Integrated Water Infrastructure Vulnerability Assessment and Climate Resiliency Plan

TOWN OF WALPOLE, MASSACHUSETTS

prepared by

FUSS & O'NEILL

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Financial assistance was provided by the Executive Office of Energy & Environmental Affairs (EEA) under the FY19 Municipal Vulnerability Preparedness (MVP) Grant Program. The MVP Action Grant offers financial resources to municipalities that are seeking to advance priority climate adaptation actions to address climate change impacts resulting from extreme weather, sea level rise, inland and coastal flooding, severe heat, and other climate impacts.

Table of Contents

List of Tables

List of Figures

List of Appendices

1 Introduction

The Town of Walpole is taking steps to pro-actively address the flooding-related vulnerabilities of some of its water infrastructure – road-stream crossings and stormwater infrastructure – to build resilience for changing climate conditions. Enhancing water infrastructure resilience through well-planned, cost-effective adaptation measures will make the community more resilient to extreme precipitation events and flooding. This report describes an assessment of the vulnerability of water infrastructure in the community and recommended adaptation measures to improve infrastructure and community resilience.

Water Infrastructure includes drinking water, wastewater, and stormwater infrastructure, as well as road-stream crossings (culverts and bridges), dams, and impoundments. Water infrastructure, like other public infrastructure, provides services and facilities that are essential to the public health, safety and well-being of a community. Storm events, flooding, and climate change has the potential to damage vulnerable water infrastructure and threaten public safety, particularly in the case of inadequate or outdated infrastructure.

1.1 Background

Extreme weather and natural and climate-related hazards are an increasing concern for the communities of the Greater Boston area. Climate changes, such as sea level rise, flooding, and extreme weather events are already affecting communities across Massachusetts. Participants at the Municipal Vulnerability Preparedness (MVP) Community Resilience Building workshops in January 2019 identified flooding as a high-priority challenge facing the community. Moreover, the threat from flooding has been growing with the increasing frequency of major storm events that deliver large amounts of precipitation over a short time period. Climate projections for Massachusetts, developed by the University of Massachusetts, suggest that the frequency and intensity of extreme precipitation events will continue to trend upward, and the result will be an increased risk of flooding (MA Climate Change Clearinghouse, http://www.resilientma.org/). Adaptation, which means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, is necessary to avoid increasingly significant impacts.

1.2 Project Objectives and Scope

In 2019, following completion of the MVP planning process[1], Walpole applied for and was awarded a FY 19 MVP Action Grant by the Massachusetts Executive Office of Energy and Environmental Affairs to conduct a detailed vulnerability assessment of road-stream crossings (culverts and bridges) and stormwater infrastructure and develop planning recommendations to enhance flood resilience in the community. The Town, in collaboration with the MVP Program, commissioned this vulnerability assessment and adaptation planning process to:

- Identify water-related infrastructure at risk of flooding under present day and projected future climate change conditions
- Prioritize at-risk infrastructure
- Recommend site-specific and community-wide adaptation measures
- Engage municipal staff and the public

The term "resiliency" or "resilience" is the ability to become strong, healthy, or successful again after something bad happens – the ability to spring back into action. Flood resilience refers to a community's ability to plan for, respond to, and recover from floods. It includes measures taken to reduce the vulnerability of communities to damages from flooding and to support long-term recovery after an extreme flood (EPA, 2014).

In addition to the MVP Planning process, this project also builds upon other related initiatives, such as a grant the Town of Walpole received to study the impacts of road-stream crossings along Traphole Brook, a designated cold-water fishery, as well as the Town of Walpole Hazard Mitigation Plan, which is a requirement to receive FEMA funding for hazard mitigation grants, and is updated every five years.

The project consisted of technical assessments (review of relevant background studies and mapping and new field data collection and analysis) focused on road stream crossings, opportunities for installing green infrastructure, and associated climate change vulnerabilities. The project included a project steering committee, which reviewed and evaluated field data and helped guide outcomes of both assessments. The results of the technical assessments, combined with input from the project steering committee, guided the development of an integrated climate resiliency plan. The plan includes prioritized adaptation recommendations and design concepts to support future implementation projects.

1.3 Purpose of the Plan

The purpose of this Integrated Climate Resiliency Plan is to:

- Enable the Town be better prepared for and mitigate the impacts of extreme precipitation events and flooding.
- Protect critical community infrastructure and the ability to deliver vital municipal services.
- Promote resiliency measures that consider both infrastructure and natural system solutions, and encourage local decision-makers to think more strategically about using natural systems to enhance flood resiliency while also benefitting water quality and ecological health.

[1] The Municipal Vulnerability Preparedness (MVP) grant program provides support for cities and towns in Massachusetts to begin the process of planning for climate change resiliency and implementing priority projects. The state awards communities with funding to complete vulnerability assessments and develop action-oriented resiliency plans. Walpole completed the MVP Planning process in 2019 to become certified as an MVP community and is eligible for MVP Action grant funding and other state funding opportunities.

- Identify recommended adaptation measures, costs, and funding sources (i.e., resiliency plan).
- Position the community to obtain grant funding (through the MVP Action Grant program and other sources) to implement the plan recommendations.

1.4 Organization of the Document

- Section 1 – Introduction describes the project background, objectives, scope and how this plan is organized.
- Section 2 – Plan Development Process describes the process used to develop the plan, including the project partners and funding, Project Steering Committee, technical assessments, and community engagement process.
- Section 3 – Flood Hazards and Vulnerable Infrastructure summarizes the flooding issues in Walpole, including the types and causes of flooding, areas susceptible to flooding, and vulnerable water-related infrastructure.
- Section 4 – Vulnerability Assessments describes the methods and results of vulnerability assessments performed for road stream crossings and opportunities for green infrastructure.
- Section 5 – Adaptation Recommendations describes recommended adaptation measures to address vulnerable infrastructure, including site-specific design concepts and policy and regulatory recommendations.
- Section 6 – Funding Sources identifies potential state and federal funding sources to augment municipal funding for implementing the plan recommendations.
- Section 7 – References contains a list of references cited in this document.
- Appendices – the plan appendices include summaries and links to technical reports documenting the technical assessments that serve as the basis for the plan recommendations.

2 Plan Development Process

2.1 Project Partners and Funding

> This project received MVP Action Grant Funding administered by the Massachusetts Executive Office of Energy and Environmental Affairs.

In 2019, the Town of Walpole received funding through the Municipal Vulnerability Preparedness (MVP) Grant Program, administered through the Massachusetts Executive Office of Energy and Environmental Affairs (EEA), for a project to conduct a climate change vulnerability assessment and develop an associated climate resiliency plan. Fuss & O'Neill, Inc. was retained by the Town to lead the development of the assessments and resiliency plan.

The climate resiliency plan addresses two major types of water infrastructure in the community - water transportation systems (culverts and bridges), and storm drainage systems. The project consisted of two technical assessments focused on these types of water infrastructure and associated climate change vulnerabilities.

The plan development process included review of relevant background information, studies, and mapping for the community, as well as screening-level evaluations (using GIS data) and field data collection and analyses. The project included public participation and outreach and input from a project steering committee. The results of the technical assessments, combined with input from the public and project steering committee, guided the development of this integrated climate resiliency plan, which includes prioritized site-specific and town-wide recommendations, conceptual designs to support future implementation projects, and potential funding sources.

The plan builds upon recent and ongoing climate and flood resiliency efforts by the community, as well as state and federal agencies, including:

- Town of Walpole MVP Planning Process and Community Resilience Building Workshop
- FEMA Flood Insurance Studies and hydrologic/hydraulic model information
- State Hazard Mitigation and Climate Adaptation Plan
- Town of Walpole Hazard Mitigation Plan
- 2019 Culvert Replacement Municipal Assistance Grant for culvert replacement along Traphole Brook

2.2 Project Steering Committee

A Project Steering Committee was formed to guide the plan development. The Steering Committee consisted of representative staff from multiple departments, including Conservation, Public Works, Engineering, and Town Administration.

Members of the Project Steering Committee attended regular meetings and provided review comments on draft deliverables. The Integrated Climate Resiliency plan reflects the feedback received form municipal government agencies, other stakeholders, and the Fuss & O'Neill project team. Members of the Project Steering Committee and other individuals involved in the plan development process are listed in the Acknowledgements section at the beginning of this document.

2.3 Technical Assessments

A series of technical assessments were conducted to inform and guide the management plan recommendations. The assessments involved review of historic information and studies, screening-level evaluations using available GIS data to prioritize field efforts, and field data collection and analysis. The methods and results of the technical assessments are documented in separate technical memoranda. Electronic versions of the technical memoranda can be accessed at the links provided in the plan appendices.

- Road-Stream Crossing Assessment: Mapped road-stream crossings (i.e., culverts and bridges) were assessed to identify crossings that are vulnerable to flood hazards under present and projected future climate conditions, and to prioritize structures for upgrade or replacement given limited financial resources and aging transportation infrastructure. The assessments involved a combination of desktop assessment, field data collection, and prioritization/ranking and considered multiple factors – hydraulic capacity, structural condition, geomorphic vulnerability, aquatic organism passage, impacts on transportation and emergency services and other flooding impacts, and climate change impacts including projections of future extreme precipitation and streamflow. The assessment and prioritization approach was adapted from methods used by MassDOT and other transportation agencies in the Northeast and stream crossing survey methods developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC).

- Green Infrastructure Assessment: A green infrastructure assessment was performed to identify green infrastructure (GI) and low impact development (LID) retrofit opportunities throughout Walpole that would increase flood resiliency by reducing runoff volumes and peak flows and improve or protect water quality. Opportunities to implement GI/LID were assessed for Town-owned properties selected based on a desktop screening-level evaluation which identified areas within the Town with the highest feasibility for and potential benefits from GI/LID retrofits. The lists of potential sites were further refined based on input from the Town to select sites for field inventories. Site-specific concept designs were developed for the ten most promising green infrastructure retrofit opportunities.

2.4 Community Outreach

Public participation and outreach was conducted as part of the MVP Action Grant and resiliency planning process to increase public understanding of issues currently affecting the Town and the potential future impacts associated with climate change, and to raise awareness of the recommendations resulting from the assessments and build support for implementation of the plan. The following community outreach activities occurred during the planning process.

Project Steering Committee Meetings

A series of meetings were held with the Project Steering Committee to provide local information and feedback on the vulnerability assessments and to guide the development of recommended adaptation measures. Steering Committee meetings and/or conference calls were held on the following dates:

- September 25, 2019
- December 12, 2019
- February 28, 2020
- April 21, 2020
- May 20, 2020

Community Meeting

A Walpole community meeting was held at the conclusion of the project. The community meeting was held as a stand-alone public information meeting on March 24, 2021. The purpose of this meeting was to present a summary of the assessment findings and recommendations and to encourage comments and questions from the public.

3 Flood Hazards and Water Infrastructure

3.1 Flooding in Walpole

Types of Flooding

> The communities of Massachusetts are susceptible to the impacts of flooding caused by hurricanes, nor'easters, and severe rainstorms or thunderstorms. Walpole has experienced historical and recent flooding that has resulted in roadway flooding, stream bank erosion, washout of roads, damages to and failure of dams, and flooding of properties and structures.

Riverine flooding is the most common type of flooding in low-lying areas of Walpole. Riverine flooding occurs when rivers or streams overflow their banks and flow into the adjacent floodplain. Hazards associated with riverine flooding include both flood inundation of developed areas (roads, homes, businesses, etc.) and riverine erosion, including erosional and depositional processes. Riverine erosion can affect structures located both inside and outside the regulatory floodplain. The recurrence interval of a flood is defined as the average time interval, in years, expected to take place between the flooding of a particular magnitude to an equal or larger flood. Flood magnitude increases with increasing recurrence interval (USGS, n.d.).

Drainage-related flooding is another common type of localized flooding, more likely to occur in developed areas such as downtown Walpole, and along transportation routes. It occurs as a result of drainage problems related to outdated or undersized storm drainage systems. Urbanization contributes to flooding by increasing impermeable surfaces, increasing the speed of drainage collection, and reducing the storage capacity of the land, all of which can overwhelm storm drainage collection systems. Poorly draining soils, steep topography, and development can exacerbate localized drainage problems and drainage-related flooding.

Dam failure or breach can result from natural or human-induced events or some combination of the two. Failures due to natural events, such as prolonged periods of rainfall and flooding, can result in overtopping, which is the most common cause of dam failure. Overtopping occurs when a dam's spillway capacity is exceeded and portions of the dam, which are not designed to convey flow, begin to pass water, erode away and ultimately fail. Other causes of dam failure include design flaws, foundation failure, internal soil erosion, inadequate maintenance or operational failure. Dam failure or breach can result in sudden downstream flooding (i.e., flash flooding) and significant damages to infrastructure and property. Although dam failure in Walpole would cause extensive damage, the risk of such a flood event is low according to the Town's 2016 Hazard Mitigation Plan. For this reason, dam failure or breach was not studied during this analysis.

Factors Contributing to Flooding

Several factors contribute to flooding in Walpole, and more broadly, in Greater Boston. Historical development resulted in the filling of wetlands, floodplains, and floodways, which has reduced natural flood storage and placed development in flood-prone areas. Many of the streams in the region, as is common in New England, have also been physically modified (i.e., moved, straightened, hardened), which can increase riverine erosion hazards in certain areas. Development of the landscape with roads, parking lots, and buildings – impervious surfaces that prevent rainfall from infiltrating into the ground naturally – has increased the amount of storm runoff. Stormwater drainage infrastructure in developed areas also conveys runoff quickly to rivers and streams. Undersized bridges and culverts, which have insufficient capacity to convey floodwater, sediment, and debris, have also contributed to flooding and erosion.

History of Flooding in Norfolk County

Flooding and related events have caused significant damage in Norfolk County, including Walpole. Between 1996 and 2014, Norfolk County experienced 45 flood events (Walpole, 2016) . Severe flooding generally occurs as a result of hurricanes or melting snows and spring rains, with more localized flooding caused by summer thunderstorms (FEMA, Revised 2015). Error! Not a valid bookmark self-reference. illustrates annual peak streamflow at a U.S. Geological Survey stream gage location near Walpole for the period 1938-2019, highlighting some of the major flooding events that have occurred in the area. Some of the more notable flooding events in the region include:

- August 1955: Both Hurricanes Connie and Diane reached Massachusetts as tropical storms and caused heavy rainfall. In Walpole, 15 inches of rain fell over a 2-day period, flooding from Diamond Brook and inundating Walpole Center as well as roads, bridges, 14 houses, a school and 42 commercial establishments (FEMA, Revised 2015).

- March 1968: A severe rainstorm on March 18, 1968 caused extensive damage throughout Norfolk County. The damage to Walpole center resulted in the Norfolk Conservation District and the Town of Walpole collaborating to develop a plan to reduce flood damage in the Diamond and Spring Brook watersheds. (FEMA, Revised 2015).

- March - April 1987: Two spring storms produced rainfall that led to record snowmelt in Massachusetts, New Hampshire, and Maine. Over a nine-day period, more than ten inches of rain fell in some locations of Massachusetts. This heavy rainfall, combined with melting snow, flooded rivers and water bodies and caused one of the worst floods in the states up to that point in history (National Oceanic and Atmospheric Administration, n.d.).

- August 1991: Hurricane Bob was classified as a category 2 when it reached Massachusetts, causing strong winds and heavy rains, leading to flooding across the state, including Norfolk County. The significant damage it caused led it to be one of the most expensive hurricanes to ever hit Massachusetts.

- June 1998: Flooding throughout Massachusetts and Rhode Island was caused by an intense, slow-moving frontal storm that rained almost 10 inches in some areas of western Massachusetts.

- September 1999: Hurricane Floyd was a tropical storm by the time it hit Massachusetts. It dropped over four inches of rain according to a USGS precipitation gage in the city (USGS, n.d.).

- March 2010: A FEMA Major Disaster Declaration was issued on March 29, 2010 in response to a severe storm and flooding in Massachusetts. Over seven and a half inches of rain was recorded on March 16, 2010 in Walpole and flooding of road crossings and streams occurred throughout the Town (Town of Walpole, 2010). (FEMA, n.d.).

- August 2011: Tropical Storm Irene was classified as a tropical storm when it reached Massachusetts. Over 5.5 inches of rain fell during a four-day period at the end of March.

- October-November 2012: Hurricane Sandy reached Massachusetts as "Superstorm Sandy," causing strong winds and heavy rainfall across Massachusetts. The USGS precipitation gage at Worcester measured almost two inches of rainfall over a two-day period (USGS, n.d.).

- October 2016: In central Massachusetts and the surrounding communities, over four inches of rain fell in less than a 24-hour period, flooding streets (USGS, n.d.).

