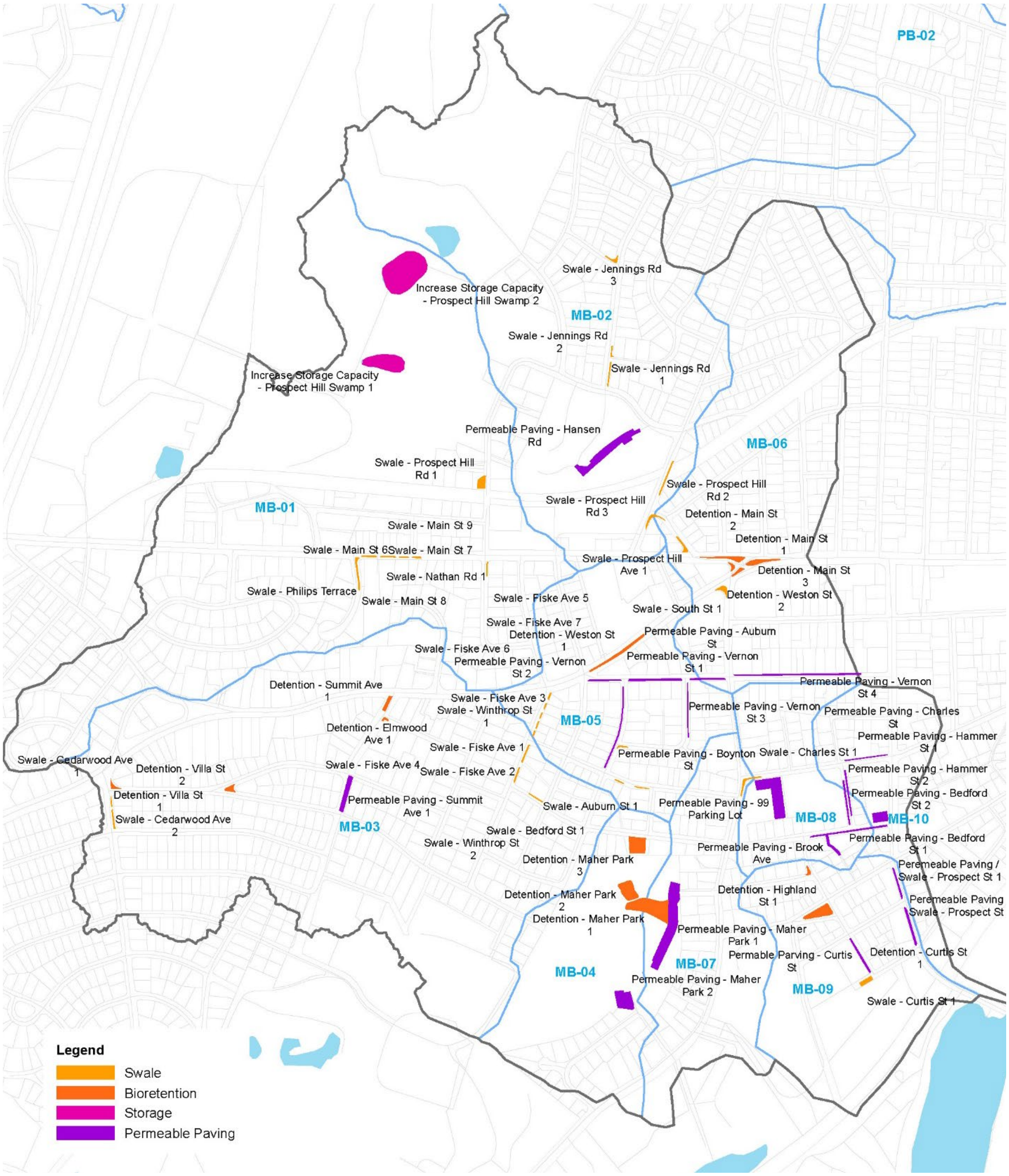
Name	Area	Type	Subbasin
Detention_YettenField_2	29663.27	Bioretention	PB-01
Swale - Emerson Rd 1	1785.19	Swale	PB-01
Detention_YettenField_1	208158.3	Bioretention	PB-02
Permeable Paving - Leary Field	23354.24	Permeable Paving	PB-02
Permeable Parking - Plympton Elementary 1	2273.352	Permeable Paving	PB-02
Permeable Parking - Plympton Elementary 2	3281.746	Permeable Paving	PB-02
Permeable Parking - Plympton Elementary 3	10217.09	Permeable Paving	PB-02
Swale - Bacon St 1	1603.239	Swale	PB-02
Swale - Bacon St 2	1127.476	Swale	PB-02

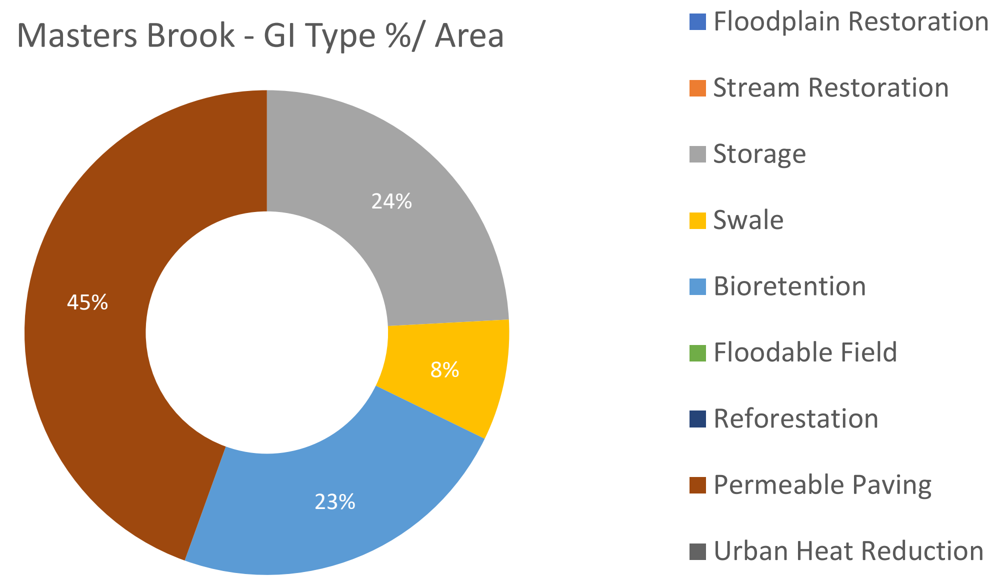
Masters Brook / Conduit

Total Area: 21,036,711.69 sq.ft (482.9 acres)

Total Subbasins: 10

Number of Green Infrastructure Projects: 65

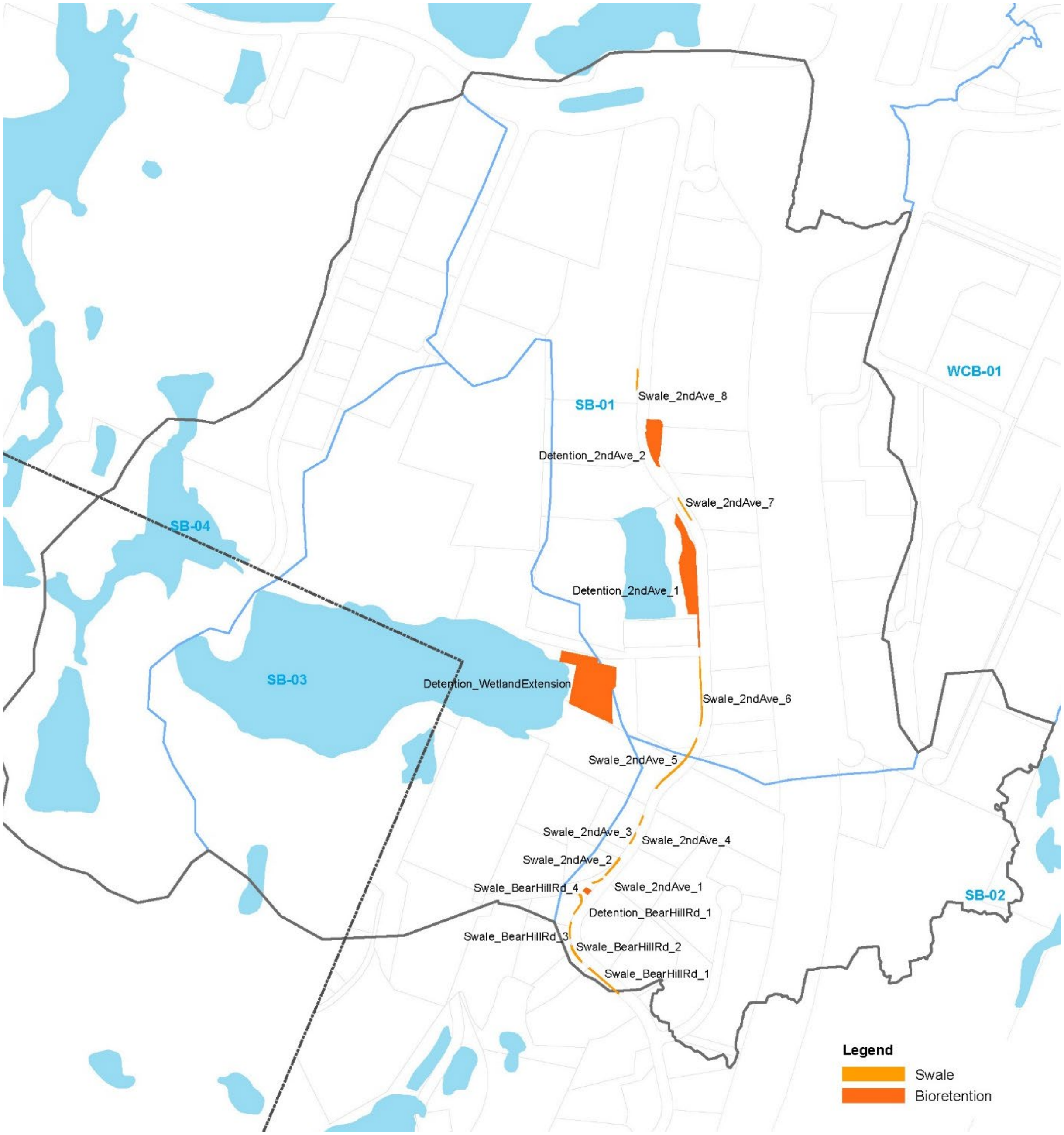


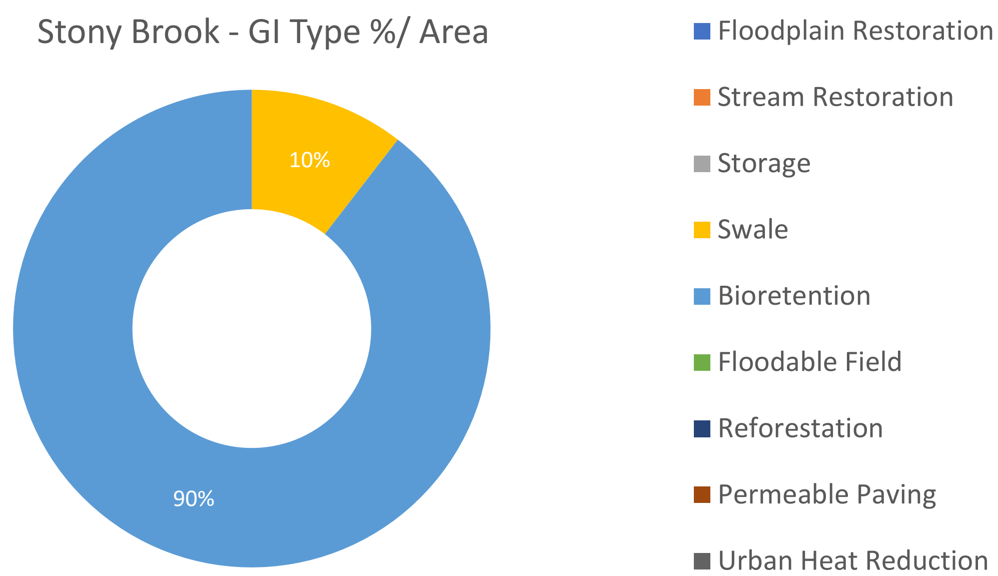


Name	Area	Type	Subbasin
Increase Storage Capacity - Prospect Hill Swamp 1	34,256.54	Storage	MB-01
Increase Storage Capacity - Prospect Hill Swamp 2	83,021.27	Storage	MB-01
Swale - Prospect Hill Rd 1	5,398.32	Swale	MB-01
Swale - Main St 6	1,052.94	Swale	MB-01
Swale - Main St 7	1,102.01	Swale	MB-01
Swale - Main St 8	637.28	Swale	MB-01
Swale - Main St 9	636.94	Swale	MB-01
Swale - Philips Terrace	2,892.38	Swale	MB-01
Swale - Nathan Rd 1	880.14	Swale	MB-01
Permeable Paving - Hansen Rd	32,709.23	Permeable Paving	MB-02
Swale - Prospect Hill Rd 2	1,990.32	Swale	MB-02
Swale - Prospect Hill Rd 3	2,192.57	Swale	MB-02
Swale - Jennings Rd 1	1,261.44	Swale	MB-02
Swale - Jennings Rd 2	676.80	Swale	MB-02
Swale - Jennings Rd 3	1,561.08	Swale	MB-02
Detention - Summit Ave 1	2,849.29	Bioretention	MB-03
Detention - Villa St 1	1,682.02	Bioretention	MB-03
Detention - Villa St 2	2,609.58	Bioretention	MB-03
Detention - Elmwood Ave 1	713.90	Bioretention	MB-03
Permeable Paving - Summit Ave 1	9,549.19	Permeable Paving	MB-03
Swale - Cedarwood Ave 1	469.38	Swale	MB-03
Swale - Cedarwood Ave 2	1,130.83	Swale	MB-03
Swale - Fiske Ave 1	1,331.74	Swale	MB-03
Swale - Fiske Ave 2	1,006.10	Swale	MB-03
Swale - Bedford St 1	696.15	Swale	MB-03
Detention - Maher Park 2	15,320.47	Bioretention	MB-04
Detention - Maher Park 3	15,800.91	Bioretention	MB-04
Permeable Paving - Maher Park 2	17,292.59	Permeable Paving	MB-04
Detention - Weston St 1	8,357.96	Bioretention	MB-05

Permeable Paving - Boynton St	5,094.30	Permeable Paving	MB-05
Permeable Paving - Auburn St	3,127.81	Permeable Paving	MB-05
Permeable Paving - Vernon St 1	5,530.73	Permeable Paving	MB-05
Permeable Paving - Vernon St 2	3,017.70	Permeable Paving	MB-05
Swale - Winthrop St 1	488.38	Swale	MB-05
Swale - Winthrop St 2	423.91	Swale	MB-05
Swale - Fiske Ave 3	514.93	Swale	MB-05
Swale - Fiske Ave 4	355.61	Swale	MB-05
Swale - Fiske Ave 5	367.63	Swale	MB-05
Swale - Fiske Ave 6	415.53	Swale	MB-05
Swale - Fiske Ave 7	381.59	Swale	MB-05
Swale - Auburn St 1	742.88	Swale	MB-05
Detention - Main St 1	5,648.15	Bioretention	MB-06
Detention - Weston St 2	1,769.33	Bioretention	MB-06
Detention - Main St 2	1,330.41	Bioretention	MB-06
Detention - Main St 3	5,664.16	Bioretention	MB-06
Permeable Paving - Vernon St 3	3,332.89	Permeable Paving	MB-06
Permeable Paving - Vernon St 4	10,434.62	Permeable Paving	MB-06
Swale - Prospect Hill Ave 1	2,217.23	Swale	MB-06
Swale - South St 1	2,814.80	Swale	MB-06
Detention - Maher Park 1	37,018.07	Bioretention	MB-07
Permeable Paving - Maher Park 1	52,829.05	Permeable Paving	MB-07
Swale - Charles St 1	2,543.80	Swale	MB-07
Permeable Paving - Hammer St 1	3,568.70	Permeable Paving	MB-08
Permeable Paving - Hammer St 2	3,578.67	Permeable Paving	MB-08
Permeable Paving - 99 Parking Lot	35,971.43	Permeable Paving	MB-08
Permeable Paving - Bedford St 1	5,337.05	Permeable Paving	MB-08
Permeable Paving - Brook Ave	3,460.62	Permeable Paving	MB-08
Detention - Highland St 1	13,116.97	Bioretention	MB-09
Detention - Curtis St 1	1,214.31	Bioretention	MB-09
Permeable Paving / Swale - Prospect St 1	2,569.21	Permeable Paving	MB-09
Permeable Paving / Swale - Prospect St 2	4,478.99	Permeable Paving	MB-09
Permeable Paving - Curtis St	3,339.64	Permeable Paving	MB-09
Swale - Curtis St 1	3,049.87	Swale	MB-09
Permeable Paving - Bedford St 2	8,629.09	Permeable Paving	MB-10
Permeable Paving - Charles St	2,249.84	Permeable Paving	MB-10

Stony Brook / 2nd Ave
Total Area: 13,831,239.96 sq.ft (317.5 acres)
Total Subbasins: 4
Number of Green Infrastructure Projects: 16





Name	Area	Type	Subbasin
Swale_2ndAve_6	3414.579	Swale	SB-01
Detention_2ndAve_1	47694.73	Bioretention	SB-01
Swale_2ndAve_7	1240.67	Swale	SB-01
Detention_2ndAve_2	21706.35	Bioretention	SB-01
Swale_2ndAve_8	1009.489	Swale	SB-01
Swale_BearHillRd_1	2318.262	Swale	SB-02
Swale_BearHillRd_2	1454.101	Swale	SB-02
Swale_BearHillRd_3	1015.021	Swale	SB-02
Swale_BearHillRd_4	1378.294	Swale	SB-02
Detention_BearHillRd_1	1147.178	Bioretention	SB-02
Swale_2ndAve_1	671.4427	Swale	SB-02
Swale_2ndAve_2	1503.281	Swale	SB-02
Swale_2ndAve_3	630.4069	Swale	SB-02
Swale_2ndAve_4	507.3	Swale	SB-02
Swale_2ndAve_5	3967.603	Swale	SB-02
Detention Wetland Extension	92738.18	Bioretention	SB-03

Attachment F. H&H Analysis and Prioritization of Actions

WALTHAM RESILIENT STORMWATER ACTION AND IMPLEMENTATION PLAN
H&H ANALYSIS

The Waltham Stormwater Management and Implementation Plan promotes nature-based solutions and green infrastructure to mitigate the impacts of climate change and develop a more resilient city. As part of the plan, green infrastructure opportunities were identified throughout the City of Waltham within 5 major watersheds. (See Green Infrastructure Opportunities Analysis Memo for more detailed information).

1.0 Stormwater Model Development

Weston & Sampson developed a stormwater model to identify potential flood-prone areas and to evaluate the potential benefit of various green and gray BMPs and drainage improvements under existing conditions and projected future climate conditions. The model was developed with the latest version of the USEPA 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.

1.1 Existing Infrastructure

To represent the City's existing stormwater infrastructure, W&S first reviewed the City's GIS database of stormwater infrastructure, which provided the layout, material, dimensions, and invert elevations of many storm drains and culverts. W&S's stream assessment, conducted between September 29th and October 28th, 2020, provided additional valuable information regarding the approximate bankfull height and top and bottom widths at dozens of locations within West Chester, Chester, and Beaver Brooks. The stream assessment also informed the condition, material, size, and inlet/outlet elevation of key culverts and road crossings as well the location, size, and invert elevation of various outfalls in those three stream systems. Following review of the City's GIS and W&S's stream assessment data, a list of approximately 143 data gaps were identified that were necessary to complete the planning level stormwater model. These data gaps were generally located in the Plympton Brook and Masters/Sibley Brook watersheds where little open channel remains as well as in the upland areas of the West Chester, Chester, and Beaver Brook watersheds, away from the channels themselves. These remaining data gaps were filled through additional field work immediately following the stream survey. Based on the City's extensive GIS database and 3+ weeks of field investigations, W&S developed a schematic-level representation of the City's stormwater infrastructure and the natural waterways within the Beaver Brook, Chester Brook, Masters/Sibley Brook, Second Avenue, and West Chester Brook watersheds.

1.2 Subcatchments

These five watersheds were represented by a series of 57 subcatchments as shown in Figure 1. Individual subcatchments were delineated based on the latest LiDAR ground elevation datasets, on surface drainage patterns, on our understanding of the City's stormwater infrastructure, and on visual observations made during our many field investigations. The entire study watershed is approximately 6,356 acres (9.93 mi^2), approximately 33% of which consists of impervious surfaces like rooves, roadways, and parking lots. The area and percent impervious cover for each of the major watersheds is provided in Table 1.

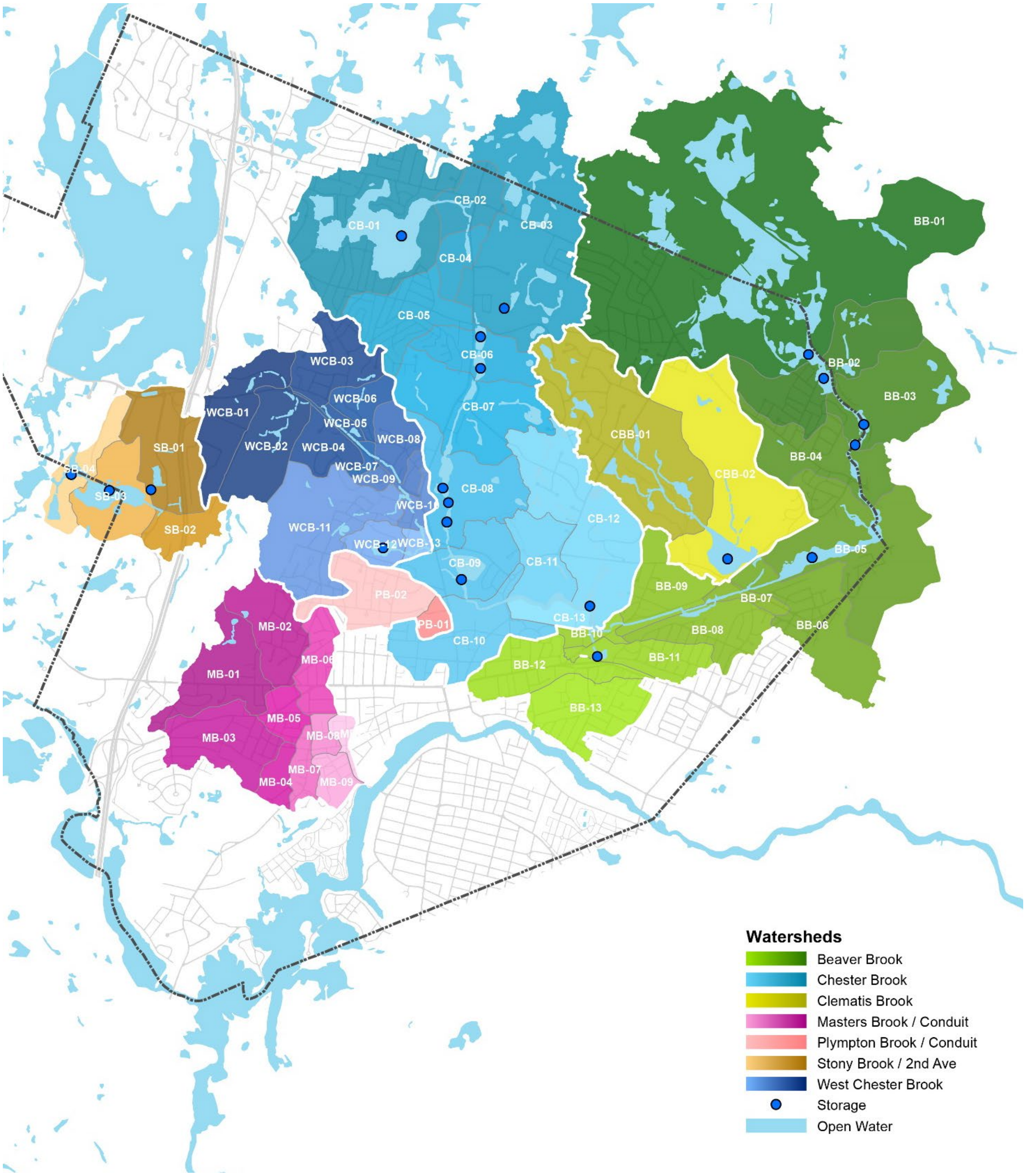


Figure 1. Waltham Major Watersheds – See Appendix B for large extent maps.

