June 2022

Town of Tewksbury

Stormwater Analysis for Nature-Based Solutions & Community Co-Benefits

Weston & Sampson
transform your environment

MVP
Municipal Vulnerability Preparedness

MRWC MERRIMACK RIVER WATERSHED COUNCIL

ACKNOWLEDGMENTS

Funding Source

This project was funded by the Executive Office of Energy and Environmental Affairs Municipal Vulnerability Preparedness (MVP) Program through a Fiscal Year 2022 Action Grant. Created in 2017 as part of Governor Baker's Executive Order 569, the MVP program pairs local leadership and climate resiliency resources with a significant investment funding from the Commonwealth to address ongoing climate change impacts like sea level rise, inland flooding, storms, and extreme temperatures.

The following Town of Tewksbury staff, along with Weston & Sampson and the Merrimack River Watershed Council, partnered to bring innovative climate resilience solutions to this project that, when fully implemented, will reduce flooding, create more green space, and lower the impacts from urban heat island effects. A vibrant community is a livable community and Tewksbury is an excellent example of responding to climate threats with new approaches that will protect residents and businesses.

Town of Tewksbury

- **Steven Sadwick**, Assistant Town Manager
- **Kevin Hardiman**, PE Town Engineer
- **Alexandra Lowder**, Community/Economic Development Planner
- **Joe Fontaine**, Conservation Agent
- **Jennifer Balch-Kenney**, Open Space & Recreation Plan Committee
- **Mark Bertonassi**, Building Commissioner
- **Melissa Maniscalco**, Tewksbury Housing Authority

Weston & Sampson

- **Jaurice Schwartz**, PE, Project Manager
- **Janet Moonan**, PE, Technical Lead
- **Andrew Wojciak**, EIT, Engineer
- **Andrew Walker**, PH, CFM, Hydrologist
- **Deanna Lambert**, EIT, Engineer
- **Caroline Passalacqua**, EIT, Engineer
- **Rupsa Roy**, PhD, Climate Resiliency Scientist
- **Ryan Thomas**, Climate Resiliency Architect
- **William Blais**, Senior Project Engineer

Merrimack River Watershed Council

- **Susie Bresney**, MA Water Resources Program Manager
- **Lauren Zielinski**, NH Water Resources Program Manager

MA Executive Office of Energy & Environmental Affairs

- **Michelle Rowden**, Northeast Regional Coordinator, MVP Program

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1 INTRODUCTION

The Town of Tewksbury is dedicated to reducing the impacts of climate change on the community's infrastructure, economy, natural features, and climate vulnerable populations. In particular, Tewksbury is frequently impacted by inland stormwater flooding.

During 2019 and 2020, the Town undertook a comprehensive Hazard Mitigation and Climate Resilience Planning Process through the Commonwealth of Massachusetts Municipal Vulnerability Preparedness (MVP) Program. Throughout this planning process, flooding was a frequently cited hazard of concern and drainage infrastructure and stormwater management were identified as vulnerable local features. Key findings of a survey of residents were that:

- Heavy precipitation and flooding are the climate hazards of most concern for residents.
- Culverts, drainage infrastructure, and stormwater management are considered to be Tewksbury's greatest vulnerabilities.

The **Municipal Vulnerability Preparedness (MVP)** grant program provides support for cities and towns in Massachusetts to identify climate hazards, assess vulnerabilities, and develop action plans to improve resilience to climate change. Communities that complete the MVP Planning Grant process become designated as an MVP Community and are eligible for MVP Action Grant funding to implement the priority actions identified through the planning process.

Figure 1-1: An image of stormwater flooding at Water Street and Adelaide Road in Tewksbury in November 2018

Participants of the Community Resilience Building (CRB) Workshop conducted during the MVP planning process considered these climate threats while brainstorming potential adaptation action items, such as:

- Increasing flood storage through gray and green infrastructure.
- Developing an action plan for the stormwater system with a vulnerability assessment for stormwater flooding.
- Using Town properties for stormwater management, green infrastructure, and low impact development.

Tewksbury has continued to conduct activities related to climate resilience, has been proactive in maintaining and improving the drainage system including installing green infrastructure, and even has established a progressive Stormwater Enterprise fund to provide dedicated funding to drainage operations and capital needs. However, combating flooding requires complex, iterative evaluations and rightsized solutions that consider present and anticipated increases in precipitation due to climate change.

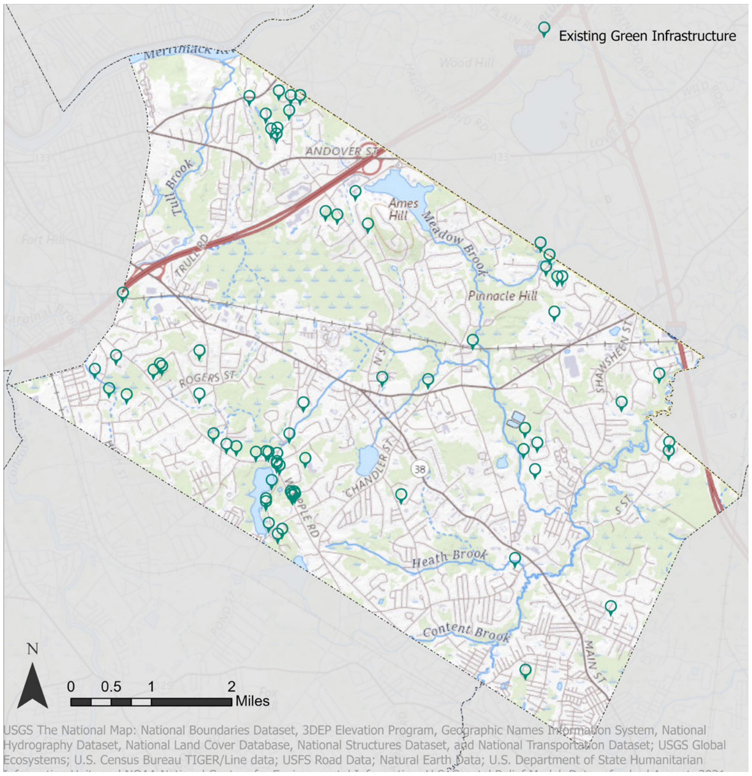


Figure 1-2: This map shows the locations of existing green infrastructure in Tewksbury. Green infrastructure often looks like gardens, a wetland, landscaping, or is not visible at all. You may not have even noticed the green infrastructure already hard at work in Tewksbury managing stormwater.

Acknowledging a comprehensive look at the opportunities for managing flooding now and in the future is necessary, the Town of Tewksbury leveraged the MVP Action Grant to develop this Stormwater Analysis for Nature-Based Solutions and Community Co-Benefits. Key items included:

- **Chapter 2:** Identification and analysis of Town-owned parcels, with an emphasis on vacant parcels, that could be used for nature-based solutions and flood storage, while considering opportunities for affordable housing.
- **Chapter 3:** Refinement of flood mitigation solutions including green infrastructure conceptual designs and costs.
- **Chapter 4:** Hydraulic and hydrologic modeling of one of the major watersheds covering Tewksbury.
- **Chapter 5:** Ongoing outreach and engagement led by the Town and the Merrimack River Watershed Council.
- **Chapter 6:** Summary and conclusions, as well as recommendations for next steps.

What is Flooding?

Flooding is defined as "the covering or submerging of normally dry land with a large amount of water". Often this is from excess water that collects in low lying areas during and after rainstorms.

We all have our own idea of what we consider flooding. A wetland with standing water is natural, but standing water in your backyard or basement might be flooding. A puddle in the road might be annoying when you're in a car, but when it means you cannot walk to your work or home, it could be flooding.

The key is - when excess stormwater becomes problematic for our way of life, we typically call it flooding. These are the areas where flooding has the biggest impact on our lives. When excess water is in an area that is not used by humans, we typically do not mind - or even notice - that it is there. In natural areas, flooding is often beneficial since it creates important habitat for various species of animals, plants, and amphibians.

Flooding may be impassible for cars….

Figure 1-3: Severe flooding in Tewksbury in 2010. Heath Brook at Shawsheen and Main Streets is shown at right.

Or create a problem for abutters and those traveling by bike or foot

Figure 1-4: Stormwater flooding in Tewksbury. Left: across from 44 Marston Street. Right: Alabama Road near Brown Street.

Flooding in Tewksbury

Tewksbury is a historically wet area with many water features, including the Concord, Merrimack and Shawsheen Rivers, plus extensive brooks, swamps, ponds, and wetlands.

Flooding that was Natural in the Past...

Tewksbury was first settled in 1637 and that settlement gradually expanded during the early decades of the eighteenth century. The early economic base depended on farming and grazing, with lumbering as a secondary activity. Tewksbury was once well known for its rural character. In the early twentieth century, Tewksbury became a haven for Boston residents and served as a summertime vacation area.

Historically, without development, rain and snowmelt could infiltrate into the soil and forested lands, and rivers could overflow into their floodplains. The excess water from these rain events, now termed "stormwater", was beneficial for river and wetland ecosystems and wildlife.

…May be Problematic Flooding Today

As described in the 2016 Master Plan, "Tewksbury was transformed by two decades of very high growth following World War II. Subdivisions consumed significant portions of the town's agricultural land. The construction of Interstate 495 and Interstate 93 had a significant impact on the rate of development within Tewksbury. By the 1960s, large outlying tracts of land were developed as residential subdivisions, and the Town adopted a zoning bylaw that was favorable to economic development in order to capitalize on its location on the interstate highway system. This trend continued until the mid1970s when the demand for land for development began to stabilize. Commercial and industrial land uses have nearly tripled since 1970, with new businesses locating in the north and western sections of the town."

This increased development has led to high levels of impervious cover. Impervious cover consists of roads, parking lots, driveways, sidewalks, roofs, and even compacted gravel areas, all of which transport precipitation and snowmelt from areas of human activity to local wetlands and waterbodies faster than natural cover and typically without any treatment.

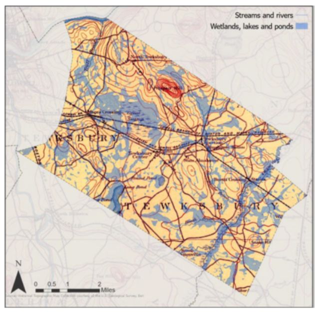
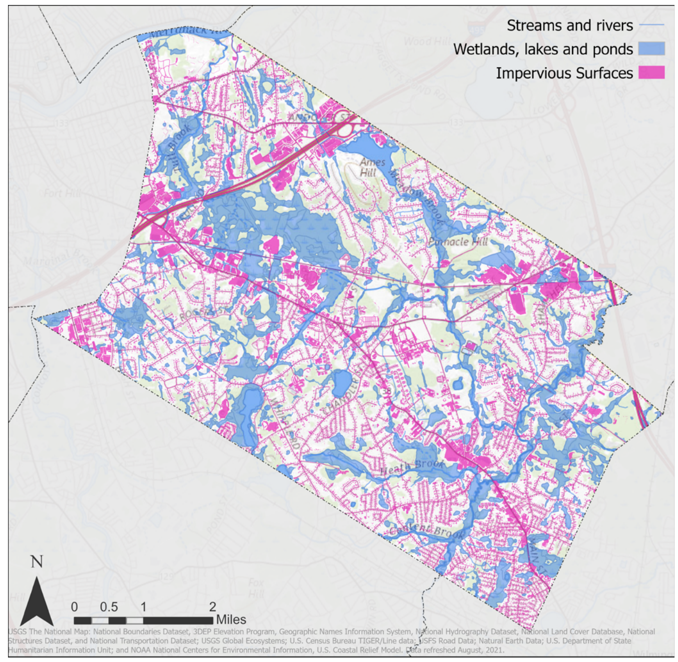


Figure 1-5: Tewksbury water bodies during 1893 (top) and 2022 (right). Prepared by MRWC.



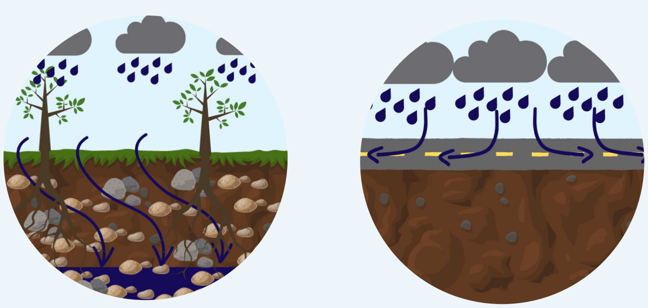


Figure 1-6: Example drawing of pervious area and infiltration (left), impervious area and stormwater runoff (right).

Figure 1-7: Example drawing of floodplain boundary before and after development.

A timeline of recent flooding since the year 2000:

- Middlesex County had **129 flood** events and **30 flash flood events** between 2000 and 2019 and the property damage totaled **$53.439 million dollars**.
- **Eight disaster declarations** were made in Middlesex County due to flooding between 2000 and 2015.
- **May 2006**: Heavy rainfall over a 100-hour period caused widespread flooding across Middlesex County, exceeding flooding caused by the 1938 Hurricane and prompting the Governor to declare a State of Emergency.
- **March 2010**: Six to ten inches of rain resulted in major flooding across eastern Massachusetts. Many streets were closed, and basements flooded in Tewksbury and surrounding towns due to flooding. The Governor of Massachusetts declared a state of emergency and this was followed by a federal disaster declaration for seven Massachusetts counties. The South Street and Bridge Street intersection was flooded and impassable. South Street is a dead-end road that extends approximately 1.1 miles from Bridge Street. There are over 200 homes in that neighborhood. Residents and emergency vehicles were forced to utilize an old steel trestle bridge that connects Regina S Drive and Shawsheen Street. Additionally, Heath Brook flooded Shawsheen Street near the intersection of Main Street (Route 38). This road then needed to be closed to all traffic. Emergency vehicles and residents had to navigate an approximately 3.5-mile detour around the flooded roadway.

Now, we find:

- The flood exposure analysis conducted during the MVP Planning process identified **13 critical facilities** that are located within the 100-year flood zone and **8 critical facilities** in the 500-year flood zone.
- A GIS analysis during the MVP Planning process found that **59 census blocks containing vulnerable populations** are located within the 100-year flood zone.
- There are **8 repetitive flood loss buildings** in Tewksbury, all residential buildings.
- Stakeholders in the MVP Planning process identified **more than 20 local areas of flooding**, which could increase emergency response times as the Town does not have high water vehicles.
- The flood exposure analysis conducted during the MVP Planning process found that **23% of the developed parcels** in Tewksbury are located within the 100-year flood zone, and 20% are located within the 500-year flood zone.
- Additionally, **2 recently developed parcels** are located in the 100-year flood zone and **4 recently developed parcels** are within the 500-year flood zone.

Current Flooding Reported

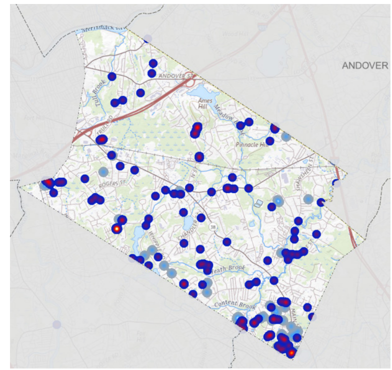


Figure 1-8: Residential Flood Survey Results (2022).