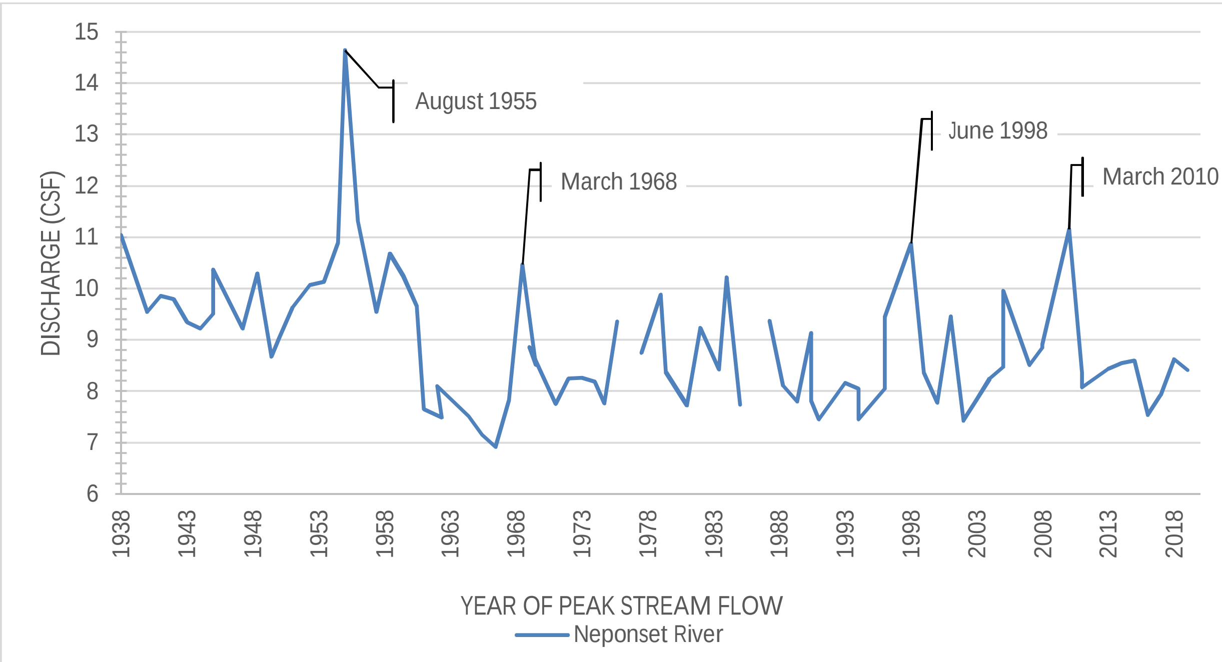


Figure 3-1. Plot of annual peak streamflow at a USGS stream gage number 01105000 near Walpole, along the Neponset River.

Flooding and Climate Change

The risk of flooding and flood-related impacts are likely to intensify with a changing climate, including more severe and frequent rainfall events. Both mean and extreme precipitation in the Northeast region has increased during the last century, with the highest number of extreme events occurring over the last decade. Continued increases in frequency and intensity of extreme precipitation events are projected. According to the Fourth National Climate Assessment, "Moderate flooding events are expected to become more frequent in most of the Northeast during the 21st century because of more intense precipitation related to climate change" (Dupigny-Giroux, et al., 2018).

> In Massachusetts, observed increases in rainfall and the intensity and frequency of extreme precipitation events are expected to continue with changing climate conditions. Given current climate change projections, flooding and flood-related impacts are likely to intensify.

Currently, the Boston Harbor and Charles River Basins, which Walpole is a part of, receives an average of 46.1 inches of rainfall per year. By mid-century, this is expected to increase by as much as 6.2 inches, and by the end of the century, it is expected to increase up to 9.0 inches. Driving this increase in average annual precipitation is an increase in the frequency and intensity of extreme rainfall events. From 1958-2010, there was a 70% increase in precipitation during heavy rainfall events in the Northeast (Melillo, Richmond, T.C., & Yohe, G.W., 2014). The total amount of precipitation falling in the heaviest 1% of rainfall events is expected to continue to increase according to resilient MA and the Fourth National Climate Assessment. More frequent and intense rainfall will lead to higher incidence of flooding in communities like Walpole, as this rainfall can overwhelm the soil's ability to absorb water, increase the burden on the stormwater system, and flood waterbodies. The risk of riverine and drainage-related flooding is expected to increase, and bridges, roads, dams, and other infrastructure will be more susceptible to flood damages.

Given this trend, the community of Walpole faces an increasing risk of flooding and storm-related damages as large storms and floods become more common. In addition to climate change, some parts of the community are susceptible to future development pressure that, if not appropriately controlled, could increase floodplain encroachments, reduce the natural water-absorbing capacity of the land, increase impervious surfaces and stormwater runoff, and worsen flooding impacts.

Existing Flood Mitigation and Resiliency Measures

Flood Control Structures

Both the Neponset Reservoir Dam in Foxborough and the Willet Pond Dam in Norwood are upstream of the Town of Walpole and provide some flood storage – although this was not their intended purpose when constructed. Both dams were constructed to provide water for the mill industry but have since been used primarily for recreation.

Several natural wetland areas located in the far western portion of Walpole along the Charles River and Norfolk town boundary are part of the Charles River Natural Valley Storage Area, which are lands controlled by the U.S. Army Corps of Engineers to provide flood risk reduction for communities along the lower Charles River. Incidental structures such as culverts and bridge openings that restrict flow enhance the natural storage capacity of these wetlands. The project was authorized as a multi-purpose project for flood control, recreation and natural resources management (USACE, 2017).

National Flood Insurance Program (NFIP)

Walpole participates in the National Flood Insurance Program (NFIP), established by Congress in 1968 to provide flood insurance to property owners in participating communities. This program is a direct agreement between the federal government and the local community that flood insurance will be available to residents in exchange for the community's compliance with minimum floodplain management requirements such as the adoption of a floodplain management or flood damage prevention ordinance. In order for property owners to purchase flood insurance through the NFIP, their community must be in good participant standing in the NFIP. Communities participating in the NFIP must:

- Adopt the FIRMs as an overlay regulatory district or through another enforceable measure
- Require that all new construction or substantial improvement to existing structures in the Special Flood Hazard Area will be compliant with the construction standards of the NFIP and State building code, which is implemented at the local level by municipal building officials
- Require additional design techniques to minimize flood damage for structures being built in high hazard areas, such as floodways or velocity zones.

3.2 Areas Vulnerable to Flooding

To implement floodplain management programs and for flood insurance rates, federal and state agencies and local communities use flood events of a magnitude which are expected to be equaled or exceeded once, on the average, during any 10-, 50-, 100-, or 500-year period (recurrence interval). These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long term average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year (FEMA, Revised 2015). For example, a 100-year flood is not a flood that occurs every 100 years. In fact, the 100-year flood has a 26-percent chance of occurring during a typical 30-year mortgage (USGS, 2010). Figure 3-2 depicts the 1-percent and 0.2-percent annual chance Special Flood Hazard Areas (FEMA flood zones) in Walpole based on the current FEMA Flood Insurance Rate Maps.[2]

The majority of the Town of Walpole is located within the Neponset River (Boston Harbor) watershed and its several major tributaries: Mine Brook, Spring Brook and School Meadow Brook. The 29 mile Neponset River flows from the Neponset Reservoir in Foxborough, near Gillette Stadium, and empties into Dorchester Bay. A smaller southwestern portion of the Town is located in the Charles River watershed. Both the Neponset River and the Charles River watershed boundaries are shown in Figure 3-2. Although these river's wetlands provide invaluable flood storage capacity, development along the river and stream corridors is still at risk of flooding. Furthermore, flooding occurs at isolated locations throughout Walpole due to undersized or outdated drainage infrastructure.

[2] FEMA is working with USGS and other federal, state, and local partners to identify flood risk and help reduce that risk through the Risk Mapping, Assessment and Planning (Risk MAP) program. Risk MAP is designed to help increase the purchase of flood insurance and increase the public's awareness of flood prone structures and potential mitigation measures, including update of FEMA flood zone mapping. Under this program, updated Preliminary Flood Insurance Rate Maps (FIRMs) and a Preliminary Flood Insurance Study (FIS) was released for Norfolk County in June 2020 (FEMA, 2020).

Documented locations of flooding in the community were identified based on information obtained from the FEMA Flood Insurance Study report for Norfolk County, the updated local hazard mitigation plan, input from the Project Steering Committee, municipal staff, and residents. The table in Appendix A lists documented flooding locations including specific sites such as individual road-stream crossings, bridges, streets, etc., as well as more generalized areas of flooding or erosion, such as entire neighborhoods or stream reaches. More detailed information on these flood-prone areas can be found in the table in Appendix A.

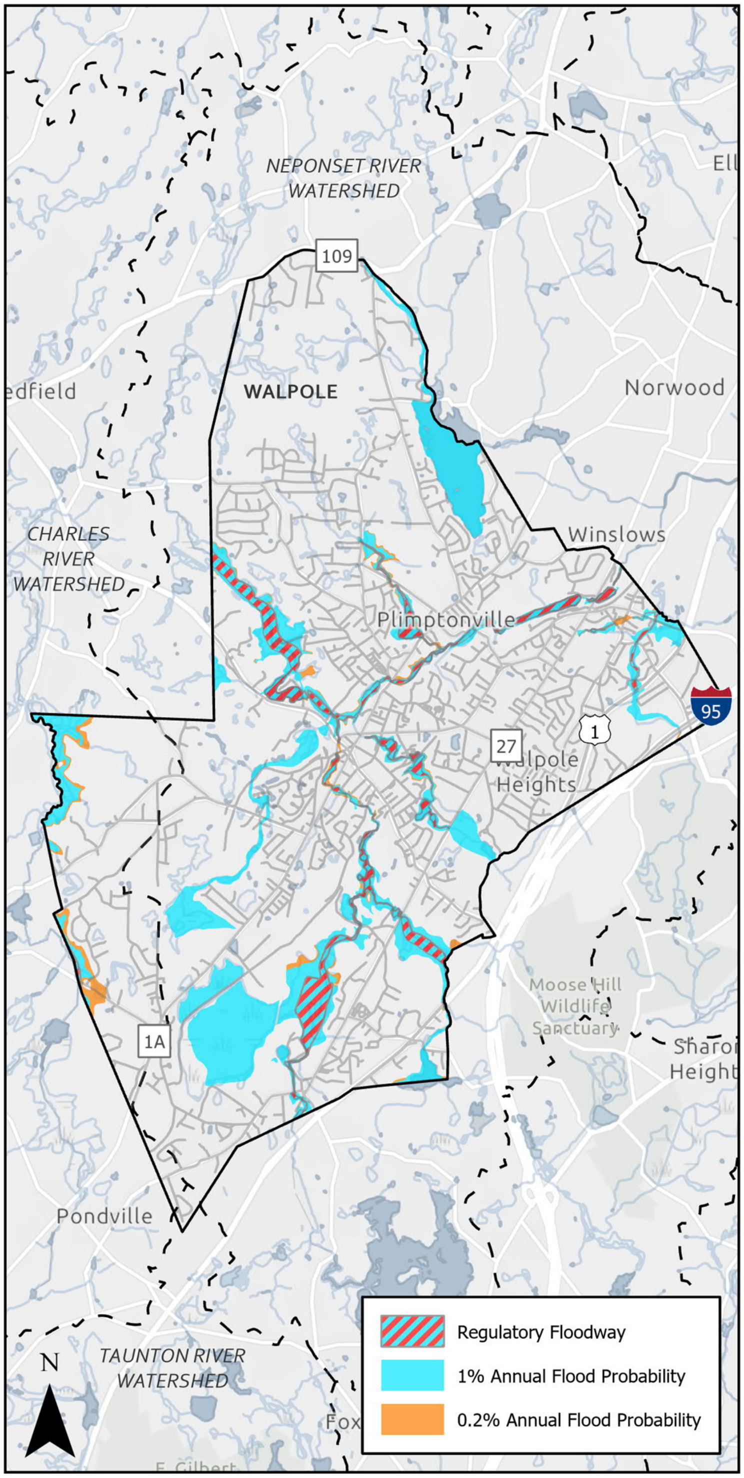


Figure 3-2. Special Flood Hazard Areas in Walpole.

3.3 Water Infrastructure

This section provides an overview of the water-related infrastructure in Walpole that was the focus of the vulnerability assessments and climate adaptation planning. Section 4 describes an assessment of both types of water infrastructure in Walpole to further evaluate the vulnerability of specific sites and facilities to flooding and flood-related impacts.

Road-Stream Crossings

There are an estimated 300+ road-stream crossings in Walpole, which include crossings of mapped "blue-line" perennial and intermittent streams (Figure 3-3). Numerous other crossings of unmapped streams likely exist throughout Walpole, as well as a significant number of smaller crossings that convey stormwater drainage beneath roads. Crossings of unmapped streams and drainage crossings were not included in the assessment as they typically pose a smaller risk of significant flooding than crossings that convey flowing streams. As is the case with much of the transportation infrastructure in New England, the road-stream crossings in the community include a variety of culverts and bridges, many of which are known or believed to be undersized, in poor structural condition, and susceptible to damages during flood events.

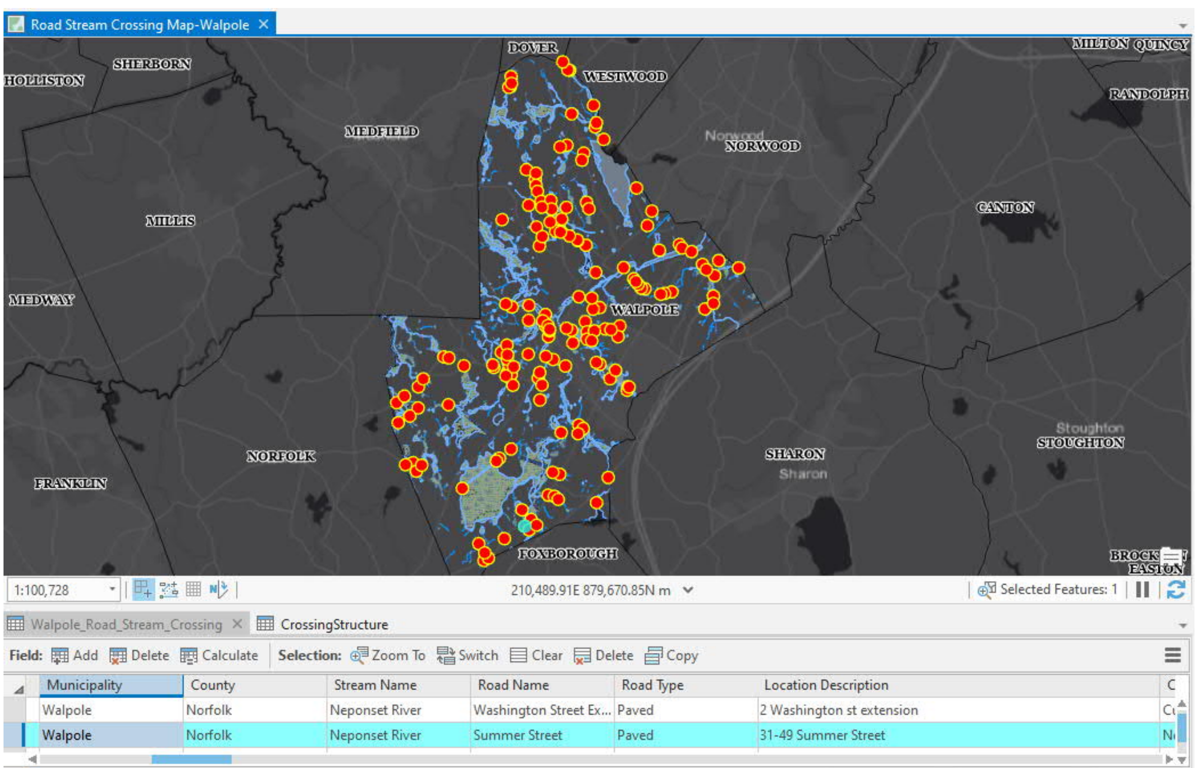


Figure 3-3. GIS interface to assess road-stream crossings in Walpole.

Stormwater Infrastructure

The Town of Walpole is served by storm drainage systems (catch basins, manholes, storm drainage pipes, outfalls, etc.) that collect and convey runoff from public roads, parking lots, buildings, and other areas to nearby rivers, streams, lakes, ponds, and wetlands (Figure 3-4). Storm drainage infrastructure tends to be more prevalent in the developed parts of the town and village centers, in residential subdivisions, and along the major transportation corridors. Storm drainage infrastructure includes areas of older drainage systems with known or suspected capacity issues that can result in localized flooding during heavy rain events. Stormwater runoff from impervious surfaces contributes to both localized drainage-related flooding and riverine flooding. The use of green infrastructure practices throughout the watershed can help to infiltrate and slow runoff, which can mitigate localized flooding and help to reduce peak discharges in rivers and streams, as well as provide water quality and other community benefits.