Subcatchments were further defined by a variety of model input parameters to reflect the degree to which rainfall infiltrates into the ground, is stored within the subcatchment instead of being released downstream, and is temporarily attenuated, reducing the peak runoff rate (but not volume).

Table 1: Watershed Summary

Watershed	*# of Model Subcatchments*	*Area (ac.)*	*% Impervious*
Beaver Brook	13	2471	29
Chester Brook	13	1721	33
Clematis Brook (part of Beaver Brook)	2	572	31
Masters/Sibley Brook	10	483	45
Plympton Brook (part of Chester Brook)	2	108	54
Second Ave	4	317	52
West Chester Brook	13	684	31

1.3 Design Rainfall Events

PCSWMM generates runoff hydrographs for each subcatchment that result from a user-specified rainfall event. In this case, W&S focused on more frequent, high intensity events, including the 2- and 10-year events. We conducted preliminary model simulations to evaluate whether the City's watersheds were more stressed by shorter duration events with higher peak runoff rates (i.e. 6-hour events) or by longer duration events with lower peak runoff rates but higher runoff volumes (i.e. 24-hour events). In nearly all watersheds, the greater stress on the City's stormwater system and the greater flooding impacts occurred as a result of the large volume event variations. Based on those preliminary simulation results, we focused our evaluation of existing conditions and the effectiveness of potential green and gray infrastructure improvements on 24-hour versions of the 2- and 10-year design events. Time intervals of 15-minutes are frequently used in stormwater simulations, however in this case, with the high impervious cover of many subcatchments and the selection of the longer 24-hour events, we selected a 6-minute time interval to ensure model simulations captured the impacts of high peak runoff rates near the peak of storm events.

Weston & Sampson modeled design events under both baseline and future climate conditions. Design rainfall depths for a baseline climate were derived from NOAA's Atlas 14: Precipitation-Frequency Atlas of the United States for Stormwater Management (NOAA 14). NOAA 14 values represent the industry-standard design rainfall depths for events under a late-1900s/early 2000s (baseline) climate condition.

To determine future design storm depths, W&S relied on a methodology we developed for the State of Massachusetts as part of their ResilientMA initiative, specifically "Draft guidance on future precipitation estimates from the Resilient MA Action Team (RMAT) project by EEA, 2020." As detailed in that guidance document, we conducted a detailed analysis of design storm projections for 9 locations across Massachusetts, using an ensemble of climate models of the RCP 8.5 emission scenario (the greenhouse gas emission scenario that EEA has selected to use). That analysis determined that with the exception of projects in Hampden County, design rainfall depths for "more frequent" events like the 2- and 10-year events are expected to increase by approximately 20% by late century (i.e. 2070/2090). Therefore, future design rainfall depths were determined by multiplying NOAA14 values by 1.2. Those calculated values for a 2070 climate scenario and their baseline climate counterparts are presented in Table 2.

Table 2: Design Rainfall Depths

Design Event	Climate Condition	
	Baseline (NOAA Atlas 14)	Estimated 2070 (NOAA Atlas 14 x1.2)
2-year, 24-hour	3.24	3.89
10-year, 24-hour	5.10	6.12

1.4 Storage Volumes

While the methodology used to model the 57 subcatchments incorporates the impact of the storage potential of small but numerous depressions, sinks, potholes, etc., large ponds and wetlands were modeled explicitly to capture their full effect. Stage-surface area curves were developed for 21 individual waterbodies scattered throughout the modeled watersheds. The location of these wetlands and ponds are shown in Figure 1. Stage-surface area curves were developed from the latest LiDAR ground elevation datasets as 1-foot intervals, extending from the normal water level to approximately three feet above the lowest point at which significant overland flooding might be expected to occur. The outlet structures for each of the 21 storage volumes were modeled directly based on the City's GIS database and on the findings of our field investigations including culvert and control structure invert elevations, stream bank dimensions, debris, and sediment buildup.

1.5 Downstream Boundary Conditions

Like most hydraulic models, PCSWMM stormwater models require that a downstream boundary condition be defined for each watershed/stream. In many cases, the downstream boundary condition was simply a node in the next downstream waterbody. For instance, West Chester Brook terminates in Square Pond, which is part of Chester Brook. In turn, Chester Brook terminates in Beaver Brook just downstream of Lyman Pond.

Ultimately, the model includes three downstream boundary conditions that were modeled independently: Hobbs Brook Pond at the downstream limit of the Second Avenue drainage, the Masters/Sibley Brook outfall into the Charles River at Prospect Street, and the Beaver Brook outfall into the Charles River at Newton Street. The dimensions and invert elevations of these three outfalls were taken from the City's GIS database or from data gathered during our stream assessment. In each case, the backwatering effect that is potential created at each outfall during flood conditions, was estimated by defining each outfall with a constant water level set to the 10-year peak water surface elevation predicted by FEMA and incorporated into their Flood Insurance Studies for Middlesex County. In Hobbs Pond, the 10-year flood level is approximately El. 132, and in the Charles River, the 10-year flood level is El. 34 and El. 24 at the Prospect St. and Newton St. outfalls, respectively. The Charles River and Hobbs Brook boundary conditions were modelled as constant for both 2-and 10-year events and for baseline and future climate scenarios using the FEMA 10-year level. Reviewing backwater elevations against conduit inverts indicated an increase of 1-3 feet in the Charles River would not significantly impact conduit capacities.

1.6 Existing Conditions

As detailed in the sections above, Weston & Sampson developed a stormwater model of the Beaver Brook, Chester Brook, Masters/Sibley Brook, Second Avenue, and West Chester Brook watersheds, in their existing condition. Based on simulations of the four design events described above, Weston & Sampson identified several flood prone areas that are generally consistent with previous flood studies and with historical/anecdotal observations. The following sub-sections highlight some of the stormwater model-predicted floodprone areas for each of the five major watersheds studied.

1.6.1 Beaver Brook

The stormwater model indicates that Beaver Brook experiences a number of flooding impacts in its existing condition during the 10-year and even during the 2-year events that are consistent with historical observations. Simulated flooding occurs where Beaver Brook overtops its bank near Brookside Ave. and further downstream in the Beaver Brook Reservation south of Trapelo Rd.

Overbank flooding is also simulated to occur on the north side of Beaver Brook into the rear parking lots of the Waverley Oaks Office Park and adjacent commercial areas. In this area, Beaver Brook is expected to jump its bank by 0.5 feet during the 10-year flood event, but not at all during the 2-year. However, under a 2070 climate condition, streamflow associated with the 2-year event will increase, causing Beaver Brook to just crest its bank, potentially having adverse impacts. In addition, the 10-year overbank depth is expected to increase from 0.5 to 1.0 feet, increasing associated impacts.

Flooding in this area is exacerbated by inflow from Clematis Brook, which drains the Fernald School area. In fact, during the 10-year event, the large wetland that impounds Clematis Brook on the north side of Waverley Oaks Rd. is expected to rise to the point of overtopping Waverley Oaks by 0.2 feet. Overtopping flows are expected to increase more than fourfold by 2070 although the overtopping depth will only double to approximately 0.4 feet, due to the wide flat nature of the roadway crossing.

Further downstream, significant backwatering occurs at the first Linden St. crossing, which, combined with the size of the Beaver Brook channel upstream, causes the brook to jump its bank and flood Waverley Oaks Rd., an experience we understand has occurred repeatedly in the City's recent history. While no roadway flooding is expected during the 2-year event, model simulations indicate flood depths may reach 0.5 feet during the 10-year event, which may increase to 1.0 feet by 2070.

Perhaps the most extensive flooding impacts in the Beaver Brook watershed, however, are experienced in the Linden St. area. The brook is expected to overtop the roadway at the first Linden St. crossing by 0.7 and 1.5 feet during the 2- and 10-year events, respectively. In the future, these flood depths are expected to worse significantly, rising to 1.5 and 2.4 feet, respectively. Some of that overtopping flow crosses Linden St. are re-enters the brook but backwatering from other crossings further downstream cause significant floodwater to travel southwest down Linden St, crossing under the overhead railroad trestle and beyond, likely causing significant impacts to buildings and infrastructure. Historical accounts and photos confirm the extensive nature of flooding in this area.

1.6.2 Chester Brook

Model simulations indicate that Chester Brook experiences a number of flooding impacts as well. The headwaters of Chester Brook surround Hardy Pond, which has experienced flooding issues repeatedly in the past. We were not able to survey the precise first floor elevations of the many homes around the pond, but we did survey the crest elevation of its small outlet structure, a 25’ Spillway Weir. During both the 2- and 10-year flooding events, the peak pond level is expected to reach to without about 0.2 feet of the crest of that structure, not quite overtopping. By the end of the century, it is expected to overtop during the 10-year event. Regardless, we understand that many impacts occur to homes around the pond at even lower elevations. Model simulations confirm Hardy Pond to be a floodprone area.

The stormwater model suggests that flooding impacts along the northern portion of Lexington St., if any, are localized to ponding in parking lots and other impervious areas with poor drainage. However, there are several floodprone areas indicated in the lower half of the brook. For instance, approximately 0.3 feet of overtopping is expected at the Bishops Forest Dr. crossing during the 10-year event. And while there is likely plenty of freeboard during the 2-year event, by 2070, that is likely to change and Chester Brook may be just starting to overtop Bishops Forest Dr. during small events like the 2-year.

Based on model simulations and field measurements of the Chester Brook channel, we expect the brook to jump its bank repeatedly in the area between Jack’s Way and Stanley Road and to an even greater degree from Stanley Rd. to the driveway for the Village at Clark’s Pond. While model simulations do not suggest any roadway flooding or even impacts to homes up above the floodplain, this is an area that is perhaps vulnerable to flooding impacts in the future, during larger events, or if development in that area or upstream were to increase.

The model also confirms the potential for significant impacts around Square Pond, which is downstream of most of the Chester Brook watershed and all of West Chester Brook. During baseline climate conditions, flooding depths are approximately 0.1 and 0.7 feet during the 2- and 10-year events, respectively. Those flood depths are shown to increase to 1.4 and 2.2 feet, respectively, under 2070 climate conditions, a noteworthy increase, particularly for an area with a floodprone history.

A final note on flooding in the Chester Brook watershed is reserved for the Plympton Ballfields area, which we understand have been constructed on the site of a former pond or wetland in the Plympton Brook system. The baseline and GI solutions within Plympton Brook watershed are modeled under the separate Scenario 16 (results in the appendix). Although the projects performance can be seen independently of Chester Brook, their impact and potential reduction of flooding are based on downstream flooding in Chester Brook. Model simulations indicate very mild flooding from existing storm drains during the 10-year event, which are expected to increase several times over by 2070. The absolute magnitude of the flooding, 60,000 gallons during the 2070 10-year event for instance, are not especially large, but in an area that has no defined channel, is fully piped and in close proximity to floodprone areas along West Chester Brook and the southern part of Lexington Street, this represents a noteworthy risk.

1.6.3 Masters/Sibley Brook

Masters and Sibley Brooks border but are not connected to the Beaver-Chester-West Chester Brook system. Model simulations indicate that this fully piped system in a relatively impervious watershed is likely to become overwhelmed at a number of locations during even small events. Flooding from catch basins and manholes is expected in many places, but model simulations suggest that some of the most significant flooding occurs near Main St., Winthrop St., Auburn St., South St., and, in particular, along Prospect St., from Felton St. to the railroad tracks adjacent to the Charles River. Flooding in these areas is expected to reach into the hundreds of thousands of gallons with peak discharge rates into roadways in the 50 to 150 cfs range during the 2-year event and the 100 to 300 cfs range during the 10-year event.

Flooding under a 2070 climate will increase significantly with roadway flooding volumes more than doubling at a number of locations.

The last segment of the Masters and Sibley Brooks conduit runs parallel with Prospect St before outfalling into the Charles River. Before Prospect St crosses the Charles River it passes under a train trestle. This stretch of road is identified as a known area of flooding and is exacerbated by grades that form a concave road section with a low spot directly under the trestle.

1.6.4 Second Avenue Drainage

Second Avenue is an area that we understand has experienced flooding of the roadway and adjacent parking lots in recent history as a result of surcharging from catch basins and manholes. Stormwater model simulations suggest that this flooding is not likely to be caused by undersized storm drains or culverts, but instead may be attributed to localized issues like raised, blocked, or otherwise isolated catch basins; insufficient drainage systems for individual parking lots or rooftops; or uneven paved surfaces that cause ponding.

1.6.5 West Chester Brook

The stormwater model confirms historical observations that West Chester Brook is a particularly floodprone system with impacts expected at many locations up and down the brook. Its floodprone nature is attributed to several characteristics of the watershed and channel, including significant development and impervious cover at the top of the watershed; the brook alignment running parallel and in close proximity to Totten Pond Rd. for much of its length and the many associated road and driveway crossings; a likely undersized channel in places; floodplain encroachment, in the lower half of the watershed in particular; and a reduction in the discharge capacity of consecutive culverts moving downstream in the lower half of the watershed.

The brook starts at the base of Prospect Hill near the intersection of Totten Pond and Winter St. Significant runoff contributions come from commercial-industrial development at the top of the ridge along 5th Ave. and from Prospect Hill Ln. and Winter St. It crosses under Glen Rd. near the entrance to Prospect Hill Park where roadway overtopping depths of more than 1.0 feet are expected even during the baseline 2-year event. Overtopping is also expected a short distance downstream where the brook crosses under Totten Pond Rd. near the skating rink. At these two crossings, some overtopping flows will carry across and rejoin the brook, however, the natural grades of Totten Pond Rd. likely serve to keep those overtopping flows in the roadway, moving southeast.

Flooding in this area is exacerbated by direct and piped runoff from the Craig Ln. and Lura Ln. areas, where the model suggests the 12-inch storm drain in Totten Pond Rd. is overwhelmed, causing additional roadway flooding. Roadway flooding from Craig Ln. ranges from 60,000 gallons during the baseline 2-year event to 760,000 gallons during the 2070 10-year event. Also in this area are a series of six driveway crossings of the brook, each one backwatering and contributing to the flooding of Totten Pond Rd. as well as driveway and lawn areas. West Chester Brook is also expected to jump its bank often in the area of the Winter Street apartments, with floodplain overtopping of 0.5 ft. during the 10-year event, worsening to 0.7 ft. by 2070.

One of most floodprone reaches of West Chester Brook appears to be the Pond End Rd. area, where model results suggest the brook jumps its bank by 0.4 feet during the 2-year event and by 0.9 feet during the 10-year. Conditions are expected to worsen by 2070, with bank overtopping depths increasing to 0.7 and 1.2 feet, respectively.

Between the Pond End Rd. area and its confluence with Chester Brook, West Chester Brook is conveyed beneath four roadways: Totten Pond Rd., Worcester Ln., Bacon St., and Lexington St. As shown in Table 3 below, only Worcester Ln. is not expected to overtop in any of the events considered. Lexington St., an area of significant known historical flooding, is shown to have the most frequent and consistent flooding impacts.

Table 3: Lower West Chester Brook Overtopping Depths

	Overtopping Depths (feet)			
Climate Scenario	Baseline		2070	
Design Event	2-year	10-year	2-year	10-year
Totten Pond Rd	---	0.2	---	0.6
Worcester Ln	---	---	---	---
Bacon St	---	---	---	0.5
Lexington St	0.0	0.3	0.2	0.5

2.0 Green and Gray Improvement Projects

Weston & Sampson has identified 332 total Green Infrastructure (GI) features throughout the 5 major watersheds in Waltham. In order to evaluate the projects, 27 scenarios were developed grouping the GI based on function, system, or proximity within a watershed. Figure 2 provides an overview of the modeling scenario locations and extents.

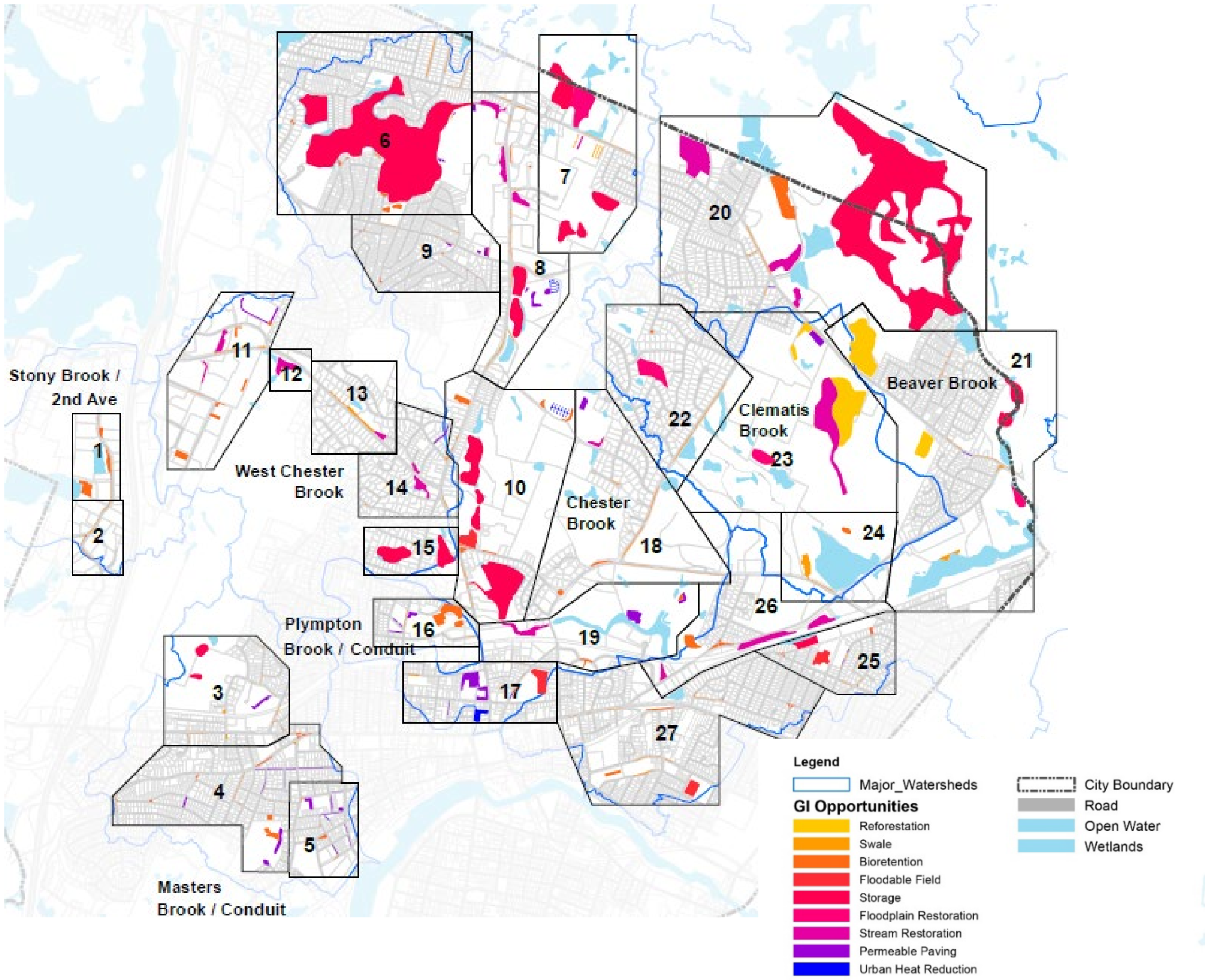


Figure 2. GI Modeling Scenarios – See Appendix B for large extent maps.

2.1 Scenario Modeling Results

The green infrastructure scenario results are summarized in Table 4 below. The scenarios are grouped by watershed and ranked by H&H performance. Although not incorporated into the model, improved maintenance and cleaning of the streams and brooks would benefit all scenarios. A summarized list of the gray infrastructure results are included in Table 5. The Near- and Long- Term Events are measured as the 2-year storm event. The full results and explanations can be found in Appendix A.

Table 4. Green Infrastructure Scenario Results Summary

Scenario	Watershed	Sub-Basins	Project Description / Justification	Near-term % Reduction Total Volume (MG)	Long-term Reduction Total Volume (MG)	H&H Performance 1: Minimal to 5: Very Significant
Scenario 1 – Northern Second Ave	Stony Brook / 2nd Ave	SB-01, SB-03	Swales will intercept and convey stormwater from the northern portion toward detention areas.	8.0%	7.0%	2
Scenario 2 – Southern Second Ave	Stony Brook / 2nd Ave	SB-02	Swales will intercept and convey stormwater from the southern portion toward detention areas.	2.0%	2.0%	1
Scenario 3 – Upper Masters/Sibley Brook	Masters / Sibley Brook	MB-01, MB-02, MB-06	Combines opportunities for storage, infiltration, and conveyance.	4.0%	0.0%	1
Scenario 4 – Middle Masters/Sibley Brook	Masters / Sibley Brook	MB-03, MB-04, MB-05, MB-06, MB-07	Predominantly narrower urban GI solutions of permeable paving, swales, and detention.	7.0%	3.0%	2
Scenario 5 – Lower Masters/Sibley Brook	Masters / Sibley Brook	MB-07, MB-08, MB-09, MB-10	Includes smaller sized GI due to high density and impervious areas.	100.0%	26.0%	5
Scenario 6 – Hardy Pond	Chester Brook	CB-01	Stormwater conveyance, treatment, and storage in and around Hardy Pond	23.0%	5.0%	5
Scenario 7 – Falzone Memorial Park and Shady's Pond Conservation Area	Chester Brook	CB-03	Increasing storage and floodplain areas near Falzone Memorial Park and Shady's Pond Conservation Area	0.0%	0.0%	1
Scenario 8 – Upper Chester Brook	Chester Brook	CB-02, CB-03, CB-04, CB-06, CB-07	Focused on stream restoration, storage in the upper Chester Brook with swales, detention, and permeable paving.	23.0%	5.0%	5
Scenario 9 – Lake Street Neighborhood	Chester Brook	CB-05, CB-06	Smaller swales, permeable paving and detention in the neighborhood around Lake St.	0.0%	0.0%	4
Scenario 10 – Middle Chester Brook	Chester Brook	CB-07, CB-08, CB-09, CB-12	Comprised of increasing storage, and detention areas between Waltham High School and Square Pond.	30.0%	6.0%	1
Scenario 11 – Upper West Chester Brook	West Chester Brook	WCB-01, WCB-02	Parking area improvements and stream restoration in the upper watershed.	3.0%	3.0%	2
Scenario 12 – Prospect Hill Park	West Chester Brook	WCB-02	Stream restoration and removal of culverts within Prospect Hill Park.	0.0%	0.0%	1
Scenario 13 – Totten Pond Road	West Chester Brook	WCB-05, WCB-07	Swales and detention within the brook along Totten Pond Rd.	2.0%	1.0%	1
Scenario 14 – Pond End Road	West Chester Brook	WCB-08, WCB-09, WCB-10, WCB-11	Stream restoration near Pond End Rd	1.0% (10-year)	0.0%	1
Scenario 15 – Lexington and Bacon St	West Chester Brook	WCB-12, WCB-13	Stream restoration and increasing storage capacity of a small pond off of Bacon St.	1.0% (10-year)	0.0%	4
Scenario 16 – Plympton Brook	Chester Brook	PB-01, PB-02	Implementing permeable paving and swales at the elementary school and detention within recreational spaces.	-	13.0% (10-year)	3
Scenario 17 – Lexington and Church St	Chester Brook	CB-10	Parking lot conversion to permeable paving with swales and detention along Church and Summer St.	-	1.0% (10-year)	1
Scenario 18 – North of Lyman Pond	Chester Brook	CB-10, CB-11, CB-12	Systems of conveyance swales and detention to intercept and treat runoff up gradient of Lyman Pond	-	1.0% (10-year)	1
Scenario 19 – Lower Chester Brook	Chester Brook	CB-10, CB-11, CB-13	Includes detention, permeable paving, and stream restoration in and around Lyman Pond.	-	1.0% (10-year)	4
Scenario 20 – Upper Beaver Brook	Beaver Brook	BB-01	North Beaver Brook storage and stream restoration with swales and detention near Trapelo Rd.	433.0%	2750.0%	5
Scenario 21 – Middle Beaver Brook	Beaver Brook	BB-02, BB-03, BB-04, BB-05	Increased storage, conveyance and reforestation projecs throughout the middle section Beaver Brook.	9.0%	40.0%	3
Scenario 22 – Upper Clematis Brook	Clematis Brook	CBB-01	Residential-scale detention and conveyance for water quality improvements.	-	1.0% (10-year)	1
Scenario 23 – Fernald Campus	Clematis Brook	CBB-01, CBB-02	Daylighting, stream restoration, and reforestation around the Fernald Campus	67% (10-year)	35% (10-year)	4
Scenario 24 – Lower Clematis Brook	Clematis Brook	CBB-02	Detention and swales adjacent to lower Clematis Brook wetland to improve water quality	-	1.0% (10-year)	1
Scenario 25 – Warrendale	Beaver Brook	BB-08	Swales, permeable paving, and detention near Fitzgerald Elementary School	-	1.0% (10-year)	1
Scenario 26 – Waverly Oaks and Linden	Beaver Brook	BB-07, BB-09, BB-10	Includes stream restoration projects along Waverly Oaks Rd and Linden St.	0.0%	0.0%	1
Scenario 27 – Lower Beaver Brook	Beaver Brook	BB-11, BB-12, BB-13	Lower Beaver Brook street side projects that address localized flooding	6.0%	6.0%	3