During this project, municipal staff provided input on areas with historical flooding which helped guide this project. In addition, the general public were given opportunities to provide input on known areas of flooding in Tewksbury. As part of this effort to identify where flooding occurs across the town, the Tewksbury Flooding and Green Infrastructure Survey was developed so residents and those who commute to or through Tewksbury could provide the project team with information on where flooding occurs, as well as specifics on the intensity, frequency, and duration of flooding, as well as how they are impacted by these flooding events. This data was utilized as part of the hydrologic/hydraulic modeling effort to identify additional flooding areas of concern as part of future climate conditions and provide additional data points for model calibration. The purpose of the model is to assess flooding issues now and under future climate conditions, and to identify potential mitigating measures. The flooding results were also made available to the town so that the Town can continue to use the data collected to further evaluate flooding issues and identify future opportunities for flood mitigation. The results of this survey are incorporated into Figure 1-8 and include mapping of noted flooding in specific neighborhoods with frequency, intensity, and/or history of repeated flooding conditions.

The survey also served as a public engagement tool, sharing information and gathering opinions on green infrastructure and affordable housing. This information, the flooding data, and demographic data collected during the survey will continue to inform short-term and long-term town planning for climate resilience.

Climate Change and Flooding

The flooding that Tewksbury typically experiences is projected to increase in both severity and frequency due to climate change. Climate change refers to changes in regional weather patterns that are linked to warming of the Earth's atmosphere as a result of both human activity and natural fluctuations. The Earth's atmosphere has naturally occurring greenhouse gases (GHGs) like carbon dioxide (CO2) that capture heat and contribute to the regulation of the Earth's climate. When fossil fuels (including oil, coal, and gas) are burned, GHGs are released into the atmosphere and the Earth's temperature tends to increase. The global temperature increase affects the jet stream and climate patterns.

Figure 1-9: Heat trapping blanket

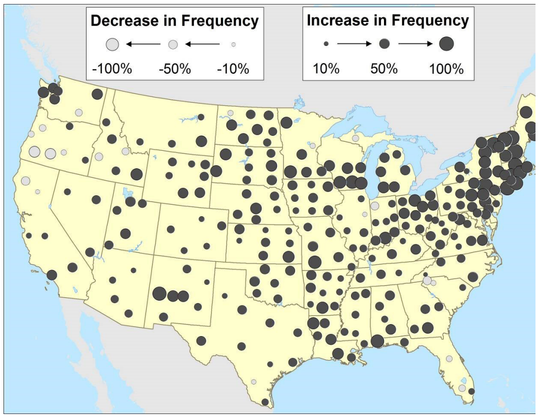


Figure 1-11:
Changes in Frequency of Extreme Downpours

Due to these changes, future climate conditions in Massachusetts are expected to resemble historic climate patterns of Southern New England or Mid-Atlantic States more closely, depending upon GHG emission scenarios. Climate change has already started to impact Massachusetts and these trends are likely to continue. Climate change is anticipated to affect the typical precipitation cycle in Massachusetts, leading to more intense storms events and more episodic or flash droughts. Temperatures will increase in both summer and winter.

Riverine Flooding: Extreme rain and snow events are becoming increasingly common and severe, particularly in the Northeast region of the country, due to climate change (Figure 1-11). Severe rain or snow events that historically happened once a year in the middle of the 20th century now occur approximately every nine months. With this projected increase in precipitation, waterbodies in and around the town will be increasingly likely to overtop their banks and cause localized flooding.

Stormwater Flooding: Most drainage infrastructure in Massachusetts is aging and was designed with rainfall estimates that are no longer accurate. Figure 1-12 shows how anticipated rainfall during design storms has increased from 1961 to 2015, especially for the larger 24-hour, 100-year event. With climate change, the intensity and duration of rainfall is projected to increase, which will further stress the current system. This combination of issues will likely result in an increase of stormwater flooding events within town.

Drought: Under climate change, drought conditions will be exacerbated with projected increasing air temperatures and changes in precipitation. Between 1970 and 2000, the median number of consecutive dry fall days in Massachusetts was 11.4 days. This is in comparison to a projected median of 13.5 consecutive days by the end of the century (EEA, 2018a). The same report also mentions that the occurrence of droughts lasting 1 to 3 months could go up by as much as 75% over existing conditions by the end of the century, under the high emissions scenario in the Northeastern States.

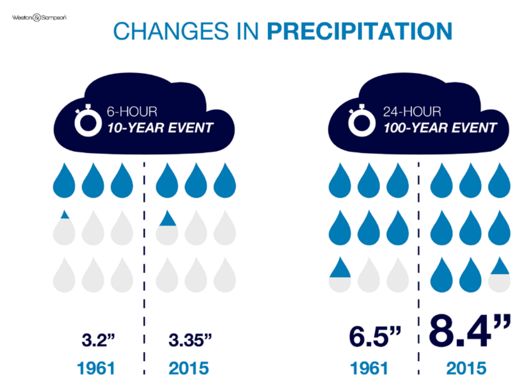


Figure 1-12:
Stormwater Design Standards (NOAA TP 40, 1961 and NOAA, 2015)

Project Goals

The goals of this Stormwater Analysis for Nature-Based Solutions and Community Co-Benefits are as follows:

- Evaluate municipally-owned parcels, with an emphasis on vacant parcels, for incorporation of nature-based solutions/ green infrastructure for opportunities to retain and infiltrate stormwater on-site to reduce the frequency and intensity of flooding within the Merrimack, Concord, and Shawsheen River Watersheds.
- Prioritize the identification of nature-based solutions that provide co-benefits for climate vulnerable populations.
- Develop creative, inclusive, and accessible public engagement for all residents, especially climate vulnerable populations.
- Identify Town-owned land that could become resilient and affordable housing. This will help avoid affordable housing being sited in flood prone areas in the future.
- Provide regional watershed benefits, including for residents outside of Tewksbury. This was accomplished through partnership with the Merrimack River Watershed Council as community liaison, providing data to share with regional partners including the hydraulic and hydrologic modeling, documenting ideas about updated local bylaws and regulations, and clarifying lessons learned to inform other communities. Once implemented, the projects contained herein will also provide environmental and community co-benefits, including improved water quality in the watershed.

A note on affordable housing:

Both the 2017-2022 Housing Production Plan and 2016 Tewksbury Master Plan include a goal to increase public awareness of and support for affordable housing through increased outreach and public education. The 2017-2022 Housing Production Plan implementation strategies section identifies specific sites for the development of affordable housing and assesses municipally-owned land that the community targeted for mixed income housing.

The goals of this MVP Action Grant support these plans by further vetting Town-owned land that may be flooded, or critical access routes that may become flooded, in the short- or long-term, due to climate change.

Public Engagement

Throughout this project, the Merrimack River Watershed Council (MRWC), with support from Town staff, provided public education, outreach, and engagement related to climate change, Tewksbury-specific flooding conditions, municipal adaptation and mitigation strategies such as green stormwater infrastructure and policy changes, and what residents can do at their own house to become more resilient to flooding, drought, and heat. This included:

- Releasing a Public Survey
- Preparing an Online StoryMap
- Preparing and Conducting a Live Presentation
- Tabling at the Farmer's Market
- Preparing Posters and other Public Engagement Materials for Long-term Use

Figure 1-13:
Public engagement flyer

Steering Committee

The Town of Tewksbury ensured continuity from the MVP Planning process by convening a similar Core Team of representatives from various town departments to guide project development and provide feedback throughout the process. The Steering Committee consisted of the following individuals and/or representatives from the following Departments or Committees:

- Assistant Town Manager
- Town Engineer
- Community/Economic Development Planner
- Conservation Commission Agent
- Open Space & Recreation Plan Committee
- Building Department
- Housing Authority
- Representatives from MRWC
- Representatives from the Town's engineering consulting firm, Weston & Sampson
- MVP Regional Coordinator

The Steering Committee met twelve times throughout the project between September and June 2022. For more information on the Steering Committee meetings, see the Core Team/Steering Committee Meeting Documentation companion document.

2 Identification and Evaluation of Municipally-Owned Property for Implementation of Nature-Based Solutions and Green Infrastructure

Once the frequency and severity of flooding is defined, targeted solutions can be developed. Traditionally, what is known as "grey infrastructure" has been used to convey stormwater from a developed area to a local waterbody or wetland. Grey infrastructure consists of inlets, gutters, culverts, and underground pipes. Many of the older systems have been designed with historic rainfall data that is no longer accurate when considering predictions of increased and more intense precipitation events. In addition, this infrastructure does not typically provide significant treatment and is more focused on capturing and conveying stormwater. Nature-based solutions, including Green Infrastructure, offer solutions that, when coupled with grey infrastructure, help slow down runoff, spread it out, and capture it where it falls and offer numerous other benefits (a.k.a. co-benefits) to a community's economy, society, and the environment.

What are Nature-Based Solutions, including Green Infrastructure?

EEA describes Nature-Based Solutions (NBS) as adaptation measures focused on the protection, restoration, and/or management of ecological systems to safeguard public health, provide clean air and water, increase natural hazard resilience, and sequester carbon. Incorporating NBS in local planning and design projects produces long-term solutions that benefit human and natural systems. NBS can be preservation of existing natural resources (e.g., protection of open space), restoration of a natural resource (e.g., stream channel stabilization, creation of floodplain, reforestation), or construction of Green Infrastructure. Green Infrastructure (GI) is considered a climate resilience best management practice that uses surface features including native vegetation, soils and other natural processes to reduce flooding and improve water quality. These systems collect and store runoff, aiding in infiltration and treatment of stormwater, and decrease burden to the grey infrastructure system.

Not only do NBS contribute to flood mitigation, they also provide economic, social/cultural, and environmental co-benefits:

Economic co-benefits can include increased tourism, increased property values, energy savings, generation of income, and sometimes even food and water provisions.

Social/cultural co-benefits can include recreation, education, creation of gathering space, opportunities to add spiritual or religious or artistic value, and overall improvement to quality of life.

Environmental co-benefits typically include temperature mitigation, regulation of the water cycle and groundwater recharge, noise mitigation, and creation of biodiversity and sources of pollination.

Types of Green Infrastructure Opportunities

There are numerous types of nature-based solutions, each with their own subset of functions and forms. Given the context of Tewksbury, the functions best suited for the watersheds of interest include stormwater conveyance, treatment, temporary storage, and infiltration. The list below represents types of opportunities that can be implemented given site conditions including rights-of ways, property ownership, protected ecosystems, floodplains, and ability to intercept meaningful runoff volumes.

Stormwater Infrastructure Toolbox

Large Footprint Nature-Based Stormwater Management Solutions

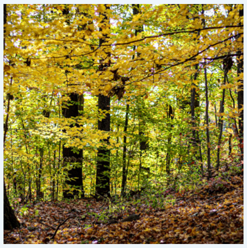


Figure 2-1: Photo example of a reforested area.

Reforestation: Reforestation or concentrated tree planting increases tree canopy, helps reduce urban heat, improves air quality, and mitigates air pollution through carbon uptake and sequestration. Reforestation can occur in empty lots, within existing parks, or interstitial spaces between roads or properties.

Figure 2-2: North Street Athletic Fields parking area.

Turf Management: Unpaved areas that are repeatedly compacted, such as dirt parking areas, can turn previously pervious soil into an impervious surface by removing the infiltration capacity of the soil. An overall increase in impervious surface within a watershed will ultimately lead to increased flooding within the watershed without proper stormwater management. A turf management plan can be utilized to promote maintenance of unpaved areas to help restore and maintain the infiltration capacity of the soil and avoid conversion to an impervious surface that would increase stormwater runoff.

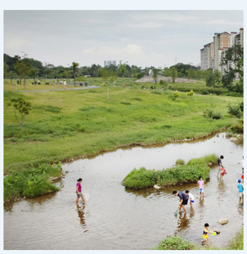


Figure 2-3: Photo example of a floodable park.

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

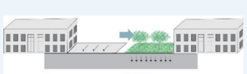


Figure 2-4: Drawing of conversion from impervious to pervious area.

Depaving (to vegetation): Open areas that do not need to remain paved (e.g., adjacent to buildings, parking medians, back of sidewalk, large areas of unused parking lot, removed buildings, etc.)

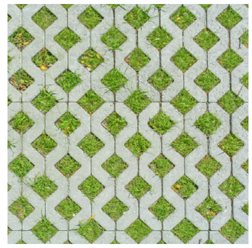


Figure 2-5: Example photo of permeable pavement.

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

Small Footprint Nature-Based Stormwater Management Solutions

Figure 2-6: Example photo of a swale.

Swales / bioswales: The primary function of swales is to intercept stormwater runoff before it enters the existing drainage system and convey runoff to other GI features. In many instances, swales can temporarily store runoff and even allow some degree of infiltration. Swales are very useful because they can fit within narrow stretches along roadways and reconnect separated surface flows.

Figure 2-7: Example photo of a bioretention area.

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

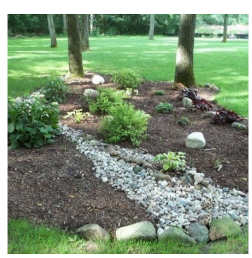


Figure 2-8: Example photo of a rain garden.

Strategic Planting (i.e., "Rain Garden"): Building or area where planted raised berms, depressed beds, or gravel pathways can be used to guide the flow of water on the site.

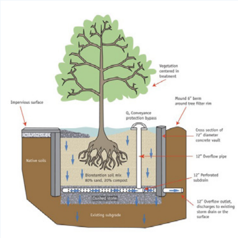
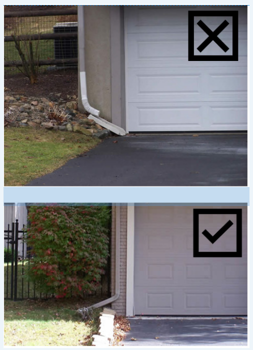


Figure 2-9: Example diagram of a tree box filter.

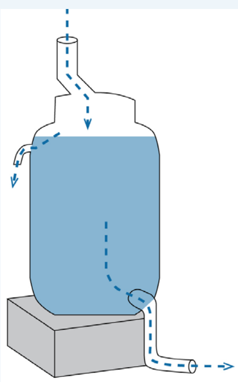
Tree box filter: A tree box filter consists of an open bottom concrete barrel filled with a porous soil media, an underdrain in crushed gravel, and a tree. Stormwater is directed from surrounding impervious surfaces through the top of the soil media. Stormwater percolates through the media to the underlying ground. Treated stormwater beyond the design capacity is directed to the underdrain where it may be directed to a storm drain, other device, or surface water discharge.

Nature-Based Stormwater Management Solutions for the Home or Small Business



Disconnecting Downspouts: A building with downspouts that can be disconnected to either a pervious surface with a splash guard or a downspout planter.

Figure 2-10: Top is an example photo of an incorrectly oriented downspout, underneath is an example photo of a correctly oriented downspout.