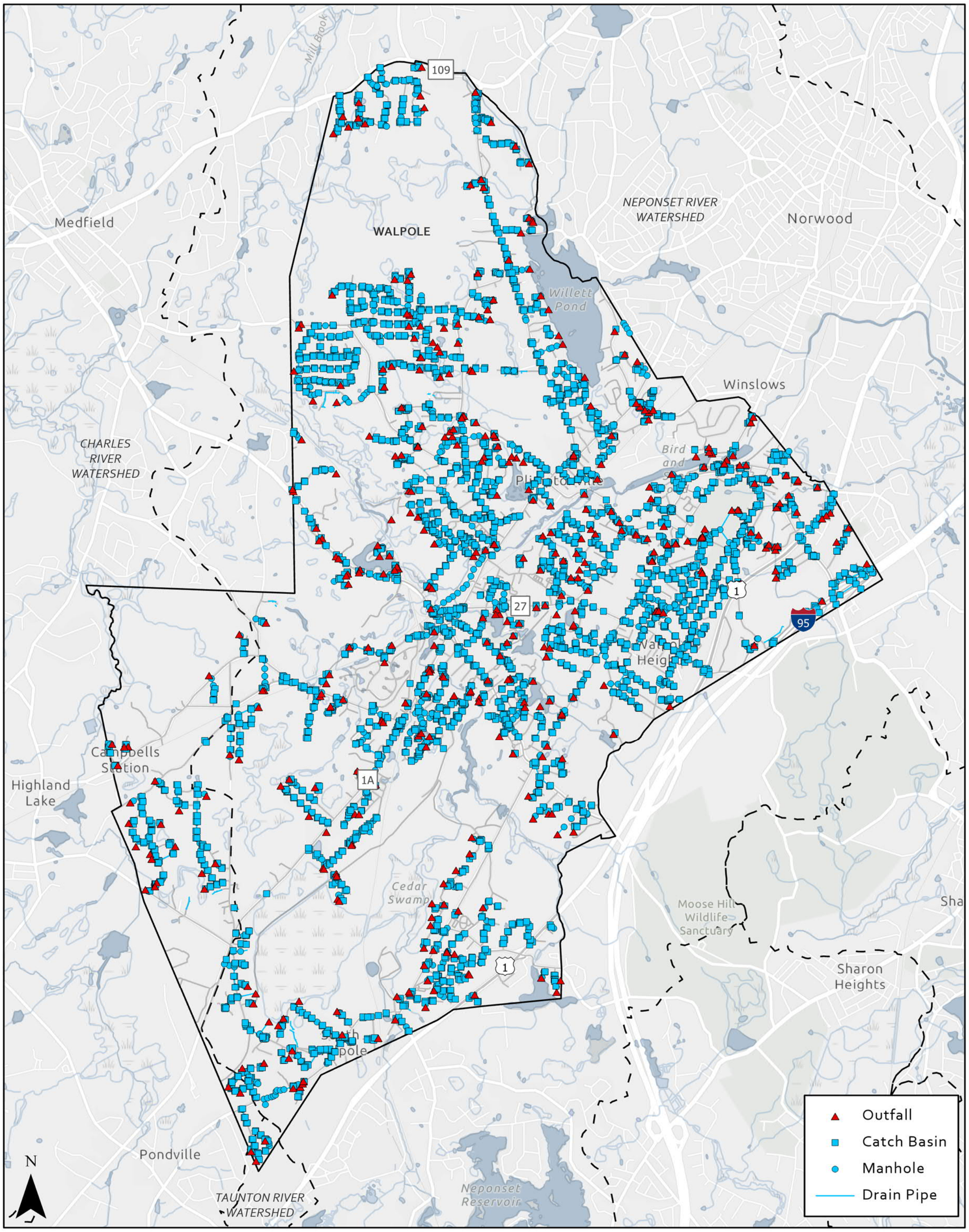


Figure 3-4. Stormwater infrastructure in Walpole.

4 Vulnerability Assessments

4.1 Road-Stream Crossings

Why are Roads Vulnerable?

Road-stream crossings (i.e., culverts and bridges) are an integral part of transportation infrastructure. Inadequate or undersized road-stream crossings can be infrastructure liabilities and flooding hazards for communities and can serve as barriers to the passage of fish and other aquatic organisms. Poorly designed and undersized crossings can increase flooding of upstream and adjacent areas or have significant impacts to the transportation system. Across the U.S., culvert failures cost communities millions of dollars every year in property and infrastructure damages (MADER, June 2012). Culverts can also serve as barriers to the passage of fish and other aquatic organisms along a river system, altering aquatic habitat and disrupting river and stream continuity.

Common Stream Crossing Problems

Undersized or Inadequate Crossings

Undersized or inadequate crossings can restrict natural streamflow during high flows, causing scour and erosion, backing up water and depositing sediment behind the crossing, creating higher flow velocity and erosion downstream, clogging, and washout. Crossings should be large enough to accommodate high flows and to pass fish and other wildlife.

Shallow Crossings

Shallow crossings have water depths that are too low for many organisms to move through, and the bottom may lack appropriate stream bed material. Crossings should have an open bottom or should be buried into the streambed. Natural substrate should be used within the crossing, it should match the upstream and downstream substrates, and it should resist displacement during floods.

Perched Crossings

Perched crossings are above the level of the stream bottom at the downstream end, restricting upstream passage by fish and other aquatic organisms and contributing to downstream bed scour. Crossings should be open-bottomed or embedded into the bottom of the stream channel to prevent perching.

As precipitation events become more intense and less predictable as a result of climate change, inadequate or undersized road-stream crossings throughout the Town of Walpole are expected to pose a greater threat of failure; flooding damage to homes and businesses, transportation infrastructure, and utilities; and stream channel erosion.

Assessment Methods

Stream Crossing Field Surveys

Road-stream crossings were initially identified based on review of aerial imagery, flood mapping, and other local, county, or state-wide data layers. The Project Steering Committee provided additional information on locations of known culvert/bridge infrastructure where flooding was already a concern. The field assessment included all crossings Town-wide which could reasonably and safely be assessed (this excluded crossings of Interstate 95 that could not be accessed due to safety and access concerns).

In total, 170 road-stream crossings throughout the Town were assessed during the fall of 2019 via field surveys and followed-up with desktop vulnerability assessments. As shown in Figure 4-1, the crossings span two watersheds. The assessment is documented in a separate *Road-Stream Crossing Assessment Technical Memorandum* (Fuss & O'Neill, 2020a) (Appendix B).

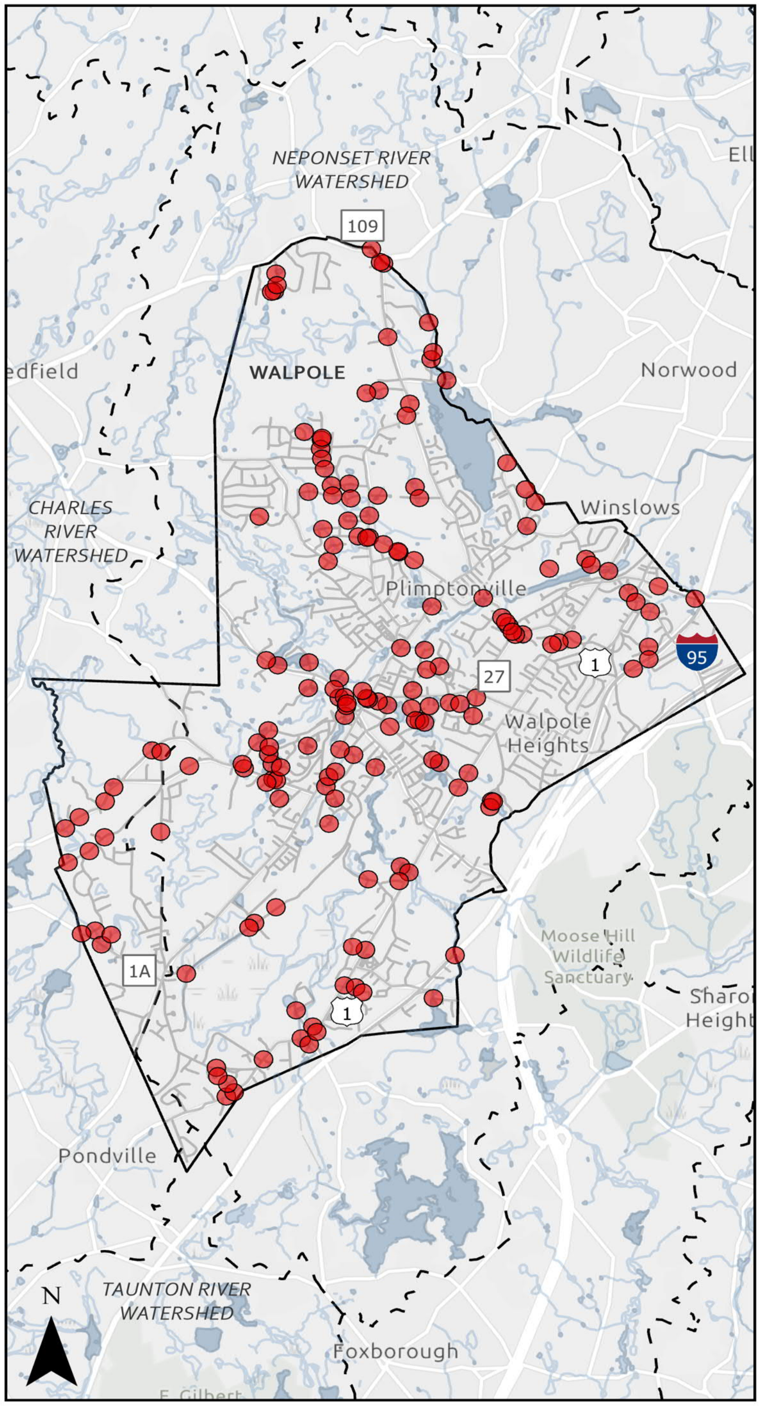


Figure 4-1. Road-stream crossings selected for assessment in the Town of Walpole. Major watershed boundaries are indicated by dotted lines.

Road-stream crossing assessment procedures were adapted from the 2016 North Atlantic Aquatic Connectivity Collaborative (NAACC) stream crossing survey protocol for assessing aquatic connectivity, and also incorporated structural condition assessment protocols from the 2017 NAACC Culvert Condition Assessment Manual, as well as collection of other field data for evaluating geomorphic vulnerability, hydraulic capacity, and potential flooding impacts to infrastructure and public services.

Assessment Findings

The major findings of the assessment are as follows:

- An estimated 36% of the assessed stream crossings are hydraulically undersized relative to their ability to convey the 10-year peak flow. This number increases to 42% for expected future conditions under climate change. Figure 4-2 shows the percentage of existing and predicted future hydraulic capacity ratings of the assessed stream crossings. Hydraulic capacity rating reflects the largest recurrence interval peak discharge that a structure can convey without failing. Circular pipes and box culverts make up the majority of the hydraulically undersized stream crossings.

- 13% of the assessed structures in the community have a severe or significant geomorphic impact (Figure 4-3). Geomorphic vulnerability of a culvert or bridge refers to the likelihood of potential impacts of the structure on channel stability based on consideration of the physical characteristics of the structure and stream channel. Crossings with the highest geomorphic risk include crossings on Smith Avenue over an unnamed tributary to Cobb's Pond and Warwick Road over an unnamed tributary to the Neponset River.

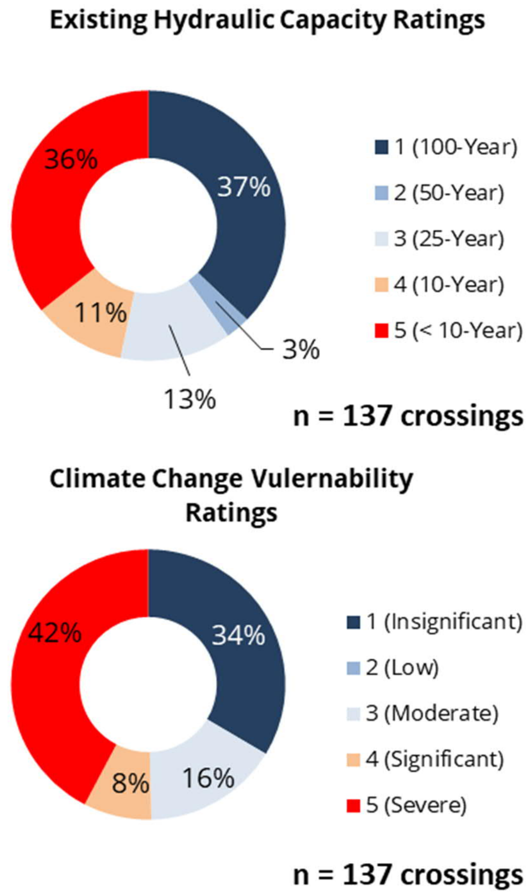
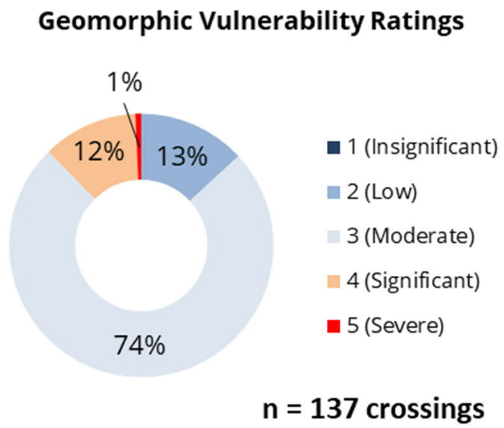


Figure 4-2. Percentage of assessed crossings by existing and future hydraulic capacity ratings.

- 29% of the assessed structures were rated as critical relative to structural condition, while 71% were rated as either good or satisfactory (Figure 4-3). Of the forty crossings that rated highest for structural risk based on structural condition and potential for flooding impacts, 10 are also among the top priority crossings overall.



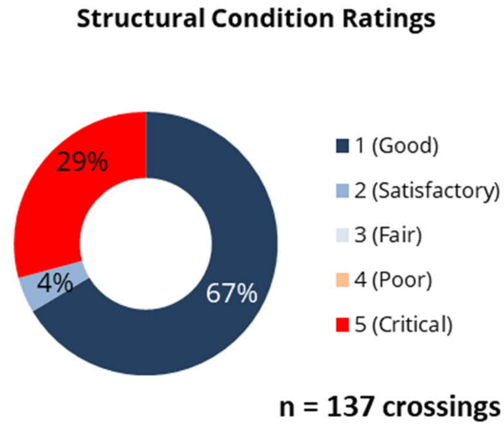


Figure 4-3. Percentage of assessed crossings by geomorphic vulnerability (left) and structural condition (right) ratings.

- 19% of stream crossings within the Town provide for full passage of aquatic organisms (Figure 4-4). The percentage of assessed structures that were identified as moderate to severe barriers (41%) to aquatic organism passage is consistent with other regional stream crossing assessments in New England. Bridges generally have the largest openings and provide the greatest continuity, while box culverts and circular pipes are the greatest barriers to aquatic organism passage. The two crossings that received the highest AOP benefit scores—that is, crossings which are barriers to aquatic organism passage but which are also at locations where improved passage would have the greatest benefit—are located on Mill Pond Road over Mine Brook and Plimpton Street over Plimpton Pond. The majority of the assessed crossings received low to moderate AOP Benefit Scores, indicating that the crossings with the most severe aquatic barriers are located in areas where habitat quality and other characteristics likely limit the ecological benefit to crossing removal or replacement.

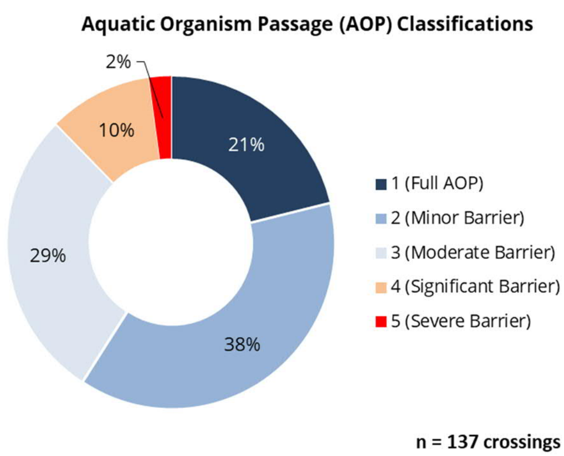


Figure 4-4. Percentage of assessed crossings by aquatic organism passage (AOP) classification.

- 23% of the assessed structures are rated as high priority for upgrade or replacement (Figure 4.5). The priority ratings are based on the combined consideration of hydraulic capacity, structural condition, geomorphic vulnerability, aquatic organism passage, and flooding impact potential. 63% were categorized as medium priority, and 14% were categorized as low priority.

Three crossings received the highest Scaled Crossing Priority Score of 0.84. These include a crossing on Smith Street near the intersection with Gould Street over an unnamed tributary to Cobb's Pond that received the highest possible Structural Risk Score and is located in an area with high flood impact potential. A crossing off of Warwick Road that conveys an unnamed tributary to the Neponset River and is buried under Wall Street received the highest Scaled Crossing Priority Score as a result of high structural, hydraulic and climate change risk, as well as high potential for flood impacts. The crossing on Main Street over an unnamed tributary to the Neponset River at the outlet of Cobb's Pond is the third crossing to receive a Scaled Crossing Priority Score of 0.84, due to high Hydraulic and Climate Change risk scores and high potential for flood impacts.

Other high-scoring crossings include 7 crossings on the main stem of the Neponset River on Lewis Avenue, West Street, Elm Street, Summer Street, Plimpton Street, Main Street, and Robbins Road. The crossings on Lewis Avenue, West Street, Elm Street, Summer Street, Main Street and Robbins Road received high scores due to high Hydraulic and Climate Change Risk Scores and high potential for flood impacts. The crossing on Plimpton Street was among the top-scoring crossings due to a high Aquatic Benefit Score (20) and a moderate Structural Risk Score (15).

4.2 Stormwater Infrastructure

Why is Stormwater Infrastructure Vulnerable?

Stormwater runoff from buildings, pavement, and other compacted or impervious surfaces contributes to drainage-related and riverine flooding. Stormwater runoff is also a source of nonpoint source pollution and a cause of water quality impairments, particularly in developed areas where impervious cover exceeds 20%. There are a number of drainage-related flooding problems in developed areas of Walpole due to outdated or inadequate drainage systems, and stormwater runoff volumes exacerbate riverine flooding during both small and large storms.

> A green infrastructure approach reduces stormwater volumes and runoff rates, reduces the risk of downstream flooding, and provides incremental flood benefits as each component is installed.

Rainfall in New England is expected to continue to increase due to climate change, which is expected to increase the risk of river-related flooding in the Town of Walpole. Development pressure in the region will continue to result in the conversion of natural areas to impervious surfaces, putting additional stress on existing drainage systems and contributing further to riverine flooding and water quality issues if such development and associated stormwater impacts are not managed appropriately.