Table 5. Gray Infrastructure Scenario Results Summary

Watershed	Gray Infrastructure Project	Description / Justification	Near-term % Reduction Total Volume (MG)	Long-term % Reduction Total Volume (MG)	H&H Performance 1: Minimal to 5: Very Significant
Stony Brook / 2nd Ave	None	NA	-	-	-
Masters / Sibley Brook	Prospect St at Highland/ Felton St	The proposed change is to widen those conduits to 10 feet wide or otherwise create a comparable increase in cross-sectional flow area.	100.0%	100.0%	5
Chester Brook	None	Noted in the discussions of Scenarios 6, 8, and 10 in Appendix A, several green infrastructure scenarios included modifications to the culverts or other outlet structures that impound ponds or wetlands within the Chester Brook watershed	-	-	-
West Chester Brook	Craig Ln. & Totten Pond Road Storm Drain Improvements	Increase the capacity of the storm drains in Totten Pond Rd. and Craig Ln	100.0%	100.0%	4
	Culvert Improvements	Increase the discharge capacity at Worcester Ln., Bacon St., and Lexington St. , (3) 4-foot diameter culverts at all four road crossings	11450.0%	1473.0%	5
Beaver Brook & Clematis Brook	Culverts near Waverly Oaks Rd and Linden St	This concept incorporates widening of the channel in this trouble area (likely to the south) so that it is consistent with upstream and downstream reaches.	-	7.0%	3

2.2 Green Infrastructure Scenario Recommendations

The following green infrastructure recommendations are organized by watershed and list the co-benefits of the scenarios. The co-benefits evaluated included projects that overlap environmental justice neighborhoods or provide benefit to environmental justice neighborhoods, reduce urban heat, have placemaking opportunities, improve the pedestrian experience, and support biodiversity. The community resilience factor was developed by input from Town staff, current priorities based on public and stakeholder input and other ongoing projects, and scenarios that would reduce repetitive flood concerns. This factor will need to be adjusted as priorities and needs change in the community. The scenarios are ranked in Table 6 below. This table does not include the grey infrastructure solutions presented in Table 5.

Table 6. Co-Benefit Prioritization and Rank

Scenario	Community Resilience Factor	Environmental Justice Neighborhood	Reduction of Urban Heat	Placemaking	Pedestrian Improvements	Biodiversity
Scenario 1 – Northern Second Ave	2	5	2	2	3	2
Scenario 2 – Southern Second Ave	1	5	1	2	3	1
Scenario 3 – Upper Masters/Sibley Brook	1	5	2	2	2	2
Scenario 4 – Middle Masters/Sibley Brook	2	3	2	4	4	4
Scenario 5 – Lower Masters/Sibley Brook	3	3	2	2	3	2
Scenario 6 – Hardy Pond	4	4	1	2	1	3
Scenario 7 – Falzone Memorial Park and Shady's Pond Conservation Area	1	3	1	3	2	4
Scenario 8 – Upper Chester Brook	4	5	2	3	5	4
Scenario 9 – Lake Street Neighborhood	4	5	1	1	3	1
Scenario 10 – Middle Chester Brook	1	2	2	4	2	4
Scenario 11 – Upper West Chester Brook	2	5	3	3	4	4
Scenario 12 – Prospect Hill Park	3	1	3	5	4	5
Scenario 13 – Totten Pond Road	1	1	1	1	3	3
Scenario 14 – Pond End Road	1	1	2	2	1	3
Scenario 15 – Lexington and Bacon St	3	1	1	2	1	3
Scenario 16 – Plympton Brook	3	4	2	4	3	4
Scenario 17 – Lexington and Church St	1	5	4	3	3	2
Scenario 18 – North of Lyman Pond	1	2	2	2	5	3
Scenario 19 – Lower Chester Brook	3	5	2	2	1	3
Scenario 20 – Upper Beaver Brook	5	2	4	4	2	4
Scenario 21 – Middle Beaver Brook	3	1	5	5	4	4
Scenario 22 – Upper Clematis Brook	1	1	3	3	3	3
Scenario 23 – Fernald Campus	5	1	5	5	2	5
Scenario 24 – Lower Clematis Brook	1	1	1	2	2	2
Scenario 25 – Warrendale	1	1	2	4	3	4
Scenario 26 – Waverly Oaks and Linden	5	3	2	4	4	4
Scenario 27 – Lower Beaver Brook	3	3	3	2	4	2

2.2.1 Stony Brook / 2nd Ave Watershed

Recommendations:

1. Maintain and clear out existing catch basins, outfalls, and channels (significant sediment buildup of debris and sediment around outfalls/buried pipes and streams) were identified during site investigation)
2. Implement the Detention Areas along Second Ave adjacent to existing wetland area.
3. Consider new traffic alignments / road diet to create additional space for swales, sidewalks, biking particularly around the Second Ave and Bear Hill Road intersection.

2.2.2 Masters / Sibley Brook Watershed

Recommendations:

1. Given the high impervious cover of this watershed, strengthen on-site stormwater management requirements through the City's building permit-related ordinances to increase the amount of runoff required to be captured and infiltrated onsite.
2. Expand the discharge capacity of the existing 6x4-foot and 6x4.5-foot storm drains on Prospect Street from the Highland/Fulton St. intersection to the Charles River to approximately 10x4-foot.
3. Implement the GI projects incorporated into Scenario 5.
4. Consider broadening Nipper Maher Park and Parking Area projects into a park masterplan
5. Main St and Weston St Intersection projects in conjunction with a Complete Streets traffic realignment.

2.2.3 Chester Brook Watershed

Recommendations:

1. Modify the Hardy Pond outlet structure so that it can be readily operated to drawdown the pond by approximately 6 inches in advance of large storm events. Combine this with floodproofing surrounding dwellings and incorporating GI projects from Scenario 6 necessary.
2. Modify the outlet structures of the wetlands/ponds upstream of a) the driveway to the YMCA, b) the exit driveway for the JFK Junior High School, c) the northern driveway to Waltham House, and d) Clark Pond to drawdown water surface levels in advance of large storm events.
3. Yetten Field Detention and Permeable Paving
4. Swales along Lexington St near Brookway Rd to help reduce surface pooling, improve street scape and provide urban heat reduction.
5. Swales and Detention along Forest St. to reduce runoff velocity and improve street scape for pedestrians.

2.2.4 West Chester Brook Watershed

Recommendations:

1. Increase the hydraulic capacity of the Worcester Ln., Bacon St., and Lexington St. crossing to match that of the last Totten Pond Rd. crossing.
2. Upsize the storm drains in Craig Ln. and Totten Pond Rd. from 12- and 15-inch to 36-inch. Note that the corresponding increases in downstream discharge volume/rate may need to be offset through the construction of GI projects elsewhere in the watershed.
3. Incorporate into an update for the Prospect Hill Park Masterplan including stream restoration, removal of culverts, parking lot design, tributary restoration along Glen Rd (park access road) and reconnect 31 acres of impervious surfaces along 5^{th} Ave to drain toward the project area.

2.2.5 Beaver Brook and Clematis Brook Watersheds

Recommendations:

1. Modify the small outlet structure that is partially responsible for creating the large wetland complex on MADCR land in the headwaters of the watershed to significantly reduce and attenuate runoff entering Beaver Brook from that area. There is a natural restriction (10ft channel) upstream of Mill Pond north of Mallard Way with significant debris and stones that restricts the wetlands in Beaver Brook North Reservation.
2. Widen the Beaver Brook channel where it parallels Waverley Oaks Rd. and widen the bridge/culverts at both Linden St. crossings of Beaver Brook and the railroad crossing between them.
3. Develop the GI projects incorporated into Scenario 23 on the Fernald School campus to reduced Clematis Brook overtopping of Waverley Oaks Rd.
4. Consider conveyance swales along Trapelo Rd to help reduce localized flooding, convey stormwater to Beaver Brook, and provide pedestrian friendly / safe walking and biking experiences.

APPENDIX A

Full Modeling Scenario Results and Explanations

1.1 Green and Gray Improvement Projects

Weston & Sampson has identified 332 total Green Infrastructure (GI) features throughout the 5 major watersheds in Waltham. In order to evaluate the projects, 27 scenarios were developed grouping the GI based on function, system, or proximity within a watershed. Figure 2 provides an overview of the modeling scenario locations and extents.

1.2 Second Ave. Watershed

Second Ave. has a history of localized ponding in the Second Ave. roadway and adjacent parking lots. Our stormwater modeling efforts suggest that at the 2- and 10-year recurrence intervals, this ponding is not the result of surface waterbodies overflowing or even due to overwhelmed storm drains surcharging from catch basins and manholes. It is possible that if the Second Ave. area were further discretized into more than four sub-basins or that some of the smaller diameter storm drains were added to the model, localized problem areas would become more apparent in the model. However, as it is, the stormwater model suggests that localized ponding is caused by small scale inabilities for stormwater to get into the existing storm drain system, which may be occurring for a number of reasons: inadequate number of catch basins, perched catch basins due to pavement settling, pavement grading that does not sufficiently direct runoff to catch basins, sedimentation, and potentially undersized drains on a small scale.

Green Infrastructure Projects

Weston & Sampson has identified 16 potential GI projects within the Second Ave. watershed. They have been grouped into two scenarios: Scenario 1 focused on the northern half of the Second Ave. watershed and Scenario 2 focused on the southern half. Weston & Sampson has evaluated the potential flood reduction benefits of both scenarios as described in the following sub-sections.

Scenario 1 – Northern Second Ave.

This scenario considers stormwater improvements through the implementation of 6 GI features: 3 street edge swales, 2 street side detention areas, and 1 detention area adjacent to the wetland located in SB-03. The larger subbasin extends north from the AstraZeneca facility to the Cambridge Reservoir and collects stormwater runoff from large parking areas and rooftops associated with several large box stores, manufacturing facilities, the hospital, and other commercial spaces. As a low point, 2nd Avenue acts as a collector of most of the subbasin runoff volume. Utilizing gravity, the GI swales will intercept and convey stormwater toward the detention areas reducing the stresses on the current drainage system. The detention areas can store runoff volume during the storm and slowly empty into the drainage system or wetland after the peak flow has passed.

The potential flood reduction benefit of this scenario was first evaluated by considering the duration, maximum discharge rate, and total volume of flooding expected in the Second Ave. roadway for the 2- and 10-year events under both baseline and 2070 climate conditions.

	Reduction				% Reduction			
	Baseline		2070		Baseline		2070	
Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Duration (hrs)	---*	---*	---*	0.01	---*	---*	---*	5%
Peak Rate (cfs)	---*	---*	---*	7	---*	---*	---*	7%
Total Volume (MG)	---*	---*	---*	0.02	---*	---*	---*	11%

** No overtopping expected at this location under existing conditions.*

As shown in the table above, model results indicate that no roadway flooding is expected during the 10-year baseline climate event or during the 2-year event under any climate condition. Modest flooding is expected during the 2070 climate 10-year event. During that design event, the proposed GI projects incorporated into Scenario 1 would have only a small impact on flooding from overwhelmed stormwater infrastructure. The duration of flooding was reduced by 5%. The maximum flood rate would be reduced from 101 cfs to 94 cfs, a 7% reduction. The total volume of flood water would also be reduced by 0.02 MG, an 11% reduction. Based on these results, Scenario appears to have only a small impact on flooding originating from overwhelmed stormwater infrastructure.

Weston & Sampson also considered the potential reductions in localized flooding due to rainwater running off directly onto parking lots and roadways by evaluating predicted changes in the total volumes and peak rates of runoff generated in the sub-basin where most of the Scenario 1 GI projects are located, in the northeastern portion of the watershed.

	% Reduction			
	Baseline		2070	
Parameter	2-year	10-year	2-year	10-year
Total Volume (MG)	8%	5%	7%	4%
Peak Rate (cfs)	0%	0%	0%	0%

Based on model simulations, runoff volumes are reduced by 4 to 8% in the northern half of the Second Ave. watershed although peak runoff rates are not expected to change significantly. However, these values are produced on a sub-basin scale with a drainage area of 120 acres. These projects may still have significant localized flood reduction benefits in the immediate vicinity of their construction as well as substantial co-benefits.

Scenario 2 – Southern Second Ave.

This scenario considers the implementation of 10 GI features: 9 street edge swales and 1 detention area within the Bear Hill Road and Second Ave intersection. The larger subbasin extends south from the AstraZeneca facility toward a crest near 293 Bear Hill Road. Similar to Northern Second Ave, Southern Second Ave is highly impervious due to many smaller commercial businesses with large parking areas and wide road widths. Additionally, Bear Hill Road has a significant slope that allows stormwater runoff to rush toward the low point along Second Ave. The first 4 GI swales will intercept and convey stormwater downslope from one feature to the next toward the detention area. With slight roadway reconfigurations, detention at the intersection, via surface detention or underground storage, can delay runoff and mitigate the peak flow volumes in the current drainage system. The remaining 5 GI swales along Second Ave convey surface stormwater from the intersection toward the existing swale and wetland near the AstraZeneca facility near 293 Second Ave.

Localized flooding due to rainwater running off directly onto parking lots and roadways is expected during each of the four modeled storm events. Weston & Sampson evaluated the potential flood reduction benefit of this scenario by evaluating predicted changes in the total volumes and peak rates of runoff generated in the sub-basin where most of the Scenario 2 GI projects are located, in the southeastern portion of the watershed.

	% Change			
	Baseline		2070	
Parameter	2-year	10-year	2-year	10-year
Total Volume (MG)	2%	2%	2%	2%
Peak Rate (cfs)	0%	1%	0%	1%

As the table above shows, the proposed GI projects incorporated into Scenario 1 would have only a small impact on runoff in the Second Ave. area. Based on model simulations, reductions in total runoff volume are expected to be approximately 2% across all events considered. Peak runoff rates are expected to be reduced by up to about 1%. However, these values are produced on a sub-basin scale with a drainage area of 48 acres. These projects may still have significant localized flood reduction benefits in the immediate vicinity of their construction as well as substantial co-benefits.

Gray Infrastructure Improvements

None.

Watershed Recommendations

As a result of the likely sources of ponding in the Second Ave. area, the GI projects that were developed for the watershed are shown to have little effect on flooding by the stormwater model. However, we expect useful reductions in ponding/flooding in the immediate vicinity of the projects, particularly if they are coupled with modifications to catch basins and/or grading that improve the movement of runoff into the existing storm drain system.

The greatest impact GI can provide in this watershed is water quality improvements. By intercepting parking area and street runoff, the swales can remove sediments, organic materials, and metals before they enter Stony Brook. Additional studies of these areas may indicate an increased ability to store and/or infiltrate stormwater rather than draining back into the drainage system. This could provide needed flood volume reductions. Second Ave remains one of the least hospitable streets for pedestrians and cyclists due its narrow or non-existent sidewalks, uneven roads, and wide road widths. Importantly, these GI features can usher forward reconsiderations of the existing street design to become more pedestrian oriented with adequate sidewalks, crossings, or bike lanes.

Recommendations:

1. Maintain and clear out existing catch basins and outfalls (significant sediment build up around outfalls/buried pipes were identified during site investigation)
2. Implement the Detention Areas along Second Ave adjacent to existing wetland area.
3. Consider new traffic alignments / road diet to create additional space for swales, sidewalks, biking particularly around the Second Ave and Bear Hill Road intersection.

1.3 Masters/Sibley Brook Watershed

Flooding within the fully piped, highly impervious Masters/Sibley Brook system occurs in several locations throughout the watershed as a result of overwhelmed catch basins and storm drains. Some of the most significant historically observed flooding has occurred along Prospect St., in the low-lying areas between its intersection with Felton/Highland St. and the Charles River. Flooding is particularly severe in the depression beneath the railroad trestle. Our stormwater modeling efforts suggest that roadway flooding may also occur in areas in and near Main St., Winthrop St., Auburn St., and South St. Roadway flooding likely occurs as a result of high impervious cover throughout much of the watershed and limited storm drain capacity, exacerbated by a small backwatering effect from the Charles River.

<u>Green Infrastructure Projects</u>

Weston & Sampson has identified 65 potential GI projects within the Masters/Sibley Brook watershed. They have been grouped into three scenarios: Upper, Middle, and Lower Masters/Sibley Brook. Scenario 3 is located in the upper watershed and combines opportunities for storage, infiltration, and conveyance. Scenario 4 includes the middle and western edge of the watershed near Brandeis University and includes predominantly narrower urban GI solutions of permeable paving, swales, and detention. Scenario 5 is the lower watershed and similarly considers smaller sized GI due to high density and impervious areas. Weston & Sampson has evaluated the potential flood reduction benefits of these scenarios as described in the following sub-sections.

Scenario 3 – Upper Masters/Sibley Brook

Scenario 3 considers stormwater improvements through the implementation of 16 GI features: 2 Storage areas within Prospect Hill Park, 1 large parking lot conversion to permeable paving at Prospect Terrace, and 13 swales that can treat and convey stormwater (6 swales along Main St, 3 along Prospect Hill Road, 1 on Lunda St, and 3 along Jennings Rd). Generally, stormwater runoff moves north to south within this subbasin toward Main St. and then southeast toward the Prospect St. Storage within Prospect Hill Park is intended to intercept stormwater runoff from the park's steep slopes. Similarly, the GI features north of Main St are intended to intercept, delay, and convey stormwater runoff moving south. Stretches of Main St are wide enough to implement 6-foot-wide swales without major traffic realignment. Swales along Main St primarily function as treatment and conveyance of stormwater downstream to other features or back into the existing drainage system.

As the GI projects incorporated into this scenario are concentrated in the northern portion of the watershed, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in the duration, maximum discharge rate, and total volume of flooding expected in the Main St. area as well as the Winthrop St. area further downstream.

		Reduction				% Reduction			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Main St	Duration (hrs)	0.01	0.01	0.00	0.01	4%	2%	0%	2%
	Peak Rate (cfs)	2	3	2	4	1%	1%	1%	1%
	Total Volume (MG)	0.01	0.02	0.01	0.03	2%	2%	2%	2%
Winthrop St	Duration (hrs)	0.00	0.00	0.00	0.00	0%	0%	0%	0%
	Peak Rate (cfs)	0	0	0	0	0%	0%	0%	0%
	Total Volume (MG)	0.00	0.00	0.00	0.00	0%	0%	0%	0%

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact on flooding from overwhelmed stormwater infrastructure in the vicinity of Main St., with reductions in duration, peak rate, and total volume generally ranging from 1 to 4% across all four design events. These small benefits are not expected to extend very far downstream in the Masters/Sibley Brook system as indicated by no change in model output parameters at the Winthrop St. area.

Scenario 4 – Middle Masters/Sibley Brook

Scenario 4 considers the implementation of 35 GI features: 14 Swales, 12 Detention Areas, and 9 Permeable Paving Areas. The features fall along three dominant flow paths and are placed to intercept, convey, detain, and store runoff. The northern flow path begins along Main St where Scenario 3 ends at the intersection of Weston St and Main St. Detention areas and swales are proposed in "low use" areas of the intersections and could be larger if combined with traffic realignment strategies. Runoff from this area connects south to the Masters/Sibley Brook Conduit near the intersection of South St and Vernon St. The next flow path moves west to east, starting near Brandeis University and south of Weston St. A series of street side wales and detention areas near intersections are proposed within this residential neighborhood. In instances where wide alleys or streets exist, permeable paving is considered to decrease runoff and provide additional storage. Surface runoff enters the Masters/Sibley Brook conduit in several locations including Summit Ave, Fiske Ave, and Vernon St. The last flow path moves from south to north, through Nipper Maher Park, and enters the conduit at Bedford St. The GI within the park includes permeable paving under the existing large parking areas and detention areas between the sports fields. Because the park is highly programmed, concepts like floodable fields, were incorporated, but would create a large surface area for temporary flood storage.

As the GI projects incorporated into this scenario are concentrated in the southwestern portion of the watershed, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in the duration, maximum discharge rate, and total volume of flooding expected in the Winthrop St. area as well as several locations further downstream.

		Reduction				% Reduction			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Winthrop St	Duration (hrs)	0.00	0.01	0.00	0.07	0%	2%	0%	9%
	Peak Rate (cfs)	1	2	1	4	1%	1%	1%	2%
	Total Volume (MG)	0.01	0.02	0.01	0.09	2%	2%	2%	8%
Auburn St (near Vernon)	Duration (hrs)	0.00	0.00	0.00	0.01	0%	0%	0%	2%
	Peak Rate (cfs)	1	1	-3*	1	2%	2%	-7%*	2%
	Total Volume (MG)	0.01	0.01	0.01	0.01	6%	3%	4%	3%
South St	Duration (hrs)	0.01	0.01	0.01	0.02	3%	2%	2%	3%
	Peak Rate (cfs)	1	2	1	2	2%	1%	1%	1%
	Total Volume (MG)	0.01	0.02	0.01	0.03	4%	3%	3%	3%
Prospect St at Highland/ Felton St	Duration (hrs)	0.01	0.00	0.00	0.00	7%	0%	0%	0%
	Peak Rate (cfs)	2	1	1	2	3%	1%	1%	1%
	Total Volume (MG)	0.01	0.01	0.01	0.01	7%	1%	2%	1%

**Negative value likely due to isolated model instability at this location; no significant change expected.*

As the table above shows, the proposed GI projects incorporated into this scenario would have a modest impact on flooding from overwhelmed stormwater infrastructure. The benefits immediately downstream in the Winthrop St. area generally ranged from 1 to 2%, with more significant reductions experienced during the 2070 10-year event, including an 8% reduction in the total flood volume surcharging into the street there. Benefits are shown to continue downstream of Winthrop St. with reductions generally in the 2 to 5% range with the most significant benefits occurring during the smallest events. In fact, model simulations suggest a reduction in flood volume surcharging in the Prospect St. area, an historically hard-hit area, of up to 7% during the baseline climate 2-year event.

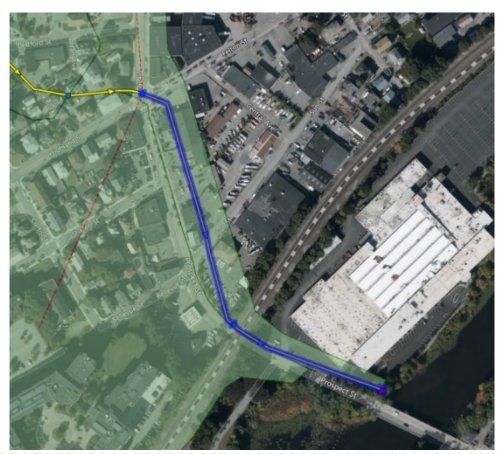
Scenario 5 – Lower Masters/Sibley Brook

Scenario 5 considers stormwater improvements through the implementation of 14 GI features: 2 swale, 2 detention areas, and 10 permeable paving areas. Located in the lower end of the watershed, the features in this scenario align with the surface flow of water and the underlying Masters/Sibley Brook Conduit (6'x4' conduit) that outfalls into the Charles River downstream of the Prospect St Bridge. Due to very narrow streets, permeable paving was the best option to provide infiltration and potential for storage. Predominantly located along streets, permeable paving is proposed under existing lanes of parking as well as two larger parking areas near Curtis St and Prospect St. Additionally, detention is possible at a larger intersection of Curtis and Highland St.