Rainwater harvesting: This simple practice reroutes rooftop drainage pipes from draining rainwater into the storm drain to instead draining it into rain barrels and cisterns. You can use it to store stormwater and/or provide targeted release of stormwater to infiltrate into the soil.

Figure 2-12: Example photo of a rain barrel.

In addition, while not explicitly considered a nature-based solution, underground stormwater storage is an important alternative to consider. Underground storage is designed to store large volumes of stormwater underground. Storage chambers can be used for reuse, retention, detention, or controlling the flow of on-site stormwater runoff. They can be implemented with various depths and forms (i.e., chambers, vaults). They can be coupled with a surface GI practice such that they capture overflow in excess of the designed volumes and flows for that specific practice.

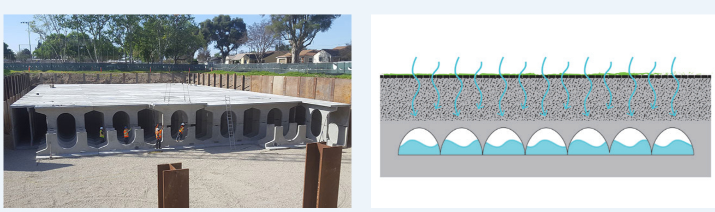


Figure 2-13: Example photos of underground storage systems.

Municipal Parcel Green Infrastructure Prioritization

There are approximately 436 municipally-owned parcels in Tewksbury. To help prioritize parcels that would be more advantageous for green infrastructure based on availability of space for either retrofit or for redirection of stormwater flows for infiltration, sites greater than one acre were analyzed using the ranking matrices. A total of 162 sites greater than one acre were analyzed and prioritized.

To help identify and prioritize these parcels for suitability for green infrastructure and nature-based solutions, a geographic information system (GIS) based desk-top exercise was performed to screen Town parcels. The analysis included consideration of a variety of factors that were divided into two main categories:

1. Site suitability for implementation of green infrastructure and infiltration-based stormwater Best Management Practices (BMP). A matrix was created that included analysis of various site suitability factors and a priority score was assigned to each parcel.
2. Impact on climate vulnerable populations and critical facilities. These factors were analyzed and prioritized in a separate matrix where a priority score was also calculated for each parcel.

In examining parcels based on these two factors, site suitability and climate vulnerability, parcels were prioritized, and the top ten sites were chosen for further evaluation for suitability for incorporation of green infrastructure.

For more information on the Prioritization Ranking Matrices, please see the Municipal Parcel Prioritization Matrices companion document.

Green Infrastructure Site Suitability Matrix

Factors that were analyzed and ranked for each parcel to determine overall site feasibility for green infrastructure are outlined in the table below.

Site Suitability Factor	Description	Prioritization Scale
Impervious/ Pervious Area	Large amounts of impervious area generate significant stormwater runoff which can be treated with green infrastructure. A large amount of pervious area provides opportunities for installation of more expansive nature-based solutions that can manage flow from adjacent drainage or impervious surfaces.	Pervious Area Available – >1.5 Acres (8 Pts), 1 to 1.5 Acres (6 Pts)
Vacant Parcels	Provides ample space for nature-based solutions.	Yes (10 Pts), No Buildings <5% IA (5 Pts)
Conservation Land	Most impacts to conservation land would be prohibited. Non-conservation land was prioritized.	Non-Conservation Land (25 Pts)
Size of Parcel	Larger parcels provide more opportunity for potential retrofits.	>25 Acres (8 Pts), 5 to 25 Acres (6 Pts), 2.5 to 5 Acres (4 Pts)
Flooding Locations	Parcels which could provide relief for historical flooding prone areas identified by the Town and through community survey were prioritized. Areas within the FEMA flood hazard area were also prioritized.	Within 500 Ft (15 Pts)
Sensitive Ecological Receptors and Wetlands Resource Areas	Parcels in proximity to water bodies, providing an opportunity for water quality benefits, were prioritized.	Within 300 Ft (5 Pts)
Source Water Protection Areas	Parcels within watersheds, which are tributary to drinking water resources, were prioritized.	Within 300 Ft (5 Pts)
Drainage Infrastructure	Parcels located in close proximity to drainage infrastructure, where stormwater could easily be conveyed and rerouted to these parcels and infiltrated.	Infrastructure within 300 Ft (15 Pts)
Hydrologic Soil Group (HSG)	Group HSG A and B soils have the best infiltration properties and are most suitable for GI/BMP retrofit.	A or B (10 Pts) A/D, B/D, C (5 Pts)
Unsaturated Thickness	High water tables limit infiltration of stormwater. Parcels with large unsaturated thicknesses were prioritized.	>10 Ft (5 Points)

Figure 2-14: Priority breakdown of green infrastructure suitability factors.

Environmental Justice and Public/Regional Benefit Prioritization & Ranking Matrix

Factors that were analyzed and ranked for each parcel to evaluate the impact on climate vulnerable populations are outlined in the table below.

EEA Environmental Justice Populations	Although there are no environmental justice blocks within Tewksbury, there are some located on the border of Tewksbury in Lowell. A neighborhood is defined as an environmental justice population if one or more of the following four criteria are true: • The annual median household income is not more than 65 percent of the statewide annual median household income; • Minorities comprise more than 40 percent or more of the population; • 25 percent or more of households lack English language proficiency; and/or Minorities comprise 25 percent or more of the population and the annual median household income of the municipality in which the neighborhood is located does not exceed 150 percent of the statewide annual median household income.
Seniors	Populations over the age of 65 based on the 2010 Census data.
Children	Populations under the age of 18 based on the 2010 Census data.
Low Income	Parcels in close proximity to affordable housing opportunities were prioritized.
Seniors/ Disabled Residents	Parcels in close proximity to nursing homes/ long-term care facilities were prioritized.
Future Potential Affordable Housing Opportunities	• Any parcel that has greater than 1 acre of land available and is outside of the FEMA flood hazard area was prioritized as these areas are good candidates for future housing projects. • Parcels in close proximity to historic properties were prioritized as interest has been shown in converting some historic properties into affordable housing options. • Parcels in close proximity to potential affordable housing opportunities identified in the 2017-2022 Housing Production Plan.
Critical Assets	• Parcels in close proximity to an evacuation/emergency route were prioritized. • Parcels in close proximity to hospitals/clinics/urgent care facilities were prioritized.

For mapping related to green infrastructure feasibility, please see the Overlay Maps companion document.

Climate Vulnerable Populations

- EEA Environmental Justice Populations
- Seniors
- Children
- Low Income
- Seniors/Disabled Residents
- Future Potential Affordable Housing
- Critical Assets

Figure 2-15: Priority Breakdown of Climate Vulnerable Populations.

Integrating Assessment into Affordable Housing Planning

During the municipal parcel prioritization, existing and potential future affordable housing was considered. The following parcels were prioritized:

- Existing affordable housing properties;
- Parcels greater than one acre and outside of the FEMA flood hazard areas, which could become sites for future affordable housing;
- Parcels outside of the floodplain that have already been identified by the Town as potential sites for future affordable housing from the 2017-2022 Housing Production Plan; and
- Historic properties, which could be turned into future affordable housing, per the Town's Master Plan.

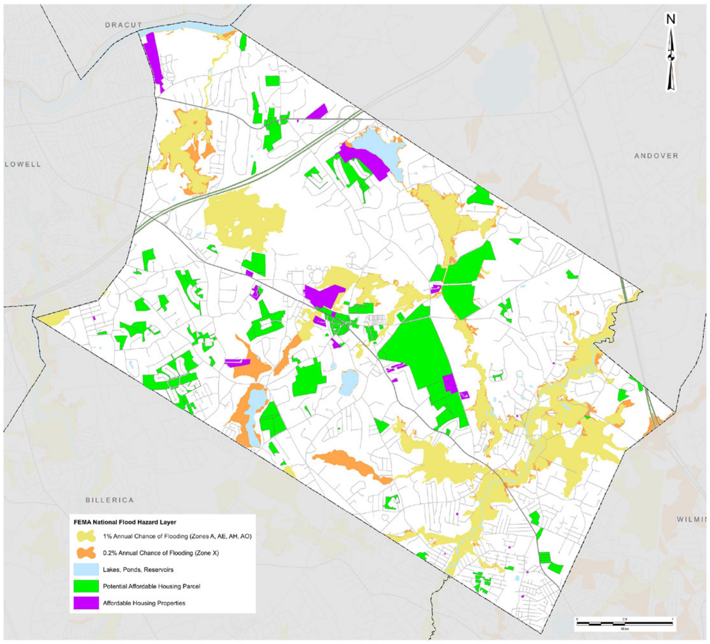


Figure 2-16: Potential Affordable Housing Parcels.

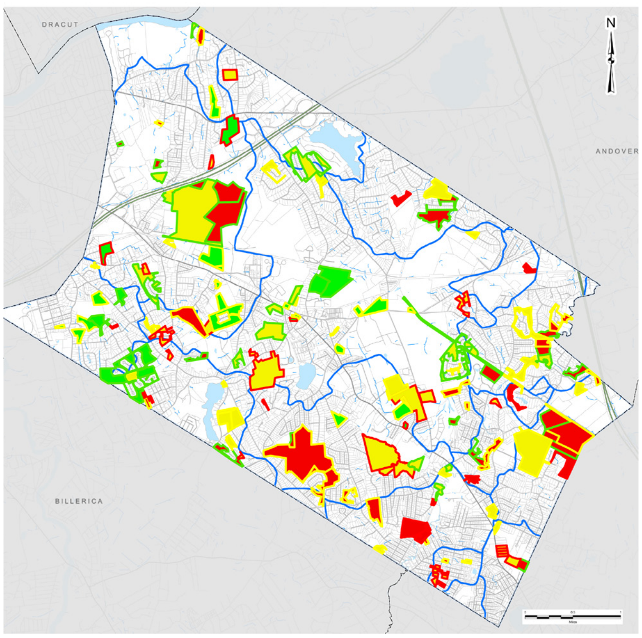


Figure 2-17: Parcel Suitability and Prioritization for Green Infrastructure.

Conclusions

Each site received one score related to suitability for green infrastructure and one score related to impacts on climate vulnerable populations. Using these two prioritization scores, sites that were high priority in both categories, or high priority for one category, and medium priority for another category, were further analyzed. There were 38 sites that were isolated for further evaluation based on this analysis. From this list of 38 sites, 10 sites were recognized as highest priority and a more comprehensive green infrastructure evaluation was conducted that included site visits. Individual parcel feasibility considered current parcel use, town priorities, location of existing BMPs, and other background information to determine which sites were most favorable for incorporation of green infrastructure and which sites offered maximum benefits to climate vulnerable populations. See Figure 2-17 for an overview map of the municipal parcel prioritization.

3 Green Infrastructure Assessments, Conceptual Design and Costs

The information obtained as part of the municipal parcel prioritization, from site investigations, and based upon discussions with the Steering Committee, was used to prioritize potential retrofit opportunities on the ten (10) priority parcels. Proposed retrofits evaluated included decreasing directly connected impervious area (DCIA) by removing impervious area or installing green infrastructure. The retrofit opportunities presented had favorable site suitability, including soil conditions; limited space constraints, including space availability within the public right-of-way and on municipal parcels; close proximity of municipally owned parcels located within each subwatershed to areas with flooding concerns; and considered any planned capital improvements.

The Project Team also assessed opportunities to implement green infrastructure (GI) to specifically address flooding concerns. The MS4 permit supports and encourages GI/Low Impact Development (LID) stormwater controls, and the Town identified GI solutions that will also help the Town to comply with MS4 Permit requirements. The Town explored opportunities to capture runoff from large impervious areas in flooding areas and convert as much of that volume into infiltration loss or detention storage for slow release. By increasing infiltration through green infrastructure designs, up to the 95th percentile (2 inches of runoff) of all rainfall events that occur in a year can be captured and stored. On an annual basis, this can be a significant volume capture and removal of pollutant loads that can alleviate water quality impairments. Various GI/LID controls were evaluated at priority areas including porous pavement, bioretention, water quality swales, underground infiltration, and protection and enhancement of natural areas.

Green Infrastructure Assessment

Green infrastructure can help manage stormwater in Tewksbury. Introducing nature-based solutions and removing impervious area upstream reduces stormwater discharges and improves water quality, and decreases loads on the grey infrastructure system. Identifying opportunities for creating new green infrastructure projects is a key component of the Town's Capital Improvement Plan. Not only does green infrastructure contribute to flood mitigation, it also provides public health and quality of life benefits by cooling surface temperatures, providing shade, and beautifying the public realm.

Green infrastructure opportunities were identified through a desktop analysis which analyzed municipally-owned parcels that are one or more acres in land area and prioritized based on suitability for green infrastructure based on various characteristics. Parcels were also prioritized based on their potential to benefit climate vulnerable populations including seniors, children, residents with limited English proficiency, residents burdened by housing costs, residents in poverty, disabled residents, and residents with health concerns.

Approximately 38 parcels were identified as medium or high priority for both green infrastructure suitability and potential benefit to climate vulnerable populations. Through further site-specific analysis and discussion with the project Steering Committee, ten sites were selected for further evaluation of green infrastructure opportunities. Sites that were not selected at this time were removed from consideration based on one or more of the following factors:

- Listing in the Assessor's database as being municipally-owned, but are now privately-owned.
- Inaccessible land that is enclosed on all sides by non-municipal parcels.
- Existing and robust stormwater management practices already constructed on site.
- Water could not easily be conveyed to the parcel due to elevation.
- Lack of nearby impervious area and/or existing drainage infrastructure.
- Primarily comprised of wetlands or forested area.

The opportunities highlighted represent various types of projects that can function independently or work together as a surface system for stormwater management. These types of small nature-based interventions also provide co-benefits to the community like contributions to the public realm and placemaking, creating healthier spaces, and broadening of ecosystem services and biodiversity. The impacts of the identified projects were modeled as part of a larger hydraulic/hydrologic (H&H) modeling effort, and were based on increased storage capacity and reduced impervious area within sub-catchments.

Site investigations were conducted to evaluate existing drainage infrastructure and stream conditions. Information gathered during this initial investigation included stream condition assessment data, culvert locations and sizes, and field surveys to validate and supplement Town drainage data. Anecdotal information was gathered from knowledgeable residents and stakeholders about existing flooding in Tewksbury.

Conceptual Level Designs and Planning Level Costs

Conceptual level designs that incorporate GI/LID stormwater controls were developed for five priority sites. For more information on the conceptual designs, please see the Concept Level Designs Memorandum companion document.

Additionally, planning level design and construction costs were developed for the five proposed sites, based on the proposed GI/LID recommendations for each priority site. The main source of information for unit pricing for the planning level Opinion of Probable Cost (OPC) was MassDOT bid prices for the time period from June 2021 to June 2022 from Districts 4,5 and 6, which generally cover middle and eastern Massachusetts. For items not found on the MassDOT site, pricing was based on experience with other recently completed projects and/or best professional judgement. Items and associated quantities for each BMP were estimated based on conceptual level designs. A total cost for each BMP can be found in each site description page. The team also provided an outline of the necessary permitting and anticipated timelines at each location. For more information on design and construction costs, please see the Planning Level Costs Memorandum companion document.