Green Infrastructure

Green infrastructure, also referred to as "green stormwater infrastructure" and "low impact development or LID," is an alternative approach to traditional stormwater management. The green infrastructure approach encourages the infiltration of stormwater into the ground close to where precipitation falls, similar to what occurs in undeveloped areas. By using natural materials including vegetation and soils, these practices restore natural stormwater recharge and filtration processes while reducing downstream flooding. Additionally, green infrastructure can be constructed in stages, as funding and resources are available. Unlike traditional drainage systems that need to be constructed in whole to provide any benefit, green infrastructure solutions can provide incremental benefits as they are implemented.

Green infrastructure includes a variety of stormwater management practices, such as bioretention, engineered wetland systems, permeable pavement, green roofs, green streets, infiltration planters, tree boxes, and rainwater harvesting. These practices capture, manage, and/or reuse rainfall close to where it falls, thereby reducing stormwater runoff and keeping it out of drainage systems and receiving waters.

In addition to reducing polluted runoff and improving water quality, green infrastructure can improve flow conditions in streams and rivers by infiltrating water into the ground, thereby reducing peak flows during wet weather and sustaining or increasing stream base flow during dry periods, which can be important for aquatic habitat, fisheries, and groundwater supplies. When applied throughout a watershed, green infrastructure can help mitigate flood risk and increase flood resiliency. At a smaller scale, green infrastructure can also reduce erosive velocities and streambank erosion. Green infrastructure and LID are the preferred approach for stormwater management in Massachusetts.

Green Infrastructure Assessment

A green infrastructure assessment was performed for the Town of Walpole to identify green infrastructure retrofit opportunities that increase flood resiliency and improve or protect water quality. The assessment consisted of: 1) a screening-level evaluation to identify areas with the greatest feasibility for and potential benefits from green infrastructure retrofits; 2) field inventories of the most promising green infrastructure retrofit opportunities in the watershed (see Figure 4-5 and Table 4-1); and 3) development of concept designs for 10 retrofit sites. The assessment is documented in a separate *Green Infrastructure Assessment Technical Memorandum* (Fuss & O'Neill, 2020b) (Appendix C). Section 5 presents recommended green infrastructure design concepts and other related recommendations for the community.

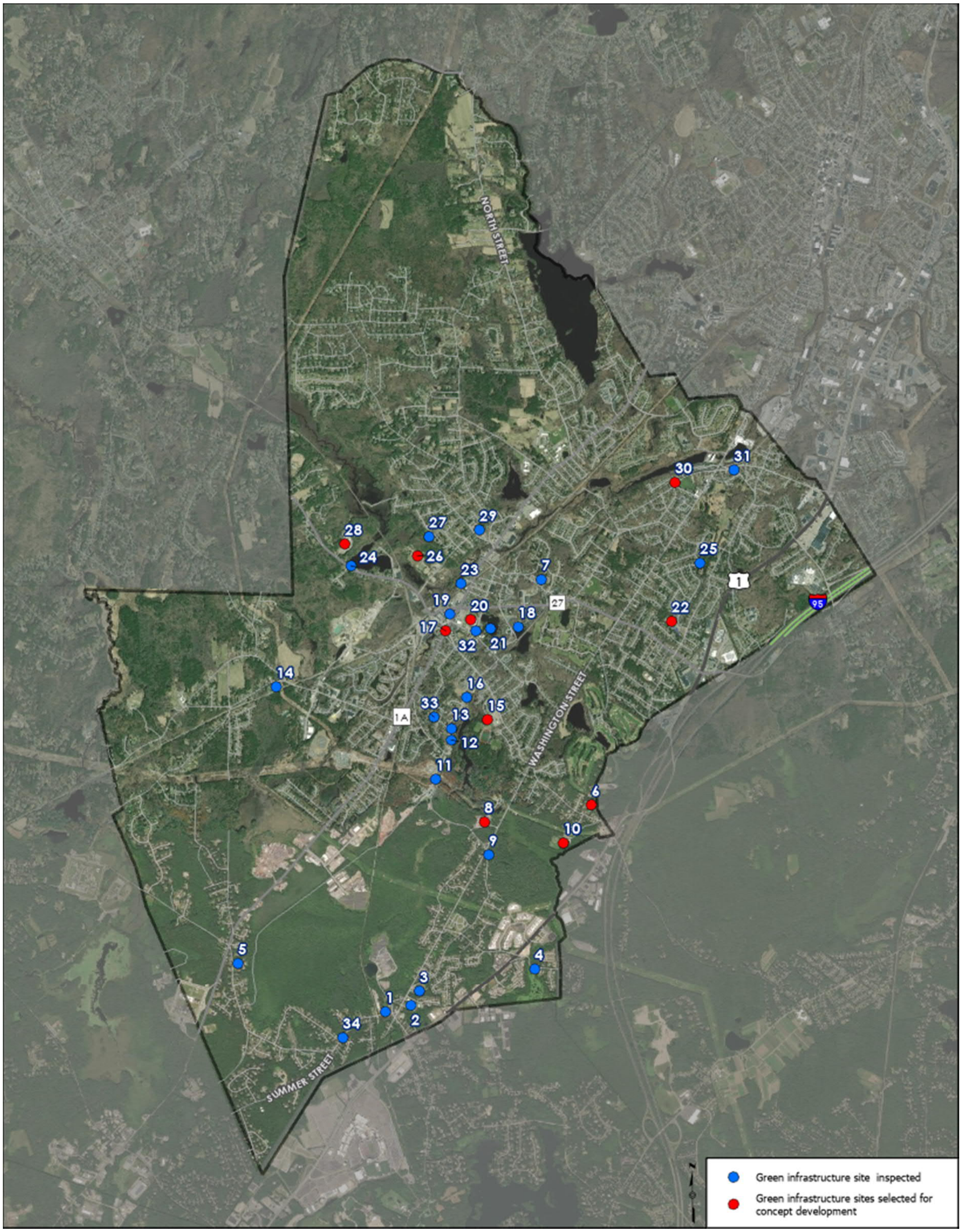


Figure 4-5. Spatial distribution of scaled crossing priority scores for all assessed crossings. Red dots indicate high priority crossings; light blue dots indicate medium priority crossings; dark blue dots indicate low priority crossings.

Table 4-1. Potential green infrastructure retrofit sites selected for field investigation.

Site No.	Site Name/Description	Address	Owner
1	Fire Station 3	Summer Street	Town of Walpole
2	Boyden Elementary School	1852 Washington Street	Walpole Public Schools
3	Terrace Hill Cemetery	Washington Street	Town of Walpole
4	Pine Street at School Meadow Brook	Across from 158 Pine Street	Town of Walpole
5	Teton Way	Across from 5 Teton Way	Town of Walpole
6	Hawthorne Drive	Across from 3 Hawthorne Drive	Town of Walpole
7	Kendall Street Cemetery	Kendall Street	Town of Walpole
8	DPW Yard	1385 Washington Street	Town of Walpole
9	Town Forest	Washington Street at South Street	Town of Walpole
10	Jarvis Farm	691 Common Street	Town of Walpole
11	South Street at Colony Drive	~299 South Street	Town of Walpole
12	South Street Trailhead Parking	Across from 221 South Street	Town of Walpole
13	South Street at Brown Drive	62 South Streets	Town of Walpole
14	Walpole Little League	West Street and Lincoln Road	Town of Walpole
15	Walpole High School	275 Common Street	Walpole Public Schools
16	South Street at Neponset River	62 South Street	Town of Walpole
17	Town Common	Main Street and Common Street	Town of Walpole
18	Walpole Housing Authority	8 Diamond Pond Terrace	Housing Authority
19	Glenwood Ave Parking	973 Main Street	Town of Walpole
20	Town Hall/Municipal Parking	135 School Street	Town of Walpole
21	Memorial Playground	144 School Street	Town of Walpole
22	Old Post Road School	99 Old Post Road	Walpole Public Schools
23	Neponset View Terrace	Neponset View Terrace	Housing Authority
24	Turner Pond	341 Elm Street	Town of Walpole
25	Pall Mall	6 Pall Mall	Town of Walpole
26	Johnson Middle School	111 Robbins Road	Walpole Public Schools
27	Dudley Street	34 Albany Road	Housing Authority
28	Elm Street School	415 Elm Street	Walpole Public Schools
29	Rural Cemetery	Pemberton at North Street	Town of Walpole
30	Ellis Field	East Street at June Street	The Trustees of Reservations
31	Studio East	5 Wolcott Avenue	Town of Walpole
32	School Street at Stone Street	143 School S. Street	Town of Walpole
33	Oak Hill Drive	15 Brown Drive	Town of Walpole
34	135 Summer Street	135 Summer Street	Town of Walpole

5 Adaptation Recommendations

This section describes recommended adaptation measures that the Town of Walpole can take to reduce the vulnerability of their water infrastructure to flooding and climate change impacts. The adaptation measures include site-specific measures focused on water-related infrastructure at a single location (e.g., a specific road-stream crossing or green infrastructure retrofit site) as well as policy or regulatory measures to increase resilience town-wide.

Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise. Well-planned, early adaptation action can save money and lives later.

Implementation of the adaptation recommendations identified in this plan will require significant financial and technical assistance. The adaptation recommendations are not intended to be implemented all at once, but are meant to be implemented over time by the Town and other public and private partners, with grants and additional sources of funding. The plan recommendations include short-term and long-term measures, which could be implemented as funding becomes available and when opportunities arise. For example, a stream crossing replacement or green infrastructure installation may be more cost-effective if implemented in conjunction with a planned roadway improvement project.

Walpole should implement high-priority site-specific adaptation measures in combination with policy/regulatory measures. Well-informed municipal policies and regulations can help communities become more resilient to flooding by preserving undeveloped land in the watershed, siting development in locations less vulnerable to flooding, and promoting designs that reduce runoff and are less likely to be damaged in a flood. In terms of site-specific adaptation measures, the community should focus on replacing and upsizing high-priority road stream crossings and implementing green infrastructure retrofits. These types of projects will have more immediate and tangible flood resilience benefits by upgrading vulnerable infrastructure and providing highly visible projects with other public benefits.

The remainder of this section describes the recommended adaptation measures presented in this resiliency plan, organized by water infrastructure type. Each sub-section includes an adaptation goal statement, a brief description of the flood-related vulnerabilities, and a description of recommended adaptation measures including a proposed timeframe and key partners for implementing the recommendations. Planning-level cost estimates are provided for some site-specific recommendations, while relative costs or a range of typical costs are presented for other recommendations. A recommendation summary tailored to the town is provided in Appendix D.

5.1 Road-Stream Crossings

Adaptation Goal: Reduce the flood and erosion hazards posed by culverts and bridges, and restore stream connectivity for fish and other aquatic organisms.

Replacing Outdated or Inadequate Crossings – Stream and Flood Friendly Culverts

Replacing outdated or inadequate crossings with crossings that maintain natural flow and substrate conditions enhances the resiliency of the transportation system, reduces expensive erosion and structural damage, reduces flood impacts on upstream and neighboring properties, and increases stream continuity for aquatic organism passage. Better standards and more effective design are critical for enhancing the resiliency and ecological benefits of new and replacement stream crossings. The text box on the following page highlights common stream crossing standards and elements of effective crossing designs.

Massachusetts has adopted stream crossing standards that promote stream continuity and flood resilience. The *Massachusetts River and Stream Crossing Standards* (*Stream Crossing Standards*) serve as comprehensive, state-specific guidance for the Commonwealth and were last revised in 2012. The *Massachusetts Stream Crossings Handbook*, prepared by the Division of Ecological Restoration, incorporates the *Stream Crossing Standards*, while the U.S. Army Corps of Engineers' Massachusetts General Permit and the Massachusetts 401 Water Quality Certification require these or similar standards be met. Further, the Massachusetts Wetlands Protection Act requires all new crossings to meet the *Stream Crossing Standards* and all replacement crossings to meet the standards to the maximum extent practicable. The Massachusetts Department of Transportation's *Stream Crossing Handbook* was originally published in 2010 as guidance for the design of bridges and culverts for wildlife passage at freshwater streams. MassDOT is in the process of updating its *Handbook* to reflect current best practices for design of replacement crossings including geomorphic and climate resilience considerations, current stream crossing regulations, and technical guidance for municipalities.

> Well-designed crossings should span the stream and banks, maintain comparable water velocities, have a natural streambed, and create no noticeable change in the river.

Crossings designed to meet the *Massachusetts River and Stream Crossing Standards* have been found to be extremely effective in safely passing water, sediment, and debris during floods, while remaining viable routes for emergency personnel and residents (MADER, June 2012). While upgrading culverts to larger and more flood-resilient and stream-friendly designs can be up to 50%-100% more expensive than in-kind replacements in the short term, long-term costs are significantly reduced as the road crossing is able to survive larger precipitation events and generally requires less maintenance. When maintenance and replacement are considered, the average annual cost of an upgraded crossing can be lower over its lifetime than that of an undersized crossing over the same time (Industrial Economics, Incorporated, January 2015; Levine, August 2013; Gillespie, et al., February 2014). Upgraded stream crossings are even more cost-effective when climate change considerations (e.g., more frequent intense storms) are factored in.

Massachusetts River and Stream Crossing Standards

Crossing Type

Bridges and bottomless arches, 3-sided box culverts, and open-bottom culverts are preferred and should be used whenever possible.

Embedment

Box and pipe culverts, if used, should be embedded into the streambed to at least 20 percent of the culvert height at the downstream invert (a minimum of 2 feet), used only on "flat" streambeds (slopes no steeper than 3 percent), and installed level.

Substrate

Natural substrate (rocks, gravel, etc.) should be used within the crossing, and it should match the upstream and downstream substrates. It should resist displacement during floods and should be designed so that appropriate material is maintained during normal flows.

Crossing Span/Width

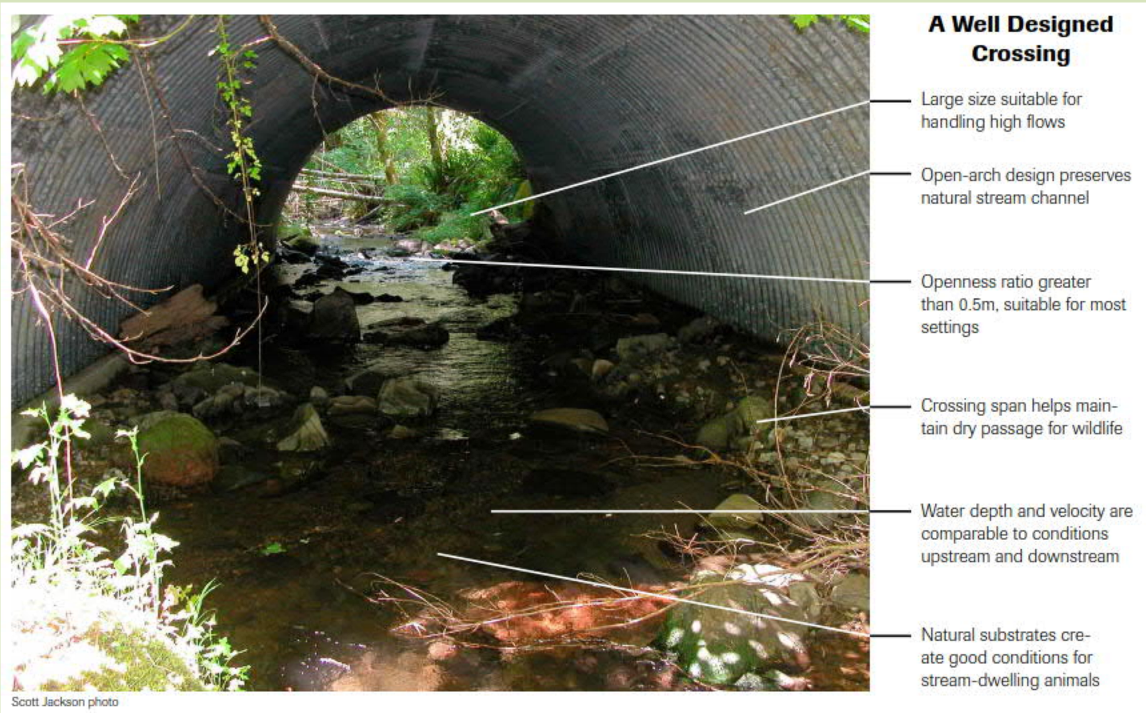
The crossing opening should be at least 1.2 times the bankfull width of the stream, measured bank to bank at the ordinary high-water level or edges of terrestrial, rooted vegetation.

Openness

The crossing should have an openness ratio (cross-sectional area divided by crossing length) of at least 0.82 feet, with 1 to 1.5 feet preferred. The crossing should be wide and high relative to its length.

Water Depth and Velocity

At low flows, water depths and velocities should be the same as they are in natural areas upstream and downstream of the crossing.



Source: Massachusetts Stream Crossings Handbook (MADER, June 2012)

Recommended Adaptation Measures

Table 5-1 provides a summary of recommended site-specific and policy/regulatory adaptation measures relative to road-stream crossings in Walpole. Site-specific design recommendations and additional discussion of the policy and regulatory recommendations follow the table.

Table 5-1. Adaptation recommendations for road-stream crossings.