As the GI projects incorporated into this scenario are concentrated in the eastern or downstream portion of the watershed, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in the duration, maximum discharge rate, and total volume of flooding expected in the hard-hit Prospect St. area near its intersection with Highland and Fulton Streets.

		Change				% Change			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Prospect St at Highland/ Felton St	Duration (hrs)	0.1	0.0	0.0	0.0	100%	0%	15%	0%
	Peak Rate (cfs)	56	4	15	5	100%	2%	16%	2%
	Total Volume (MG)	0.11	0.03	0.07	0.03	100%	4%	26%	3%

As the table above shows, the proposed GI projects incorporated into this scenario are expected to have a significant impact on flooding from overwhelmed stormwater infrastructure in the Prospect St. area, particularly during more frequent events. That area experienced 100% flooding relief during the baseline 2-year event and a 25% reduction in roadway flooding during the 2-year event under 2070 climate conditions. More modest improvements, up to 4%, are expected as a result of this scenario's GI projects during more uncommon events, typified by the 10-year event under baseline and 2070 climate conditions.



Gray Infrastructure Improvements

In addition to the three GI scenarios depicted above, Weston & Sampson also considered improvements to the City's existing stormwater infrastructure or "gray" projects. One gray infrastructure improvement project in particular stood out.

The concept behind this gray infrastructure improvement is to increase the capacity of storm drains in the hard-hit Prescott St. area in order to discharge runoff more effectively to the Charles River. The storm drains in this area are currently 6-foot-wide box conduits with heights of 4 or 4.5 feet. The proposed change is to widen those conduits to 10 feet wide or otherwise create a comparable increase in cross-sectional flow area. This change will have the combined benefit of increasing the system's discharge capacity but also its temporary storage capacity. The table below highlights how flooding in this area may improve as a result.

		Reduction				% Reduction			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Prospect St at Highland/ Felton St	Duration (hrs)	0.1	0.3	0.2	0.3	100%	100%	100%	100%
	Peak Rate (cfs)	56	164	93	226	100%	100%	100%	100%
	Total Volume (MG)	0.11	0.56	0.25	0.86	100%	100%	100%	100%

Model simulations indicate that widening or otherwise expanding the discharge capacity of the conduit in this area will have a significant impact on flooding in the lowest portion of the Masters/Sibley Brook watershed. Surcharging from overwhelmed storm drains into Prospect Street is largely eliminated during 2- and 10-year events under both baseline and 2070 climate conditions.

Watershed Recommendations

Flooding within the fully piped, highly impervious Masters/Sibley Brook system occurs in multiple locations throughout the watershed with historical impacts most severe along Prospect St. from its intersection with Highland and Fulton Streets down to the Charles River. Roadway flooding likely occurs as a result of high impervious cover throughout much of the watershed and limited storm drain capacity, exacerbated by a small backwatering effect from the Charles River.

Based on this understanding of the likely flooding sources in the Masters/Sibley Brook watershed and on the results of stormwater model simulations of green and gray infrastructure projects as described above, Weston & Sampson recommends the following actions be taken to reduce flooding in the Masters/Sibley Brook watershed:

Recommendations:

1. Given the high impervious cover of this watershed, strengthen on-site stormwater management requirements through the City's building permit-related ordinances to increase the amount of runoff required to be captured and infiltrated onsite.
2. Expand the discharge capacity of the existing 6x4-foot and 6x4.5-foot storm drains on Prospect Street from the Highland/Fulton St. intersection to the Charles River to approximately 10x4-foot.
3. Implement the GI projects incorporated into Scenario 5.
4. Consider broadening Nipper Maher Park and Parking Area projects into a park masterplan
5. Main St and Weston St Intersection projects in conjunction with a Complete Streets traffic realignment.

1.4 Chester Brook Watershed

Flooding impacts along Chester Brook have historically been noted in the Hardy Pond and Square Pond areas of the watershed. Our stormwater modeling efforts confirm the vulnerability of these areas and suggest that the Bishops Forest Dr. crossing and the reaches of Chester Brook between Jack's Way and Stanley Rd. and from Stanley Rd. to the driveway for the Village at Clark's Pond are likely floodprone as well. In an effort to identify means of reducing impacts in those areas, Weston & Sampson has evaluated the potential benefits of both green and gray infrastructure projects as discussed below.

Green Infrastructure Projects

Weston & Sampson has identified 139 potential GI projects within the Westchester Brook. watershed. They have been grouped into nine scenarios. Scenario 6 includes Hardy Pond and adjacent features. Scenario 7 considers increasing storage and floodplain areas near Falzone Memorial Park and Shady's Pond Conservation Area. Scenario 8 includes the upper Chester Brook from Trapelo Rd to Jack's Way. Scenario 9 is comprised of smaller GI systems in the neighborhood around Lake St from Lakeview to Lexington St. Scenario 10 is includes the middle Chester Brook from Jack's Way to Square Pond. Scenario 16 includes the athletic fields and local streets within the historic Plympton Brook Conduit that outfalls into Chester Brook south of Square Pond. Scenario 17 considers several larger scale urban interventions near Lexington St and Church St. Scenario 18 includes GI from the Waltham High School athletic fields down to Beaver St upgradient of Bentley University Athletic Facilities. Scenario 19 covers Lower Chester Brook including Lyman Pond and adjacent areas. Weston & Sampson has evaluated the potential flood reduction benefits of these scenarios as described in the following sub-sections.

Scenario 6 – Hardy Pond

Scenario 6 proposes stormwater improvements benefitting Hardy Pond and surrounding community through the implementation of 19 GI features: 8 swale, 7 detention areas, 2 permeable paving areas, and increasing the storage capacity for Hardy Pond and adjacent ponds. The detention projects are located around the edges of the pond within interstitial park and street areas with several located near Lazazzero Playground. Permeable paving is proposed for several pond side parking areas on the steep edges of Windsor Village. The projects are placed to intercept and store runoff. The swales are associated with streets to the north of Trapelo Road that are low lying and experience nuisance flooding. Increasing the storage capacity of Hardy Pond and smaller surrounding ponds would involve modifying the outlet structure of the pond to so that the pond level could be drawn down 6" or more prior to a storm event.

The GI projects and modification of the Hardy Pond outlet that were incorporated into this scenario are concentrated in the northwest corner of the watershed, in and around Hardy Pond. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at the outlet from Hardy Pond and then at floodprone areas along Chester Brook as far downstream as Square Pond.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Hardy Pond	0.4	0.3	0.4	0.3	---*	---*	---*	175%**
Bishops Forest Dr.	---*	0.0	0.2	0.0	---*	0%	N/A***	2%
Jack's Way to Stanley Rd.	---*	0.1	---*	0.0	---*	4%	---*	2%
Stanley Rd. to Village at Clarks Pond	0.1	0.0	0.1	0.0	4%	1%	2%	0%
Square Pond	0.0	0.0	0.0	0.0	23%	2%	5%	2%

** Location not expected to be impacted during this event.*

*** Percent reduction in overtopping depth exceeds 100% because the proposed conditions reduce the peak water level below the level of overtopping.*

**** Cannot be calculated due to division by zero.*

As the table above shows, model simulations suggest that the proposed GI projects and modification of the Hardy Pond outlet structure are expected to significantly reduce flood depths and related impacts along the perimeter of Hardy Pond with reductions of 0.3 to 0.4 feet for all four design events that were considered. The benefits, however, are expected to peter out relatively quickly, as the minimal change in flooding at Bishops Forest Dr. suggest.

Scenario 7 – Falzone Memorial Park and Shady's Pond Conservation Area

Scenario 7 considers stormwater improvements through the implementation of 11 GI features: 5 swales, 4 areas for increasing storage capacity, 1 area for floodplain restoration, and 1 conduit to potential daylight. Starting north of Trapelo Rd, near the intersection with Lexington St., surface water flows from an existing small pond adjacent to the Glenmeadow Condominiums through a wooded area of James Falzone Memorial Park into a storm drain under Trapelo Rd. The storm drain runs underneath the Our Lady Comforter of the Afflicted Parish (OLCA) and outfalls into the Shady's Pond Conservation Area east of Chester Brook. The GI concepts look to increase storage capacity of the existing ponds (by 1-2 feet), clear and restore the potential floodplain with Falzone Memorial Park to accommodate an additional 1 foot of runoff, and use of swales on Trapelo Rd to intercept and convey water downstream. The large parking surface of OCLA can be redesigned to accommodate parking and stormwater swales as well as daylighting the conduit the flows under the parking lot.

As the GI projects incorporated into this scenario are concentrated in the northeast corner of the watershed, which drains to Chester Brook upstream of Bishops Forest Dr., the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at floodprone areas along the brook from Bishops Forest Dr. as far downstream as Square Pond.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Bishops Forest Dr.	---*	0.0	0.0	0.0	---*	0%	N/A**	0%
Jack's Way to Stanley Rd.	---*	0.0	---*	0.0	---*	1%	---*	0%
Stanley Rd. to Village at Clarks Pond	0.0	0.0	0.0	0.0	0%	0%	0%	0%
Square Pond	0.0	0.0	0.0	0.0	0%	0%	0%	0%

** Location not expected to be impacted during this event.*

*** Cannot be calculated due to division by zero.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in Chester Brook or its floodplain, with overtopping depth reductions not more than 1%. However, it is worth noting that the proposed GI projects may have a significant impact on localized ponding in roadways and parking lots in their immediate vicinity that do not translate well to the scale of runoff originating in the 351-acre sub-basin in which they are located in the stormwater model. They may also have useful co-benefits.

Scenario 8 – Upper Chester Brook

Scenario 8 includes 31 GI stormwater improvements located along the upper portion of Chester Brook as its outlets from Hardy Pond near Trapelo Rd.: 3 areas for stream restoration along Lexington St, 15 swales along Trapelo and Lexington Rd that intercept, treat and convey stormwater, 2 detention areas within Waltham Overlook/Northgate Gardens, tree planters and permeable paving in the parking lots of the Waltham YMCA, and 2 areas for increased storage between Bishops Forest Dr and Jacks Way. Chester Brook passes through several culverts before entering a conduit from Lionel Ave to Bishops Forest Dr. It continues to flow parallel to Lexington St in a series of impounded wetlands and shallow ponds. The GI concepts are intended to restore the capacity of the existing brook system while reducing the stresses of the drainage system through street level surface solutions like permeable paving and swales. Additionally, the implementation of swales combined with a traffic realignment of Lexington St can help create a pedestrian oriented street and opportunities for increasing shade. Increasing storage will look similar to Hardy Pond with potential for draw down outlet modifications. The upstream pond has room for an additional 4 feet of storage, whereas the lower wetland may only have room for 2 feet of additional storage.

As the GI projects incorporated into this scenario are concentrated along Lexington St. from its intersection with Trapelo Rd. to the JFK Junior High School, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at floodprone areas along Chester Brook from Bishops Forest Dr. as far downstream as Square Pond.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Bishops Forest Dr.	---*	0.0	0.5	0.0	---*	4%	N/A***	2%
Jack's Way to Stanley Rd.	---*	1.9	---*	2.3	---*	105%**	---*	93%
Stanley Rd. to Village at Clarks Pond	0.4	0.9	0.1	1.3	19%	24%	5%	29%
Square Pond	0.0	0.0	0.0	0.0	23%	1%	5%	0%

** Location not expected to be impacted during this event.*
*** Percent reduction in overtopping depth exceeds 100% because the proposed conditions reduce the peak water level below the level of overtopping.*
**** Cannot be calculated due to division by zero.*

As the table above shows, the proposed GI projects incorporated into this scenario are expected to have a significant impact on water levels, and consequently flood depths, in the upper and middle sections of Chester Brook. The benefits are only modest at Bishops Forest Dr. because most of the projects are further downstream. However, while the brook is currently expected to jump its bank between Jack's Way and Stanley Rd. during the 10-year event, this scenario would eliminate or nearly eliminate floodplain flooding in that area. The brook is still expected to jump its bank between Stanley Rd. and Clarks Pond, but flood depths should be reduced by 5 to 30%. These benefits are experienced throughout the middle portion of Chester Brook but appear to be largely eliminated by Square Pond, which is a considerable distance downstream.

Scenario 9 – Lake Street Neighborhood

Scenario 9 is located south of Hardy Pond and surface flow discharges east toward Lexington St and Bishops Forest Dr. The scenario includes 17 GI features: 7 swales, 7 detention areas, and 3 areas for permeable paving. The neighborhood along Lake St is predominantly residential with narrow secondary streets. Areas of detention include small intersections within interstitial spaces. Surface flow runs parallel with Lake St, so the majority of swales and permeable paving locations are aligned with the street conveying runoff from one feature to the next. Further down gradient near the intersection of Lake St and Lexington, permeable paving and detention can be implemented withing the parking lot of the Nahum Hardy Residences. The overall function of the scenario is to slow surface runoff, reduce volume in the drainage system via storage, and improve water quality. Combined with increased planting and tree pits, the GI can help reduce urban heat.

As the GI projects incorporated into this scenario are concentrated in the neighborhoods along Lake St., an area which drains to Chester Brook right at Bishops Forest Dr., the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at floodprone areas along the brook from Bishops Forest Dr. as far downstream as Square Pond.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Bishops Forest Dr.	---*	0.0	0.0	0.0	---*	0%	N/A**	0%
Jack's Way to Stanley Rd.	---*	0.0	---*	0.0	---*	0%	---*	0%
Stanley Rd. to Village at Clarks Pond	0.0	0.0	0.0	0.0	0%	0%	0%	0%
Square Pond	0.0	0.0	0.0	0.0	0%	0%	0%	0%

** Location not expected to be impacted during this event.*

*** Cannot be calculated due to division by zero.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in Chester Brook or its floodplain, with overtopping depth reductions not more than 1%. However, it is worth noting that the proposed GI projects may have a significant impact on localized ponding in roadways and parking lots in their immediate vicinity that do not translate well to the scale of runoff originating in the 102-acre sub-basin in which they are located in the stormwater model. They may also have useful co-benefits.

Scenario 10 – Middle Chester Brook

Scenario 10 considers stormwater improvements through the implementation of 24 GI features: 9 swales, 6 detention areas, 1 floodable field, 6 tree planters, and increased storage capacity for Clarks Pond and a pond on the Chapel Hill – Chauncy Hall School. Starting in the northern-most section of the scenario, tree planters and detention basins in front of Waltham High School can capture and store runoff from the parking lot without losing spaces. Even greater benefits could be observed if permeable paving were to be implemented throughout the parking lot. Downstream along Chester Brook, a large detention basin near the entrance to the Stigmatine Monastery is proposed that can store runoff from Lexington St. before it outfalls into the brook. Increasing storage within the ponds can be achieved by modifying the shape and size of the outlet structure. The recreation field at the intersection of Lexington and Beaver St can easily be converted to a floodable field though regrading. The proposed flooding limits the depth to 1 foot of temporary storage for safety reasons, but the topography and road heights would allow for significantly greater storage depth. The detention basins at the same intersection help intercept, store, and convey runoff from the street through the park to the brook. Swales along the lower end of Lexington St near Square Pond help to capture surface runoff before it reaches the drainage system. They provide additional surface storage in an area of known flooding cause by the confluence of West Chester and Chester Brooks and significant impervious cover.

As the GI projects incorporated into this scenario are concentrated along Lexington St. from the JFK Junior High School to Square Pond, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in Square Pond.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Square Pond	0.0	0.0	0.0	0.0	30%	3%	6%	1%

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact downstream. While the percent reductions in flood levels around Square Pond are notable, with a maximum value of 30% during the 2-year event under a baseline climate condition, the actual change in flood depth there is less than 0.1 feet. While the GI projects incorporated into this scenario do not appear to have a significant impact on flooding in Chester Brook, they may have more localized flood reduction benefits or useful co-benefits.

Scenario 16 – Plympton Brook

Scenario 16 considers stormwater improvements through the implementation of 9 GI features: 3 swales, 2 large detention areas, and 4 areas for permeable paving. The Plympton Brook conduit is a small drainage area west of Square Pond. The area transitions from commercial buildings along Lexington St to sports facilities, playgrounds, the elementary school, and residential areas toward the west. The concept proposes implementing permeable paving around the elementary school and playground parking/drop-off areas, as well as in the stadium parking areas. Swales on Bacon St assist in conveying water toward the permeable paving. Detention areas are integrated into the playing surfaces at Yetten Field and overlay the existing conduit. The intention is that surface runoff is collected and conveyed toward these temporary storage areas during a storm. Their impact can be increased if regrading and surface connections/opening from Dale St can be created.

As noted in our discussion of the development of the stormwater model, we understand the Plympton Ballfields have been constructed on the site of a former pond or wetland in the Plympton Brook system, which is now fully piped. Model simulations indicate very mild flooding from existing storm drains during the 10-year event, which are expected to increase several times over by 2070. The absolute magnitude of the flooding, 60,000 gallons during the 2070 10-year event for instance, is not especially large, but in an area that has no defined channel, is fully piped, and is in close proximity to floodprone areas along Westchester Brook and the southern part of Lexington Street, this represents a noteworthy risk.

We evaluated the GI projects incorporated into this scenario by considering the duration, maximum discharge rate, and total volume of flooding expected at the ballfields for the 2- and 10-year events under both baseline and 2070 climate conditions. 2- and 10-year events under both baseline and 2070 climate conditions.

	Reduction				% Reduction			
	Baseline		2070		Baseline		2070	
Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Duration (hrs)	---*	---*	---*	0.0	---*	---*	---*	20%
Peak Rate (cfs)	---*	---*	---*	2	---*	---*	---*	3%
Total Volume (MG)	---*	---*	---*	0.1	---*	---*	---*	13%

** No overtopping expected at this location under existing conditions.*

The GI incorporated into this scenario is expected to modestly reduce overtopping depths and flood rates in the immediate downstream area, near the Plympton Ballfields. The duration of flooding is expected to be reduced by 20% and the total flooding volume is expected to be reduced by 13%. Additional localized benefits in the immediate vicinity of these projects may also occur and they may have useful co-benefits. However, large-scale flooding in Chester Brook is not expected to change as a result of these projects.

Scenario 17 – Lexington and Church St

Scenario 17 is comprised of 13 GI features: 6 swales, 4 permeable paving areas, 1 area for detention, and 1 project focused on urban heat reduction (solar panel/ shade structure over parking at Central Square parking lot) that was not incorporated into the stormwater modeling. The scenario is located north of the Waltham Common where surface water accumulates and flows near Pond St / Lexington St intersection, running parallel with church street before reaching Chester Brook near the Lyman St Bridge. The subbasin is small and streets are narrow, but there are several large areas that can be converted to GI features. The large parking lots of the Waltham Government Center and Saint Mary's Church are located along the surface flow path and can be converted to permeable parking areas. The large open field next to McDevitt Middle School intersects another flow path and can be regraded to accommodate at least 1 foot of stormwater storage. Swales and detention along Church and Summer St intercept street runoff, providing temporary storage during storm events.

The GI projects incorporated into this scenario are concentrated in a sub-basin at the southeast corner of the Chester Brook watershed, near the southern end of Lexington St. and the Waltham Vocational High School. Drainage from this area discharges into Chester Brook immediately upstream of the Lyman St. crossing. The next floodprone area downstream of where that runoff enters the Chester Brook system is actually the second Linden St. crossing of Beaver Brook near Dunkin Donuts. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at that Linden St. crossing.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Linden St	---*	0.0	0.0	0.0	---*	0%	N/A**	1%

** No overtopping expected at this location under existing conditions.*
*** Cannot be calculated due to division by zero.*

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact downstream. While this scenario does not appear to have a significant impact on flooding in Chester Brook, its GI components may have other useful co-benefits.

Scenario 18 – North of Lyman Pond

Scenario 18 considers the implementation of 10 GI features: 6 swales, 2 detention areas, 1 area for permeable paving, and 1 area for stream restoration. Starting in the northern-most section of the scenario, permeable paving to the side of Waltham High School can capture and store runoff from the lower parking. Nearby along the southern edge of Harding Filed, stream restoration is proposed to remove sediment/overgrowth, and widen the stream top width to restore its capacity. A large swale on Ivy Lane intercepts runoff before it enters into the drainage system. Swales along a steep stretch of Forest St help capture and slow stormwater as it moves south toward Bentley University and Lyman Pond. At the intersection of Forest and Beaver St, a large detention area captures runoff conveyed by the swales on Forest St. Another detention area integrated into a traffic circle collects and delays runoff from Beaver St. The swales along Beaver St line the entrance road of Bentley's Sports Facilities. Beaver St is wide enough to accommodate 5-foot-wide swales from Falcon Way to Cedar Hill Ln. The swales intercept, treat and convey runoff toward a series of ponds adjacent to Field Road.

The GI projects incorporated into this scenario are concentrated in the uplands north of Lyman Pond in the vicinity of Beaver St. and Forest St, which discharges into Lyman Pond. The next floodprone area downstream of where that runoff enters the Chester Brook system is actually the second Linden St. crossing of Beaver Brook near Dunkin Donuts. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at that Linden St. crossing.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Linden St	---*	0.0	0.0	0.0	---*	5%	N/A**	1%

** No overtopping expected at this location under existing conditions.*
*** Cannot be calculated due to division by zero.*

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact downstream. While this scenario does not appear to have a significant impact on flooding in Chester Brook, its GI components may have other useful co-benefits.

Scenario 19 – Lower Chester Brook

Scenario 19 considers stormwater improvements around Lyman Pond through the implementation of 5 GI features: 2 detention areas, 2 areas for permeable paving, and 1 area for stream restoration. The scenario represents the Lower Chester Brook before it forms Lyman Pond and outfalls into Beaver Brook. The stream restoration project combines clearing of sediment build up (significant build was found during site investigation) and overgrowth to regain lost stream flow and capacity. Outside of the stream, a detention basin are located within Garden Circle. Reconsideration of the traffic alignment within the neighborhood and/or conversion of parking to permeable paving can create greater impacts. An additional detention basin can be located along Access Road between the permeable parking lot next to the DeFelice Baseball Field. A large permeable paving area can be created in the back lot of the Dana Athletic Center. With further studies, underground storage could be integrated with permeable paving to reduce runoff entering the pond directly and has the potential for reuse.

The GI projects incorporated into this scenario are concentrated in the relatively flat valley north of Lyman Pond in the vicinity of Bentley University's ballfields, which discharges into Lyman Pond. As with Scenarios 17 and 18, the next floodprone area downstream of where that runoff enters the Chester Brook system is actually the second Linden St. crossing of Beaver Brook near Dunkin Donuts. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at that Linden St. crossing.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Linden St	---*	0.0	0.0	0.0	---*	5%	N/A**	1%

** No overtopping expected at this location under existing conditions.*
*** Cannot be calculated due to division by zero.*

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact downstream. While this scenario does not appear to have a significant impact on flooding in Chester Brook, its GI components may have other useful co-benefits.

Gray Infrastructure Improvements

No gray infrastructure only improvements were identified in this watershed. However, as noted in the discussions of Scenarios 6, 8, and 10 above, several green infrastructure scenarios included modifications to the culverts or other outlet structures that impound ponds or wetlands within the Chester Brook watershed. Though these modifications are not GI, they are significantly less intensive than traditional gray infrastructure and work in tandem with green infrastructure strategies.

Watershed Recommendations

Chester Brook is a relatively large watershed in central Waltham with a mix of forested and urban land uses. Flooding impacts along Chester Brook have historically been noted in the Hardy Pond and Square Pond areas of the watershed. Our stormwater modeling efforts confirm the vulnerability of these areas and suggest that the Bishops Forest Dr. crossing and the reaches of Chester Brook between Jack's Way and Stanley

Rd. and from Stanley Rd. to the driveway for the Village at Clark's Pond may be flood prone as well. Small flooding impacts may also be expected in the Plympton Ballfields area.