Sites #1 & #2 – Town Hall Campus Area

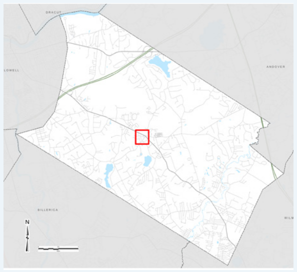


Figure 3-1: Town Hall Campus Location

The Town Hall "Campus Area", which consists of the Town Hall Annex, the Fire Department and Tewksbury Town Hall, provides Tewksbury with a highly visible opportunity to install green stormwater infrastructure and flood reduction solutions that improve public spaces, create "places", reduce long-term heat island concerns, and show the Town's commitment to solutions to localized and neighborhood flooding.

Figure 3-2: Example photo of a Bioretention Area.

Figure 3-3: Example photo of a Planter Box

Figure 3-4: Example diagram of a Tree Trench

In this area, the proposed solutions to creating a more climate ready Tewksbury include:

Town Hall Annex – **Before**

Figure 3-5

Town Hall Annex – **After**

Figure 3-6

Town Hall Annex – **Before**

Figure 3-7

Town Hall Annex – **After**

Figure 3-8

The proposed Best Management Practices at this site include:

- A bioretention area at the northwest corner on the Town Hall Annex/Fire department Building property and additional drainage infrastructure on Dewey Street to capture flow and route to a bioretention area.
- Tree trench along the northern edge of Town Hall Avenue. Overflow discharges to drainage system on Town Hall Avenue.
- Bioretention planter box in the parking lot of the Town Hall Annex building. Runoff diverted through new drain manhole and perforated pipe. Overflow discharges to drainage system on Town Hall Avenue.
- Bioretention area at the west end of the Town Hall Common. Overflow discharges to drainage system on Main Street.
- Two tree trenches in the open space at the intersection of Main Street and East Street.

Renderings

Figures 3-5 through 3-8 show renderings of the Town Hall Common and Town Hall Avenue before and after the proposed green infrastructure.

Co-Benefits

- **Temperature Mitigation**
- **Biodiversity and Habitat**
- **Improved Water Quality**
- **Placemaking for Community**

Anticipated Permitting

Due to the location and nature of the BMPs, it is not anticipated that environmental permits will be required. Local Street and Sidewalk Opening Permit is expected to be necessary.

Opinion of Probable Cost (OPC) for Design and Construction

BMP	OPC (June 2022$)
Bioretention (Town Hall Annex) & Dewey Street Drainage	$356,000
Bioretention (Common Area)	$212,000
Bioretention Planter	$158,000
Two Tree Trenches (Town Hall Ave) with Underground Storage for Infiltration	$294,000
Two Tree Trenches (Main & East St) with Underground Storage for Infiltration	$154,000

This is an engineer's Opinion of Probable Cost (OPC). Weston & Sampson has no control over the cost of availability of labor, equipment or materials, or over market conditions or a Contractor's method of pricing. The OPC is made on the basis of Weston & Sampson's professional judgement and experience. Weston & Sampson makes no guarantee that bids or negotiated cost of any work will not vary from this OPC. Costs presented are considered planning level and therefore have an estimated accuracy range of -15% to +40%. Costs are presented in June 2022 dollars.

Site #3 – Tewksbury Public Library

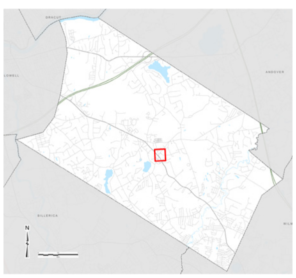


Figure 3-9: Public Library Location

The Tewksbury Public Library provides the Town with an opportunity to install a highly visible "rain garden" at the entrance to the building and educate residents about what they can achieve at their own homes to reduce flooding, recharge groundwater, and avoid polluting local wetlands and waterbodies. In addition, the existing detention basin offers an opportunity to retrofit to manage future anticipated storm events.

Figure 3-10: Example diagram of a Rain Garden.

Figure 3-11: Example photo of a Detention Basin.

In this area, the proposed solutions to creating a more climate ready Tewksbury include:

The proposed Best Management Practices include:

- Two rain gardens near the entrance of the library building.
- Expansion of the existing detention basin to increase storage volume for more intense future storm events.

Co-Benefits

- **Public Education**
- **Biodiversity and Habitat**
- **Improved Water Quality**

Anticipated Permitting

Due to the location and nature of the proposed BMPs, it is not anticipated that environmental permits will be required. Local permits are unlikely to be needed for the rain gardens. Permitting for the detention basin will be determined as part of the assessment.

Opinion of Probable Cost (OPC) for Design and Construction

BMP	OPC (June 2022$)
Rain Gardens	$41,000
Detention Basin Assessment	$10,000

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Site #4 – Lowell Street Neighborhood

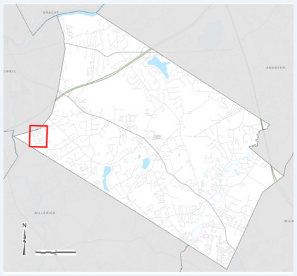


Figure 3-12: Lowell Street Neighborhood

The Lowell Street neighborhood, consisting of several residential streets, has some unique challenges to flood reduction solutions since the area is generally very flat. Green Infrastructure to reduce flooding can also improve roadway travel, beautify the neighborhood, and demonstrate the Town's commitment to solutions to localized and neighborhood flooding.

In this area, the proposed solutions to creating a more climate ready Tewksbury include:

Figure 3-13: Example photo of a Bioretention Area.

Figure 3-14: Example photo of a Planter Box

Lowell Street – **Before**

Figure 3-15

Lowell Street – **After**

Figure 3-16

The proposed Best Management Practices include:

- Bioretention areas in the corner of the roadway at four intersections: Lowell Street & Kernwood Avenue, Lowell Street & James Avenue, Lowell Street & Highland Avenue, and Lowell Street & Greenwood Avenue.
- Pervious pavement with subsurface infiltration is proposed for each of the four intersections mentioned above.
- Pervious pavement with subsurface infiltration along Greenwood Avenue from Woburn Street to Lowell Street.

Co-Benefits

- **Biodiversity and Habitat**
- **Improved Water Quality**
- **Increased Property Values**

Renderings

Figures 3-15 and 3-16 show a rendering of one intersection in the Lowell Street neighborhood before and after the proposed green infrastructure.

Anticipated Permitting

Due to the location and nature of the BMPs, it is not anticipated that environmental permits will be required. Local Street and Sidewalk Opening Permit is expected to be necessary.

Opinion of Probable Cost (OPC) for Design and Construction

BMP	OPC (June 2022$)
Bioretention Areas	$116,000
Pervious Pavement & Subsurface Infiltration	$603,000

This is an engineer's Opinion of Probable Cost (OPC). Weston & Sampson has no control over the cost of availability of labor, equipment or materials, or over market conditions or a Contractor's method of pricing. The OPC is made on the basis of Weston & Sampson's professional judgement and experience. Weston & Sampson makes no guarantee that bids or negotiated cost of any work will not vary from this OPC. Costs presented are considered planning level and therefore have an estimated accuracy range of -15% to +40%. Costs are presented in June 2022 dollars.

Site #5 – East Street Athletic Fields

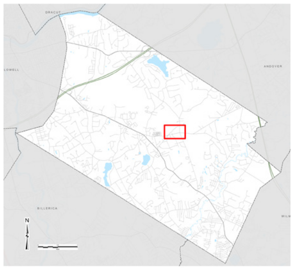


Figure 3-17: . East Street Athletic Fields Location

The East Street Athletic Fields offer ample space to install green stormwater infrastructure and flood reduction solutions that improve public spaces, create “places”, reduce long-term heat island concerns, and show the Town’s commitment to solutions to localized and neighborhood flooding.

In this area, the proposed solutions to creating a more climate ready Tewksbury include:

Figure 3-18: Example photo of a Bioretention Area.

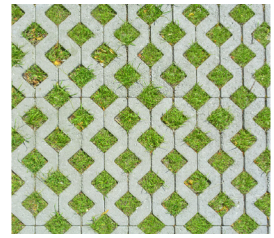


Figure 3-19: Example photo of Pervious Pavement

Lowell Street – **Before**

Figure 3-20

Lowell Street – **After**

Figure 3-21

The proposed Best Management Practices include:

- Bioretention area in the open space at the corner of the parcel at East Street and Chandler Street.
- Pervious pavement/permeable parking to replace the compacted gravel parking area adjacent to the baseball fields.

Renderings

Figures 3-20 and 3-21 show a rendering of the site before and after the proposed green infrastructure.

Anticipated Permitting

Due to the location and nature of the BMPs, it is not anticipated that environmental permits will be required. Local Street and Sidewalk Opening Permit is expected to be necessary.

Co-Benefits

- **Temperature Mitigation**
- **Biodiversity and Habitat**
- **Improved Water Quality**
- **Placemaking for Community**

Opinion of Probable Cost (OPC) for Design and Construction

BMP	OPC (June 2022$)
Bioretention Area	$400,000
Pervious Pavement	$576,000

This is an engineer’s Opinion of Probable Cost (OPC). Weston & Sampson has no control over the cost of availability of labor, equipment or materials, or over market conditions or a Contractor’s method of pricing. The OPC is made on the basis of Weston & Sampson’s professional judgement and experience. Weston & Sampson makes no guarantee that bids or negotiated cost of any work will not vary from this OPC. Costs presented are considered planning level and therefore have an estimated accuracy range of -15% to +40%. Costs are presented in June 2022 dollars.

4 Hydraulic/Hydrologic Analysis

Climate Projection Modeling

Baseline and Future Climate Rainfall

Extreme precipitation events have become more prominent in the United States since 1950[1]. Recently, extreme storm events like Ida and Harvey have wreaked havoc due to unprecedented high rainfall amounts. The Midwest and Northeast have seen the most significant increase in impactful rain events. Numerous studies have shown that extreme precipitation events will likely worsen as the climate trends warmer[2,3,4]. Warm air can hold more moisture and thus lead to heavier precipitation events. Extreme precipitation leads to heavy flooding especially in urban areas with high amounts of impervious surfaces. Existing infrastructure is not designed to drain such large volumes of water within a short period of time. Therefore, it is crucial to incorporate the potential increases in extreme precipitation as part of the project evaluation process, to mitigate the severity of these impacts.

The climate projection modeling effort helped identify the projected changes in rainfall depths, to better prepare to reduce the impact of future heavy precipitation events. This work included selecting design storms and their associated temporal distributions, to determine appropriate rainfall intensities and storm durations for stormwater retrofit evaluation. The latest available climate change future precipitation data projections for the year 2050 for the greater Boston area were evaluated as derived by the Resilient Massachusetts Action Team (RMAT). These inputs helped develop a hydrologic and hydraulic model that was used to assess green infrastructure opportunities in Tewksbury.

Key conclusions that resulted from this analysis include:

- The recommended design storm rainfall depths for the project's hydrologic/hydraulic model were the 2-, 10-, 25-, and 100-year, 24-hour recurrence intervals events and the 2-, 10-, 25-, and 100-year, 6-hour recurrence intervals events.
- The recommended temporal distribution was the NOAA 30% temporal curve, as it is a median selection for design of Green Infrastructure projects.
- The use of the 6-hour and 24-hour storm events allowed flexibility in the analysis regarding varying specific recommended improvements around infiltration and storage.

Weston & Sampson modeled design events under both baseline and future climate conditions. Baseline climate design rainfall depths over 6- and 24-hour durations 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.

For future climate conditions, Weston & Sampson utilized design storm data recently generated by Cornell University, in collaboration with the MA Executive Office of Energy and Environmental Affairs (EEOA). Based on the technical documentation provided by Cornell University, the dataset was derived from the Multivariate Adaptive Constructed Analogs (MACA) statistically downscaled product. Based on detailed statistical analyses of 11 different global climate models (GCMs), Cornell University has generated future design storm estimates for a range of durations and return periods. Design rainfall depths for both baseline and 2070 design storms are presented in the table below.

Storm Duration	Design Event	Design Rainfall Depth (in.) by Climate Scenario	
		Baseline	Estimated 2070
6-hour	2-year	2.10	2.8
	10-year	3.23	4.4
	25-year	3.93	5.3
	100-year	5.02	6.8
24-hour	2-year	3.19	4.3
	10-year	5.02	6.8
	25-year	6.16	8.4
	100-year	7.92	10.7

For more information on future climate conditions, please see the Climate Projection Modeling Technical Summary companion document.

[1] Climate Change Indicators: Heavy Precipitation (2021). https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation

[2] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

[3] Howarth, M. E., Thorncroft, C. D., & Bosart, L. F. (2019). Changes in Extreme Precipitation in the Northeast United States: 1979–2014, Journal of Hydrometeorology, 20(4), 673-689.

[4] Agel, L., Barlow, M., Polonia, J., & Coe, D. (2020). Simulation of Northeast U.S. Extreme Precipitation and Its Associated Circulation by CMIP5 Models, Journal of Climate, 33(22), 9817-9834. Retrieved Dec 7, 2021, from https://journals.ametsoc.org/view/journals/clim/33/22/jcliD190757.xml

Hydrologic & Hydraulic Analyses

Model Development

The team performed hydrologic and hydraulic analyses on a subcatchment-level to identify areas of potential flooding under both a baseline (current) climate scenario and a projected climate change scenario. The model domain of the Strong Water Brook Watershed and the Lowell Street neighborhood were selected. These two areas encompass all of the green infrastructure projects/ sites portrayed in Chapter 4. Four of these parcels are in the Strong Water Brook Watershed. A point along Strong Water Brook, downstream of all four parcels, was used as the downstream boundary condition for this area. This model domain provided an opportunity to analyze the effectiveness of the cumulative proposed green infrastructure projects throughout these four sites. One of the five parcels was located outside of the Strong Water Brook watershed and was modeled separately. The green infrastructure improvements along Lowell Street were located within a single stormwater catchment and were modeled as a single catchment area.

The stormwater model was developed with the EPA's Storm Water Management Model (SWMM) software, v. 5.1.015, which combines hydrologic rainfall-routing methods with river reach and pipe flow routing hydraulic methodologies. To represent the Town's existing stormwater infrastructure, Weston & Sampson first reviewed the Town's GIS database and any available as-builts depicting existing stormwater infrastructure, which provided the layout, material, dimensions, and invert elevations for many storm drains and culverts. Any additional information required for the model was collected through field investigations completed by Weston & Sampson throughout the spring of 2022. The two model areas, Strong Water Brook and Lowell Street watersheds, were represented by a series of 177 subcatchments. The subcatchments were delineated based on watershed hydrology, the location of waterbodies, land use patterns, project goals, and potential future modeling needs. The entire study area is approximately 5,320 acres (8.31 mi2), approximately 20% of which consists of impervious surfaces like roofs, roadways, and parking lots.