	Adaptation Measure	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
Site-Specific Recommendations					
1.	Upgrade existing vulnerable stream crossings by replacing crossings with more resilient and ecologically-friendly designs.	The Town of Walpole (MassDOT for crossings under state jurisdiction)	5-10+ years and as opportunities arise	$$$ to $$$$$	MVP Action Grant Program, DER Culvert Replacement Municipal Assistance Grant Program, MassDOT Small Bridge Program and Chapter 90 funding, FEMA flood hazard mitigation assistance funding
Policy and Regulatory Recommendations					
1.	Incorporate priority stream crossings identified in this study into local hazard mitigation plans. Update and integrate local comprehensive land use plans and hazard mitigation plans.	The Town of Walpole, Metropolitan Area Planning Council (MAPC)	1-2 years	$	Municipal funds
2.	Update design storm precipitation amounts in local land use regulations and policies to promote more resilient road crossing design.	The Town of Walpole	2-5 years	$$	Municipal funds
3.	Establish adequate, sustained sources of funding.	The Town of Walpole, State Agencies	Ongoing	$$	See Site-Specific Recommendation 1
4.	Provide training to highway departments, engineers, and contractors.	The Town of Walpole, MassDOT	2-5 years	$$	Municipal/state funds
5.	Implement ongoing inspection and maintenance programs.	The Town of Walpole	1-2 years and ongoing	$$	Municipal funds

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = Greater than $100,000

Site-Specific Recommendations

1. *Upgrade existing vulnerable stream crossings by replacing crossings with more resilient and ecologically-friendly designs.*

The Town of Walpole should replace existing vulnerable stream crossings with more flood-resilient and ecologically-beneficial designs. Replacement stream crossings should be upgraded to meet the *Massachusetts River and Stream Crossing Standards* whenever feasible.

The road-stream crossing vulnerability assessments classified stream crossings as high, medium, or low priority for upgrade or replacement. Table 5-2 lists the top-ranked high priority stream crossings. A complete list of all of the assessed stream crossings, including additional high, medium, and low priority crossings, is provided in the technical memorandum in Appendix B.

Note that the priority ratings are relative. Upgrade or replacement of higher-rated or higher-priority structures will generally provide greater overall benefits relative to flood resiliency and stream continuity based on a number of factors. The priority ratings are not meant as definitive recommendations since the ratings do not account for cost and other site-specific factors. The individual assessment ratings (i.e., hydraulic capacity, flooding impact potential, geomorphic vulnerability, and aquatic organism passage) should also be considered on a case-by-case basis when evaluating replacement and upgrade of specific structures. Crossings that are rated as medium or low priority overall, based on consideration of all four factors, may still be good candidates for replacement or upgrade to achieve a particular objective such as increased hydraulic capacity, improved geomorphic compatibility, or aquatic organism passage.

The text box following Table 5-2 provides a recommended approach for implementing crossing replacements based upon the vulnerability assessment priority ratings, as well as additional required site-specific data collection and analysis for permitting and design of individual crossings.

Crossing replacement design concepts were developed for the 10 highest rated stream crossings that were assessed. The concepts are intended to enhance the resilience of the stream crossings and river system by better accommodating extreme flows, providing for the passage of sediment and debris during floods, and providing for passage of aquatic organisms under normal flow conditions. Each two-page concept includes a description and photographs of existing conditions, key data and findings from the field assessment, a description of the proposed design concept, and a plan view drawing of the site conditions and proposed replacement crossing.

Planning-level cost estimates are also provided for each of the replacement concepts. Estimated costs are presented as screening-level cost ranges. The estimated costs include anticipated design and construction costs, which are based on costs of recent similar stream crossing replacement projects in the northeastern U.S.

Table 5-2. Top-ranked high priority crossings: road-stream crossing vulnerability assessment and prioritization results summary.

Road Name	Stream Name	Impact Score	Existing Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42099387127399	Warwick Road	Unnamed Tributary to Neponset River	5	25	25	15	25	9	25	0.84	High
xy42158337124241	Main Street	Unnamed Tributary to Neponset River	5	25	25	15	5	9	25	0.84	High
xy42165037124747	Smith Avenue	Unnamed Tributary to Cobbs Pond	5	20	20	20	25	9	25	0.84	High
xy42140017125451	Lewis Avenue	Neponset River	5	25	25	10	10	8	25	0.83	High
xy42165167124759	Gould Street	Unnamed Tributary to Cobbs Pond	5	20	25	15	5	8	25	0.83	High
xy42100287127547	Wall Street	Unnamed Tributary to Neponset River	5	25	25	15	5	6	25	0.81	High
xy42144837125583	West Street	Neponset River	5	25	25	15	5	4	25	0.79	High
xy42146067125557	Elm Street	Neponset River	5	25	25	15	5	4	25	0.79	High
xy42104937126264	Summer Street	Neponset River	4	20	20	20	4	15	20	0.75	High
xy42159347123453	Plimpton Street	Neponset River	3	3	3	9	15	20	15	0.75	High
xy42136137125876	Oak Street	Unnamed Tributary to Neponset River	4	20	20	12	20	12	20	0.72	High
xy42138987124132	Stone Street	Spring Brook	4	12	12	12	20	12	20	0.72	High
xy42139387124233	Stone Street	Unnamed Tributary to Railroad Pond	4	12	12	12	20	12	20	0.72	High
xy42140687125658	Main Street	Neponset River	5	20	20	15	5	12	20	0.72	High
xy42147047123565	Peach Street	Unnamed Tributary to Rainbow Pond	4	12	12	16	20	12	20	0.72	High
xy42149497125665	Robbins Road	Neponset River	4	16	20	12	4	12	20	0.72	High
xy42163417121799	Bird Drive	Unnamed Tributary to Neponset River	5	5	5	20	5	12	20	0.72	High
2173527125505	Sunnyrock Drive	Unnamed Tributary to Cobbs Pond	4	4	4	8	20	12	20	0.72	High

Recommended Approach for Stream Crossing Replacement

- Start with high-priority crossings identified in this assessment.
- Consider other upstream and downstream crossings (including additional high-priority, intermediate- and low-priority crossings) on the same river/stream system.
- Generally replace downstream crossings first to:
    1. Avoid inadvertently increasing downstream peak flows at outdated or undersized stream crossings by enlarging upstream crossings, and
    2. Open up stream segments to passage of fish and other aquatic organisms by starting downstream and progressing upstream.

  Coordinate with upstream and downstream communities to implement projects on shared river systems.
- Lower-priority crossings downstream of high priority crossings should be considered for replacement if they are hydraulically undersized, have high geomorphic vulnerability, or are in poor structural condition.
- Include priority crossings in the Town's capital planning process.
- Implement upgrades as part of planned capital improvements such as road rehabilitation or reconstruction.
- Perform site-specific data collection, geotechnical evaluation, hydrologic and hydraulic evaluation, and structure type evaluation to support design and permitting (see below for typical requirements).

Site Assessment Needs for Stream Crossing Replacement

Geotechnical Evaluation

Perform subsurface investigation and soils analysis.

Site Reconnaissance and Wetland Delineation

Delineate wetlands, perform a riverbed substrate analysis to understand the existing riverbed substrate and provide data to calculate the design bed material; identify the type and integrity of stream grade controls; identify and flag bankfull width measurement locations and representative cross-sections to be surveyed upstream and downstream of culvert; determine appropriate reference reaches.

Topographic Survey

Perform topographic survey and include other relevant features such as wetlands and waterbodies, headwall/wingwall locations and elevations, centerline elevation of the road, and geotechnical boring locations, river longitudinal profiles, culvert invert elevations, top of culvert, representative cross-sections above and below the culvert, mean annual high water, property lines and roadway right-of-way.

Hydrologic and Hydraulic Study

Conduct a detailed hydrologic analysis of the site, using appropriate methods. Identify typical low flows, the bankfull discharge, and peak flows required for the engineering and design process. The hydraulic analysis should assess existing water depths, velocities and water surface profiles and potential upstream and downstream impacts of stream crossing modifications.

Traffic Analysis

Analyze the traffic over the project culvert, including volume, peak volume, and type of vehicle traffic.

Structure Type Selection

Compare various crossing types (3-sided culverts, arches, embedded box culverts, and large diameter pipes) based on relative construction cost, ease of construction, and anticipated benefits. For recommended alternative, provide opinion of probable cost and structure characteristics.

Policy and Regulatory Recommendations

1. *Incorporate priority stream crossings identified in this study into local hazard mitigation plans.*

Communities with FEMA-approved hazard mitigation plans are eligible to apply for Hazard Mitigation Grant Program funding from FEMA for measures identified in their plans. Stream crossing upgrade priorities need to be included in these plans before floods occur. Vulnerable stream crossings identified in this plan and the accompanying *Road-Stream Crossing Assessment Technical Memorandum* in Appendix B, particularly crossings identified as high- and medium-priority, should be identified in the hazard mitigation plans of the community.

The town should update and integrate their comprehensive land use plans and hazard mitigation plans. Coordinating these two planning processes can ensure that stakeholders involved in resilience planning, such as emergency managers, also help develop the comprehensive plan and that planners help develop the hazard mitigation plan. Future updates to comprehensive land use plans and hazard mitigation plans of the community should include or incorporate by reference recommendations of this Integrated Climate Resiliency plan.

2. *Update design storm precipitation amounts in local land use regulations and policies to promote more resilient road crossing design.*

The Rainfall Frequency Atlas of the United States, also known as Technical Paper 40 (TP-40), published by the U.S. Department of Commerce, National Weather Service (formerly the U.S. Weather Bureau) in 1961, has served as the primary source of precipitation frequency estimates used in the design of storm drainage systems and other water infrastructure in the United States. The TP-40 estimates are based on a limited and outdated data set that extends over only an average of 40 years, with the most recent data ending in 1958. The TP-40 estimates do not account for the increases in precipitation that have been observed at many locations over the past 60 years since they do not include most current precipitation data. The TP-40 estimates can therefore underestimate precipitation and runoff, particularly in the face of a changing climate.

Updated extreme precipitation data is available from Cornell University's Northeast Regional Climate Center (NRCC). The NRCC design storm rainfall amounts offer significant advantages over TP-40 since the design storm rainfall amounts are based on a much longer period of record, including more recent data. The most recent rainfall frequency statistics for the region were published by NOAA in October 2015 (revised 2019) in Atlas 14, Volume 10. This publication replaces TP-40 and supersedes the 2013 NRCC data products.

While NOAA Atlas 14 provides more reliable precipitation data for design purposes, it assumes climatic stationarity and therefore does not account for future climate change. The Northeast Climate Adaptation Science Center at the University of Massachusetts Amherst projects that, given a medium to high future emissions pathway, Walpole will see as much as nine inches of additional rainfall per year by the end of the century. More critically in terms of flood potential, the town could see up to 4.5 additional days with precipitation over one inch, with the greatest increases occurring during the winter season, when partially frozen ground reduces infiltration and further exacerbates flooding risk. Communities should account for potential climate change (i.e., more frequent and intense precipitation) in drainage and flood mitigation design policies and standards.

The Resilient MA Action Team (RMAT), an inter-agency steering committee responsible for implementation, monitoring, and maintenance of the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP), has developed draft climate resilience design standards and guidance. The focus of the RMAT standards is to integrate climate resilience in projects with physical assets owned and maintained by state agencies. When complete in early 2021, these tools will be accessible at ResilientMA.org, and are likely to become relevant to state grant-funded projects throughout the Commonwealth. The RMAT standards provide a consistent and scientifically-defensible methodology for determining appropriate design criteria values to account for estimated increases in the frequency and intensity of extreme precipitation and peak stream flow given future climate change projections.

At a minimum, stormwater and drainage-related infrastructure should be designed with storm intensities based on NOAA Atlas 14 (or NRCC atlas) to represent current precipitation conditions. For more resilient water infrastructure design, including design of replacement stream crossings, Walpole should consider using the methods presented in the RMAT standards for determining appropriate design criteria values for peak intensity 24-hour design storms and riverine peak discharge. The Town should also incorporate the updated MassDOT culvert design guidance into its local design policies for road-stream crossing replacement projects. Both the RMAT standards and updated MassDOT culvert design guidance are anticipated to be released in early 2021.

Note that the Massachusetts Department of Environmental Protection is in the process of updating design storm intensities as part of anticipated revisions to the *Massachusetts Stormwater Handbook* and state wetland regulations. The Town should revisit the recommendations relative to the revised design storm intensities that are expected to be issued as part of the updated Massachusetts Stormwater Handbook and state wetland regulations.

3. *Establish adequate, sustained sources of funding.*

With aging and vulnerable infrastructure in many places in Walpole, a sustained source of funding will be required to offset the higher initial cost of upgrading stream crossings, which can reduce future damages and save money in the long term. Funding for stream crossing upgrades is extremely limited, with local highway departments maintaining the majority of roads in the Town and carrying most of the financial burden for stream crossing improvements. In addition to FEMA post-disaster funding programs, other potential funding sources for crossing replacement include:

- Massachusetts Municipal Vulnerability Preparedness (MVP) Action Grant Program, which provides financial assistance to MVP-certified municipalities for implementation of climate adaptation and resilience projects.
- Massachusetts Division of Ecological Restoration Culvert Replacement Municipal Assistance Grant Program, which prioritizes culvert replacement projects with both public benefits (e.g., access to critical locations) and environmental benefits (e.g., aquatic connectivity).
- MassDOT Small Bridge Program, which provides financial support to cities and towns to replace or preserve bridges with spans between 10 and 20 feet.
- MassDOT Chapter 90 Funding, which provides funding for capital improvement such as road construction, preservation, and improvement projects including bridges.
- FEMA hazard mitigation assistance grant programs administered by the Massachusetts Emergency Management Agency, specifically, the Building Resilient Infrastructure and Communities (BRIC) program.
- Cost-share grant programs in which government agencies provide a portion of the funding through grant programs (e.g., the Eastern Brook Trout Joint Venture and grant programs of the National Fish and Wildlife Foundation) and the local town responsible for the crossing covers the remaining amount.

4. Provide training to highway departments, engineers, and contractors.

Training is recommended for local highway departments, engineers, and contractors involved in stream crossing replacement. A number of stream crossing training programs have been developed in Massachusetts:

- Massachusetts Rivers and Roads Training, MassDOT Highway Division
  https://www.umasstransportationcenter.org/umtc/Rivers-and-Roads.asp

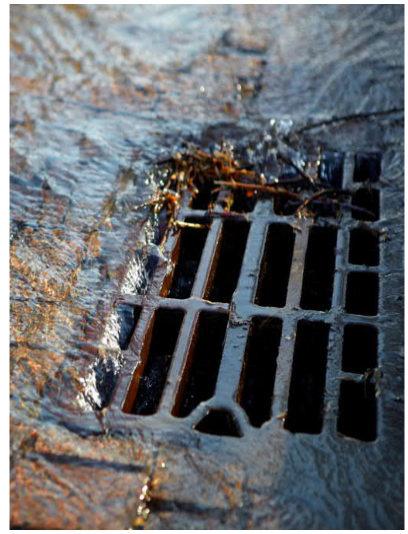
- Division of Ecological Restoration Municipal Culvert Replacement Training
  https://www.mass.gov/news/municipal-culvert-replacement-training

- UMass Amherst RiverSmart Communities
  https://extension.umass.edu/riversmart/resources-municipalities

5. Implement ongoing inspection and maintenance programs.

The Town should implement regular inspection and maintenance programs for local road-stream crossings. Vulnerable stream crossings should be inspected for debris removal and to check the structural integrity of the structure such as the headwalls and pipe. Public works staff should also inspect and remove existing debris from vulnerable road-stream crossings prior to an anticipated flood event.

5.2 Stormwater Infrastructure



Adaptation Goal: Implement green infrastructure to reduce stormwater runoff volumes and peak discharges, drainage-related flooding, and pollutant discharges to receiving waters.

Recommended Adaptation Measures

Table 5-3 provides a summary of recommended site-specific and policy/regulatory adaptation measures related to stormwater and green infrastructure in Walpole.

Table 5-3. Adaptation recommendations for stormwater and green infrastructure.

Adaptation Measure	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
Site-Specific Recommendations				
1. Incorporate green infrastructure into municipal stormwater infrastructure planning and capital projects, and implement identified retrofit projects.	Town of Walpole	5-10+ years	$$$$$	MVP Action Grant Program, 319 NPS Grant Program, Community Development Block Grants, Stormwater Utility, municipal funds
Policy and Regulatory Recommendations				
1. Review and update existing municipal land use regulations and policy to require the use of green infrastructure and LID for new development and redevelopment projects and to meet MS4 Permit requirements.	The Town of Walpole, Metropolitan Area Planning Council (MAPC)	2-5 years	$$	Municipal funds
2. Update design storm precipitation amounts in local land use regulations and policies to promote more resilient stormwater drainage design.	The Town of Walpole, Metropolitan Area Planning Council (MAPC)	2-5 years	$$	Municipal funds
3. Pursue sustainable, long-term funding sources for larger-scale GI implementation.	The Town of Walpole, Metropolitan Area Planning	5-10 years	$$$$	Stormwater utility district, enterprise fund, or similar fee-based system

Table 5-3. Adaptation recommendations for stormwater and green infrastructure.

Adaptation Measure	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
	Council (MAPC)			

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = greater than $100,000

Site-Specific Recommendations

1. *Incorporate green infrastructure into municipal stormwater infrastructure planning and capital projects, and implement identified retrofit projects.*

The Town should incorporate green infrastructure approaches into municipal stormwater infrastructure planning and capital improvement plans to address drainage, flooding, and water quality priorities including MS4 Permit requirements. Green infrastructure retrofits can be implemented on public sites including existing municipal parking lots using techniques such as bioretention, permeable pavement, and subsurface infiltration, as well as within the public right-of-way through the use of roadside bioswales, subsurface infiltration below roads and sidewalks, infiltrating catch basins, permeable pavement, and tree boxes.