Based on our understanding of the watershed's hydrology, historical flooding issues, and stormwater model results, Weston & Sampson recommends the following actions be taken to reduce flooding in the Chester Brook watershed:

Recommendations:

1. Modify the Hardy Pond outlet structure so that it can be readily operated to drawdown the pond by approximately 6 inches in advance of large storm events. Combine this with floodproofing surrounding dwellings and incorporating GI projects from Scenario 6 necessary.
2. Modify the outlet structures of the wetlands/ponds upstream of a) the driveway to the YMCA, b) the exit driveway for the JFK Junior High School, c) the northern driveway to Waltham House, and d) Clark Pond to drawdown water surface levels in advance of large storm events.
3. Yetten Field Detention and Permeable Paving
4. Swales along Lexington St near Brookway Rd to help reduce surface pooling, improve street scape, and provide urban heat reduction.
5. Swales and Detention along Forest St. to reduce runoff velocity and improve street scape for pedestrians.

1.5 West Chester Brook Watershed

West Chester Brook is, generally speaking, a rather flood prone system, with significant flooding impacts noted at multiple locations within the watershed. Historically some of the worst impacts have been experienced in the vicinity of Pond End Rd. and Totten Pond Rd. in the middle of the watershed and at the brook's Lexington St. crossing near the mouth of the watershed. Our stormwater modeling efforts confirm the vulnerability of the Pond End Rd. and Lexington St. areas and suggest that the Totten Pond Rd. roadway flooding likely occurs in multiple locations where it runs close to the brook.

There are likely several contributing factors to the flooding issues facing West Chester Brook, including a highly impervious headwaters area that results in high runoff rates and volumes very high up in the watershed, undersized drains in Craig Ln. and Totten Pond Rd, channel and floodplain encroachments and numerous road and driveway crossings along Totten Pond Rd., and the fact that the culvert capacity of four stream crossings in the lower half of the brook (Totten Pond Rd., Worcester Ln., Bacon St., and Lexington St.) decreases as their respective contributing drainage areas increase. To address these concerns, Weston & Sampson has evaluated the potential benefits of both green and gray infrastructure projects as discussed below.

<u>Green Infrastructure Projects</u>

Weston & Sampson has identified 28 potential GI projects within the West Chester Brook. watershed. They have been grouped into five scenarios. Scenario 11 is comprised of parking area improvements and stream restoration in the upper watershed. Scenario 12 considers stream restoration and removal of culverts within Prospect Hill Park. Scenario 13 consists of swales and detention within the brook along Totten Pond road. Scenario 14 considers stream restoration near Pond End Road. Scenario 15 considers stream restoration and increasing storage capacity of a small pond off of Bacon St. Weston & Sampson has evaluated the potential flood reduction benefits of these scenarios as described in the following sub-sections.

Scenario 11 – Upper West Chester Brook

Scenario 11 considers stormwater improvements through the implementation of 13 GI features: 3 swales, 6 detention areas, 2 permeable paving areas, and 1 area designated for stream restoration. The upper watershed of West Chester Brook is similar in commercial and retail land use to the Stony Brook watersheds in the West End of Waltham. Comprised of large office buildings and parking areas nested on the western edge of Prospect Hill, the upper watershed represents a large impervious surface area with potential for high velocity runoff. However, development in this area is more recent and some LID strategies are already implemented. The proposed GI features for Scenario 11 work with the existing drainage system/GI, and topography to intercept parking lot runoff via swales and convey it to detention areas taken from interstitial spaces between parking areas. Permeable paving is located along the edges of a large parking area in the northern portion of the subbasin. Stream restoration is proposed on two sides of a culvert underneath Totten Pond Road in the form of widening and clearing out sediment/overgrowth to provide additional storage capacity. Lastly swales near 440 Totten Pond Road can assist in removing localized flooding as the road narrows and straddles two high points.

As the GI projects incorporated into this scenario are concentrated in the upstream-most portion of the watershed, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at the first Totten Pond Rd. crossing, near its intersection with

Winter St., and then the next few downstream crossings to get a sense for how those benefits might persist downstream.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Totten Pond Rd (near Winter St)	0.0	0.0	0.0	0.0	3%	2%	1%	3%
Glen Rd	0.0	0.0	0.0	0.0	1%	0%	1%	0%
Totten Pond Rd (near skating rink)	0.0	0.0	0.0	0.0	3%	0%	2%	0%
Driveway at 245 Totten Pond Rd	**	0.0	**	0.0	**	1%	**	0%

** *Location not expected to be impacted during this event.*

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact on overtopping depths at the first Totten Pond Rd. crossing, with a reduction of up to 3% flood depth (and up to 4% in overtopping flow rates) across all four design events. These small benefits are not expected to extend very far downstream in the West Chester Brook system as indicated by no significant change in model output parameters indicated at the driveway crossing for 245 Totten Pond Rd.

Scenario 12 – Prospect Hill Park

Scenario 12 proposes restoration of the stream within Prospect Hill Park. The stream crosses under Totten Pond Road from the north into the park. It travels through three culverts that are under small access roads and pedestrian paths. The concept for the park is to realign the overly large parking area, widen the stream boundary and floodplain, remove at least two of the culverts that cross under the pedestrian access and replace them with smaller / spanning foot paths. The project can be incorporated into and masterplan update and represents a single large project with significant co-benefits from park improvements, reduction of impervious area, and water quality improvements.

Given the nature of this scenario, a single GI project at the entrance to Prospect Hill Park, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at the Glen Rd. crossing and at the next downstream crossing, Totten Pond Rd. (near the skating rink), to understand how those benefits might persist downstream.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Glen Rd	0.0	0.0	0.0	0.0	0%	0%	0%	0%
Totten Pond Rd (near skating rink)	0.0	0.0	0.0	0.0	0%	0%	0%	0%

As the table above shows, the proposed GI project at the entrance to Prospect Hill Park is not expected to have a significant impact on streamflow in West Chester Brook or, consequently, in the depths of overtopping expected at Glen Rd. or any other crossings downstream. However, it is worth noting that the proposed GI project may have a useful impact on ponding within the Glen Rd. roadway slightly uphill from its intersection with Totten Pond Rd. In addition, the project has some significant co-benefits.

Scenario 13 – Totten Pond Road

Scenario 13 considers 6 GI stormwater improvements along Totten Pond Road and West Chester Brook: 5 swales and 1 area for stream restoration. This middle stretch of Totten Pond Road is an area of known flooding. The road runs parallel to the brook which narrowly passes through 9 small culverts before broadening downstream. The swales are placed to intercept and delay surface runoff from the existing drainage system before it enters the brook. Stream restoration is proposed at the downstream end of the scenario and includes widening and clearing out sediment/overgrowth to provide additional storage capacity.

As the GI projects incorporated into this scenario are concentrated along West Chester Brook and Totten Pond Rd. upstream of the cul-de-sac at the end of Pond End Rd., the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in flood depths over the driveway of 203 Totten Pond Rd. (in the middle of the scenario area) and in the depth of floodplain flooding near the Winter Street Apartments and in the Pond End Rd. area.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Driveway at 203 Totten Pond Rd	---*	0.0	0.0	0.0	---*	0%	2%	1%
Winter Street Apartments	---*	0.0	0.0	0.0	---*	0%	0%	1%
Pond End Rd	0.0	0.0	0.0	0.0	2%	0%	1%	0%

** Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in this reach of West Chester Brook and its floodplain, with overtopping depth reductions not more than 2%. However, it is worth noting that the proposed GI projects may have useful co-benefits.

Scenario 14 – Pond End Road

Scenario 14 considers stormwater improvements through the implementation of 6 GI features: 3 swales, 1 permeable paving area, and 2 areas for stream restoration. The scenario includes the drainage areas along the lower end of Totten Pond Rd and is a known area of flooding. West Chester Brook courses through backyards and passes under Totten Pond Rd through a culvert (3 x 48” culverts). Stream restoration is proposed on both sides of the culvert. The upper stream restoration can be greatly increased by traffic realignment (or removing the small road completely) and widening the stream floodplain. The lower stream restoration focuses on sediment removal and clearing vegetation to regain/gain storage capacity. Two of the swales are located along Lexington St at the intersections of Bacon St and Lincoln St. Wide road widths along Lexington St allow for easy conversions of interstitial spaces to stormwater capture and conveyance. Permeable paving is proposed along the full stretch of Piety Corner Rd and can provide additional benefits with underground storage. One swale located at the intersection of Clark Lane and Sanders Lane intercepts runoff from the road before draining to an adjacent smaller stream.

As the GI projects incorporated into this scenario are concentrated in the downstream third of West Chester Brook, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in flood depths over Bacon St. and Lexington Dr. and in Square Pond at the confluence of West Chester and Chester Brooks.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Bacon St	---*	---*	---*	0.0	---*	---*	---*	2%
Lexington St	0.0	0.0	0.0	0.0	0%	4%	0%	0%
Square Pond	0.0	0.0	0.0	0.0	0%	1%	0%	0%

* *Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in the lower third of West Chester Brook, with overtopping depth reductions generally negligible. However, it is worth noting that the proposed GI projects may have useful co-benefits.

Scenario 15 – Lexington and Bacon St

Scenario 15 is comprised of 2 GI features: Increasing Storage Capacity within a small residential pond and stream restoration at the furthest downstream end of West Chester Brook before it enters a culvert to Square Pond/Chester Brook. A small tributary from the pond flows down toward Lexington St and the stream restoration area. Increasing storage capacity of the pond would incorporate protecting any low-lying adjacent properties via small berms and considering modifications to the pond outlet structure to reduce its volume prior to a storm. The stream restoration project includes widening and clearing out sediment/overgrowth to provide additional storage capacity.

As the two GI projects incorporated into this scenario are concentrated in a small tributary system that discharges into West Chester Brook just upstream of its Lexington St. crossing, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in flood depths over Lexington St. and in Square Pond at the confluence of West Chester and Chester Brooks.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Lexington St	0.0	0.0	0.0	0.0	25%	4%	0%	2%
Square Pond	0.0	0.0	0.0	0.0	0%	1%	0%	0%

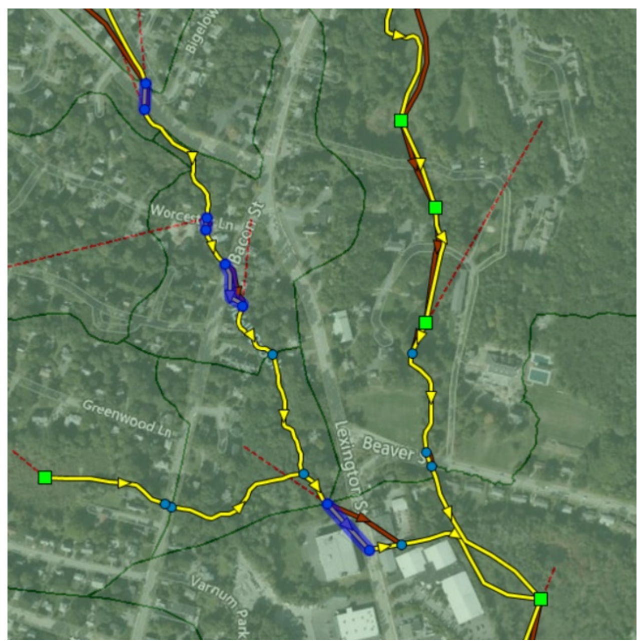
* *Location not expected to be impacted during this event.*

As the table above shows, model simulations suggest that the proposed GI projects incorporated into this scenario would have a minimal impact on overtopping depths at Lexington St. or further downstream at Square Pond. While the percent reduction, 25%, at Lexington St. during the baseline climate 2-year event is noteworthy, the absolute benefit is less than 0.1 feet. Benefits are even smaller during larger events or further downstream. However, it is worth noting that the proposed GI projects may have useful co-benefits.

<u>Gray Infrastructure Improvements</u>

In addition to the five GI scenarios depicted above, Weston & Sampson also considered improvements to the City's existing stormwater infrastructure or "gray" projects. Two gray infrastructure improvement projects stood out in particular.

Craig Ln. & Totten Pond Road Storm Drain Improvements
There are several contributing factors to the flooding issues facing West Chester Brook, and Totten Pond Rd. in particular, one of which is the volume and/or peak runoff rate of runoff coming off the hillside southwest of the road, including from neighborhoods on Craig Ln. and Lura Ln. That runoff is currently conveyed via 12- and 15-inch storm drains that appears to be overwhelmed even under 2-year event conditions.



The concept behind this gray infrastructure improvement is to increase the capacity of the storm drains in Totten Pond Rd. and Craig Ln. to discharge runoff generated from those areas more effectively. The proposed change is to upsize the existing 12- and 15-inch storm drains in Totten Pond Rd. and Craig Ln. to 36-inch drains or to otherwise create a comparable increase in cross-sectional flow area. The table below highlights how flooding in this area may improve as a result.

		Reduction				% Reduction			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Craig Ln at Totten Pond Rd	Duration (hrs)	0.2	1.5	0.2	2.3	100%	100%	100%	100%
	Peak Rate (cfs)	12	43	30	63	100%	100%	100%	100%
	Total Volume (MG)	0.06	0.20	0.09	0.76	100%	100%	100%	100%
Pond End Rd	Overtopping Depth (ft)	0.0	0.0	0.0	-0.2	-9%	-3%	-4%	-13%
	Overbank Flooding (cfs)	-13	-18	-15	-17	-13%	-6%	-7%	-5%
Totten Pond Rd	Roadway Overtopping Depth (ft)	-0.1	-0.1	-0.1	-0.1	5%	-43%	12%	-18%
	Roadway Overtopping Flow (cfs)	---*	-44	---*	-47	---*	-96%	---*	-15%

** No overtopping expected at this location.*

Model simulations indicate that expanding the discharge capacity of the storm drains in this area will have a significant impact on surcharging into the Craig Ln. roadway, which flows downhill into Totten Pond Rd. In fact, upsizing those storm drains to 36 inches appears to eliminate all surcharging at that intersection. However, increasing the capacity of those storm drains also increases the runoff arriving downstream in West Chester Brook near both Pond End Rd. and where it crosses under Totten Pond Rd. As a result, flood depths in the Pond End Rd. roadway and at the Totten Pond Rd. crossing are expected to increase by roughly 0.1 feet. When viewed in its entirety, this project will likely produce significant benefits in terms of reduced flooding near Craig Ln. Increased stormwater loading downstream would likely need to be offset through construction of additional simultaneous projects further downstream in West Chester Brook.

Culvert Improvements

Some of the more significant flooding are experienced in the lower half of the West Chester Brook system occurs where the brook is conveyed beneath four roadways: Totten Pond Rd. (near Pond End), Worcester Ln., Bacon St., and Lexington St. There are several contributing factors to the flooding issues facing West Chester Brook, one of which is that the culvert capacity of those four consecutive roadway crossings decreases from upstream to downstream despite increasing contributing drainage areas. West Chester Brook is conveyed beneath Totten Pond Rd. by three (3) 4-foot culverts, beneath Worcester Ln. by two (2) 4-foot culverts, beneath Bacon St. by a 4-foot culvert and a 3-foot overflow culvert, and finally beneath Lexington St. by a single 5x3-foot arch opening.

The concept behind this gray infrastructure solution is to increase the discharge capacity at Worcester Ln., Bacon St., and Lexington St. to match that of the Totten Pond Rd. crossing. The idea is that by increasing the discharge capacity of those three roadways, they will experience reduced overtopping and will decrease the backwater effect they are currently generating further upstream. This concept was modeled with three (3) 4-foot diameter culverts at all four road crossings. The table below highlights how flooding in this area may improve as a result.

	Reduction in Overtopping (feet)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Pond End Rd	0.0	0.0	0.0	0.0	-2%	0%	0%	3%
Totten Pond Rd	---*	0.1	---*	0.1	---*	43%	---*	13%
Worcester Ln	---*	---*	---*	---*	---*	---*	---*	---*
Bacon St	---*	---*	---*	2.7	---*	---*	---*	568%**
Lexington St	4.6	0.1	2.2	0.1	11450%**	50%	1473%**	18%
Square Pond	0.0	0.0	0.0	0.0	0%	-1%	-2%	-1%

** No overtopping expected at this location under existing conditions.*
***Percent reduction in overtopping depth exceeds 100% because the proposed conditions reduce the peak water level below the level of overtopping.*

Model simulations indicate significant improvements in peak water levels and, consequently, in overtopping depths throughout the lower half of West Chester Brook. Under existing conditions, Lexington St. is currently simulated to overtop during both the 2- and 10-year events. This gray infrastructure scenario would eliminate overtopping during the 2-year flood event, and during the 10-year event, the peak overtopping depth would drop from 0.3 feet to 0.1 feet under a baseline climate and from 0.5 to 0.4 feet under a 2070 climate. Bacon St. is currently only expected to overtop during the 10-year event under a 2070 climate condition. The proposed project would eliminate that overtopping. Totten Pond Rd. is expected to overtop by 0.2 and 0.6 feet during the 10-year event under baseline and 2070 climate conditions, respectively, but is not expected to overtop during either 2-year event. While significant flooding reductions are expected in the area of these four road crossings, the benefits of the expanded culvert capacity does not appear to extend upstream of Totten Pond Rd. as indicated by no significant change at Pond End Rd.

Watershed Recommendations

West Chester Brook is, generally speaking, a rather flood prone system, with significant flooding impacts noted at multiple locations within the watershed. Historically some of the worst impacts have been experienced in the vicinity of Pond End Rd. and Totten Pond Rd. in the middle of the watershed and at the brook's Lexington St. crossing near the mouth of the watershed.

There are likely several contributing factors to the flooding issues facing West Chester Brook, including a highly impervious headwaters area that results in high runoff rates and volumes very high up in the watershed, undersized drains in Craig Ln. and Totten Pond Rd, channel and floodplain encroachments and numerous road and driveway crossings along Totten Pond Rd., and the fact that the culvert capacity of four stream crossings in the lower half of the brook (Totten Pond Rd., Worcester Ln., Bacon St., and Lexington St.) decreases as their respective contributing drainage areas increase.

Based on this understanding of the likely flooding sources in the West Chester Brook watershed and on the results of stormwater model simulations of green and gray infrastructure projects as described above, Weston & Sampson recommends the following actions be taken to reduce flooding in the West Chester Brook watershed:

Recommendations:

1. Increase the hydraulic capacity of the Worcester Ln., Bacon St., and Lexington St. crossing to match that of the last Totten Pond Rd. crossing.
2. Upsize the storm drains in Craig Ln. and Totten Pond Rd. from 12- and 15-inch to 36-inch. Note that the corresponding increases in downstream discharge volume/rate may need to be offset through the construction of GI projects elsewhere in the watershed.
3. Incorporate into an update for the Prospect Hill Park Masterplan including stream restoration, removal of culverts, parking lot design, tributary restoration along Glen Rd (park access road) and reconnect 31 acres of impervious surfaces along 5th Ave to drain toward the project area.

1.6 Beaver Brook Watershed

Flooding impacts along Beaver Brook have historically been noted in multiple locations within the watershed. To our understanding, the most significant flooding impacts have occurred along Waverley Oaks Rd. (due to overtopping from both Beaver Brook and Clematis Brook) and perhaps more significantly in the Linden St. area. Our stormwater modeling efforts confirm the vulnerability of these areas and suggests that the large conduit downstream of Massassoit Street, where Beaver Brook goes underground, may also become a floodprone area. In an effort to identify means of reducing impacts in those areas and elsewhere in the Beaver Brook watershed, Weston & Sampson has evaluated the potential benefits of both green and gray infrastructure projects as discussed below.

<u>Green Infrastructure Projects</u>

Weston & Sampson has identified 84 potential GI projects within the Westchester Brook. watershed. They have been grouped into nine scenarios. Scenario 20 includes Upper Beaver Brook and solutions near Trapelo Rd. Scenario 21 is Middle Beaver Brook and most significantly includes increased storage capacity with the brook. Scenario 22 is Upper Clematis Brook and is located within North Waltham to the border of Cedar Hill Reservation. Scenario 23 contains the Fernald Campus and stream restoration/daylighting projects. Scenario 24 is the Lower Clematis Brook and focuses on smaller water quality improvements that feed into the wetland. Scenario 25 is located in the Warrendale neighborhood and focuses on street and school improvements. Scenario 26 includes stream restoration projects along Waverly Oaks Rd and Linden St. Scenario 27 focuses on Lower Beaver Brook street side projects that address localized flooding. Weston & Sampson has evaluated the potential flood reduction benefits of these scenarios as described in the following sub-sections.

Scenario 20 – Upper Beaver Brook

Scenario 20 is comprised of 9 GI features: 4 swales, 1 large detention area, 1 area for permeable paving, and 3 areas for stream restoration. Starting in the northern portion of Upper Beaver Brook, surface water accumulates in a low-lying, forested wetland near the intersection of Woburn St and Trapelo Rd. Stream Restoration is proposed for this area to reduce overgrowth and reestablish the stream profile and capacity. Further downstream along Metropolitan Parkway S, Waltham's City Dog Ranch can be converted to a temporarily floodable open area during a storm event similar to the floodable field features. The feature can be expanded to include the hard sports courts or include permeable paving in the parking area. Down the road at the intersection of Trapelo Rd and Metropolitan Parkway, restoration of an existing stream/tributary into Beaver Brook can provide additional space for stormwater drainage through regrading and widening the stream profile. Similarly, restoration of the wetland next to Turner Field can include regrading to expand the area of the wetland, creating more opportunities for storage and treatment Swales along the same intersection help to convey runoff toward the restored stream section. Permeable paving on Doty St can provide additional storage water quality improvements if the one-way road was narrowed to one lane.

The GI projects incorporated into this scenario are concentrated in the northern quarter of the watershed, in and around the massive wetland complex on MADCR land near Concord Ave. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at floodprone areas throughout the watershed.

	Overtopping Depth Reduction (feet)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Beaver Brook Reservation	1.4	0.7	1.6	0.7	433%**	86%	235%**	69%
Waverley Oaks Office Park	---*	0.5	0.5	0.7	---*	108%**	940%**	69%
Waverley Oaks Rd	---*	0.5	---*	0.3	---*	94%	---*	39%
Linden St crossing (at Waverley Oaks Rd)	0.2	0.3	0.2	0.2	25%	20%	21%	9%
Linden St crossing (at Dunkin)	---*	---*	0.0	0.2	---*	---*	0%**	36%

** Location not expected to be impacted during this event.*
*** Percent reduction in overtopping depth exceeds 100% because the proposed conditions reduce the peak water level below the level of overtopping.*

As, the table above shows, the proposed GI and LID projects would have a significant impact on flooding in the Beaver Brook watershed. Based on model simulations, the greatest benefits were experienced in the Brookside Ave., Beaver Brook Reservation, and Waverley Oaks Office Park areas. Brookside Ave. had a 100% reduction in overbank flooding during both 2- and 10-year events. The Beaver Brook Reservation experienced a flood depth reduction of 1.4 ft. during the 2-year event, causing the banks to no longer be overtopped. Overtopping was greatly reduced, by 86%, during the 10-year event as well. During the 10-year event, Waverley Oaks Office Park would no longer overtop due to a reduction in bank overtopping of 0.5 ft. Significant benefits can be seen as far downstream as Linden St.

A similar pattern was observed in Beaver Brook under 2070 climate conditions. Similar to the baseline climate model simulations, the greatest benefits were experienced in the Brookside Ave., Beaver Brook Reservation, and Waverley Oaks Office Park areas. However significant benefits were experienced throughout the watershed. Brookside Ave. had a 100% reduction in overbank flooding during both 2- and 10-year events. The Beaver Brook Reservation experienced a flood depth reduction of 1.6 ft. during the 2-year event, causing the banks to no longer be overtopped. Overtopping was greatly reduced, by 69%, during the 10-year event. During the 2-year event, Waverley Oaks Office Park would no longer overtop due to a reduction in bank overtopping of 0.5 ft. Similar to Beaver Brook Reservation, Waverley Oaks Office Park experienced significant reductions in overtopping depth, up to 0.7 ft. during the 10-year event. The benefits of this scenario diminish significantly by Linden Street however, with smaller albeit still significant reductions of roughly 20% at the first Linden Street crossing near Waverley Oaks Road. The benefits of this scenario are minimal by the second Linden Street crossing, near Dunkin Donuts.