In addition to subcatchments, 1-dimensional (1D) model components also included storage nodes to reflect some wetland/open water storage; a series of junctions to represent stream banks, manholes and catch basins; and a series of conduits to represent stream channels and stormwater drains. A detailed 2-dimensional (2D) mesh was created to represent the flood storage and conveyance capacity of the floodplains associated with Strong Water Brook and its tributaries. The figure below shows the modeled storage, conduit and 2D mesh components.

The simulated flooding was compared with anecdotal areas of flooding identified during the MVP Planning phase of work, and the location of municipal parcels identified as suitable for NBS. The model was calibrated against field measurements and anecdotal information regarding historical flood events provided by Public Works staff and collected through the town-wide resident survey.

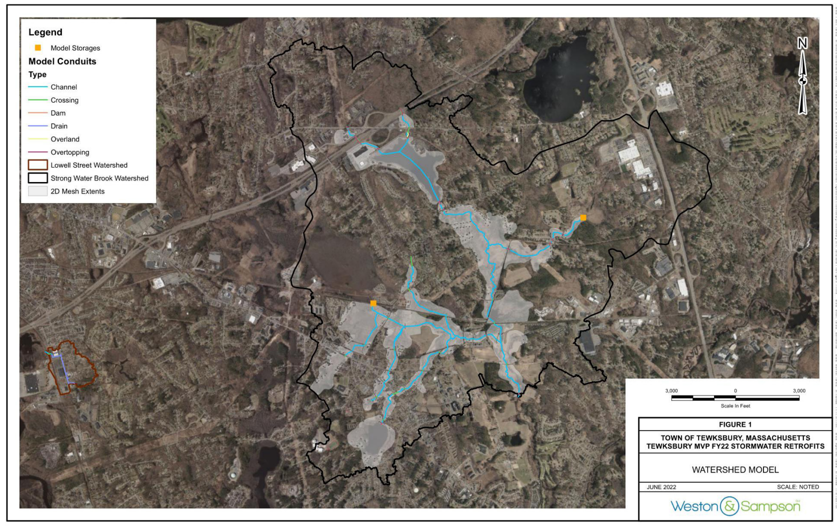


Figure 4-1: Watershed Model

Existing and Anticipated Future Flooding

As detailed in the prior sections, Weston & Sampson developed a stormwater model of the Strong Water Brook Watershed and the Lowell Street stormwater collection system watershed based on existing conditions under a wide range of design storms. The total inundated area within the Strong Water Brook Watershed is summarized for each design event and climate scenario in the table below.

Storm Duration	Design Event	Existing Inundated Area (acres)	Future Inundated Area (acres)	% Increase
6-hour	2-year	178	223	25%
	10-year	258	345	34%
	25-year	317	396	25%
	100-year	381	464	22%
24-hour	2-year	285	362	27%
	10-year	402	466	16%
	25-year	448	531	19%
	100-year	519	567	9%

In general, inundation extents and associated impacts are more severe during the 24-hour events than their 6-hour counterparts, which is typical of a watershed of this size. For small drainage areas, shorter design storms with higher peak intensities can produce more extensive flooding. However, for moderately sized watersheds like Strong Water Brook, peak flooding is more commonly controlled by the greater volume of runoff produced by the greater rainfall depth associated with longer duration storm events.

The following figures show the flooding extents during baseline and future climate scenarios for the 10- and 100-year, 24-hour events.

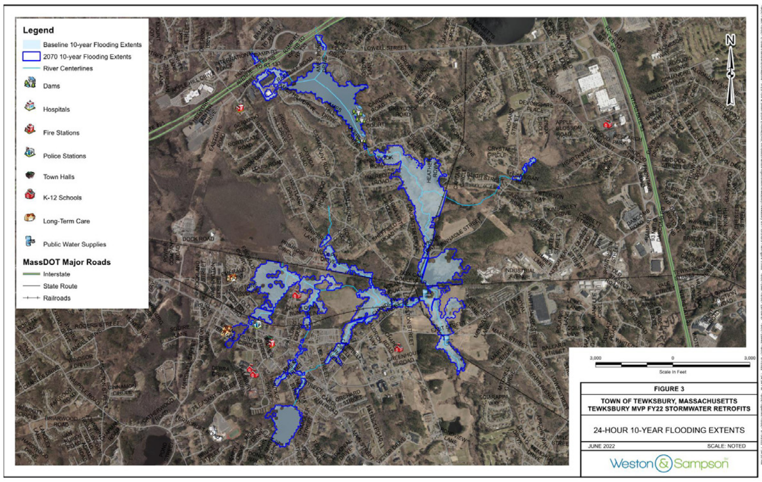


Figure 4-2: 24-hour 10-year Flooding Extents

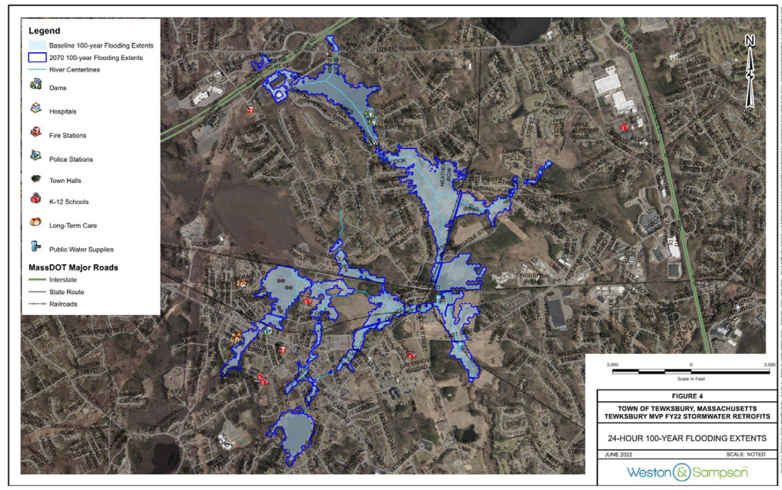


Figure 4-3: 24-hour 100-year Flooding Extents

Flooding conditions in the Strong Water Brook and Lowell Street watersheds worsen under future climate conditions, typified by a 2070 climate scenario. As expected, flooding extents and flood depths increase between baseline climate and future climate scenarios.

The Lowell Street stormwater network was modeled in 1D only. In 1D models, flooding occurs when catch basin nodes back-up and discharge water out the top of the catch basin node onto the roadway. The following table summarizes the total roadway flood volumes associated with each of the simulated storm events in the Lowell Street area.

Storm Duration	Design Event	Existing Flood Volume (MG)	Future Flood Volume (MG)	% Increase
6-hour	2-year	0.39	0.66	69%
	10-year	0.84	1.45	73%
	25-year	1.17	2.09	79%
	100-year	1.87	3.31	77%
24-hour	2-year	0.15	0.59	293%
	10-year	1.07	2.58	141%
	25-year	1.99	4.15	109%
	100-year	3.67	6.58	79%

Catch basins in the Lowell Street stormwater network experience increased flooding during future climate scenarios during every event for both the 6- and 24-hour storm durations. Flooding during the smaller storms is caused by overwhelmed catch basins along Park Street, Kernwood Avenue, James Avenue, and Lowell Street. During larger events, one additional catch basin along Lowell Street becomes overwhelmed while the volume of flooding from the other catch basins worsens.

Flood Reduction Strategies

The benefits of several GI projects and watershed-wide strategies on flooding within the Strong Water Brook Watershed and Lowell Street area were evaluated, and 20 potential GI projects throughout the Strong Water Brook Watershed and Lowell Street area were identified. For more information on these projects, refer to Chapter 3. In addition to the 20 GI projects, Weston & Sampson also identified a floodable field scenario and two watershed-wide flood mitigation strategies. For more information on the results of these simulations, refer to the Hydrologic and Hydraulic Summary Report companion document. The locations of the GI projects as well as the floodable field strategy are shown in Figure 4-4.

Figure 4-4: Stormwater BMP Locations

GI Projects

As previously mentioned, 20 GI projects were identified. Nine of these projects are in the Lowell Street area. The remaining eleven projects are located within the Strong Water Brook Watershed. The individual projects are listed below.

Project 1: This project involves replacing impervious pavement with pervious pavement and subsurface infiltration along Greenwood Avenue between Woburn Street and Lowell Street;

Project 2: This project involves creating a bioretention cell at the intersection of Greenwood Avenue and Lowell Street;

Project 3: This project involves creating a bioretention cell at the intersection of Highland Avenue and Lowell Street;

Project 4: This project involves creating a bioretention cell at the intersection of James Avenue and Lowell Street;

Project 5: This project involves creating a bioretention cell at the intersection of Kernwood Avenue and Lowell Street;

Project 6: This project involves replacing impervious pavement with pervious pavement and infiltration at the intersection of Greenwood Avenue and Lowell Street;

Project 7: This project involves replacing impervious pavement with pervious pavement and infiltration at the intersection of Highland Avenue and Lowell Street;

Project 8: This project involves replacing impervious pavement with pervious pavement and infiltration at the intersection of James Avenue and Lowell Street;

Project 9: This project involves replacing impervious pavement with pervious pavement and infiltration at the intersection of Kernwood Avenue and Lowell Street;

Project 10: This project involves creating a bioretention cell at the corner of Dewey Street and Town Hall Avenue;

Project 11: This project involves creating a tree trench along Town Hall Avenue;

Project 12: This project involves creating a tree trench in the Town Hall parking lot;

Project 13: This project involves creating a bioretention cell between Town Hall and Main Street;

Project 14: This project involves creating a tree trench in the median between Main Street, East Street, and Pleasant Street;

Project 15: This project involves creating a bioretention cell at the Tewksbury Public Library;

Project 16: This project involves creating a bioretention cell at the Tewksbury Public Library;

Project 17: This project involves expanding an existing detention basin at the Tewksbury Public Library;

Project 18: This project involves creating a bioretention cell at the corner of East Street and Chandler Street;

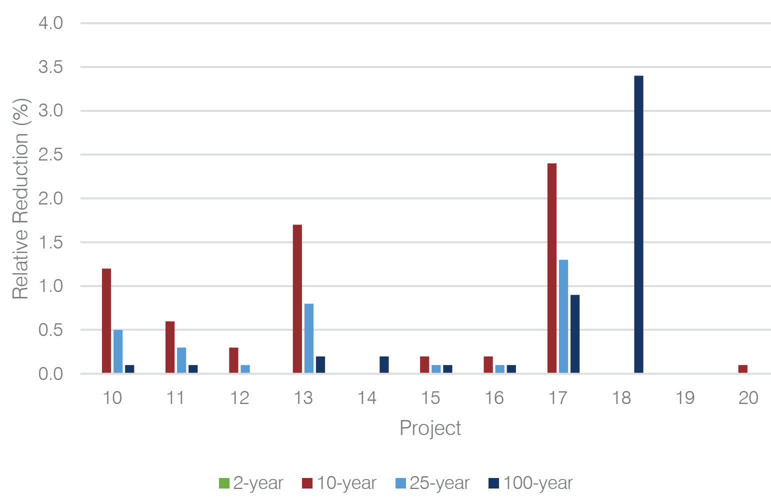
Project 19: This project involves replacing impervious pavement with pervious pavement at the Sullivan Field parking lot off of Chandler Street;

Project 20: This project involves creating a tree trench in the median between Main Street, East Street, and Pleasant Street.

GI projects have primarily localized benefits and do little to improve flooding impacts downstream. Therefore, the benefits of each of these projects were evaluated on a sub-basin scale. Occasionally multiple GI projects are located within the same sub-basin. Each project will have its own relative benefits within that sub-basin. Those relative benefits were determined based on the storage capacity of each project versus the total storage capacity of all the projects within the same sub-basin.

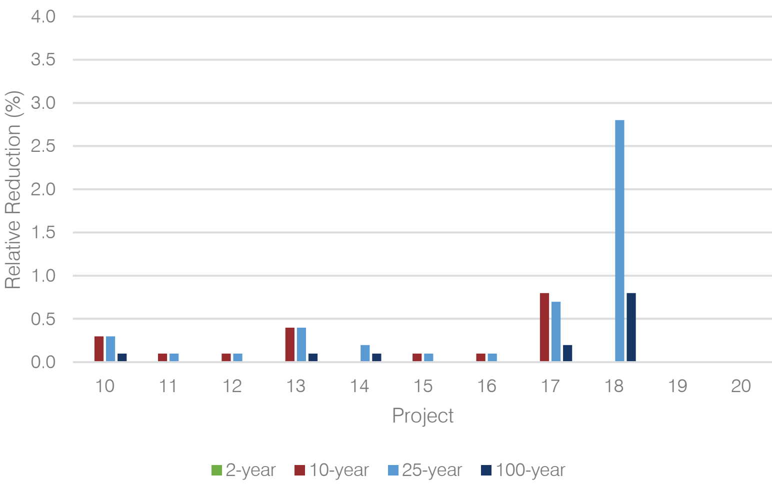
Strong Water Brook

Projects 10 through 20 listed above are located within the Strong Water Brook Watershed. Below is a figure summarizing the relative reductions in sub-basin peak runoff rate for each of the projects in the Strong Water Brook area for each of the 6-hour storm events under baseline climate conditions.



Relative reductions during future climate simulations are generally smaller than the baseline climate simulations. As noted above, many of these GI projects show no relative reduction for small storms like the 2-year event because these sub-basins have sufficient pervious surfaces to store significant runoff from those pervious surfaces. During the 10-year event, most relative reductions in peak runoff are less than 1%, but simulations indicate that Projects 10 (Dewey Street and Town Hall Avenue), 13 (Town Hall and Main Street), and 17 (Tewksbury Public Library) may produce relative reductions of between 1 and 2.5%. Most relative reductions in peak runoff during the 25-year event are less than 0.5%, but simulations indicate that Projects 13 (Town Hall and Main Street) and 17 (Tewksbury Public Library) may produce relative reductions of between 0.5 and 1.5%. Benefits are generally reduced during more extreme events like the 100-year with most projects showing benefits of less than 1%, although Project 18 (East Street and Chandler Street) reduces peak runoff by nearly 3.5%.

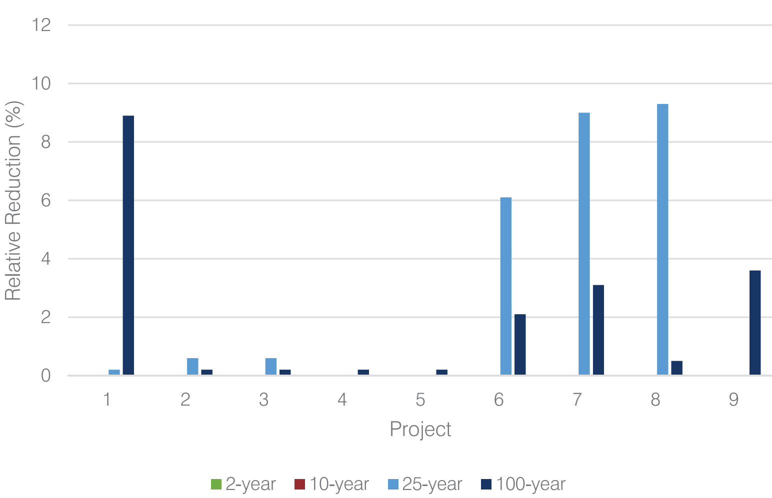
The following graph summarizes reductions in sub-basin peak runoff rate for each of the projects in the Strong Water Brook area for each of the 6-hour storm events under 2070 climate conditions.