The green infrastructure retrofit concepts presented in *Green Infrastructure Assessment Technical Memorandum* (see Appendix C) provide potential on-the-ground projects for future implementation. They also serve as examples of the types of projects that could be implemented at other similar locations in the community.

Table 5-9 lists proposed green infrastructure retrofit concepts that have been developed for the Town of Walpole, followed by concept design summaries for 10 of the assessed sites. The concept summaries include a site description, the proposed retrofit concept, field images and/or renderings of retrofit opportunities, typical details of recommended practices, and planning-level cost estimates (see Appendix C.

Table 5-4. Proposed green infrastructure retrofit locations.

Site No.	Site Name	Address	Green Infrastructure Practice Type
8	DPW Yard	1385 Washington Street	Bioretention Basin
10	Jarvis Farm	691 Common Street	Infiltration Basin, Subsurface Infiltration
15	Walpole High School	275 Common Street	Subsurface infiltration, Infiltration Basin, Pervious Pavers
17	Town Common	Main Street and Common Street	Subsurface Infiltration, Pavement Removal
20	Town Hall/Municipal Parking	135 School Street	Bioretention Basin, Parking Lot redesign with Bioretention Planters
22	Old Post Road School	99 Old Post Road	Infiltration Basin, Subsurface Infiltration

Table 5-4. Proposed green infrastructure retrofit locations.

Site No.	Site Name	Address	Green Infrastructure Practice Type
26	Johnson Middle School	111 Robbins Road	Infiltration Basins, Pervious Pavers
28	Elm Street School	415 Elm Street	Infiltration basins, Subsurface Infiltration, Tree Box Filter, Bioswale/infiltration basin
30	Ellis Field	East Street at June Street	Infiltration Basin

Policy and Regulatory Recommendations

1. *Review and update existing municipal land use policy and regulations to require and eliminate barriers to the use of green infrastructure and LID for new development and redevelopment projects and to meet MS4 Permit requirements.*

   Flood resiliency can be enhanced through well-informed land use policy and municipal land use regulations by preserving undeveloped land, siting development in locations less vulnerable to flooding, and promoting designs that reduce runoff and are less likely to be damaged in a flood. Municipal land use policies and regulations also play an important role in protecting water quality and natural resources.

   The Town of Walpole has adopted requirements for green infrastructure or LID in their local Stormwater Bylaw and Regulations, which reference the LID standards and design guidance contained in the latest edition of the *Massachusetts Department of Environmental Protection Stormwater Management Handbook* (*Massachusetts Stormwater Handbook*). Similarly, Walpole implements stormwater management requirements for new development and redevelopment projects through a local Stormwater Management and Erosion Control Bylaw administered by the Walpole Conservation Commission. Walpole's Stormwater Management and Erosion Control Bylaw references the specifications and standards of the *Massachusetts Stormwater Management Policy*, which is now incorporated in the *Massachusetts Stormwater Handbook* and includes information on the use of LID.

   EPA's current Massachusetts Municipal Separate Storm Sewer System General Permit (MS4 Permit) requires regulated municipalities, including Walpole, to update their local land use bylaws and/or regulations for consistency with the post-construction stormwater management standards contained in the permit. The permit also requires regulated communities to review their land use regulations to eliminate any barriers or impediments to the use of green infrastructure and LID such as street design and parking lot guidelines, as well as identify potential stormwater retrofit projects to reduce impervious area and stormwater pollutant loads.

   Walpole should review and update their local land use policies and regulations/bylaws to promote the use of green infrastructure and LID and to meet MS4 Permit requirements.

2. *Update design storm precipitation amounts in state and local land use regulations and policies to promote more resilient stormwater drainage design.*

   As discussed in the Road-Stream Crossings recommendations, stormwater and drainage-related infrastructure should be designed with storm intensities based on NOAA Atlas 14 (or NRCC atlas) to represent current precipitation conditions. For more resilient stormwater drainage design, Walpole should consider using the methods presented in the RMAT climate resilience design standards for determining appropriate design criteria values for 24-hour rainfall amounts and peak intensity 24-hour design storms. The RMAT standards are anticipated to be released in 2021. The town should also revisit these recommendations relative to the revised design storm intensities that are expected to be issued as part of the updated *Massachusetts Stormwater Handbook* and state wetland regulations.

3. *Pursue sustainable, long-term funding sources for large-scale GI implementation.*

A stormwater utility operates much like a drinking water or sewer utility. Fees collected from property owners go into a dedicated fund to pay for the operation and maintenance of stormwater infrastructure. Stormwater utilities, which create a more equitable relationship between revenues collected and runoff generated from a site, are common in many parts of the U.S., although relatively few have been implemented in New England. There are now over fifteen Massachusetts communities with stormwater utilities including but are not limited to Agawam, Ashland, Belchertown, Braintree, Chicopee, Milton, Northampton, Newton, Reading, Shrewsbury, and Westfield.

Stormwater utilities could provide a dedicated source of funding to construct and maintain green stormwater infrastructure, implement drainage system improvements (including culvert upgrades or replacements), and address MS4 permit compliance.

A list of additional funding sources, including grant and loan programs, is maintained by the Commonwealth of Massachusetts at https://www.mass.gov/service-details/available-funding-for-stormwater-projects-in-massachusetts.

6 Funding Sources

In addition to traditional municipal funding sources (i.e., the use of General Funds and municipal bonds), a variety of state and federal sources are also available to provide financial assistance for implementation of the plan recommendations. The funding sources identified in this section should be re-evaluated periodically to account for potential changes to existing funding programs (i.e., priorities, eligibility, funding cycles, and amounts) and to identify new or emerging sources of funding for flood mitigation, climate resiliency, and habitat restoration projects.

6.1 State Funding Sources

Division of Ecological Restoration (DER) Project Grants

The DER offers small grants to fund wetland, river, and flow restoration projects that are high-priority and provide significant ecological and community benefits to the Commonwealth. The DER considers funding for several types of "priority projects," including dam removal and culvert replacements. In addition to small grants, eligible projects also receive technical services (data collection, engineering, design work, and permitting) and project management and fundraising help.

DER website: https://www.mass.gov/how-to/become-a-der-priority-project
Dam removal website: https://www.mass.gov/river-restoration-dam-removal)
Culvert replacements website: https://www.mass.gov/river-restoration-culvert-replacements

State Revolving Fund (SRF) Loan Program

The SRF provides a low-cost financing option for communities through two programs: the Clean Water Program and the Drinking Water Program. The Clean Water Program provides loans to help municipalities comply with federal and state water quality requirements by focusing on watershed management priorities, stormwater management, and green infrastructure. The Drinking Water SRF Program provides loans to communities to improve water supply infrastructure and drinking water safety.

SRF Clean Water Program website: https://www.mass.gov/service-details/srf-clean-water-program
SRF Drinking Water Program website: https://www.mass.gov/service-details/srf-drinking-water-program

Clean Water Act, Section 319 Nonpoint Source Implementation Grants

Section 319 Grants are available for projects that promote restoration and protection of water quality through reducing and managing nonpoint source pollution. These grants are made possible by federal funds provided to MassDEP by the USEPA under Section 319 of the Clean Water Act. Eligible applicants include municipal, state, or regional governments, quasi-state agencies, public schools and universities, and non-profit watershed, environmental, or conservation organizations. Pursuant to federal guidelines for Section 319 funding, projects can only be funded in those areas in which a Watershed-Based Plan has been completed. MassDEP created the Massachusetts Watershed-Based Plan (WBP) for all watersheds in the state that can be used to develop proposals for 319 grants.

Clean Water Act Section 319 grants may be used for green stormwater infrastructure projects (if not mandated by a stormwater permit) and certain restoration activities such as dam removal. The EPA's guidance, "Nonpoint Source Program and Grants Guidelines for States and Territories," includes hydrologic modification as a type of nonpoint source pollution and therefore projects that address hydrologic modification such as dam removal are potentially eligible for funding. Dam removal projects need to be consistent with a state's written Nonpoint Source Management Program Plan. Dam removal projects that are included in local watershed-based plans that are consistent with EPA Guidelines would also be eligible for 319 funds.

MassDEP WBP website: https://www.mass.gov/guides/watershed-based-plan-information
MassDEP 319 website: https://www.mass.gov/info-details/grants-financial-assistance-watersheds-water-quality

Chapter 90 Program

The Chapter 90 program is operated by the Massachusetts Department of Transportation. The program provides 100% reimbursement for approved roadway projects, including projects such as road resurfacing, roadside drainage structures, bridges, side road approaches, and landscaping and tree planting.

Website: https://www.mass.gov/chapter-90-program

Massachusetts Department of Transportation (MassDOT) Municipal Small Bridge Program

The Municipal Small Bridge program is administered by the Massachusetts Department of Transportation. It is a five year program that provides assistance to municipalities to replace or preserve bridges that span between 10 and 20 feet (which are not currently eligible for federal aid under existing programs). The program is need and merit based and municipalities may be eligible for up to $500,000 per year. To be eligible, projects must be critical to the community (emergency closure/long detour routes for first responders) and the project must greatly extend the lifespan of the bridge. Bridges must be on public ways and must be structurally deficient or load posted.

Website: https://www.mass.gov/municipal-small-bridge-program

MassWorks Infrastructure Program

The MassWorks Infrastructure Program is administered by the Executive Office of housing and Economic Developing, the Department of Transportation, and the Executive Office for Administration and Finance. The program provides public infrastructure funding to support sustainability in Massachusetts, as well as job creation and economic development. Although the program is not specifically for hazard mitigation, the infrastructure improvements covered under MassWorks could help protect communities from natural disasters such as flooding.

Website: https://www.mass.gov/service-details/massworks-infrastructure-grants

Municipal Vulnerability Preparedness (MVP) Action Grant Program

The MVP Action Grant Program is administered through the Executive Office of Energy and Environmental Affairs. To be eligible for funding, communities must complete the MVP Planning Grant process. The MVP Action Grant offers financial assistance to municipalities that are interesting in implementing climate adaptation actions to address the impacts of climate change (extreme weather, sea level rise, inland and coastal flooding, severe heat, etc.). The program funds projects relating to planning, assessments, and regulatory updates; nature-based solutions for ecological and public health; and resilient redesigns and retrofits for critical facilities and infrastructure. In past funding rounds, applicants were able to request $25,000 to $2,000.000 in funding (up to $5,000,000 available for regional projects). A 25% match, either through cash or in-kind services, is required.

Website: https://www.mass.gov/service-details/mvp-action-grant

6.2 Federal Funding Sources

HUD Community Development Block Grants

Title 1 of the Housing and Community Development Act of 1974 authorized the Community Development Block Grant program. The program is sponsored by the US Department of Housing and Urban Development. The Massachusetts program is administered through the Massachusetts Department of Housing and Community Development.

CDBG-DR (disaster recovery) funds may be used to restore public facilities and infrastructure, rehabilitate or replace housing, acquire property, promote economic revitalization, and support hazard mitigation planning. CDBG-DR funds are intended to support long-term recovery from a specific natural disaster and may not be applied to recovery activities associated with other disasters. Annual CDBG Program funds may also be used for certain eligible hazard mitigation and disaster recovery activities (Commonwealth of Massachusetts, n.d.). Implementation of green stormwater infrastructure and drainage system upgrades to mitigate drainage-related flooding is potentially eligible for CDBG funding.

Website: https://www.mass.gov/service-details/community-development-block-grant-cdbg

Army Corps of Engineers Aquatic Ecosystem Restoration Program

Under Section 206 of the Water Resources Development Act of 1996 (33 U.S.C. 2330), the Army Corps of Engineers can participate in the study, design and implementation of ecosystem restoration projects. Projects conducted in New England under this program have included eelgrass restoration, salt marsh and salt pond restoration, freshwater wetland restoration, anadromous fish passage and dam removal, river restoration, and nesting bird island restoration. Projects must be in the public interest and cost effective and are limited to $10 million in Federal cost.

Non-Federal project sponsors must be public agencies or national non-profit organizations capable of undertaking future requirements for operation, maintenance, repair, replacement and rehabilitation (OMRR&R), or may be any non-profit organization if there are no future requirements for OMRR&R. The Corps of Engineers provides the first $100,000 of study costs. A non-Federal sponsor must contribute 50 percent of the cost of the feasibility study after the first $100,000 of expenditures, 35 percent of the cost of design and construction, and 100 percent of operation and maintenance costs.

Website: http://www.nae.usace.army.mil/Missions/Public-Services/Continuing-Authorities-Program/Section-206/

NFWF New England Forests and Rivers Fund

The National Fish and Wildlife Foundation (NFWF) New England Forests and Rivers Fund is dedicated to restoring and sustaining healthy forests and rivers that provide habitat for diverse native bird and freshwater fish populations in the six New England states. This program annually awards competitive grants ranging from $50,000 to $200,000 each. Since its creation in 2015, the Fund has awarded 48 grants to restore early successional habitat, modify and replace barriers to fish movement, restore riparian and instream habitat, and engage volunteers in forest habitat restoration and stream connectivity projects. Major funding for the New England Forests and Rivers Fund is provided by Eversource Energy, the U.S. Fish and Wildlife Service, and the U.S. Department of Agriculture's Natural Resources Conservation Service and Forest Service.

Website: http://www.nfwf.org/newengland/Pages/home.aspx

USDA NRCS Funding Programs

The USDA Natural Resources Conservation Service (NRCS) works with land owners in Massachusetts to improve and protect soil, water, and other natural resources. NRCS has several funding programs in Massachusetts that help property owners address flooding and water quality issues.

- The Emergency Watershed Protection (EWP) Program is designed to help people and conserve natural resources by relieving imminent hazards to life and property caused by floods, fires, wind-storms, and other natural occurrences. EWP is an emergency recovery program, which responds to emergencies created by natural disasters. It is not necessary for a national emergency to be declared for an area to be eligible for assistance. EWP is designed for installation of recovery measures. Activities include providing financial and technical assistance to remove debris from stream channels, road culverts, and bridges, reshape and protect eroded banks, correct damaged drainage facilities, establish cover on critically eroding lands, repair levees and structures, and repair conservation practices.

  Website: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/ewpp/

- The Emergency Watershed Protection - Floodplain Easement Program (EWP-FPE) provides an alternative measure to traditional EWP recovery, where it is determined that acquiring an easement in lieu of recovery measures is the more economical and prudent approach to reducing a threat to life or property. The easement area is restored to the maximum extent practicable to its natural condition using structural and nonstructural practices to restore the flood storage and flow, erosion control, and improve the practical management of the easement. Floodplain easements restore, protect, maintain and enhance the functions of floodplains while conserving their natural values such as fish and wildlife habitat, water quality, flood water retention and ground water recharge. Structures, including buildings, within the floodplain easement must be demolished and removed, or relocated outside the 100-year floodplain or dam breach inundation area.

  Website: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ct/programs/financial/ewp/?cid=stelprdb1244478

- The Watershed and Flood Prevention Operations Program provides technical and financial assistance to states, local governments and Tribes to plan and implement watershed project plans for the purpose of watershed protection, flood mitigation, water quality improvement, fish and wildlife enhancement, wetlands and wetland function creation and restoration, groundwater recharge, and wetland and floodplain conservation easements.

Website: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/wfpo/

- The Regional Conservation Partnership Program (RCPP) promotes coordination of NRCS conservation activities with partners that offer value-added contributions to expand our collective ability to address on-farm, watershed, and regional natural resource concerns. Through RCPP, NRCS seeks to co-invest with partners to implement projects that demonstrate innovative solutions to conservation challenges and provide measurable improvements and outcomes tied to the resource concerns they seek to address.

  Website: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/rcpp/

FEMA Hazard Mitigation Assistance Grant Programs

The Federal Emergency Management Agency (FEMA) administers two major programs related to hazard mitigation: the National Flood Insurance Program (see Section 3.1 of this plan) and the Hazard Mitigation Assistance Program. FEMA's hazard mitigation assistance grant programs provide funding to protect life and property from future natural disasters. In Massachusetts, these programs are administered by the Massachusetts Emergency Management Agency (MEMA). FEMA flood hazard mitigation assistance funding is available to Massachusetts communities through the following programs:

- Building Resilient Infrastructure and Communities (BRIC) BRIC provides funds to support public infrastructure projects that increase a community's resiliency to reduce to effects of future disasters. The goal of the program is to reduce overall risk to the population and structures, while at the same time, also reducing reliance on Federal funding from actual disaster declarations. The program was introduced in October 2018 and as of June 2019 is still under a public comment period. The BRIC program is replacing the Pre-Disaster Mitigation (PDM) program.

- Flood Mitigation Assistance (FMA) provides funds for projects to reduce or eliminate risk of flood damage to buildings that are insured under the National Flood Insurance Program (NFIP) on an annual basis. These are cost share grants for pre-disaster planning and projects, with a federal share (up to 100%) and non-federal share (local government or other organization).

- Severe Repetitive Loss (SRL) is designed to reduce flood damages to residential properties that have experienced SRLs under flood insurance coverage. The program provides funds that measures can be taken to reduce or eliminate risk of flood damage to buildings insured under the NFIP. Funding is available on an annual basis (as available). SRL provides up to 90% Federal funding for eligible projects.

- Hazard Mitigation Grant Program (HMGP) assists in implementing long-term hazard mitigation measures following Presidential disaster declarations. Funding is available to implement plans or projects in accordance with State, Tribal, and local priorities. HMGP grants are post-disaster cost share grants consisting of 75% federal share and 25% non-federal share (local government or other organization).