Scenario 21 – Middle Beaver Brook

Scenario 21 considers stormwater improvements through the implementation of 21 GI features: 13 swales, 1 detention area, 1 area for permeable paving, 3 areas for increased storage (Beaver Brook North, Duck Pond and Mill Pond) 1 area for floodplain restoration, and 2 areas for reforestation. Furthest north, Mackerel Hill contains a large underutilized paved parking area that can be removed and replanted and reforested. A second location for reforestation south of the Fernald Campus Main building off Trapelo Rd can help mitigate runoff while helping to reduce urban heat. Reforestation can help reduce stormwater runoff through infiltration encouraged by root development. Moving southeast along Trapelo Rd numerous swales are proposed within the small neighborhood adjacent to Beaver Brook, specifically along Marlborough and Albemarle Rd. The wide residential streets and surface flow sheeting down the street provides an opportunity to intercept, delay, and convey the stormwater before it enters the brook. Modifying / creating an outlet structure for the northern portion of Beaver Brook can create an expanded storage area greater than 95 acres. Increasing storage capacity by 1 foot for Mill Pond and 2 feet for Duck Pond can help reduce downstream flooding. This can occur though modification of the outlet structure to build up more volume or draw down the pond level prior to a storm to increase storage. Swales and permeable paving moving southeast along Trapelo Rd toward the intersection of Waverly Oaks Rd help collect, convey, and treat stormwater before it enters in the Beaver Brook. Restoring and widening the floodplain near Beaver Brook Field can increase flood storage and slow down runoff during a storm event. Through simple regrading of the adjacent park, portions of the park can be allowed to occasionally flood. At the downstream end of the scenario, a water quality swale in the Vistec Parking Lot adjacent to the large wetland can improve water quality and reduce nuisance flooding when combined with a small berm or permeable paving.

The GI projects incorporated into this scenario are concentrated in the eastern half of the watershed. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at floodprone areas along the middle reach of the brook. Specifically, the lowest spot elevations were identified to determine overtopping pathways and incorporated into the model. Features like the retaining wall on the downstream side of the intersection of Trapelo Rd and Beaver Brook used the low point elevation of the opening of the wall into the park rather than the top of the wall.

	Overtopping Depth Reduction (feet)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Beaver Brook Reservation	0.0	0.0	0.0	0.0	9%	1%	3%	5%
Waverley Oaks Office Park	---*	0.0	0.0	0.0	---*	0%	40%	3%
Waverley Oaks Rd	---*	0.0	---*	0.0	---*	0%	---*	2%

** Location not expected to be impacted during this event.*

The proposed green infrastructure in this scenario is expected to have a minor impact on overtopping depths and flood rates in the downstream area, particularly near Beaver Brook Reservation and Waverley Oaks Rd. While some of the percent changes are noteworthy, such as a 40% reduction in flood depth at the Waverley Oaks Office Park, the actual magnitude of the change expected is less than 0.1 feet. In short, while localized benefits in the immediate vicinity of the various projects may occur, but large-scale flooding in Beaver Brook is not expected to change as a result of these projects. It is worth noting that the proposed GI projects may have a significant impact on localized ponding in roadways and parking lots in their immediate vicinity that do not translate well to the scale of runoff originating in the 100+ acre sub-basins in which they are located in the stormwater model. They may also have useful co-benefits.

Scenario 22 – Upper Clematis Brook

Scenario 22 considers stormwater improvements through the implementation of 4 GI features: 2 swales, 1 detention area and 1 area of floodplain restoration. The scenario starts in North Waltham with a large detention basin carved out of a large cul-de-sac. The basin intercepts and delays runoff from the drainage system that outfalls into an open, neighborhood wetland. Floodplain restoration is proposed for this area to clear debris and overgrowth and widen the floodplain for greater storage capacity. The swales along Forest St intercept and treat runoff from the neighborhood before it enters in the Cedar Hill Reservation and Clematis Brook. The projects represent large examples of residential street and pedestrian improvements.

The GI projects incorporated into this scenario are located in the headwaters of Clematis Brook, which discharges into Beaver Brook just upstream of the Beaver St. crossing. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth where Clematis Brook crosses Waverley Oaks Rd, which the stormwater model indicates currently overtops during the 10-year event under existing conditions, and where Beaver Brook has historically jumped its bank and flooded Waverley Oaks Rd. between Marianne Rd. and Linden St.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Waverley Oaks Rd (Clematis Brook)	---*	0.0	---*	0.0	---*	6%	---*	3%
Waverley Oaks Rd (Beaver Brook)	---*	0.0	---*	0.0	---*	0%	---*	1%

** Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in Clematis or Beaver Brooks. It is worth noting that the proposed GI projects may have a significant impact on localized ponding in roadways and parking lots in their immediate vicinity that do not translate well to the scale of runoff originating in the 306-acre sub-basin in which they are located in the stormwater model. They may also have useful co-benefits.

Scenario 23 – Fernald Campus

Scenario 23 consists of 6 GI features: 1 permeable paving area, 3 reforestation areas, 1 stream restoration/daylighting, and 1 floodplain restoration. The scenario starts near the National Archives building off of Trapelo Rd and moves southward toward Waverly Oaks Rd through the Fernald School Campus. Large parking and grass areas surround the National Archives building on three sides. The concept proposes replacing the existing parking with permeable paving and reforesting the side and back lots. Within Clematis Brook near Malone Park, floodplain restoration is proposed to expand the width and floodable area of the stream as a way to store runoff and decrease stress on downstream drainage systems. The largest project in this scenario is the daylighting and design of the stream through the former Cottage St housing complex. The stream restoration would create 10.6 acres of stream and floodplain aligned toward the west side of Cottage St with the other 10.8 acres of the site designated to reforestation. The stream daylighting extends downstream to connect with current open stream running parallel to Chapel Rd.

The GI projects incorporated into this scenario are located in the middle reaches of Clematis Brook within the Fernald School campus. As Clematis Brook discharges into Beaver Brook just upstream of the Beaver St. crossing, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth where Clematis Brook crosses Waverley Oaks Rd, which the stormwater model indicates currently overtops during the 10-year event under existing conditions, and where Beaver Brook has historically jumped its bank and flooded Waverley Oaks Rd. between Marianne Rd. and Linden St.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Waverley Oaks Rd (Clematis Brook)	---*	0.1	---*	0.1	---*	67%	---*	35%
Waverley Oaks Rd (Beaver Brook)	---*	0.1	---*	0.1	---*	11%	---*	7%

** Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are expected to have a modest impact on water levels, and consequently flood depths, in Clematis Brook and a short distance downstream in Beaver Brook. Overtopping of Waverley Oaks Rd. by Clematis Brook is expected to decrease by about 0.1 feet, which translates to 67 and 35% reductions during the 10-year event under baseline and 2070 climate conditions, respectively. The benefit decreases moving downstream into Beaver Brook, but reductions in the depth of flooding in Waverley Oaks Rd. where Beaver Brook jumps its bank range are around 10%. These GI projects may also have excellent co-benefits on the Fernald School campus.

Scenario 24 – Lower Clematis Brook

Scenario 24 considers stormwater improvements through the implementation of 3 GI features: 2 swales and 1 detention area. The scenario is located at the lower end Clematis Brook north of Waverly Road and east of Beaver St. Characterized by a large wetland, solutions for this scenario were limited to the surrounding areas rather than increasing storage within the wetland due to the low-lying roadway to the south. A large detention basin at the base of Chapel Road collect surface runoff and the newly daylighted stream from the Fernald Campus before drainage into the wetland. Long swales along Beaver St capture street runoff and provide an initial level of treatment and sediment removal before conveying stormwater to the wetland.

The GI projects incorporated into this scenario are located around the large wetland created by the Waverley Oaks Rd. crossing of Clematis Brook, near its confluence with Beaver Brook. Therefore, the potential flood reduction benefits of this scenario were evaluated by considering the anticipated reductions in overtopping depth at that crossing and where Beaver Brook has historically jumped its bank and flooded Waverley Oaks Rd. between Marianne Rd. and Linden St.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Waverley Oaks Rd (Clematis Brook)	---*	0.0	---*	0.0	---*	0%	---*	3%
Waverley Oaks Rd (Beaver Brook)	---*	0.0	---*	0.0	---*	0%	---*	1%

** Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in Clematis or Beaver Brooks. It is worth noting that the proposed GI projects may have a significant impact on localized ponding in roadways and parking lots in their immediate vicinity that do not translate well to the scale of runoff originating in the 266-acre sub-basin in which they are located in the stormwater model. They may also have useful co-benefits.

Scenario 25 – Warrendale

Scenario 25 is comprised of 13 GI features: 4 swales, 5 detention areas, 3 areas of permeable paving, and 1 floodable field. Located in Warrendale and primarily around the Fitzgerald Elementary School, the scenario concept involves utilizing swales on Candace and Beall Rd, permeable paving in front of the school, and detention areas at nearby intersections to intercept, store and convey runoff toward the recreation fields behind the school. Regrading around the edges allows the field to temporarily flood up to 1 foot of runoff during a storm event. A large, underutilized parking area downstream of the school and adjacent to Beaver Brook can be converted to permeable paving with underground storage.

As the GI projects incorporated into this scenario are concentrated south of the brook in the middle reaches of the watershed, in the vicinity of the Fitzgerald School, Candace Ave., and Beal Rd., their potential benefits are most likely to be experienced where Beaver Brook has historically jumped its bank and flooded Waverley Oaks Rd. between Marianne Rd. and Linden St.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Waverley Oaks Rd (Beaver Brook)	---*	0.0	---*	0.0	---*	0%	---*	1%

** Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in Beaver Brook. It is worth noting that the proposed GI projects may have a significant impact on localized ponding in roadways and parking lots in their immediate vicinity that do not translate well to the scale of runoff originating in the 83-acre sub-basin in which they are located in the stormwater model. They may also have useful co-benefits.

Scenario 26 – Waverly Oaks and Linden

Scenario 26 considers stormwater improvements through the implementation of 9 GI features: 6 detention areas and 3 areas for stream restoration. Located along a narrow stretch of Beaver Brook that is known to overtop its bank and flood Waverly Oaks Rd and Linden St, this scenario concept focuses on stream restoration within Beaver Brook just south of Beaver St intersection. Restoration focuses on clearing of sediment, debris, and overgrowth to regain existing capacity as well as expanding the stream width with light regrading. A longer length of stream restoration downstream starts near Marianne Rd ending near the Linden St traffic circle. The same traffic area can include areas for detention and with slight traffic realignment can include 4 larger areas to intercept and store runoff coming down both streets Further downstream, two detention areas straddling Access Rd help capture stormwater before it outfalls into Beaver Brook and a significant known flooding area along Linden St. Stream restoration is proposed after the confluence of Chester and Beaver Brooks to remove sediment and overgrowth and utilize the empty lot next the stream to widen its profile.

As the GI projects incorporated into this scenario are concentrated along Waverley Oaks Rd. and Linden St., their potential benefits are most likely to be experienced where Beaver Brook has historically jumped its bank and flooded Waverley Oaks Rd. between Marianne Rd. and Linden St. and the first Linden St. crossing, two areas with noted, recent flooding issues.

	Overtopping Depth Reduction (ft)				% Reduction			
	Baseline		2070		Baseline		2070	
Location	2-year	10-year	2-year	10-year	2-year	10-year	2-year	10-year
Waverley Oaks Rd (Beaver Brook)	---*	0.0	---*	0.0	---*	0%	---*	0%
Linden St. (near Waverley Oaks)	0.0	0.0	0.0	0.0	0%	0%	0%	0%

** Location not expected to be impacted during this event.*

As the table above shows, the proposed GI projects incorporated into this scenario are not expected to have a significant impact on water levels, and consequently flood depths, in Beaver Brook. They may reduce localized ponding in roadways and parking lots in their immediate vicinity and provide significant co-benefits, but they are not expected to have an impact on large-scale flooding trends in Beaver Brook.

Scenario 27 – Lower Beaver Brook

Scenario 27 is comprised of 20 GI features: 13 swales, 5 detention areas, and 1 floodable field. The GI strategies are predominantly street edge locations and reflect the denser urban environment in the lower end of Beaver Brook which is in a conduit from Main St until it outfalls into the Charles River near the Newton St Bridge. Swales along Main St intercept stormwater from before it reaches the drainage system. A large detention basin along Massasoit St can reduce additional runoff from flooding the low-lying backyards parallel to Bright St. Lowell Playground off of Grove St represents an opportunity to capture and temporarily store up to 1 foot of runoff that would typically inundate the existing drainage system. The most downstream GI feature is a potential detention basin located in the back Sacred Heart Parish parking lot. The parking lot is concave, and runoff naturally drains toward the middle of the lot directly into the Beaver Brook conduit. With simple parking area realignment and excavation, a 16,000+sq.ft. detention basin could intercept and delay stormwater without losing parking spaces. The GI projects incorporated into this scenario are located in the lowest reaches of Beaver Brook and its watershed, generally downstream of where the brook goes underground at Massassoit St. Therefore, their potential benefits were evaluated by considering changes in the peak runoff rate and total runoff volume of the 106-acre sub-basin that represents the Grove St. area.

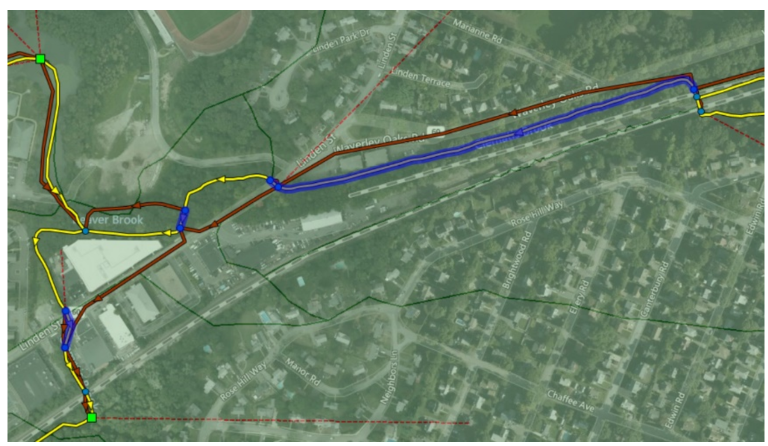
		Reduction				% Reduction			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-yr	10-yr	2-yr	10-yr	2-yr	10-yr	2-yr	10-yr
Grove St	Total Volume (MG)	0.27	0.30	0.28	0.32	6%	5%	6%	4%
	Peak Rate (cfs)	1	2	2	3	1%	1%	1%	1%

As the table above shows, the proposed GI and LID projects in this scenario would have a moderate impact in reducing runoff at Grove St. Runoff volumes were reduced by 4 to 6% and peak runoff rates reduced by 1%. More significant localized benefits may be expected in the immediate vicinity of the various projects as well as noteworthy co-benefits, but large-scale flooding in Beaver Brook is not expected to change as a result of these projects.

<u>Gray Infrastructure Improvements</u>

In addition to the gray-green concept of augmenting the flood storage capacity of the massive wetland complex on MADCR land in the headwaters of the Beaver Brook watershed by modifying its small outlet structure, Weston & Sampson also considered improvements to the City's existing stormwater infrastructure or "gray" projects. One gray infrastructure improvement project stood out in particular.

Culvert Improvements



Model simulations suggest that flooding in the lower half of the Beaver Brook watershed is likely attributed to the high impervious cover in that area, to encroachment reducing the channel capacity in some reaches, and to undersized culverts/bridge openings that are restricting flow.

The concept behind this gray infrastructure solution is to address the latter two issues. Beaver Brook crosses under the railroad embankment at three locations; the reach of the brook from the second railroad crossing (near Parsons Ave.) to Linden St. was measured in the field with a bottom width as narrow as 4 feet. However, reaches of the brook upstream and downstream of that area generally have measured bottom widths of at least 10 feet. This concept incorporates widening of the channel in this trouble area (likely to the south) so that it is consistent with upstream and downstream reaches. Also, the bridge/culvert openings at the two Linden St. crossings downstream and the railroad crossing between them are smaller than the channel in that area, restricting flow. Those three bridge crossings were widened to 10 feet. The table below highlights how flooding may improve as a result:

		Reduction				% Reduction			
		Baseline		2070		Baseline		2070	
Location	Parameter	2-yr	10-yr	2-yr	10-yr	2-yr	10-yr	2-yr	10-yr
Waverley Oaks Road	Overtopping Depth (ft)	---*	0.5	---*	0.3	---*	98%	---*	36%
	Overtopping Flow (cfs)	---*	45	---*	76	---*	100%	---*	57%
Linden St (at Waverley Oaks)	Overtopping Depth (ft)	0.2	0.1	0.1	0.1	21%	7%	10%	4%
	Overtopping Flow (cfs)	56	25	30	41	32%	8%	16%	7%
Linden St (at Dunkin' Donuts)	Overtopping Depth (ft)	---*	---*	---*	0.4	---*	---*	---*	56%

** No overtopping expected at this location under existing conditions.*

Model simulations indicate some improvements in peak water levels and, consequently, in overtopping depths throughout the lower half of Beaver Brook. Under existing conditions, the only impacts expected during a 2-year storm event originate from the first Linden St. crossing, with overland flows likely running southwest down Linden St. Flood depths here are estimated at 0.7 and 0.9 feet under baseline and 2070 climate conditions, respectively. As a result of the proposed project, those flood depths are marginally improved to 0.6 and 0.8 feet, reducing flows running down Linden St. by 15 to 35%.

During the 10-year event, flooding is again currently expected at that first Linden St. crossing. However, Beaver Brook is also expected to jump its bank upstream, flowing down Waverley Oaks Rd. In addition, Beaver Brook is expected to overtop the second Linden St. crossing. Model simulations predict flooding reductions at all those locations. For instance, the flood depth in Waverley Oaks Rd. is expected to decrease from 0.5 and 0.9 feet under baseline and 2070 climate conditions, respectively, to 0.0 and 0.5 feet as a result of the proposed improvements, likely eliminating the need for road closures. Flooding reductions at the Linden St. crossings are noteworthy but more modest. These results suggest that while expanding the three bridge/culvert openings may have some benefit, widening the Beaver Brook channel where it closely parallels Waverley Oaks Rd. and restoring it to roughly match upstream and downstream reaches would offer the greatest benefit.

Watershed Recommendations

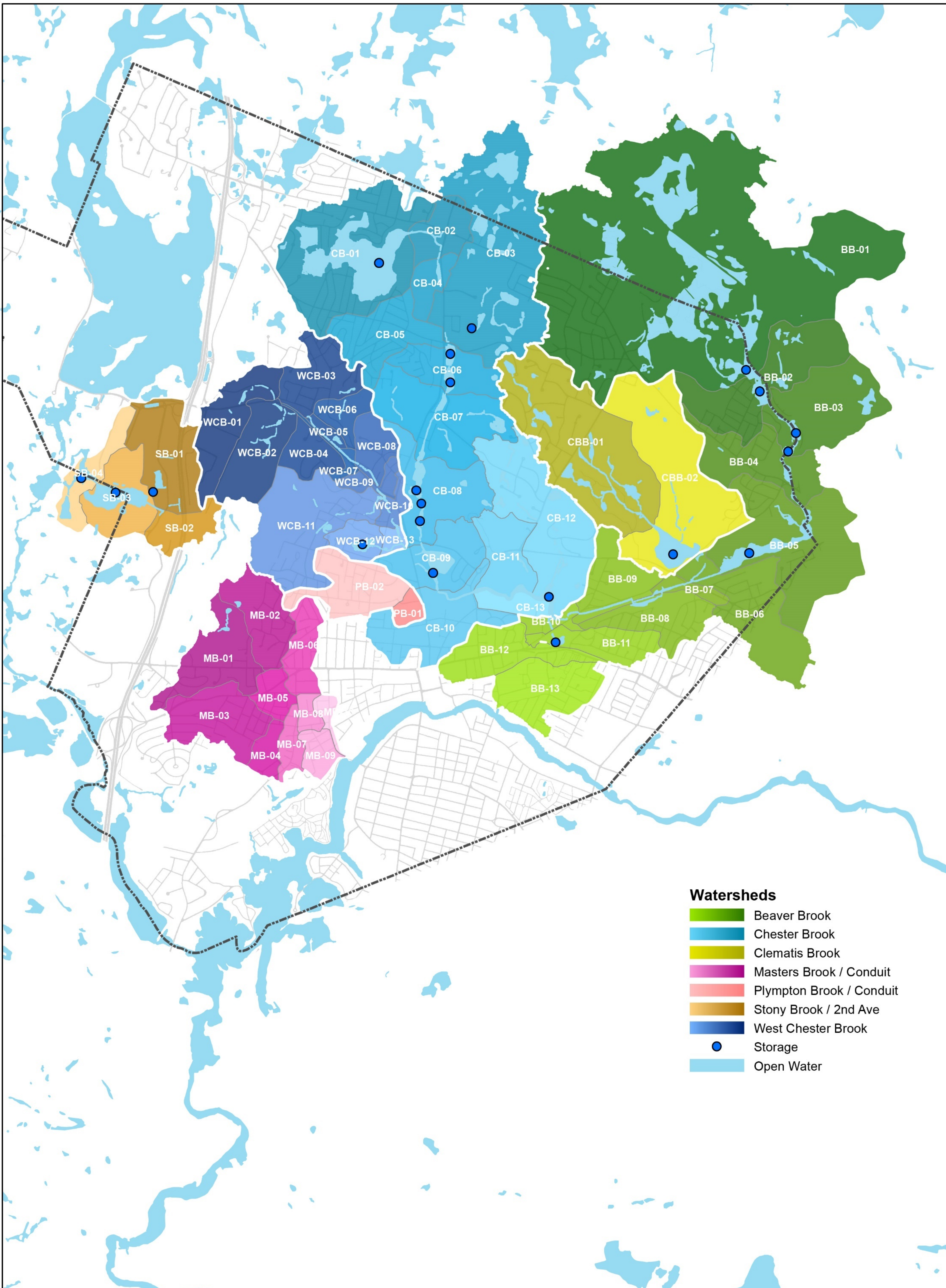
Beaver Brook is a large watershed in eastern Waltham with a mix of forested and urban land uses. Historically the most significant flooding impacts have occurred along Waverley Oaks Rd. (due to overtopping from both Beaver Brook and Clematis Brook) and perhaps more significantly in the Linden St. area. Our stormwater modeling efforts confirm the vulnerability of these areas and suggests that the large conduit downstream of Massassoit Street, where Beaver Brook goes underground, may also become a floodprone area. Based on our understanding of the watershed's hydrology, historical flooding issues, and stormwater model results, Weston & Sampson recommends the following actions be taken to reduce flooding in the Beaver Brook watershed:

Recommendations:

1. Modify the small outlet structure that is partially responsible for creating the large wetland complex on MADCR land in the headwaters of the watershed to significantly reduce and attenuate runoff entering Beaver Brook from that area. There is a natural restriction (10ft channel) upstream of Mill Pond north of Mallard Way with significant debris and stones that restricts the wetlands in Beaver Brook North Reservation.
2. Widen the Beaver Brook channel where it parallels Waverley Oaks Rd. and consider widening the bridge/culverts at both Linden St. crossings of Beaver Brook and the railroad crossing between them.
3. Develop the GI projects incorporated into Scenario 23 on the Fernald School campus to reduced Clematis Brook overtopping of Waverley Oaks Rd.
4. Consider conveyance swales along Trapelo Rd to help reduce localized flooding, convey stormwater to Beaver Brook, and provide pedestrian friendly / safe walking and biking experiences.