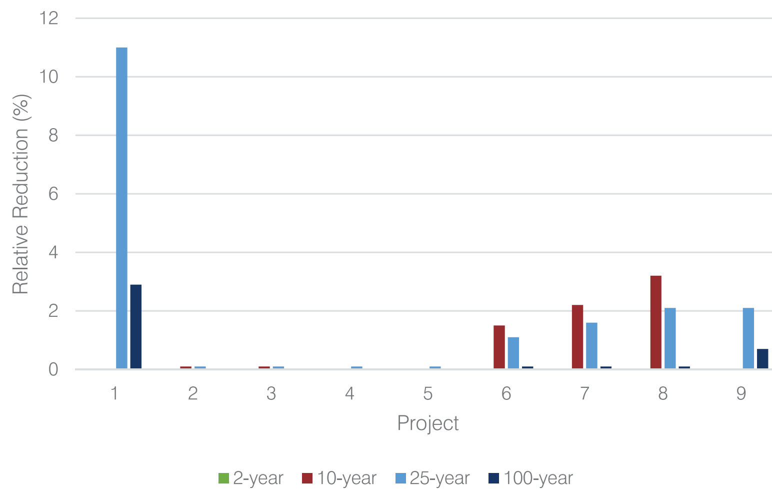
Relative reductions during future climate simulations are generally smaller than the baseline climate simulations. As noted above, many of these GI projects show no relative reduction for small storms like the 2-year event because these sub-basins have sufficient pervious surfaces to store significant runoff from those pervious surfaces. During the 10-year event, most relative reductions in peak runoff are less than 0.5%, but simulations indicate that Project 17 (Tewksbury Public Library) may produce a relative reduction of nearly 1%. Relative reductions during the 25-year event are generally less than 1% although Project 18 (East Street and Chandler Street) shows a reduction of nearly 3%. Benefits are generally reduced during more extreme events like the 100-year with benefits under 0.5% but Project 18 (East Street and Chandler Street) has a reduction of almost 1%.

Lowell Street

Nine GI projects were identified for the Lowell Street Neighborhood area. The projects consisted of bioretention areas and pervious pavement with subsurface infiltration. The following graph summarizes the maximum benefits in reducing peak runoff rate during the baseline climate 6-hour duration events.



No relative reductions are expected during the 2- or 10-year events because the additional storage created by the GI project was assumed to be located in pervious areas, which do not produce significant runoff during small storm events. However, during the 25-year and larger events, that storage is saturated, and the additional storage incorporated into the GI projects generally provide a notable benefit. During the 25-year event, most relative reductions in peak runoff are less than 1%, but simulations indicate that Projects 6 (Greenwood Avenue and Lowell Street), 7 (Highland Avenue and Lowell Street), and 8 (James Avenue and Lowell Street) may produce relative reductions of between 6 and 9%. Benefits are generally reduced during more extreme events like the 100-year with Projects 6 (Greenwood Avenue and Lowell Street), 7 (Highland Avenue and Lowell Street), and 9 (Kernwood Avenue and Lowell Street) showing benefits between 2 and 4%, although Project 1 (Greenwood Avenue between Woburn Street and Lowell Street) reduced peak runoff by nearly 9%. Simulations for the 2070 climate scenario show generally more modest benefits in reducing peak runoff rate as shown in the following graph.



Relative reductions during future climate simulations are generally smaller than the baseline climate simulations. As noted above, many of these GI projects show no relative reduction for small storms like the 2-year event because these sub-basins have sufficient pervious surfaces to store significant runoff from those pervious surfaces. Projects 6 (Greenwood Avenue and Lowell Street), 7 (Highland Avenue and Lowell Street), and 8 (James Avenue and Lowell Street) may produce relative reductions between 1 and 4% during the 10-year event. During the 25-year event, most relative reductions in peak runoff are less than 3%, but simulations indicate that Project 1 (Greenwood Avenue between Woburn Street and Lowell Street) may produce a relative reduction of 11%. Benefits are generally reduced during more extreme events like the 100-year with Projects 1 (Greenwood Avenue between Woburn Street and Lowell Street) and 9 (Kernwood Avenue and Lowell Street) showing benefits between 1 and 3%.

Watershed-Wide Strategies

Two watershed-wide, flood mitigation strategies were identified to reduce flooding impacts in the Strong Water Brook Watershed and Lowell Street area. The scenarios consist of two types of projects: increased on-site stormwater management and converting public roadways to "Green Streets." Those scenarios and their potential benefits are experienced differently in various corners of the Strong Water Brook Watershed and the Lowell Street stormwater collection system drainage area. Therefore, their benefits were evaluated on a tributary or subwatershed basis.

Green Streets Strategy

This project involves implementing Green Streets for 5% and 25% of Town-owned roads in the Strong Water Brook and Lowell Street watersheds within Tewksbury. Under the baseline climate scenario, 5% of Town roads will become Green Streets and under the future climate scenario, 25% of Town roads will become Green Streets. The streets selected were based on the size and length with the larger or more major streets being selected first. There were no roads selected within the Lowell Street area for the 5% scenario. The figure below highlights the locations of the Green Streets selected for these scenarios. The 5% Green Streets

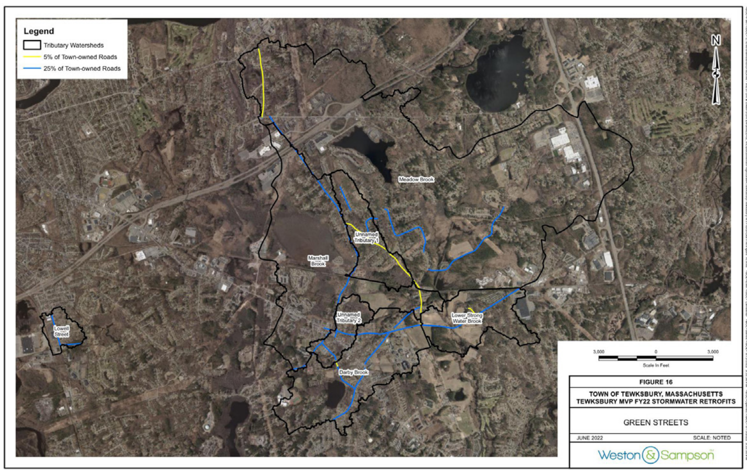
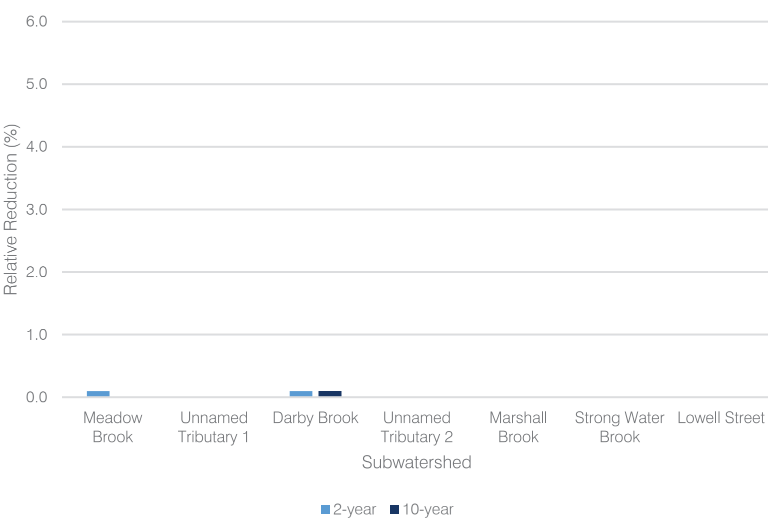


Figure 4-5: Green Street Locations

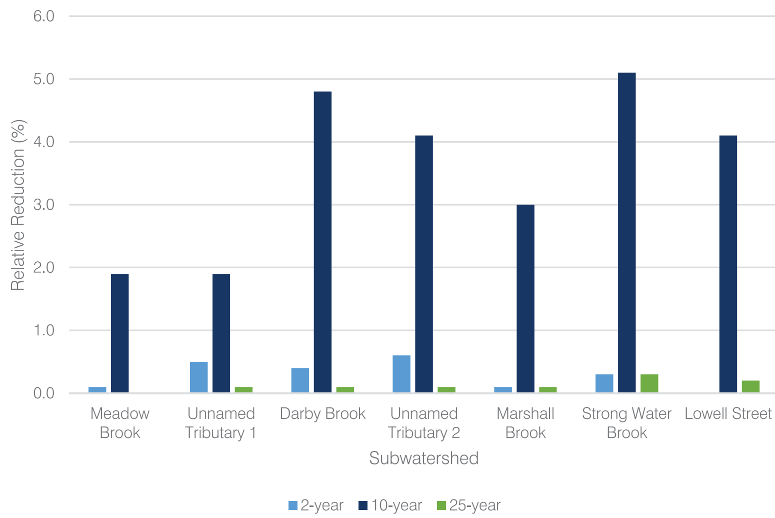
are yellow, and the 25% Green Streets are both the blue and yellow roads.

The following graph summarizes reductions in peak runoff



rate by tributary as a result of implementing Green Streets for 5% of Town-owned roads.

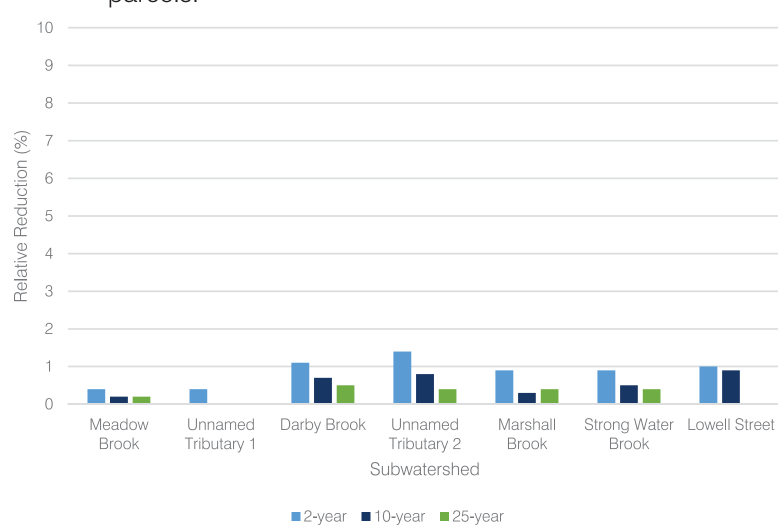
During the baseline climate scenario, reductions are not expected in the Unnamed Tributary 1 and Lowell Street subwatersheds since no Green Streets were selected in these areas. Relative reductions for the Meadow Brook and Darby Brook subwatersheds were 0.1% for the 2- and 10-year events. The following graph summarizes reductions in peak runoff rate by tributary as a result of implementing Green Streets for 25% of Town-owned roads.



Benefits within the subwatersheds increase with the future climate scenario of 25% Green Streets. Relative reductions for the 2-year event are generally less than 1%. The greatest reductions are seen during the 10-year event. Relative reductions are generally between 3 and 6%, however the Meadow Brook and Unnamed Tributary 1 subwatershed show reductions around 2%. Benefits are generally reduced during the 25-year event with relative reductions in peak runoff being less than 1%.

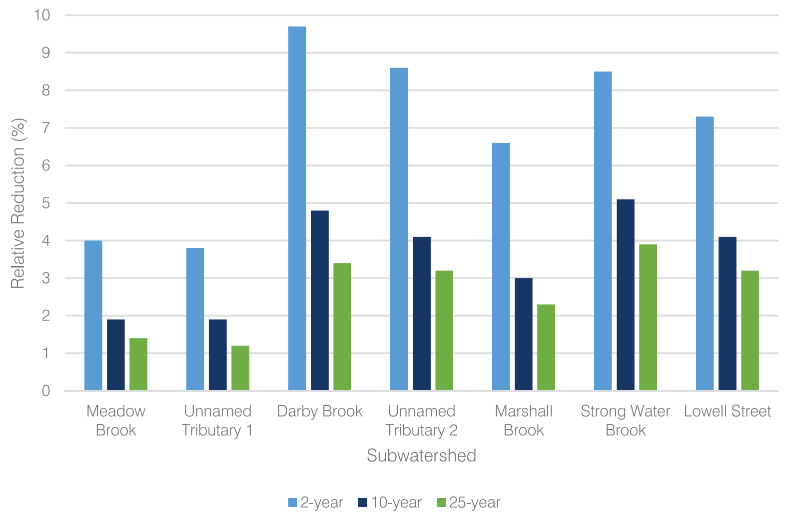
On-site Stormwater Management Strategy

This watershed-wide flood mitigation strategy involves retaining 2.0 inches of stormwater from 5% and 25% of impervious surfaces on parcels in the Strong Water Brook watershed and Lowell Street area watershed within Tewksbury. Under a baseline climate, the 2.0 inches of stormwater were retained for 5% of impervious surfaces on Tewksbury parcels. It was assumed that by 2070, the Town would be able to implement stormwater management techniques to retain 2.0 inches for 25% of impervious surfaces on Tewksbury parcels. The following figure summarizes reductions in peak runoff rate by tributary as a result of retaining two inches of stormwater on 5% of parcels.



The greatest benefits are generally felt in the Darby Brook and Unnamed Tributary 2 subwatersheds. Relative reductions for the 2-year storm event are generally between 0.8 and 1.4%, but the Meadow Brook and Unnamed Tributary 1 subwatersheds show reductions of

0.4%. During the 10-year event, relative reductions are generally between 0.4 and 1%, however the Meadow Brook and Marshall Brook subwatersheds show reductions between 0.2 and 0.4%. Benefits are generally reduced during the 25-year event with most of the relative reductions in peak runoff being less than 0.4%, but simulations indicate that the Darby Brook subwatershed has a reduction between 0.4 and 0.6%. The following figure summarizes reductions in peak runoff rate by tributary as a result of retaining two inches of stormwater on 25% of parcels.



Benefits within the subwatersheds increase with the future climate scenario of storing 2 inches of stormwater on 25% of impervious cover. Relative reductions for the 2-year event are generally between 6 and 10%, but the Meadow Brook and Unnamed Tributary 1 subwatersheds show reductions of close to 4%. During the 10-year event, relative reductions are generally between 2 and 6%, however the Meadow Brook and Unnamed Tributary 1 subwatersheds show reductions around 2%. Benefits are generally reduced during the 25-year event with most of the relative reductions in peak runoff being between 2 and 4%, but simulations indicate that Meadow Brook and the Unnamed Tributary 1 subwatersheds have reductions less than 2%.

Conclusion

A variety of design storms were simulated in the model under baseline and future climate scenarios. Under existing conditions, the Strong Water Brook Watershed had between 178 and 519 acres of inundated area. The Lowell Street stormwater collection system had between 0.15 and 3.67 million gallons of stormwater overflow from overwhelmed catch basins. Under future climate scenarios, flooding extents in the Strong Water Brook Watershed are expected to increase by between 10 and 35%. Flood volumes in the Lowell Street area are expected to increase by between 70 and 290% by 270.