- Public Assistance (PA) Grants provide assistance to local, tribal and state governments and certain types of Private Non-Profit (PNP) organizations so that communities can quickly respond to and recover from major disasters or emergencies declared by the President. Through the PA Program, supplemental Federal disaster grant assistance is provided for debris removal, emergency protective measures, and the repair, replacement, or restoration of disaster-damaged, publicly owned facilities and the facilities of certain PNP organizations. The PA Program also encourages protection of these damaged facilities from future events by providing assistance for hazard mitigation measures during the recovery process.

Website: https://www.fema.gov/hazard-mitigation-assistance

Community Rating System (CRS) under NFIP

The Community Rating System is a voluntary program under the NFIP that encourages municipalities to participate in flood management actives that exceed the minimum requirements of the NFIP. There are three goals of the CRS: reduce flood damage to insurable property, strengthen and support the insurance aspects of the NFIP, and encourage a comprehensive approach to floodplain management. Communities participating in the CRS receive reduced insurance premiums as a result of their compliance.

Website: https://www.fema.gov/community-rating-system

National Fish and Wildlife Foundation (NFWF) New England Forests and Rivers Fund

The National Fish and Wildlife Foundation (NFWF) New England Forests and Rivers Fund is dedicated to restoring and sustaining healthy forests and rivers that provide habitat for diverse native bird and freshwater fish populations in the six New England states. This program annually awards competitive grants ranging from $50,000 to $200,000 each. Since its creation in 2015, the Fund has awarded 48 grants to restore early successional habitat, modify and replace barriers to fish movement, restore riparian and instream habitat, and engage volunteers in forest habitat restoration and stream connectivity projects. Major funding for the New England Forests and Rivers Fund is provided by Eversource Energy, the U.S. Fish and Wildlife Service, and the U.S. Department of Agriculture's Natural Resources Conservation Service and Forest Service.

Website: http://www.nfwf.org/newengland/Pages/home.aspx

Repetitive Flood Claims (RFC) under NFIP

The RFC grant program provides funding on an annual basis to reduce or eliminate long-term risk flood damages to properties covered by the NFIP that have had one or more claim payments for flood damages. RFC provides up to 10% of federal funds. RFC only applies to properties in NFIP-insured communities that do not meet requirements of the Flood Mitigation Assistance program (FMA) because they do not have the capacity to manage the activities or cannot provide the non-federal cost share.

Website: https://www.fema.gov/repetitive-flood-claims-grant-program-fact-sheet

6.3 Other Funding Sources

Healthy Watersheds Consortium Grant Program - U.S. Endowment for Forestry and Communities, USEPA, USDA NRCS

The goal of the Healthy Watersheds Consortium Grant Program is to accelerate strategic protection of healthy, freshwater ecosystems and their watersheds. The program supports:

- Developing funding mechanisms, plans, or other strategies to implement large-scale watershed protection, source water protection, green infrastructure, or related landscape conservation objectives.
- Building the sustainable organizational infrastructure, social support, and long-term funding commitments necessary to implement large-scale protection of healthy watersheds.
- Supporting innovative or catalytic projects that may accelerate funding for or implementation of watershed protection efforts, or broadly advance this field of practice.

Eligible applicants include not-profit organizations, for-profit companies, tribes, intertribal consortia, interstates, state, and local government agencies including water utilities and wastewater facilities, and colleges and universities. Funding amounts range from $50,000 to $300,000.

Website: https://www.epa.gov/hwp/healthy-watersheds-consortium-grants-hwcg

Resilient Communities Program

Wells Fargo, in partnership with the National Fish and Wildlife Foundation, launched the Resilient Communities Program in 2017. The program is designed to prepare for future environmental challenges by enhancing community capacity to plan and implement resiliency projects and improve the protections afforded by natural ecosystems by investing in green infrastructure and other measures. The program will focus on water quality and quantity declines, forest health concerns, and sea level rise. The program emphasizes community inclusion and assistance to traditionally underserved populations in vulnerable areas. In the northeast, eligible project types include wetland restoration and aquatic organism passage. The program will awarded approximately $2 million in grants to projects in 2019. Each grant will range from $100,000 to $500,000 depending on category and will be awarded to eligible entities working to help communities become more resilient. This program has one round of applications per year and awards approximately 3 to 6 grants annually.

Website: http://www.nfwf.org/resilientcommunities/Pages/home.aspx

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Appendix A

Flooding Vulnerability Tables

Table 1. Documented Areas of Flooding, Erosion, or Infrastructure Damage Due to Storms – Town of Walpole

Vulnerability Point	Flooding Source	Description	Information Source
Walpole center	Diamond Brook & Neponset River	Flooding occurred as a result of heavy rainfall from Hurricanes Connie and Diane (1955). 14 houses, a school & 42 commercial establishments around Walpole center were damaged in the flood event (1% annual chance flood event).	FEMA, Revised 2015
Walpole Center	Spring Brook	Flooding occurred due to severe rainstorm (1968)	FEMA, Revised 2015
Moderate flood risk locations in Walpole	Rivers and Streams	Spring storms producing over 9 inches of rain combined with melting snow, lead to record flooding (1987)	FEMA, Revised 2015
Moderate flood risk locations in Walpole	Rivers and Streams	Hurricane Bob (1991) heavy rain	FEMA, Revised 2015
Lewis Avenue	Neponset River	Road crossing flooded (Spring 2010 storm event)	FEMA-1985-DR-MA
Norfolk Street	Possible flood area	Flooding occurred in public roads and driveways (Spring 2010 storm event)	FEMA-1985-DR-MA
Elm Street Train Parking lot	Neponset River	Parking lot flooded (Spring 2010 storm event)	FEMA-1985-DR-MA
Route 27 (East Street) at elm Street	Neponset River	Flooding under train bridge and into downtown area (Spring 2010 storm event)	FEMA-1985-DR-MA
Hoover Road	Plimpton Pond	Flooding	Walpole HMP 2016
Cobbs Brook at Gould Ave and Smith Road	Deans Brook	Flooding	Walpole HMP 2016
Bird Park at Wolcott Ave.	Bird Pond	Flooding (Spring 2010 storm event)	FEMA-1985-DR-MA
Appletree Lane	Mill Brook	Flooding	Walpole HMP 2016
Winter Street at Elm	Neponset River and unnamed pond	Flooding	Walpole HMP 2016
Main Street at Industrial Park	Unnamed Pond	Flooding	Walpole HMP 2016
West Pine Drive at high tension wires	Stop River	Flooding	Walpole HMP 2016
North Street Near Gould Ave.	Streams and crossings that flow to Cobbs Pond	Flooding	Walpole HMP 2016
Railroad tracks at Mill Brook, near Turner Pond	Mill Brook & Turner Pond	Flooding	Walpole HMP 2016
School and Stone Streets	Spring Brook & Memorial Pond	Flooding	Walpole HMP 2016

Table 1. Documented Areas of Flooding, Erosion, or Infrastructure Damage Due to Storms – Town of Walpole

Vulnerability Point	Flooding Source	Description	Information Source
School and East Streets	Spring Brook & Memorial Pond	Flooding	Walpole HMP 2016
Common and Washington Streets	Spring Brook and School Meadow Brook	Flooding	Walpole HMP 2016
Stone and Washington. At Allen Dam	Spring brook & Clarks Pond Conservation Area	Flooding	Walpole HMP 2016
Neponset River Choke points	Neponset River	Flooding	Walpole HMP 2016
Oak Street AT Audubon/spring Valley Drive	Streams off the Neponset River	Flooding (spring 2010 storm event)	FEMA-1985-DR-MA
Brown Drive to Spring Valley and Autum Lane	Neponset River	Flooding (spring 2010 storm event)	FEMA-1985-DR-MA
West Street at Spring Street under the bridge	Neponset River & adjacent unnamed ponds	Flooding (Spring 2010 storm event)	FEMA-1985-DR-MA
Meadow Ridge Detention Basin at Pall Mall & Polly Lane	Adjacent unnamed pond, Bird Pond & Plimpton Pond	Flooding (Spring 2010 storm event)	FEMA-1985-DR-MA
Hummingbird Detention Basin	Rainbow Pond	Flooding	Walpole HMP 2016
Plimpton Pond Dam	Plimpton Pond & Neponset River	Risk of flooding possible due to dam failure (low hazard)	Walpole HMP 2016
Ruck-A-Duck Pond Dam	Upstream source	Risk of flooding possible due to dam failure (small unregulated dam)	Walpole HMP 2016
Bird Pond Dam	Bird Pond, Plimpton Pond & Neponset River	Risk of flooding possible due to dam failure (high hazard)	Walpole HMP 2016
Turner Pond Dam	Mine Brook & Turner Pond	Risk of flooding possible due to dam failure (significant hazard)	Walpole HMP 2016
Cobbs Pond Dam	Cobbs Brook & Cobbs Pond	Risk of flooding possible due to dam failure (high hazard)	Walpole HMP 2016
Memorial Pond Dam	Diamond Brook	Risk of flooding possible due to dam failure (significant hazard)	Walpole HMP 2016
Diamond Pond Dam	Diamond Brook 7 brook from Clarks Pond	Risk of flooding possible due to dam failure (significant hazard), 1% annual chance of flooding; no BFE	Walpole HMP 2016

Table 1. Documented Areas of Flooding, Erosion, or Infrastructure Damage Due to Storms – Town of Walpole

Vulnerability Point	Flooding Source	Description	Information Source
Clarks Pond Dam	Upstream source	Risk of flooding possible due to dam failure (N/A hazard class)	Walpole HMP 2016
Shacounda Dam	Upstream source	Risk of flooding possible due to dam failure (small unregulated dam)	Walpole HMP 2016
Rieth Pond Dam	Upstream source	Risk of flooding possible due to dam failure (small unregulated dam)	Walpole HMP 2016
Smith Pond Dam	Upstream source	Risk of flooding possible due to dam failure (small unregulated dam)	Walpole HMP 2016
Summer Street culvert	Clark Pond	Risk of flooding possible due to culvert failure (low hazard)	Walpole HMP 2016
Hollingsworth & Vose Dam	Neponset River	Risk of flooding possible due to dam failure (significant hazard)	Walpole HMP 2016
Neponset River Dam (BlackBurn Dam)	Neponset River	Risk of flooding possible due to dam failure (low hazard)	Walpole HMP 2016
Allen Reservoir Dam	Upstream source	Risk of flooding possible due to dam failure (high hazard), 1% annual chance of flooding; no BFE	Walpole HMP 2016
Kendall Mill Dam	Upstream source	Risk of flooding possible due to dam failure (significant hazard)	Walpole HMP 2016
Stetson Pond Dam	Upstream source	Risk of flooding possible due to dam failure (small unregulated dam)	Walpole HMP 2016
Ganawatte Farm Pond Dam	Upstream source	Risk of flooding possible due to dam failure (small unregulated dam)	Walpole HMP 2016

Notes:

1. FEMA Revised 2015– Federal Emergency Management Agency, Revised 2015
2. Walpole Hazard Mitigation plan – Local hazards identified by Town of Walpole as part the metropolitan area planning council
3. FEMA-1985-DR-MA – Town of Walpole, March 12 through April 26, 2010 storm event

Appendix B

Road-Stream Crossing Assessment Technical Memorandum

MEMORANDUM

TO: Project Steering Committee

FROM: Celicia L. Boyden, EIT
William Guenther, MS
Fuss & O'Neill, Inc.
317 Iron Horse Way, Suite 204
Providence, RI 02908

DATE: July 20, 2020

RE: **Road Stream Crossing Assessment**
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment, and Climate Resiliency Plan
MVP Action Grant – Town of Walpole

1 Introduction

Inadequate or undersized road-stream crossings can be flooding and washout hazards and can serve as barriers to the passage of fish and other aquatic organisms. As precipitation events become more intense and less predictable as a result of climate change, inadequate or undersized road-stream crossings throughout the Town of Walpole are expected to pose a greater threat of failure; flooding damage to homes and businesses, transportation infrastructure, utilities; and stream channel erosion.

Fuss & O'Neill assessed road-stream crossings throughout the Town in support of Walpole's *Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment, and Climate Resiliency Plan*, a project which was funded through the Commonwealth's Municipal Vulnerability Preparedness (MVP) Action Grant funding for Fiscal Year 2019. The primary goal of the overall project is to increase resilience to flooding and flood-related impacts throughout the Town. To that end, the project systematically assessed road-stream crossings Town-wide to identify vulnerabilities and rank high priority culvert/bridge replacement projects that would address flood vulnerability, reduce flooding impacts, and increase stream continuity for aquatic organism passage.

The assessments consisted of field surveys of individual stream crossings using established road-stream crossing assessment protocols, followed by analysis of the field data to assign vulnerability ratings to each crossing based on multiple factors including hydraulic capacity, structural condition, geomorphic risk, aquatic organism passage, transportation disruption, other flooding impacts, and climate change considerations. The vulnerability ratings are used to prioritize structures for upgrade or replacement. The results of the stream crossing assessments will inform the selection of infrastructure and natural system solutions to increase flood resilience in Walpole.

This memorandum summarizes the methods and results of the road-stream crossing field surveys and vulnerability assessment. Recommendations are presented based on field observations and the vulnerability assessment and prioritization process.

2 Assessment Methods

2.1 Selection of Crossings

Road-stream crossings to be included in the assessment were initially identified based on review of aerial imagery, flood mapping, and other local, county, or state-wide data layers. The Project Steering Committee reviewed these maps and provided additional information on locations of known culvert/bridge infrastructure where flooding was already a concern. The project sought to assess all crossings Town-wide which could reasonably and safely be assessed. Crossings on interstate highways (Route 95) were not assessed due to safety and access issues. Two crossings on Union Street over Traphole Brook and one crossing on Bullard Street at the Willet Pond Dam were not assessed because the Town has plans to upgrade and/or replace these crossings through other funding sources. Crossings that were located on utility access roads were not assessed. At several locations where multiple crossings were mapped within a short distance, it was found that only one crossing actually existed at that location. At these locations data was collected at the existing crossing and the mapping was updated to reflect the actual number of crossings. The locations of the crossings that were visited in the field are shown on the map in *Figure 1*. As shown in *Figure 1*, the crossings span two watersheds (the Charles River watershed and the Neponset River watershed).

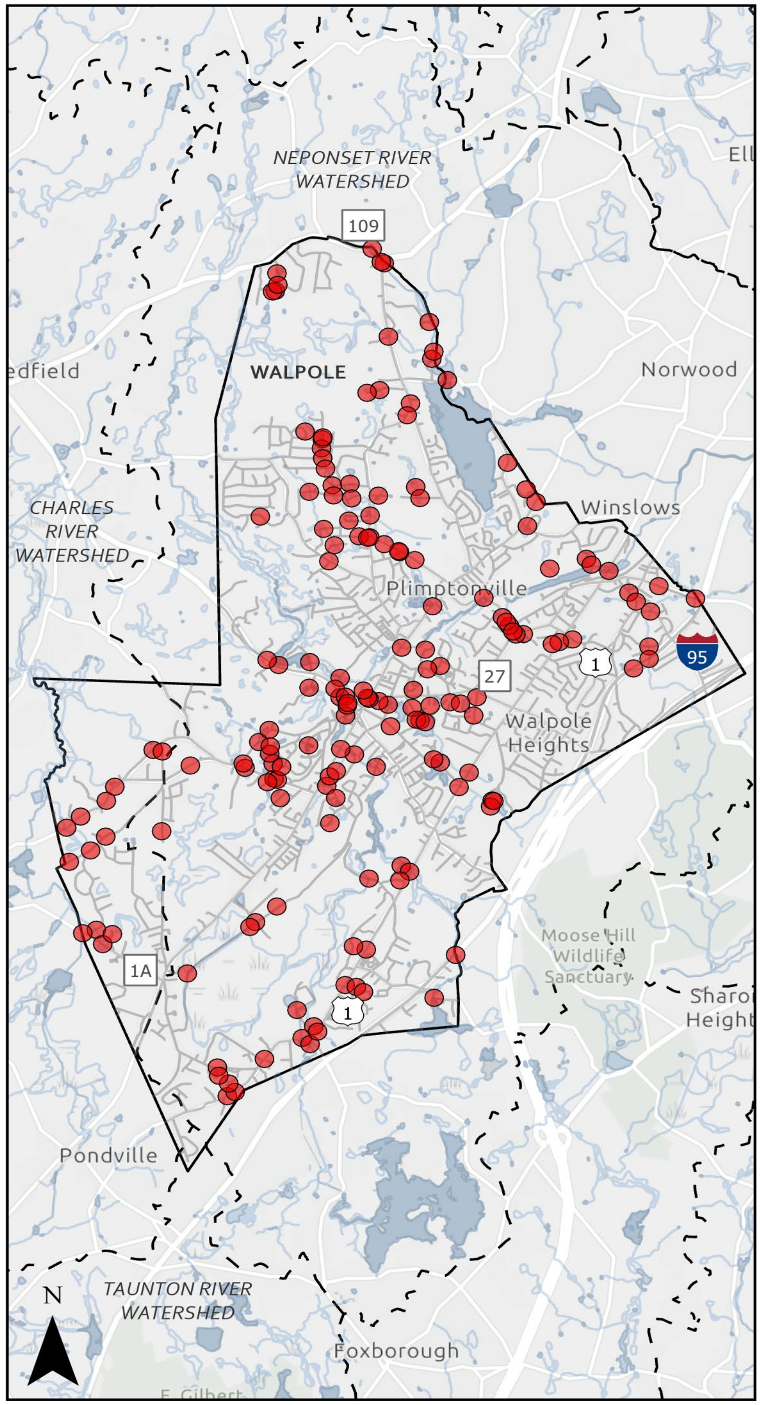

Figure 1. Road-stream crossings selected for assessment in the Town of Walpole. Watershed boundaries are indicated by dotted lines.