APPENDIX B

Maps



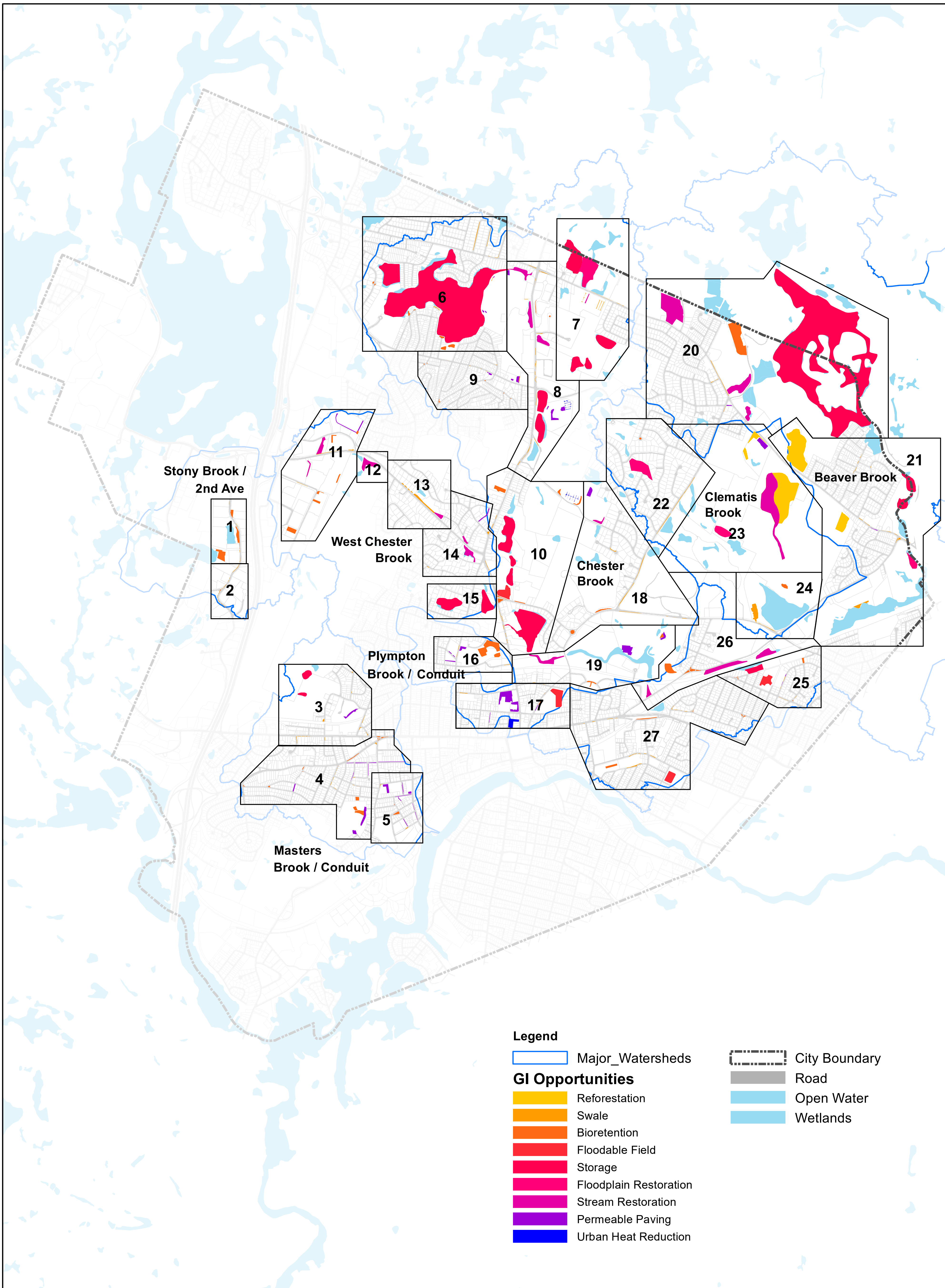
CITY OF WALTHAM
MASSACHUSETTS

Resilient Stormwater Management
and Implementation Plan

Model Development Watersheds

JANUARY 2021

Weston & Sampson



CITY OF WALTHAM
MASSACHUSETTS

Resilient Stormwater Management
and Implementation Plan

Green Infrastructure Opportunities Scenarios

JANUARY 2021

1 inch = 2,476 feet

0 0.25 0.5 1
Miles

Weston & Sampson

Attachment G. Regulatory Review Recommendations

Waltham, Massachusetts Regulatory Review

Review of existing ordinances to identify opportunities for climate resiliency regulations, guidance, or provisions.

June 29, 2021

Introduction

The following document provides a comprehensive review of existing ordinances in Waltham Massachusetts in order to identify opportunities to enhance the resilience of the stormwater system and the City as a whole. The following ordinances were reviewed and opportunities to update the regulatory language to include accommodations for climate resilience were identified. Suggestions vary from general assessments of potential new standards to specific, rule-based language.

The City departments charged with stormwater management include the Director of Consolidated Public Works or the City Engineer. In addition, The Conservation Commission has authority over projects that fall within their jurisdiction under the Wetland Protection Act. The Building Department also has limited responsibilities for stormwater management. The Board of Survey and Planning has authority over the review and approval of subdivisions. References to the Stormwater Enforcement Agent refer back to the City Engineer.

ORDINANCES

Ordinance 32081: Chapter 16 Sewers, Drains, and Sewage Disposal

Purpose: The purpose of this ordinance is to regulate the discharge of stormwater or other non-sewer drainage and to ensure proper operations and maintenance of the sewers, drains, and sewer disposal process.

Enabling Legislation: Not explicitly stated except to appoint the Director of CPW or Engineer as the Commissioner of Sewers via MGL Ch.41.

Enforcement Authority: Director of Consolidated Public Works or City Engineer

Section	Summary	Suggestions/Opportunity
16-3b	Stormwater and all other unpolluted drainage shall be discharged to such sewers that are specifically designated as combined sewers or storm sewers or to a natural outlet approved by the Director, but only after determination by the City Engineer. Combined sewers or storm sewers must have sufficient capacity to accommodate such discharge and all federal, state or local laws, regulations, and administrative or judicial orders, agreements or judgments must be complied with.	Waltham could require the reduction or elimination of inflow through stormwater management practices that capture and retain stormwater onsite (through low impact development [LID]). This could help to reduce associated combined and sanitary sewer overflows, which could increase as precipitation becomes more extreme. The City can require that a user design, construct, install, operate and maintain best management practices (BMPs) that provide regulation and control of the rate, volume and pollution discharge of the stormwater, prior to discharge to the City's storm drainage system. These BMPs must be approved by the Engineering Division. The City could develop assessment tools for more effectively understanding the capacity of storm sewers.
16-28	Connection of sources of surface runoff or groundwater to a sewer or drain connected directly or indirectly to the sewer is prohibited.	Adequate as written.
16-32	Infiltration and inflow mitigation fee: projects must mitigate additional wastewater infiltration/inflow sources, which add extraneous water to the City's sewer system thereby reducing its capacity and capability, at a specified rate of four gallons of infiltration/inflow removal for each additional gallon of wastewater that will be discharged to the sewer system, or pay a one-time infiltration/inflow mitigation fee per unit.	The City could require a higher ratio of I/I removal. The designated I/I removal ration could be lower for developments which implement BMPs.

Chapter 25 Stormwater Ordinance

Purpose: This ordinance authorizes the City to promulgate stormwater management standards for development and redevelopment projects to minimize adverse impacts to the public health, safety and welfare of Waltham residents, and protect the natural resources, water bodies, groundwater resources, environment and municipal facilities of the City, as required for the National Pollutant Discharge Elimination System (NPDES) general permit for stormwater discharges issued by the U.S. Environmental Protection Agency.

Enabling Legislation: Home Rule Amendment and Clean Water Act

Enforcement Authority: Stormwater Enforcement Agent

Regulatory Tool: Stormwater management permit, authorizes Stormwater Enforcement Agent to develop rules and regulations. Authorization power can be delegated in writing to employees or agents. Rules and regulations are amended through a public hearing and public notice.

The Stormwater Management Ordinance can further incorporate climate adaptation and resilience goals into the language by specifying performance standards for development projects.

Section	Summary	Suggestions/Opportunity
25-1 C	Details the objectives of article.	The City can expand upon the objectives of the article to include the following: To require practices to control the flow of stormwater from new and redeveloped sites into the municipal storm drainage system to prevent flooding and erosion *informed by the best available climate data.* To ensure the stormwater system is adequately designed to handle increased precipitation loads caused by climate change. To promote the incorporation of both green and grey infrastructure solutions to reduce the peak load on the stormwater management system, mitigate flooding, contribute to the quality of stormwater, and the reduction of urban heat islands.
25-3 A	Sets the requirements for large-scale developments over 1-acre. Any disturbance to land 1-acre or over draining to the City's MS4 must have a stormwater management permit from the Stormwater Enforcement Agent	Change to allow the threshold of disturbance to be defined in the Stormwater Rules and Regulations developed by the Stormwater Enforcement Agent; or Reduce the disturbance threshold to ~10,000 SF, given the density of development in Waltham. Amend the ordinance to allow the Stormwater Enforcement Agent to have jurisdiction of projects ranging from 10-000 to greater than or equal to 1 acre.

City of Waltham Site Plan Review and Permit Application Requirements

Purpose: This City's Site Plan Review and Permit Application Requirements include all documentation required of owners or developers prior to permit award. The required documents aid the City in evaluating whether the proposed design meets utility requirements, complies with Massachusetts State Building Code, and stormwater and drainage requirements.

Enabling Legislation: Massachusetts State Building Code.

Enforcement Authority: Director of Consolidated Public Works and City Engineer

Section	Summary	Suggestions/Opportunity
Plan and Utility Requirement #7	Peak storm flow rates shall be determined for pre- and post development conditions for the 10-., 25- and 100- year storm events. Piped drainage systems shall be designed with capacity for a 25-year. storm event. Detention basins, tanks, and pits shall be designed to be capable of safely storing and infiltrating the 100-yr. storm event. (See Policy on Drainage Calculations) In general it is required that all impervious surface drainage be retained or recharged on site for a 100-year storm with no connection to city system.	Waltham could require the reduction or elimination of inflow through stormwater management practices that capture and retain stormwater onsite through low impact development [LID]. The City can require that a user design, construct, install, operate and maintain best management practices (BMPs) that provide regulation and control of the rate, volume and pollution discharge of the stormwater, prior to discharge to the City's storm drainage system. These BMPs must be approved by the Engineering Division. Require applicant to submit a statement regarding how climate change projections were considered in the design or require that design storm events for future conditions using the Resilient Massachusetts's Action Team's Climate Resilient Design Standards and Guidelines.
Plan and Utility Requirement #8	Large development projects shall consider the use of detention basins or underground storage tanks to retain any flows, and if allowed, discharge either on-site or off-site to existing waterways, with flows not to be discharged directly or indirectly to existing municipal storm drainage systems. Smaller parcels can consider use of underground storage tanks with orifice regulated outflows.	'Large development projects' should be defined by square footage Large developments should incorporate nature-based solutions, green infrastructure, or other Low Impact Development techniques. Site plans should be reviewed for landscape measures that will reduce urban heat island impacts and mitigate flooding. Waltham could consider developing climate resilience design guidelines that are used to aid the review of new development plans.

Section	Summary	Suggestions/Opportunity
		Incorporation of climate resilience measures could be considered based on the size of the project. For example, large development projects would be required to implement a greater amount of square footage of landscape features contributing to the mitigation of climate impacts.
Plan and Utility Requirement #10	All drainage designs shall comply with the City of Waltham requirements and guidance set forth in the Massachusetts Department of Environmental Protection Stormwater Standards and Policies.	Drainage designs should incorporate projected loads under climate change.
Plan and Utility Requirement #21	All plans must be followed by a SURVEY RECORD (as-built plan) at the completion of final inspection (survey record to be certified with stamp, signed in ink, by a MA Registered Land Surveyor and stating the date of the record field survey).	As-built plans could be reviewed to ensure incorporation of proposed climate resilience measures if required by the climate resilience design guidelines for large developments. (Contingent on the implementation of the above recommendation for climate resilience design guidelines.)
Policy on Drainage Calculations #2	Plans for all residential projects involving the construction of new buildings, additions to existing buildings or addition/modification to impervious surface where the proposed roof exceeds 150 square feet, shall be accompanied by drainage calculations.	This requirement could be incorporated into the City's proposed Stormwater Rules and Regulations. New residential construction plans could be reviewed in relationship to the projected flood elevation for that parcel. The City can recommend that designs are adapted so that the ground level of the building is above the design flood elevation which is equal to the projected 100-year flood elevation plus 1ft of freeboard.
Policy on Drainage Calculations #3	Drainage calculations shall include calculations showing the proposed drainage system ability to remove 60% of the phosphorus load from additional and modified impervious areas. Owner occupied single family residential permit submissions are not required to show phosphorus load reduction calculations.	This requirement could be incorporated into the City's proposed Stormwater Rules and Regulations. The City could add a description of the methodology to show the removal of phosphorus control.

Waltham, Massachusetts Chapter Z, Zoning Code

Purpose: This ordinance regulates land use, structures, water, and open space to promote the health, safety, convenience, morals and welfare of its inhabitants. The zoning code is organized by regulations for Districts (Section 3), Dimensional Requirements (Section 4), Land, Buildings, Wetlands, Floodplain, Parking (Section 5), and Incentive Zoning (Section 8).

Enforcement Authority: Building Department

Section	Summary	Suggestions/Opportunity
1.3	Objectives	The City could consider adding climate resilience objectives including: - Flood resilient new development - Mitigation of flooding through the limitation of impervious area - Integration of green building practices to limit green house gas impacts - Integration of climate resilience design standards into new sites. Amend 1.31 to include 'floodplain'
2.3	Definitions	The City could add definitions for the following terms which relate to climate resilience and flood mitigation measures and reference these throughout the zoning code: - 100-year flood - Design flood elevation - Green infrastructure - Impervious surfaces - Urban heat island impacts - Solar reflectance index (SRI)
3.12	Establishes a floodplain district.	The City could update the ordinance language to require the regular update of the floodplain district extents based on the best available data for future flood projections, rather than relying on FEMA maps which use historical data.
3.5	Special permits	The City could consider requiring large developments seek a special permit. Special permits could be issued only when certain climate resilience targets were met through the site and building design. Boston Article 37 Green Buildings as a precedent example.
4.218	Lot area. This section lays out lot area requirements such as setbacks and side yards.	This section could be updated to account for dimensional requirements that facilitate the creation of congruent open spaces across properties. Additionally, this section could require that a certain ratio of the lot are be designated to planted areas to contribute to flood mitigation and urban heat island reduction.

		A new section could be added for lot area requirements in the floodplain to accommodate additional buffer area around waterways and high probability flood areas.
4.22	Dimensional requirements for residential properties.	The City could update this section to include dimensional requirements for the ground level of a new residence to meet the design flood elevation.
5.4	Design of parking areas for 5 or more cars.	This section of the zoning code could be updated to include requirements for pervious paving, high SRI paving, or green infrastructure to mitigate the impacts of heat and stormwater flooding.
8.5	Riverfront Overlay District lays out design requirements for Riverwalk and associated public area.	Design guidelines for bank stabilization can be updated to include flood mitigation measures and recommendations based on projected flood elevations. Planting guidance should be updated to include best practices for riverine floodplain management.

Other amendments to the Zoning Code could include the addition of a Tree Protection Ordinance; an ordinance to promote the reduction of urban heat island impacts through site and building strategies; incentive-based zoning for implementation of BMPs on properties; climate resilience design guidelines; the expansion of the Floodplain Overlay District based on future-looking flood projections; updates to area requirements to include formula-based limitations on impervious area.

STORMWATER MANAGEMENT PLAN

Purpose: The City of Waltham developed this Stormwater Management Plan (SWMP) to satisfy the requirements of the US EPA Phase II stormwater permit that is effective July 1, 2018. The SWMP describes and details the activities and measures that will be implemented to meet the terms and conditions of the permit. This plan provides a status update and timeline for implementation of the stormwater management programs, policies, guidelines required by the Environmental Protection Agency for the 2016 MS4 Permit.

Stormwater Management Rules and Regulations

The Stormwater Management Rules and Regulations are in draft-form as of June 2021 and have yet to be adopted by the City. Because this language has not yet been adopted as a singular regulatory document, the review of this was as comprehensive as the draft format allowed. Further assessment of the standards could be completed when the regulation is in a finalized format.

Enabling Legislation: Home Rule Amendment of MA Constitution; Clean Water Act (40 CFR 122.34); EPA NPDES Requirements; Waltham General Ordinance Chapter 16 Sewers, Drains and Sewage Disposal; and Waltham General Ordinance Chapter 25 Stormwater Management

Purpose: These regulations establish stormwater management standards and permitting processes for development and redevelopment projects to minimize stormwater runoff and associated impacts to abutters and the general public, as authorized by Article 1, Sections 25-4 and 25-20 of the City of Waltham General Ordinances.

Enforcement Authority: City Engineer and Stormwater Enforcement Agent

Regulatory Tool: Stormwater Management Permit (SWMP)

The first seven sections of the Stormwater Management Rules and Regulations define the purpose, authorizing statutes, applicable projects, administration, and permit processes for developments to reduce adverse impacts from stormwater. Section 8 sets requirements for stormwater management plans, plot plans, and performance standards for each project to meet the Standards of the Massachusetts Stormwater Management Policy. Section 9 sets requirements for operation and maintenance plans to ensure compliance with the City's Stormwater Ordinance and Massachusetts Surface Water Quality Standards. Section 10 sets requirements for the Waste, Erosion, and Sediment Control Plans to prevent erosion and sediment from reaching neighboring water bodies. The final sections (11-16) discuss inspections and enforcement procedures. Sections 8 and 10 provide the greatest opportunity to use the Stormwater Rules and Regulations as a climate resilience tool.

Section	Summary	Suggestions/Opportunity
Section 1 Purpose	Lists objectives of the rules and regulations for stormwater management	Include climate resilience as a stated objective.
Sec 8.a Stormwater Management Plan	Section 8 outlines components required of a stormwater management plan.	
Sec 8.a.7	Designates contours at one-foot intervals	Adequate as written.
Sec 8.a.9	Stormwater conveyances and wetlands on or connected to the site	Delineation of projected wetlands, floodplains, and other regulated areas could be used to identify preferred future development areas that are less vulnerable or sensitive under climate change. Rules could be used that enable wetlands to migrate with the expansion of the floodplain.
Sec 8.a.11	Defines the floodplain by the FEMA 100-year flood zone	Update to define the floodplain as the 500-year FEMA flood zone.
Sec 8.a.12	Includes the estimated seasonal high groundwater elevation	Estimates should incorporate projections of increased precipitation under climate change
Sec 8.a. 13	Includes the existing and proposed vegetation and ground surfaces with runoff coefficient for each.	Include a site landscape plan which includes a planting plan with species called out. Consider species that have benefits such as water-tolerance in the instance of flood submersion or drought tolerance in upland areas.
Sec 8.a.15F	The 10-yr, 25-yr, and 100-yr storm events should be used to determine peak storm flow rates	Consider adding 500-year storm event to peak storm flow rates to understand severe or future conditions.
Sec. 8.a.15	Drawings of drainage system should include onsite stormwater retention and detention measures	Plan can identify areas that would benefit from disconnected impervious surfaces, open channel design, and LID. The City could add language limiting the ratio of impervious

Section	Summary	Suggestions/Opportunity
		surfaces on various sites based on parcel size or use. The City should require onsite disposal and treatment of up to 2 inch of rain as often as possible, providing guidance on LID techniques to achieve this. The City might include language stating that the Director of Water and Sewer could also require the owner to disconnect its building storm drain and replace the connection with onsite LID practices.
	Soil conditions are not required as part of stormwater management plan	Require description of soil conditions in plan to allow annual recharge rates to be calculated based on soil types (in Sec 8.c.3); or, suggest in Sec 8.c.3 using the soil description in the erosion and sediment control plan.
Sec 8.c. Performance Standards	Prohibits discharging stormwater directly to wetlands or water; requires that post-development does not exceed peak discharge rates and maintains recharge rate from existing conditions; encourages maximum infiltration; requires 80% of TSS removed; requires erosion and sediment controls and operation and maintenance plan	Consider incorporating a "green ratio" requirement into stormwater guidelines. This criterion may be expanded to include greater than 1:1 offset criterion to increase retention capacity over time. Consider requiring each project to evaluate cumulative effects from future development, in addition to the individual project impacts. Include in Sec 8.c.8 a reference to the City's Erosion and Sedimentation Control Standard Operating Procedures (SOP 6) document for recommended stormwater management practices Consider making BMPs listed in the SOP 6 required Include language that addresses the impact of increased stormwater on soil erosion and sediment control and encourage the use of best available data to understand future conditions and use best practices for operations and maintenance.
Sec 10 Waste, Erosion, and Sediment Control Plan	BMPs described in the plan shall follow the MA DEP Report on Erosion and Sediment Control in Urban and Suburban Areas	Consider making BMPs listed in the SOP 6 required
Sec 10.b	Waste, Erosion, and Sediment Control Plan's required elements	Include reference to the City's Erosion and Sedimentation Control Standard Operating Procedures document for recommended

Section	Summary	Suggestions/Opportunity
		stormwater management practices and considerations
Sec 10.b.4	Soil Description should describe drainage conditions and soils that will be exposed during grading.	Could recognize Natural Resource Conservation Service soils classification system which identifies soils susceptible to high erosion and runoff. This may be a useful source of information for project design standards and guidelines.

The following appendices to the Stormwater Management Plan are described below but were not reviewed as a component of this regulatory review. However, it should be noted that catch basin cleaning, street sweeping, and deicing are important procedures that contribute to the proper functioning of the stormwater system, which in turn mitigates flood impacts. By keeping a standard cleaning schedule, the City can reduce opportunities for catch basins to become clogged and result in flooding and water quality impairments. .

Catch Basin Cleaning Standard Operating Procedures (Stormwater Management Plan Appendix E)

Purpose: These procedures guide municipal operations and good housekeeping practices for catch basin cleaning to ensure effective capture of stormwater runoff.

Street Sweeping and Deicing Standard Operating Procedures (Stormwater Management Plan Appendix F & G)

Purpose: These procedures guide municipal operations and good housekeeping practices for street sweeping and deicing to ensure effective capture of stormwater runoff and contribution to water quality.

Construction Site Inspection Standard Operating Procedures (Stormwater Management Plan Appendix H, SOP 5)

Purpose: The Standard Operating Procedures guide municipal operations for a municipal Stormwater Construction Inspection Plan and provides guidance on evaluating compliance of stormwater controls at construction sites.

Enforcement Authority: City Engineer and Stormwater Enforcement Agent

Section	Summary	Suggestion/Opportunity
Stormwater Construction Inspection Plan	Requires staff conducting sections to be trained	Require inspectors to be certified

Erosion and Sedimentation Control Standard Operating Procedures (Stormwater Management Plan Appendix H, SOP 6)

Purpose: This section discusses methods for reducing or eliminating pollutant loading from development activities and guidance for design and planning, construction, and post-construction operations to ensure all permanent BMPs function over the long term.

Enforcement Authority: City Engineer and Stormwater Enforcement Agent

Section	Summary	Suggestions/Opportunity
Section 1 Controlling Erosion and Sediment through Design and Planning	Guidelines encourage building footprints to avoid highly erodible, high permeability soils.	Could specify Soil Groups A and B; could also limit site designs to areas farther from watercourse Set limits on allowable disturbance of existing vegetation. Consider adding provisions to include measures to identify and prevent soil compaction of soils with the highest infiltration capacity, and to require the identification and use of specified travel paths for heavy construction equipment to limit overall site compaction, in addition to preventing and controlling soil erosion and sedimentation. Also require the placement of temporary construction trailers to be shown on plans to ensure they are placed outside of environmentally sensitive areas and off soils with the highest infiltration capacity.
Section 2 Controlling Erosion and Sediment on Construction Sites	Requires maintenance of old and establishment of new vegetation to minimize exposed soil (Section 2: #5, #7, #11) Soils should be stabilized by mulching and/or seeding (Section 2: #12) Encourages avoiding soil compaction from heavy machinery (Section 2:#15)	Recommend using native plantings and preserving existing trees to provide shade, reduce erosion, reduce urban heat island impacts, and contribute to flood mitigation. Limit the total open space are that can be turf grass, encouraging planting that will provide great resilience benefits. The EPA's Watersense program recommends 40%:https://www.epa.gov/sites/production/files/2017-01/documents/ws-outdoor-home-turfgrass-report.pdf. Provide guidance on the proper use and handling of fertilizers, herbicides, and watering practices. Consider revising as-built inspection process to ensure that soil compaction is addressed and mediated prior to the issuance of occupancy.