Weston & Sampson evaluated the benefits of several potential green infrastructure (GI) projects. Individual GI projects improve flooding locally and have several co-benefits but do little for reducing downstream flooding. Weston & Sampson also looked at two watershed-wide flood mitigation strategies and found that they provided greater benefits than the individual GI projects. The watershed-wide scenarios showed reductions up to 1.4% in peak runoff rate under baseline climate conditions and up to nearly 10% under future climate conditions.

5 Outreach and Engagement

Stormwater management programs are much more effective when the community is fully involved. As part of the MVP Grant, a series of public engagement products and outreach events were conducted to connect with the community in Tewksbury. The goal was to understand where residents were experiencing flooding, provide more information about stormwater and green infrastructure, and share the progress of the project. This was completed through several activities and outputs:

- the development and distribution of a public survey on the location and severity of flooding, interest in green infrastructure, and preferences on affordable housing;
- the development of an online StoryMap, which provides the public with more information on why flooding occurs in Tewksbury, what is green infrastructure and how it could help, activities completed under the MPV grant, and ways they can mitigate flooding on their own property;
- a public presentation at the Tewksbury Public Library to share project results and answer questions;
- tabling at the Tewksbury Farmer's Market for one-on-one engagement with the public; and
- the creation of four posters and a 1-page flyer that showcased why it floods in Tewksbury, what is green infrastructure and how it can help mitigate flooding, ways the public can implement green infrastructure in their own homes, and renderings of potential green infrastructure projects around Tewksbury.

Tewksbury Flooding and Green Infrastructure Survey

The Tewksbury Flooding and Green Infrastructure Survey was created so residents and those who commute to or through Tewksbury could provide the project team with more information on where flooding occurs, as well as the intensity, frequency, and the impacts this flooding has on their lives. This survey also served as a public engagement tool, sharing information and gathering opinions on green infrastructure and affordable housing in the town.

The survey went public on Friday, January 14 and closed on Friday, March 25, 2022. It was announced through press releases in eight local newspapers in the Tewksbury region in English and Spanish. Hard copies of the survey were left at four locations in Tewksbury for those who did not have access to a computer or smart phone or preferred to complete a paper survey. Flyers about the survey were posted at 26 locations around Tewksbury, and 935 residents and 56 businesses within the 500-year flood zone were mailed postcards asking them to complete the survey. Posts about the survey were also shared on social media through the Facebook and Instagram accounts of the Town of Tewksbury, Tewksbury Department of Public Works, and Merrimack River Watershed Council. MVP Steering Committee members shared the announcement within their networks via email and social media.

Overall, there were 123 responses submitted to the Tewksbury Flooding and Green Infrastructure Survey. All of these responses were submitted online, with no hard copy surveys returned. Most responses were recorded in the first week of the survey, when there were heavy rainstorms in the area causing flooding (likely encouraging people to complete the survey). There was another group of responses around February 7, 2022 from another email blast to the Town of Tewksbury email list.

The flooding-specific data were incorporated into hydrologic and hydraulic models in different parts of the town to identify new flooding problem areas and provide additional data points for model calibration. The complete dataset collected during this survey and a detailed report and mapping tool to explore responses were provided to the Town. A public facing report is shared on the Town's Hazard Mitigation and Climate Resilience Planning website (tewksbury-ma.gov/flooding).

StoryMap: Flooding and Green Infrastructure in the Town of Tewksbury

A StoryMap, which is an online communications tool developed in ArcGIS, was developed to provide detailed descriptions of flooding and green infrastructure in Tewksbury. The StoryMap is a website where people can engage with the outputs of the project in a visual and interactive way.

The content of the StoryMap includes detailed information about:

- what flooding and stormwater are;
- why flooding occurs in Tewksbury, looking at historical maps to present day conditions;
- how climate change could impact flooding in Tewksbury;
- how to manage flooding and stormwater through green infrastructure;
- examples of different green infrastructure elements;
- what green infrastructure projects have already been installed in Tewksbury;
- where flooding occurs in Tewksbury;
- areas in Tewksbury suitable for green infrastructure;
- the parcel prioritization process;
- renderings of potential green infrastructure projects around Tewksbury; and
- ways homeowners can install green infrastructure at their own property.

This StoryMap is available in English and Spanish and links directly from the Town of Tewksbury's website for Hazard Mitigation & Climate Resilience Planning.

Presentation at the Tewksbury Public Library

On Monday, May 23rd, members of the Steering Committee gave a public presentation about the progress and outputs of the MVP grant activities at that moment. Outreach prior to the presentation included distribution to approximately 80 residents at the Town cleanup day, an email to all survey respondents who indicated they were interested in learning more about the project, a press release to 8 local news outlets, and postings and email blasts via the Town's and MRWC's social media accounts, websites and email lists.

The presentation was delivered in a hybrid fashion: Steering Committee members gave the presentation in-person at the library, but it was also livestreamed on YouTube with MentiMeter questions, which is an online tool so that the online viewers could engage with the presenters and ask questions. Topics covered in the presentation included:

- Introduction to the MVP grant
- A MentiMeter poll of what is (or is not) flooding
- Past stormwater issues in Tewksbury
- Future impacts of climate change
- Green infrastructure and potential new solutions
- Past and future stormwater management
- Questions via MentiMeter

Seven people attended the live presentation and five people were watching via the YouTube stream. The audience members were quite engaged and there was good discussion on a variety of topics related to flooding, stormwater, and green infrastructure. Slides for the presentation are available on the Town's Hazard Mitigation & Climate Resilience Planning website, and the recording of the meeting is on the Town of Tewksbury's YouTube channel.

Figure 5-1: Tewksbury, MA Farmers Market Public Education Display

Tabling at the Tewksbury Farmer's Market

On Thursday, June 16th, members of the Steering Committee tabled at the Tewksbury Farmer's Market, allowing members of the public to engage one-on-one with members of the project team. Approximately 1,150 people attended the Farmer's Market, and it is estimated that approximately 40 people stopped by the table to discuss flooding and green infrastructure, what activities occurred under the MVP grant, and next steps for addressing flooding in Tewksbury. In addition, approximately 20 children visited the watershed table to learn how green infrastructure works in a fun and interactive way.

Posters on Flooding and Green Infrastructure in Tewksbury

As part of the public meeting and Farmer's Market outreach, four posters were developed that provided more details on the project. The topics included:

- why stormwater is an issue in Tewksbury;
- what is green infrastructure and how can it alleviate flooding;
- how to implement green infrastructure at home; and
- before and after photos (with renderings) of potential green infrastructure projects that could be installed in Tewksbury.

These posters were displayed at the public meeting as well as at the Tewksbury Farmer's Market. The poster on how to implement green infrastructure at home was displayed in the Tewksbury Public Library between May 23rd (the day of the public meeting) until June 16th (the day of the Tewksbury Farmer's Market). Figures 5-2 through 5-5 show the public education posters.

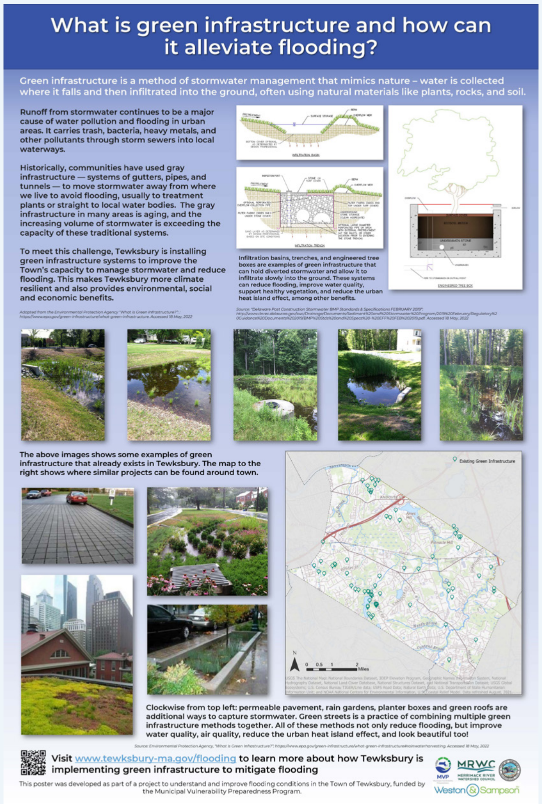


Figure 5-2: Green infrastructure educational poster

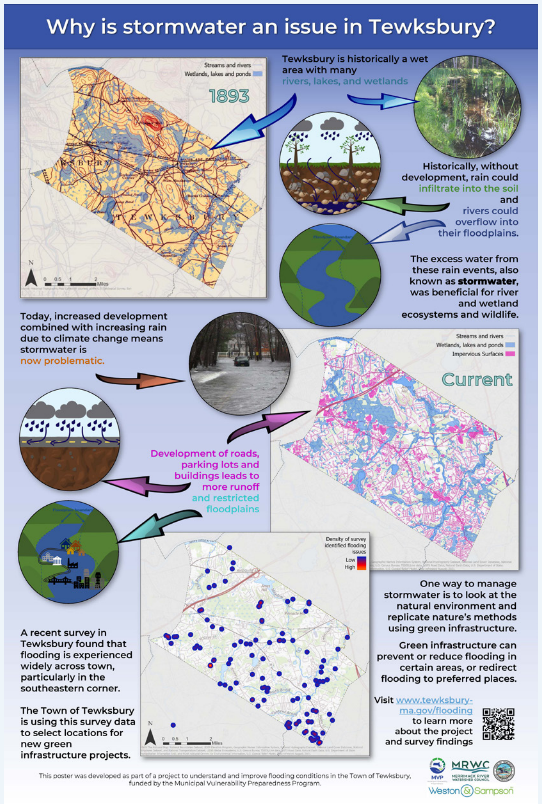


Figure 5-3: Stormwater educational poster

Figure 5-4: Green infrastructure at home educational poster

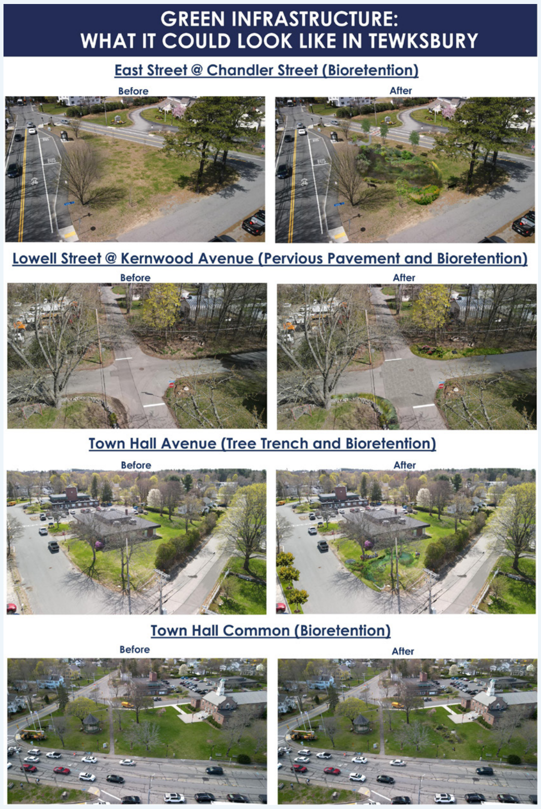


Figure 5-5: Green infrastructure renderings

Using the same information, a 1-page flyer was developed and handed out to members of the public at the Farmer's Market. See Figures 5-6 through 5-9 below. These flyers will also be available at public events that the Town of Tewksbury will hold in the future. This flyer was developed in both English and Spanish to reach a wider audience.

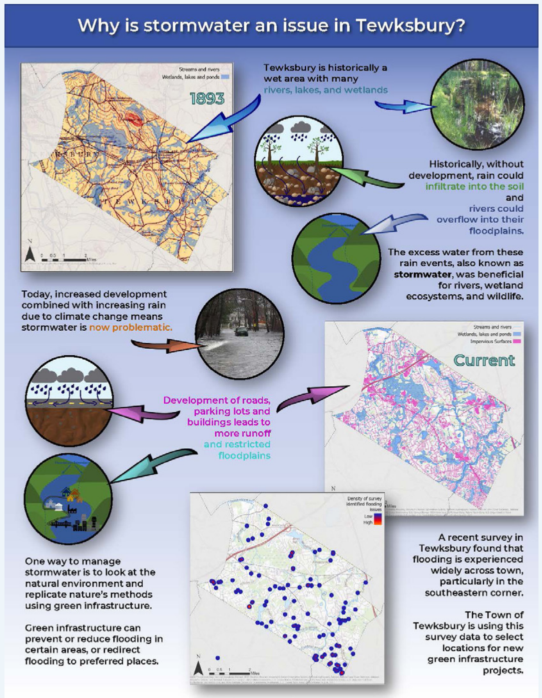


Figure 5-6: Front page of flyer (English)

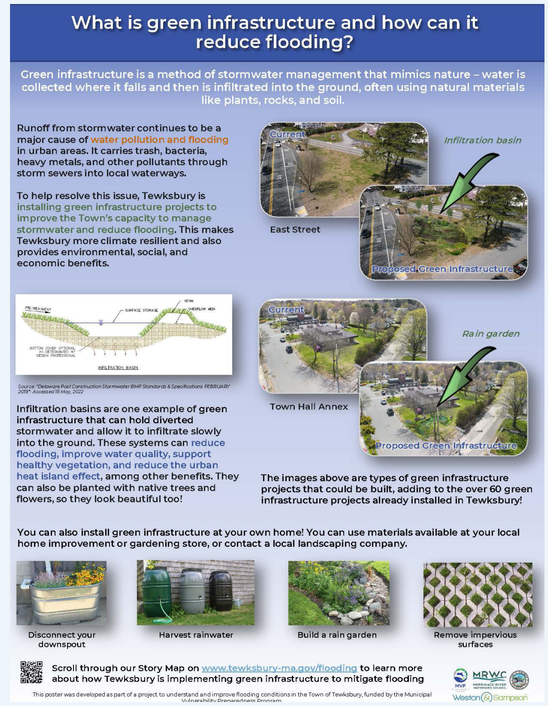


Figure 5-7: Back page of flyer (Spanish)

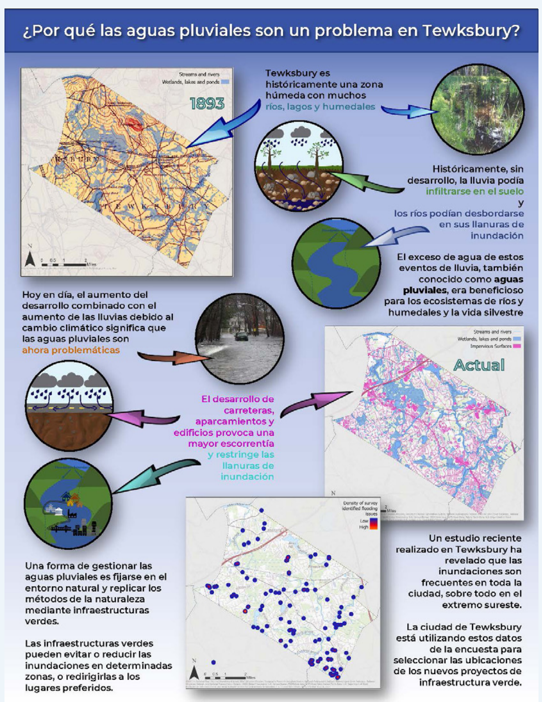


Figure 5-8: Front page of flyer (Spanish)