BMP Inspection Standard Operating Procedures (Stormwater Management Plan Appendix H, SOP 9)

Purpose: These procedures state the frequency, maintenance standards, and required inspection forms for eight types of constructed BMPs.

Enforcement Authority: City Engineer and Stormwater Enforcement Agent

OTHER REGULATIONS

Land Subdivision Rules and Regulations

Enabling Legislation: 81-Q of Chapter 41 of MGL

Reviewers: BSP, Engineering Department via BSP

Purpose: This regulation establishes standards for subdivision layout and construction to protect the safety and welfare of Waltham residents. Sec. 2: Procedures/Plans; 3; Sec 4: design standards (Streets, open space), Sec 5: required improvements and standards

Enforcement Authority: Board of Survey and Planning

Section	Summary	Suggestions/Opportunity
2.5 Subdivision standards for Flood Plain Districts and Water Resource Areas	Proposed development projects must be reasonably safe from flooding. Development proposals in the Floodplain District or Water Resource Area must minimize flood or stormwater damage. Drainage systems should be designed to adequately manage project stormwater loads from the latest FEMA 100-year zone.	Encourage the use of the 500-year storm event as the design storm for proposed development projects. Encourage site designs that island future development and use topography to manage onsite floodwaters. Integrate green infrastructure into landscape plans.
3.1 and 3.2	Submission and Definitive Plan – Details elements that must be submitted in drawing set for review.	Included with plan set should be flood maps overlaid on to the site plan. Include language that states that the proposed design and associate drawing set will be reviewed for climate resilience and green building practice considerations. Incorporation of such practices if favorable for all proposed developments and required for developments with the Flood Plain District or Water Resources Area.
3.1.28 Preliminary plan	Designates that contours are shown at 10-foot intervals or less	Language could be updated to be more specific, requiring 1' contours.
3.1.29	Major site features must be submitted, including large trees (12' canopy)	Adequate as written but could encourage the preservation of small to medium tree canopy as well, if in good health.

Section	Summary	Suggestions/Opportunity
		Include language that review of major site features will include identification of large tree species for preservation.
3.2.112 Definitive Plan	Maintains that the locations and species of existing trees of 12' tree canopy or greater should be identified.	Adequate as written but could encourage the preservation of small to medium tree canopy as well, if in good health. Include language that review of major site features will include identification of large tree species for preservation.
3.2.119 and 3.2.2.5	Designates that contours are shown at two-foot intervals	Update to require 1' contour intervals.
4.2.3	Provides Right of Way width requirements.	Streets should be laid out with a public right of way with adequate dimension for the implementation of green infrastructure such as tree box filters, bioswales, and urban tree canopy.
4.3	Details requirements for Easements	A section could be added to 4.3 easements that requires a buffer from existing waterways or waterbodies; or a buffer around the extents of the projected floodplain for the 50-year flood event.
4.4	Details requirements for open spaces onsite.	Section 4.4 should be expanded upon to include open space requirements related to the ratio of are that is covered with vegetation that cools surface temperature, mitigates flood impacts, and provides shaded areas for residents. Section 4.4 could also include topographic requirements for proper site drainage and the encouragement of green infrastructure. This section could use rule-based language or provide general design guidance.
4.5	Details expectations for the protection of natural resources.	This section could be expanded upon to explicitly detail the value of natural resource preservation to climate resilience. It should be emphasized that existing, healthy trees should be maintained and that waterbodies should be protected. Waterways and waterbodies should have an adequate buffer between the extents of their bank and the proposed development.
4.5.1	Requires the protection of trees from removal during construction.	Section 4.51 should be updated to include specific tree calipers that should be maintained. Large and medium size trees should be preserved.
5.4.3	Details requirements for subgrade preparation	Subgrade preparation should include consideration of the natural water table level and take reasonable measures to mitigate impacts to the water table with the addition of new construction.

Section	Summary	Suggestions/Opportunity
5.4.4	Details design criteria for roadways	Criteria for roadways could include ratio requirements for pervious pavement or pavement with a high Solar Reflectance Index (SRI).
5.5.1	Details design requirements for storm drains	Storm drains should be designed to address stormwater loads based on future flood projections.
5.8	Details design requirements for curbing.	This section should include curb cut requirements that facilitate stormwater management
9.2 Site Plans	Requires two-foot contour intervals	Update to require 1’ contour intervals.

Attachment H. Implementation Plan

55 Walkers Brook Drive, Suite 100, Reading, MA 01867
Tel: 978.532.1900

MEMORANDUM

TO: Catherine Cagle, Planning Director, City of Waltham

FROM: Amanda Kohn and Steve Roy, Weston and Sampson

DATE: June 29, 2021

SUBJECT: Stormwater Capital Improvement Plan Implementation

The City of Waltham is dedicated to reducing the impacts of natural hazards to the City's buildings and infrastructure, environment, and vulnerable populations. According to the City of Waltham's *Hazard Mitigation Plan – Municipal Vulnerability Preparedness Plan 2019 (HMP-MVP Plan)*, flooding is the most prevalent and serious natural hazard. Flooding in Waltham occurs both by inland/riverine flooding and as urban stormwater flooding. Both types of flooding are expected to worsen with the more intense precipitation projected to occur under climate change.

Waltham was awarded an MVP Action Grant for FY20/FY21 to develop a Resilient Stormwater Action and Implementation Plan (RSAIP) to identify projects to reduce flooding and urban heat island in six subbasins. The RSAIP includes this Capital Improvement Plan (CIP) Memo, which lays out a recommended implementation plan over a 10-year period. The RSAIP met the following high priority actions from the HMP-MVP plan:

- Reduce the impact of riverine and stormwater flooding on roads, floodplains, and adjacent properties.
    - Assess and inventory stream crossings such as culverts and bridges.
    - Recommend improvements and develop an implementation plan for projects such as replacement of culverts and storm drainage structures that cause flood hazards and areas where elevation of roads would improve resilience.
    - Identify and upgrade infrastructure to handle flooding, maintain drains, and create upstream storage to reduce flooding.
    - Invest in low impact development to reduce flooding.
    - Work locally, and in cooperation with, surrounding communities to reduce flooding through watershed management, stormwater management, flood mitigation, and roadway improvements.
- Promote and collaborate between City departments and private entities to plan stormwater improvements.
- Restore wetlands and floodplains for flood mitigation and flood storage. As an example, restoring wetlands and floodplains to reduce flooding risk downstream of Beaver Brook. Wetlands can provide flood protection for culverts.

CAPITAL IMPROVEMENT PLANNING BACKGROUND

The Engineering and Public Works Departments complete capital improvements and perform operation and maintenance of the City's Stormwater Infrastructure. Financial planning, and the creation of this capital improvement plan, will allow for the allocation of resources to complete projects by providing a roadmap to focus efforts on high priority projects. This CIP along with MVP planning information, identifies short term and long- term needs, solutions, and implementation costs. The primary projects in the capital improvement plan were developed primarily concentrating on flood mitigation projects; however, culvert maintenance and repair and stream maintenance are also needed. Projects were prioritized based on flood mitigation improvements, asset condition, and risk of failure.

Yoon S. Byun/Globe Staff

Images of 2018 Flooding of Linden Street

CAPITAL IMPROVEMENT PLAN PROJECT TYPES

This section provides a breakdown of the types of projects incorporated into the capital improvement plan.

Stream Maintenance

- Removal of sediment along the bottom of the stream bed restricting flow (assuming required permit approvals can be obtained)
- Removal of debris, such as downed tree limbs
- Cutting back of overgrowth along embankments
- Bank stabilization
- Repair of retaining walls

BMP Retrofits

- Retrofit of the existing drainage system to incorporate green infrastructure to assist in meeting MS4 Permit requirements

Flood Mitigation

- Based on evaluation and hydrologic/hydraulic modeling of catchment areas, proposed solutions developed to address localized flooding.
- Based on inspection of existing drainage infrastructure, maintenance projects identified to alleviate localized flooding

Culvert Rehabilitation and Upgrades

- Cleaning of culverts to remove sediment obstructing flow and preventing a comprehensive visual inspection of the culvert
- Follow-up TV inspection of longer pipe culverts that could not be viewed with the ZoomCAM
- Structural evaluation of road-width culverts to document condition and assess need for repair/ replacement
- Rehabilitation or replacement of failing culverts and culverts that are undersized

Culvert inspection – Stanley Road

CIP IMPLEMENTATION

The Capital Improvement Plan is divided in yearly segments with estimated individual project costs ranging from $200 thousand to over $5.5 million. The capital improvement plan has a 10-year outlook assuming consistent funding is available into the future. Tables 1 and 2 summarize the stormwater management and implementation plan prioritization based on flood mitigation, stream and culvert assessments, and City needs.

Culvert Replacement - Beaver Street

As the City performs more detailed analysis and collects more condition assessment data in the early years of the program, especially as it pertains to larger projects where outside consultant/contractor support is needed for implementation, the City will need to re-evaluate whether the allocated budget amounts are still adequate to meet the City's drainage infrastructure needs.

If additional evaluation or changes in the drainage infrastructure system requires that the schedule be reprioritized or additional projects added early in the program or there is an immediate need, the City will need to re- evaluate the funding sources at that time, and explore changes to the capital improvement plan that condenses the implementation timeframes and increases the amount of capital available annually to direct towards these critical projects.

Many of the recommended stream and culvert improvements projects incorporated into the CIP are smaller and therefore are combined into larger capital project which will help assure competitive pricing is received. Implementation of this plan will require coordination with various City departments.

The full capital improvement plan is summarized in Table 3 and includes projects through Year 10.

CAPITAL IMPROVEMENT PLAN UPDATES

The capital improvement plan is a living document, and should be periodically reviewed and updated as new project priorities arise and as new information becomes available. For instance, the capital improvement plan currently includes funding for further inspection, assessment, and preliminary design, which will ultimately inform the final design and construction cost of new projects or changes that will need to be incorporated into the plan. In addition, TV inspection and comprehensive structural inspections are being recommended for numerous culverts to gain additional insight on the extent of defects noted and potential repairs. Once the evaluations are complete in the early years of the plan, the design and construction project costs will need to be incorporated.

COMPLETING IDENTIFIED STORMWATER DRAINAGE PROJECTS

The Capital Improvement Plan implementation included in Table 3 summarizes recommended stormwater improvement projects that were identified during development of the RSAIP.

Tables 1 and 2 summarize the recommended stormwater scenarios for stormwater management and implementation. Based on the recommendations of the City's Stormwater Team, a 10-year timeline for individual project implementation was developed. As described elsewhere, the scenarios summarized in Tables 1 and 2 were primarily ranked based on City need and preliminary hydrologic and hydraulic modeling that showed areas of greater flood mitigation.

The City has several capital projects that are currently underway and identified for implementation during Year 1. In addition to the evaluation factors taken into account in Tables 1 and 2, it is recommended that the City consider risk (likelihood and consequence of failure), based on input from future investigations, to further prioritize critical known infrastructure that needs maintenance/replacement within each of the recommended scenarios. Additional investigations are required to finalize the risk assessment.

Stormdrain Replacement and Improvements – Ash and Lowell Streets – Completed in Year 2020

Over the past decades, the City has knowledge of the number and severity of existing flooding issues within the City's watersheds. Based on this and the MVP evaluation, Beaver Brook, Chester and West Chester Brooks are considered priority watersheds that have significant flow conveyance restrictions due to sediment and debris in stream channel, vegetation overgrowth, undersized culverts and/or restricted opening due to sediment and debris.

Other factors that will need to be further considered include identifying planned capital projects such as roadway improvements and paving, park and open space construction, schools, public utility upgrade projects etc. by other City departments and pair them with the stormwater projects in the area.

OPERATION AND MAINTENANCE

The development and implementation of this Capital Improvements Plan partially fulfills the requirements of the City's MS4 Permit and also is an important component for maintaining the stormwater drainage system. Each permittee is required to develop a written program detailing the activities and procedures that will be implemented to ensure that MS4 infrastructure is maintained in a timely manner to reduce the discharge of pollutants. In addition, the City has developed separate written operation and maintenance procedures for municipal facilities and activities in accordance with MS4 Permit requirements. These include procedures for the following:

- Parks and Open Space
- Catch Basin Cleaning
- Street Sweeping
- Winter Road Maintenance
- Municipal Buildings and Facilities
- Municipal Vehicles and Equipment
- Structural BMPs

As the City moves forward with implementation of the Improvements Plan, emphasis will be placed on developing a routine maintenance schedule such that drainage infrastructure is maintained in a timely manner and the City can move from reactive to proactive maintenance. The City should strive to accomplish the following when it comes to operation and maintenance of the drainage system:

- Inspect and maintain streams once every 3 to 5 years to ensure that flow of water is not being hindered, which can contribute to localized flooding.
- Clean sediment and debris from culverts every 2 to 4 years and conduct basic structural assessments to monitor for further deterioration that warrants more immediate replacement or rehabilitation.
- Inspect BMPs following proper procedures and recommended frequency of inspection and maintenance. The MS4 Permit requires annual inspection of BMPs at a minimum.
- Identify and televise critical drainage infrastructure to gain a baseline condition assessment. Most of the City's drainage piping has never been inspected and its condition is unknown. As a mitigation measure, City staff may complete a focused inspection of the condition of critical drainage infrastructure to identify potential problems and schedule future improvements.

OPTIONS FOR FUNDING

The City may also explore funding mechanisms such as Stormwater Enterprise Fund to secure dedicated revenues to implement projects. This would provide a reliable and recurring revenue source that could significantly increase the City's ability to plan and execute stormwater system maintenance, flood controls, and water quality improvement projects.

The City could also apply for various Federal and State Agency Grants that are typically available every year. Below is a summary of the grant opportunities:

Category	Grant	Description
Infrastructure	EPA's Clean Water State Revolving Fund (CWSRF)	Low-interest source of funding for stormwater management projects that includes traditional stormwater conveyance pipe, storage, and treatment systems and green infrastructure for water quality
	Flood Mitigation Assistance Grant Program (FMA)	Implement cost-effective measures that reduce or eliminate the long-term risk of flood damage, including localized flood control and stormwater management.
	Building Resilient Infrastructure & Communities (BRIC)	Provides funds for hazard mitigation planning and the implementation of mitigation projects prior to a disaster event, with a focus on infrastructure projects and "community lifelines." Replaced FEMA's Pre-Disaster Mitigation (PDM) Program.
	DER Culvert Replacement Municipal Assistance Grant Program	Grant to replace undersized, perched, and/or degraded culverts located in an area of high ecological value.
Stream Restoration and Green Infrastructure	DER Priority Projects	Funds projects that offer ecological value and community benefits, including river restoration.
	Municipal Vulnerability Preparedness (MVP) Action Grant	Provides support to implement climate change resiliency priority projects. Project types include planning, assessment and regulatory updates; nature-based solutions; and resilient redesigns and retrofits for critical facilities and infrastructure.
	USDA Natural Resources Conservation Services Watershed and Flood Prevention Operations Program	Financial and technical assistance for projects including erosion and sediment control and flood prevention.
Water Quality	Federal Clean Water Act, 604b Grant Program: Water Quality Management Planning	Funds nonpoint source assessment and planning projects, including projects related to green infrastructure.
	Federal Clean Water Act, Section 319 Nonpoint Source (NPS) Competitive Grants Program	Funds implementation projects that address the prevention, control, and abatement of NPS pollution.

Tree Planting	Arbor Day Foundation TD Green Space Grant	Supports green infrastructure development, tree planting, forestry stewardship, and community green space expansion as a way to advance environmental and economic benefits toward a low-carbon economy. $20,000 is available. The program's annual themes may vary. Applicants are encouraged to apply with community partners.
Parks & Recreation	Massachusetts Land and Water Conservation Fund Grant Program	Funding for the acquisition, development, and renovation of parks, trails, and conservation areas.
	EEA Parkland Acquisitions and Renovations for Communities (PARC) Program	Aids in acquisition and developing land for park and outdoor recreation purposes. Can be used to acquire parkland, build a new park, or renovate an existing park.
	EEA Local Acquisitions for Natural Diversity (LAND) Grant Program	Helps cities acquire land for conservation and passive recreation.

Table 1 Stormwater Implementation Plan – Flood Mitigation Co-Benefits

Scenario	Community Resilience Factor	Environmental Justice Neighborhood	Reduction of Urban Heat	Placemaking	Pedestrian Improvements	Biodiversity
Scenario 1 – Northern Second Ave	2	5	2	2	3	2
Scenario 2 – Southern Second Ave	1	5	1	2	3	1
Scenario 3 – Upper Masters/Sibley Brook	1	5	2	2	2	2
Scenario 4 – Middle Masters/Sibley Brook	2	3	2	4	4	4
Scenario 5 – Lower Masters/Sibley Brook	3	3	2	2	3	2
Scenario 6 – Hardy Pond	4	4	1	2	1	3
Scenario 7 – Falzone Memorial Park and Shady's Pond Conservation Area	1	3	1	3	2	4
Scenario 8 – Upper Chester Brook	4	5	2	3	5	4
Scenario 9 – Lake Street Neighborhood	4	5	1	1	3	1
Scenario 10 – Middle Chester Brook	1	2	2	4	2	4
Scenario 11 – Upper West Chester Brook	2	5	3	3	4	4
Scenario 12 – Prospect Hill Park	3	1	3	5	4	5
Scenario 13 – Totten Pond Road	1	1	1	1	3	3
Scenario 14 – Pond End Road	1	1	2	2	1	3
Scenario 15 – Lexington and Bacon St	3	1	1	2	1	3
Scenario 16 – Plympton Brook	3	4	2	4	3	4
Scenario 17 – Lexington and Church St	1	5	4	3	3	2
Scenario 18 – North of Lyman Pond	1	2	2	2	5	3
Scenario 19 – Lower Chester Brook	3	5	2	2	1	3
Scenario 20 – Upper Beaver Brook	5	2	4	4	2	4
Scenario 21 – Middle Beaver Brook	3	1	5	5	4	4
Scenario 22 – Upper Clematis Brook	1	1	3	3	3	3
Scenario 23 – Fernald Campus	5	1	5	5	2	5
Scenario 24 – Lower Clematis Brook	1	1	1	2	2	2
Scenario 25 – Warrendale	1	1	2	4	3	4
Scenario 26 – Waverly Oaks and Linden	5	3	2	4	4	4
Scenario 27 – Lower Beaver Brook	3	3	3	2	4	2

Table 2 Stormwater Management Implementation – Flood Mitigation Benefits – Gray Infrastructure

Watershed	Gray Infrastructure Project	Description / Justification	Near-term % Reduction Total Volume (MG)	Long-term % Reduction Total Volume MG)	H&H Performance 1: Minimal to 5: Very Significant
Stony Brook / 2nd Ave	None	NA	-	-	-
Masters / Sibley Brook	Prospect St at Highland/ Felton St	The proposed change is to widen those conduits to 10 feet wide or otherwise create a comparable increase in cross-sectional flow area.	100.0%	100.0%	5
Chester Brook	None	Noted in the discussions of Scenarios 6, 8, and 10 in Appendix A, several green infrastructure scenarios included modifications to the culverts or other outlet structures that impound ponds or wetlands within the Chester Brook watershed	-	-	-
West Chester Brook	Craig Ln. & Totten Pond Road Storm Drain Improvements	Increase the capacity of the storm drains in Totten Pond Rd. and Craig Ln	100.0%	100.0%	4
	Culvert Improvements	Increase the discharge capacity at Worcester Ln., Bacon St., and Lexington St. , (3) 4-foot diameter culverts at all four road crossings	11450.0%	1473.0%	5
Beaver Brook & Clematis Brook	Culverts near Waverly Oaks Rd and Linden St	This concept incorporates widening of the channel in this trouble area (likely to the south) so that it is consistent with upstream and downstream reaches.	-	7.0%	3

Table 3 Stormwater Management CIP Implementation Plan

City of Waltham - Years 1 through 10

Project Description	Base Year	COST Year #1	COST Year #2	COST Year #3	COST Year #4	COST Year #5	COST Year #6	COST Year #7	COST Year #8	COST Year #9	COST Year #10
Engineering Evaluation, Stormwater Infrastructure Assessment and Green Infrastructure Projects											
H/H modeling studies and updates, CCTV and inspection of infrastructure		$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 250,000
Major Operation and Maintenance of the Collection System		$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000
Green Infrastructure Projects from relevant H/H scenarios		$ 250,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000
Sub-Total	**$ -**	**$ 550,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**	**$ 1,300,000**
Infrastructure Projects											
Scenario 23 - Fernald Wetland Pond and Stream Daylighting	$ 2,500,000										
Scenario 5 Incorporate floodable field design into proposed Nipper Maher Park improvements		$ 200,000									
Scenario 15 - Culvert replacement under 260 Lexington Street		$ 950,000									
Scenario 26 - Beaver Brook - Waverley Oaks and Linden Street Culvert Replacements/Enlargements			$ 5,500,000								
Scenario 20 - Outlet Control Structure Mallard Way - Create Flood Storage			$ 175,000								
Scenario 8 - Replace/rehab/install flow control strucrures to create storage from YMCA to Clarks Pond				$ 1,600,000							
Scenario 6 - Modify Hardy Pond flow control structure to create additional storage				$ 1,250,000							
Lowell St area drainage improvements					$ 3,250,000						
Scenario 15 - Culvert replacements under Totten Pond Road, Worcester Ln and Bacon Street						$ 3,250,000					
Scenario 13 - Upsize storm drains in Craig Lane and Totten Pond Road with 36" outfall							$ 2,500,000				
Scenario 5 Replace Prospect Street drain from Highland St/Fulton St intersection to outfall (Near NOVA Biomedical)								$ 4,200,000			
Scenario 12 - Prospect Hill Park Master Plan update - Stream restoration, removal of culverts and reconnecting 5 th avenue drain									$ 3,250,000		
Scenario 1 - Second Avenue drainage improvements										$ 1,600,000	
Sub-Total	**$ 2,500,000**	**$ 1,150,000**	**$ 5,675,000**	**$ 2,850,000**	**$ 3,250,000**	**$ 3,250,000**	**$ 2,500,000**	**$ 4,200,000**	**$ 3,250,000**	**$ 1,600,000**	**$ -**
Stream Improvements - Sediment and Debris Removal, Vegetation Cutback and Bank Stabilization											
Lower Chester Brook - Stanley Road to Beaver Brook		$ 450,000									
Stony Brook - Second Avenue			$ 250,000								
Lower Beaver Brook (Culvert near #85 Linden Street to Culvert entrance at Main Street)			$ 325,000								
Upper Chester Brook - Stanley Road to Hardy Pond				$ 250,000							
Upper Beaver Brook (Trapelo Road to Culvert near Waverly Oaks Road and Linden Street Intersection)				$ 450,000							
Middle Beaver Brook Stream Restoration (Culvert near Waverley Oaks Rd & Linden St Intersection to Culvert near #85 Linden St)					$ 1,250,000						
West Chester Brook Stream Restoration (Totten Pond Road - Winter Street and Prospect Hill Stream)						$ 2,500,000					
Sub-Total	**$ -**	**$ 450,000**	**$ 575,000**	**$ 700,000**	**$ 1,250,000**	**$ 2,500,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
Culvert and Drain System Repair and Replacement (No Upsize)											
Scenario 20 - Trapelo Road Beaver Brook Culvert Replacement	$ 1,000,000										
Scenario 4 - In-Situ Rehabilition of 36" CMP Storm Drain in Easement - Cabot and Fiske Avenue		$ 900,000									
Sub-Total	**$ 1,000,000**	**$ 900,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
Total Annual Estimated Cost	**$ 3,500,000**	**$ 3,050,000**	**$ 7,550,000**	**$ 4,850,000**	**$ 5,800,000**	**$ 7,050,000**	**$ 3,800,000**	**$ 5,500,000**	**$ 4,550,000**	**$ 2,900,000**	**$ 1,300,000**

Note: Project Costs listed include design, permitting and construction administration costs