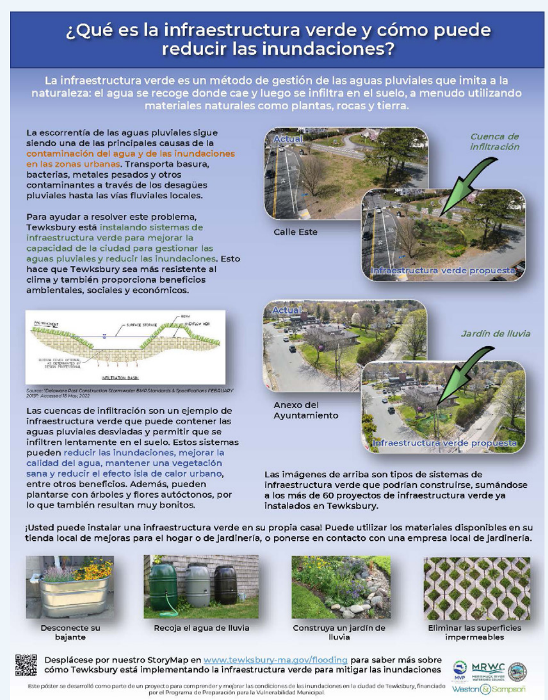


Figure 5-9: Back page of flyer (Spanish)

6 Conclusions & Next Steps

This project has helped Tewksbury understand areas of existing and anticipated future flooding, identify priority sites and opportunities for incorporation of green infrastructure, and develop a framework for integrating nature-based solutions into Tewksbury's landscape to provide for flood mitigation, reduced urban heat island impacts, and improved water quality. As the Town of Tewksbury continues to take steps towards climate resilience, the following next steps are recommended:

Proceed with Design & Construction of Green Infrastructure Concepts on the Five Priority Sites: Utilize the Stormwater Enterprise Fund, supplemented by grant funding where possible, to design and construct solutions to reducing runoff volume, peak rates, and pollutant loads to waterbodies and wetlands, including the projects identified in this report.

Continue to Use & Update Tools provided in this Project to Identify Opportunities: Utilize the prioritization matrices and the nature-based solutions toolkit developed as part of this project to continue to further evaluate and identify opportunities to incorporate green infrastructure on town-owned parcels beyond the priority projects identified and consider/integrate climate vulnerable populations.

Program green streets and climate resilience stormwater management into local roadway and facilities projects: Plan for the incorporation of climate resilient initiatives in the early planning stages of municipal projects and have representatives from municipal departments engaged in the process from the start.

Develop a Green Streets Policy to promote the incorporation of green streets practices and green infrastructure into public and private development, including road reconstruction, bicycle/pedestrian projects, stormwater improvements, new development, and redevelopment projects: This type of policy, which has been adopted by multiple communities in Massachusetts, promotes the capture and infiltration of stormwater on-site.

Continue proactive operation and maintenance of the drainage system Because of the Stormwater Enterprise Fund, the Town has had funding annually to proactively inspect and clean catch basins, to perform closed-circuit television inspection of a percentage of their drainage system, and to inspect and maintain their stormwater treatment structures.

Integrate Findings Related to Likely Future Flood Areas into Affordable Housing Planning and Discussions: This project provided a list of parcels that are favorable for affordable housing for a variety of reasons as well as protections related to future flood zones. This information can be used as one of many factors related to planning for and building affordable housing.

Expand Education to Homeowners. Promote continued discussion with homeowners regarding what they can do on their own properties and the benefit it provides the community, including those residents that already have stormwater BMPs on their property.

Action – Proceed with Design & Construction of Green Infrastructure Concepts on the Five Priority Sites

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

1. Sites #1 & #2 – Town Hall "Campus Area" – Bioretention Areas, Planter Box & Tree Trenches
2. Site #3 – Tewksbury Public Library – Rain Garden & Educational Signage, Evaluation of Detention Basin Expansion
3. Site #4 – Lowell Street Neighborhood – Bioretention Areas & Pervious Pavers
4. Site #5 – East Street Athletic Fields – Bioretention Area & Pervious Pavement

These five prioritized sites represent projects that create the greatest impact on municipally-owned parcels in terms of flood risk reduction and reducing flood timing. They also prioritize water quality improvements and creation of better, healthier, public spaces. The integration of nature-based solutions into the Town's existing drainage system will create a more resilient infrastructure that can accommodate future climate, social, and environmental challenges. Next steps toward implementation include:

- Identification of a viable funding source to continue to move the project forward, whether that be pursuing the next phase of funding under the MVP Action Grant Program, leveraging existing funds available through the stormwater enterprise fund, and/or pursuing other grant

opportunities, such as a 604b or 319 water quality grant or funding through the Clean Water State Revolving Fund in the form of a low-interest loan.

- Additional site investigations to further evaluate feasibility including conducting test pits to evaluate soil conditions including soil permeability, drainage system connectivity investigations, and performing topographic survey of each project area to identify any potential utility or other conflicts.
- Proceeding with design and preparing contract documents for each site individually or as a group for public bidding.

Action – Continue to Use & Update Prioritization Tools provided in this Project to Identify Opportunities

A detailed assessment was performed to evaluate hundreds of municipal parcels for suitability to incorporate green infrastructure and consider climate vulnerable populations. As the Town works to further incorporate green infrastructure as part of future projects, this information provides a valuable resource. The matrices developed will serve as a useful tool to identify additional priority sites and provide an initial evaluation of viability. The nature-based solutions toolkit provides an overview of nature-based stormwater management solutions appropriate for Tewksbury and how they may be applied to retrofit sites going forward.

Action – Program Green Streets and Climate Resilience Stormwater Management into Local Roadway and Facilities Projects.

As the Town moves forward with roadway reconstruction projects and facility updates, opportunities to incorporate green infrastructure and other climate resilient strategies should be a priority and incorporated into planning, design, and construction. The Town should ensure that even as projects are in the early planning stages, municipal departments, boards and commissions consider incorporation of climate resilient initiatives as a top priority. Once projects advance into later stages, it becomes more difficult and more costly to incorporate these initiatives, resulting in missed opportunities. The Town should prioritize capitalizing early on, as the flood mitigation and water quality benefits these projects offer is of value to the community. It is also recommended that the Town identify and allocate funding early in the concept planning process so the resources are available during the planning stage through completion of construction.

Action – Continue Proactive Operation and Maintenance of the Drainage System

In recent years, the Town has been able to leverage funding available through their Stormwater Enterprise Fund to inspect and maintain various components of their stormwater system, including infrastructure that has not been maintained or inspected in decades. Proactive maintenance of the Town's drainage system will ensure the system continues to function as designed, providing flood mitigation and water quality benefits. Tewksbury can continue to improve tracking of the work they provide the community and communicate those metrics to voters, stakeholders, and elected and appointed discussion makers to build consensus about the value of existing stormwater infrastructure.

Action - Integrate findings related to likely future flood areas into affordable housing planning and discussions.

During the municipal parcel prioritization, existing and potential future affordable housing was considered, and the following parcels were prioritized:

- Existing affordable housing properties;
- Parcels greater than one acre and outside of the FEMA flood hazard areas, which could become sites for future affordable housing;
- Parcels outside of the floodplain that have already been identified by the Town as potential sites for future affordable housing from the 2017-2022 Housing Production Plan; and
- Historic properties, which could be turned into future affordable housing, per the Town's Master Plan.

In addition, the hydraulic and hydrologic modeling identified anticipated future areas of flooding, which may encroach on parcels that are currently considered suitable for affordable housing or impact access to or egress from those parcels.

In the Town's next update of the Town-wide Master Plan (dated 2016), Housing Production Plan (currently through 2022), and Annual Affordable Housing Plan, the evaluation of parcels and flood mapping prepared through this project should be incorporated into planning and decision making.

Action – Expand education to homeowners about what they can do on their own properties and the benefit it provides the community, including those residents that already have stormwater BMPs on their property.

The extensive public outreach and engagement completed through this project was meaningful in the context of this phase of Tewksbury's overall climate resilience planning. It also re-emphasized the value of teaching residents about stormwater – the basics of drainage, the future of flooding, what the Town is doing about it – from proactive and reactive operations and maintenance, to thinking about mitigation of and adaptation to impacts from climate change. While Tewksbury is promoting stormwater water-quality focused public education through the MS4 General Permit, it will serve Tewksbury well to include messaging about climate change and creating resilience to garner support to spend additional funds on capital projects and have abutter patience with construction projects related to flood and climate change mitigation, and overall foster a great place to live and work. The immediate next step is to develop a social media outreach campaign to reach a broader audience. Continuing to partner with MRWC will help reach a wide array of supporters, as well.

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Glossary

Best Management Practices (BMPs) – schedules of activities, practices (and prohibitions of practices), structures, vegetation, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Catch Basin – a structure for the interception of stormwater and settling of grit, sand, and other sediments prior to discharge of stormwater into the collection system.

Climate – the pattern of weather events observed over time.

Climate Change – a phenomenon caused by the increase of greenhouse gases in the Earth's atmosphere, which results in a warmer global temperature.

Climate Vulnerable Populations – Those who have lower adaptive capacity or higher exposure and sensitivity to climate hazards like flooding or heat stress due to factors such as access to transportation, income level, disability, racial inequity, health status, or age.

Co-Benefits – Economic, social/cultural, and environmental benefits of nature-based solutions aside from flood mitigation.

Culvert – a closed conduit for the free passage of surface drainage water under a highway, railroad, or other embankment.

Design Storm – the storm that is modeled to inform the design of a hydraulic structure such as a bridge or culvert.

Discharge – the stormwater or pollutant being conveyed, treated, or released into waterbodies.

Drainage – the removal of surface water from a given area either by gravity or by pumping.

Drainage System – all man-made stormwater collection and conveyance infrastructure. The drainage system includes catch basins, drain manholes, outfalls, culverts, channels, and stormwater treatment structures.

Environmental Justice Populations – Typically include climate vulnerable populations, who may have lower adaptive capacity or higher exposure and sensitivity to climate hazards like flooding or heat stress due to factors such as access to transportation, income level, disability, racial inequity, health status, or age.

Flooding – Excessive stormwater runoff, inundation of infrastructure, roads, or built structures due to overbank flooding, flash flood, or overwhelmed drainage capacity.

Green Infrastructure – captures rainfall and stormwater runoff and mimics natural processes to infiltrate and treat stormwater.

Grey Infrastructure – Conventional, built infrastructure including impervious roadways. Grey infrastructure is often contrasted with green infrastructure, which can increase porosity, provide public co-benefits, and improve stormwater management. See definition for Green Infrastructure above.

Impervious Surface – any surface that prevents or significantly impedes the infiltration of water into the underlying soil. This can include but is not limited to roads, driveways, parking areas and other areas created using nonporous material, such as buildings, rooftops, structures, artificial turf and compacted gravel or soil. Areas with large amounts of impervious surface lead to greater amounts of stormwater runoff conveyed into the drainage system rather than seeping into the ground.

Low Impact Development – Systems and practices that use or mimic naturals processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and surrounding habitat.

Municipal Separate Storm Sewer System (MS4) – a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains) owned or operated by a State, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law) that must meet NPDES permit requirements.

MVP Program – created in 2017 as part of Governor Baker's Executive Order 569, provides support for cities and towns in Massachusetts to identify climate hazards, assess vulnerabilities, and develop action plans to improve resilience to climate change. Communities that complete the MVP Planning Grant process become designated as an MVP Community and are eligible for MVP Action Grant funding to implement the priority actions identified through the planning process.

Nature-Based Solutions – as adaptation measures focused on the protection, restoration, and/or management of ecological systems to safeguard public health, provide clean air and water, increase natural hazard resilience, and sequester carbon. Incorporating NBS in local planning and design projects produces long-term solutions that benefit human and natural systems. NBS can be preservation of existing natural resources (e.g., protection of open space), restoration of a natural resource (e.g., stream channel stabilization, creation of floodplain, reforestation), or construction of Green Infrastructure.

Outfall – the point, usually a pipe end, where stormwater exists the drainage system and discharges into a river, lake, pond, or wetland.

Pollutant – dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal and agricultural waste discharged into water.

Pollutant of concern – a pollutant which causes or contributes to a violation of a water quality standard, including a pollutant which is identified as causing an impaired waterbody.

Resilience – the ability to withstand and recover from an extreme event. Ideally, resilient systems "bounce forward" to create healthier, greener, and more equitable systems and spaces.

Stormwater – the excess water running off from the surface of a drainage area during and immediately after a period of rain or snow melt. Stormwater soaks into the soil and recharges groundwater, naturally drains into waterbodies, or is conveyed through a series of pipes until it is discharged into a nearby waterbody.

Stormwater System – a system of drains and other apparatuses for conveying the runoff from surfaces, such as streets.

Watershed – includes all land that contributes runoff to a body of water and may extend many miles away from the water's edge.

100-year Floodplain – Area with a 1% annual chance of flooding.

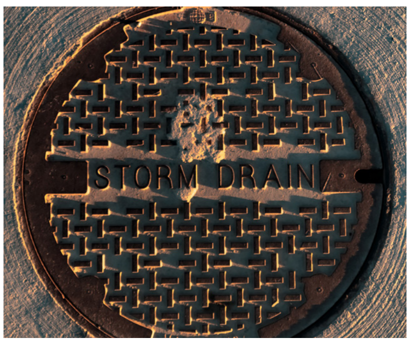
500-year Floodplain – Area with a 0.2% annual chance of flooding.

Examples of Stormwater Infrastructure/Terms

Catch Basin

Culvert

Drainage Channel



Drain Manhole (Cover)

Drain Manhole (Internal)

Outfall

Rain Garden

Stormwater Detention Area

Stormwater Flooding

Stormwater Pollution

Underground Infiltration Basin

Wetland

Acronym List

BMP – Best Management Practice

MassDEP – Massachusetts Department of Environmental Protection

MassDOT – Massachusetts Department of Transportation

DPW – Department of Public Works

EEA – Executive Office of Energy and Environmental Affairs

EPA – U. S. Environmental Protection Agency

FEMA – Federal Emergency Management Agency

FY – Fiscal Year

GI or GSI – Green Infrastructure or Green Stormwater Infrastructure

GIS – Geographic Information System

GPS – Global Positioning System

IA – Impervious Area

LID – Low Impact Development

LiDAR – Light Detection and Ranging

MGL – Massachusetts General Law

MS4 – Municipal Separate Storm Sewer System

MRWC – Merrimack River Watershed Council

MVP – Municipal Vulnerability Preparedness

RMAT – Resilient Massachusetts Action Team

SWMP – Stormwater Management Program