2.2 Field Data Collection

Field surveys of the selected crossings were conducted between October 24th and December 13th, 2019 using road-stream crossing assessment procedures and field data collection forms adapted from the North Atlantic Aquatic Connectivity Collaborative (NAACC) and similar standardized assessment protocols used in the northeastern U.S. In addition to the 2016 NAACC stream crossing survey protocol for assessing aquatic connectivity, the road-stream crossing survey methods used for this project also incorporated structural condition assessment protocols from the 2017 NAACC Culvert Condition Assessment Manual and collection of other field data for evaluating geomorphic vulnerability, hydraulic capacity, and potential flooding impacts to infrastructure and public services. Digital photographs were also taken at each crossing. A blank copy of the field data collection form is provided in *Appendix A*.

The crossing surveys were performed by a two-person field crew consisting of water resources scientists. The field crew was led by a NAACC-Certified Lead Observer; additional training was also provided for all field personnel prior to the field work. Digital field data collection methods were used to complete the crossing surveys, using a GPS-enabled tablet with a pre-loaded digital version of the field form and aerial imagery for the project locations. Field data for the project were saved and managed using an ArcGIS database and web application *(Figure 2)*. Following the stream crossing surveys, field data were checked for quality control purposes.

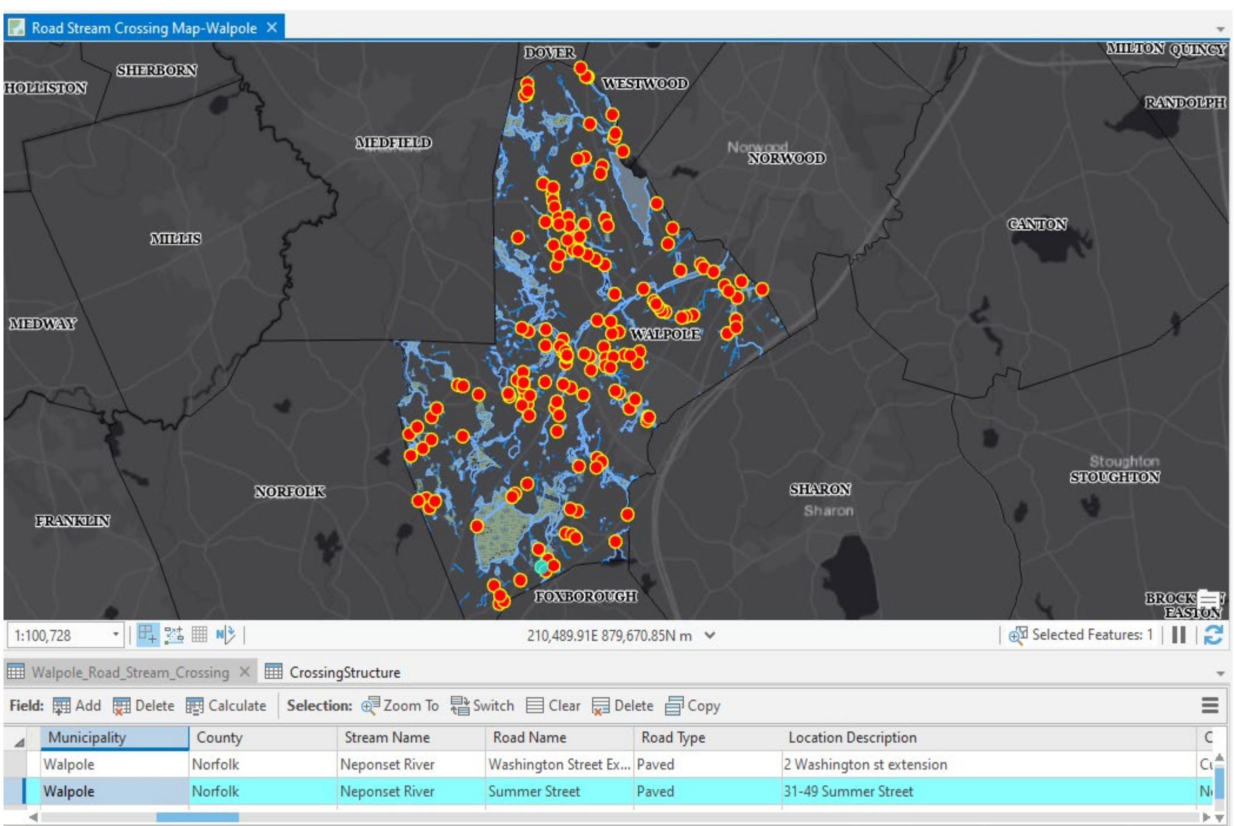

Figure 2. ArcGIS web application for Walpole stream crossing survey data.

2.3 Vulnerability Assessment

Using data from the stream crossing surveys and available GIS data, each of the assessed crossings was assessed for vulnerability to flooding and associated impacts relative to hydraulic capacity, structural condition, geomorphic conditions, aquatic organism passage, transportation services, and climate change considerations. The vulnerability and impact ratings were then combined to generate an overall rating, which was used to assign a priority to each crossing for potential upgrade or replacement. The assessment methods are described generally below and are further detailed in *Appendix B*.

2.3.1 Assessment Method

The following individual assessments were performed for each stream crossing:

- **Existing Streamflow Conditions:** Existing peak discharge for common recurrence intervals (10-year, 25-year, 50-year, and 100-year events) was estimated for each crossing using regional regression equations developed by the United States Geological Survey (USGS) for estimating peak flows at ungauged locations (i.e., USGS StreamStats). Drainage area ratios were used to estimate peak flows for crossing locations where regional regression equations were unreliable or unavailable.

- **Hydraulic Capacity:** The hydraulic capacity of each road-stream crossing was estimated using standard Federal Highway Administration culvert/bridge hydraulic calculation methods following FHWA Hydraulic Design Series Number 5 (HDS-5). Bentley CulvertMaster, which employs HDS-5 methods, was used for the analysis. Hydraulic capacity was determined for a selected headwater depth, which represents that depth at which the crossing is at risk of structural failure or the roadway is at risk of overtopping, depending on crossing type and material. Headwater depth at failure was defined for each culvert according to *Table 1* in the Hydraulic Capacity Worksheet in *Appendix B*. Tailwater depth was selected based on *Table 2* in the Hydraulic Capacity Worksheet in *Appendix B*. Manning's Equation for uniform open channel flow was used to estimate the crossing hydraulic capacity for larger structures (bridges) or where the cross-sectional area could not be approximated with CulvertMaster. A Capacity Ratio (defined as the ratio of estimated hydraulic capacity to the estimated peak discharge for a specified return interval) was calculated for each crossing and recurrence interval analyzed (10-year, 25-year, 50-year, and 100-year events). The crossing has sufficient capacity to convey a given return interval peak discharge if the Capacity Ratio for that return interval is greater than or equal to 1. The crossing is undersized for the return interval peak discharge if the Capacity Ratio is less than 1. A Hydraulic Capacity Score was assigned to each crossing according to *Table 3* in the Hydraulic Capacity Worksheet in *Appendix B*.

- **Climate Change Vulnerability:** Peak discharge under a future climate change scenario was estimated for each road-stream crossing by multiplying existing peak discharge values by a peak flow multiplier of 1.2 for all return intervals. The design flow multiplier of 1.2 represents a 20% increase in rainfall intensity above current conditions to account for anticipated increases in design rainfall intensities associated with future climate change projections. The recommended 20% increase in design rainfall intensity is consistent with MassDOT future precipitation projections for extreme precipitation under a medium to high emissions scenario and a 50- to 100-year planning horizon, based on the typical design life (50 years) of most drainage infrastructure, and the useful life, which is typically 50-100 years for drainage infrastructure. It should be noted that design life is different from useful life, which is typically longer than the design life and more accurately represents the extended service life of infrastructure, assuming regular maintenance. Capacity Ratios were recalculated for each crossing and return interval using these future peak discharge values. A Future Hydraulic Capacity Score and a Hydraulic Capacity Change Score was assigned to each crossing according to *Table 1* and *Table 2* in the Climate Change Vulnerability Worksheet in *Appendix B*. These scores were used to assign each crossing a Climate Change Vulnerability Score according to *Table 3* in the Climate Change Vulnerability Worksheet in *Appendix B*.

- **Geomorphic Impacts:** The geormorphic impact assessment evaluated the potential for crossing structures to impact geomorphic processes that might, in turn, threaten the structure itself and other adjacent infrastructure. The assessment procedure distinguishes between crossings that are: 1) not prone to and have not experienced geomorphic adjustments; 2) prone to but have not experienced geomorphic adjustments; and 3) prone to and have experienced geomorphic adjustments. The approach rates the relative likelihood that impacts could occur and the type and severity of impacts that have already occurred. Factors that were considered include stream alignment, bankfull width, degree of constriction, significant breaks in valley slope, bank erosion, sediment deposition, structure and channel slope, stream bed material, and other geomorphic parameters. An overall Geomorphic Impact Score was assigned to each crossing according to the tables provided in the Geomorphic Vulnerability Worksheet in *Appendix B*.

- **Structural Condition:** Condition ratings and scores were assigned based on visual observation of the structural condition of the crossing inlet, outlet, and barrel adapted from the latest version of the NAACC Culvert Condition Assessment Manual, which was developed with input from state transportation departments throughout the Northeast and other stakeholders. The NAACC condition assessment methodology is designed as a rapid assessment tool for use by trained observers for purposes of flagging crossings that should be examined more closely for potential structural deficiencies. The Structural Condition Worksheet in *Appendix B* provides the structural parameters included in the assessment and tables that demonstrate how the Structural Condition Score was calculated.

- **Aquatic Organism Passage:** Aquatic organism passage (AOP) was assessed using the latest NAACC protocols and rating system for assessing stream continuity. The method was adapted from the NAACC Numeric Scoring System for AOP, which was developed with input from multiple experts in aquatic passability. The NAACC Numeric Scoring System methodology is designed as a quantitative but rapid assessment tool for use by trained observers. The assessment is not species-specific, but rather seeks to evaluate passability for the full range of aquatic organisms likely to be found in rivers and streams. The potential ecological benefit of removing an existing barrier to aquatic passage is also an important consideration. The additional habitat value accessed after a crossing replacement depends on both the quality and the extent of aquatic habitat that is reconnected as a result of replacing the existing crossing with a structure that provides for improved aquatic passage. The potential ecological benefit of removing an existing barrier to aquatic passage was evaluated for each crossing using aquatic Index of Ecological Integrity (IEI) values developed by the Landscape Ecology Lab at UMass

Amherst as part of the Conservation Assessment and Prioritization System (CAPS) program. Crossings were assigned an Aquatic Passability Score and an Ecological Integrity Score according to the tables provided in the Aquatic Organism Worksheet in *Appendix B*.

- **Impacts to Transportation Services:** Potential disruption of transportation services resulting from single crossing failure was evaluated by considering the functional classification of the roadway (i.e., level of travel mobility and access to property that it provides). Disruption of transportation services is assumed to occur if the crossing is either overtopped or washed away by flooding, as either failure mode would prohibit the use of the road-stream crossing by traffic. *Table 1* in the Transportation Services Disruption Worksheet in *Appendix B* details how crossings were assigned a Transportation Disruption Component Score.
- **Flood Impact Potential:** The potential impacts of flooding in the event of crossing failure were assessed using a screening-level approach by examining the existing development, infrastructure, and land use around each crossing. A potential impact area was approximated for each crossing, having a width defined by buffering the stream centerline by a distance equal to two times the bankfull width, and a length defined as 0.5 miles upstream and downstream of the crossing. Flooding vulnerability within the potential impact area was quantified based on the percentage of developed land cover, using land cover data from the Massachusetts statewide Land Cover/Land Use (2016) data layer, and the presence of upstream or downstream crossings within the impact area, as well as any infrastructure (gas, sewer, water, etc.) observed to be attached to or located within the crossing structure. See the Flood Impact Potential Worksheet in *Appendix B* for detailed scoring methods.

2.4 Prioritization Method

The crossing structures were assigned a relative priority for upgrade or replacement based on the results of the individual assessments and consideration of failure risk. Failure risk is defined as the product of the probability of failure of a crossing (i.e., hydraulic, climate change, geomorphic, & structural vulnerability) and the potential consequences of failure (i.e., flood and transportation impacts). Failure risk for each crossing is represented through the calculation of Hydraulic Risk, Climate Change Risk, Geomorphic Risk and Structural Risk Scores. The overall failure risk for a crossing (represented by the Crossing Risk Score) is dictated by the highest (i.e., worst-case) level of risk, which is calculated as the maximum of the Hydraulic Risk Score, Climate Change Risk Score, Geomorphic Risk Score, and Structural Risk Score.

An Aquatic Passage Benefit Score was assigned to each crossing by combining the degree of passability (Aquatic Passability Score) of the crossing with the potential ecological benefit of removing an existing barrier at each crossing (Ecological Integrity Score).

A Crossing Priority Score was calculated for each crossing by combining the Crossing Risk Score with the Aquatic Passage Benefit Score. (The two scores are combined by adding the maximum of the two scores to the average of the two scores. This approach ensures that if there is a very high score for one factor, it is preserved. It does however prioritize those crossings that rate highly for both factors.) The Crossing Priority Score is then re-scaled or normalized to a range from 0 to 1 for ease of interpretation. It is important to note that the crossing priority scores should only be used for relative comparisons between crossings. Refer to the Prioritization Worksheet in *Appendix B* for details on the prioritization equations.

Several Crossing Flags are included in the vulnerability assessment methodology to note information that may be relevant to a crossing but is not captured in the vulnerability assessment. Flagging a crossing may provide supplemental information that is useful to consider in the final prioritization and in determining which structures to upgrade or replace. The following crossing flags were used in the vulnerability assessment:

- **Unknown Structural Variable:** Crossings that have one of more Level 1 structural variables marked "Unknown" or more than four Level 2 structural variables marked "Unknown".
- **Local Knowledge**: Crossings that are of local importance or have known issues that are not captured in the analysis (e.g., frequent flooding, clogging, or traffic problems) or that have been recently replaced or repaired.
- **Adjacent Crossing:** Other crossings that are located within the upstream or downstream flood impact area of a crossing.
- **Wildlife Crossing:** Crossings where wildlife, roadkill, and/or wildlife crossing signs were noted in the field.

3 Results

3.1 Field Data Collection

One-hundred and seventy crossings were visited in the field between October 24th and December 13th, 2019. Eleven crossings were located on private property and were assessed for presence/absence only at the request of the Project Steering Committee. Twenty-two (22) mapped crossings that were visited in the field were not included in the vulnerability assessment because they were either buried, inaccessible or there was no crossing found at the mapped location. One-hundred and thirty-seven crossings associated with 170 structures were ultimately included in the vulnerability assessment.

There are a variety of circumstances that resulted in collection of some, but not all required data for a crossing including:

- No access was available to the crossing inlet or outlet.
- The upstream or downstream structure was buried or could not be found.
- The inlet or outlet was partially submerged.
- The water was too deep to safely enter.

Crossings with limited access were assessed to the extent possible by estimating the missing parameters when appropriate and/or adjusting the vulnerability assessment scoring based upon the analyst's judgement. All assumptions were noted in the data analysis spreadsheet. The assumptions were made with the intention of capturing any issues that could be identified at the crossing using the partially-collected data, without artificially raising or lowering the crossing score or overall priority.

FUSS & O'NEILL

3.1.1 Crossing Survey Findings Summary

The following general conditions were observed at the surveyed stream crossings:

- **Structure Type:** The majority of the assessed crossings were round culverts (88; 64%), followed by boxes/bridges with abutments (26; 19%), box culverts (10; 7%), open-bottom arch bridges/culverts (8; 6%) and elliptical culverts (3; 2%). The structure type was unknown on one crossing because it was submerged. One crossing with multiple structures contained both a bridge with abutments and an open-bottom arch culvert.

- **Poor Structural Condition:** Many of the structures were observed to be in poor condition and in need of significant repairs or replacement. Fifty seven (34%) of the assessed structures had at least one structural variable rated as poor while 30 (18%) of the assessed structures had at least one structural variable rated as critical. Headwall/wingwall condition, level of blockage, and invert condition were the variables most frequently rated as poor or critical. *Figure 3* provides examples of some of the structural issues observed in the field.

Figure 3. Examples of crossing structures in poor or critical structural condition observed at various locations during field assessments. Left: Degraded headwall; Center: Critical level of blockage; Right: Deteriorated pipe invert.

- **Flow Constriction:** The majority of the assessed crossings are significantly narrower than the bankfull width of the stream channel and therefore appear to constrict flood flows. One hundred and twelve (82%) of the assessed crossings were rated as severely constricted, indicating that the bankfull width of the stream channel was at least twice as wide as the structure opening(s). The hydraulic capacities of many of the crossings in the watershed are limited due to undersized crossing structures and/or significant accumulation of sediment at some locations.

- **Physical Barriers:** Thirty-one (18%) of the assessed structures serve as moderate to severe barriers to aquatic organism passage. Freefalls within the structure or upstream of the structure were the most common physical barrier seen in the field. Twenty-eight (16%) structures have cascading or freefalling outlets. Most structures do not have substrate that matches the streambed, creating a discontinuity for organisms trying to pass through the crossing.

- **Sediment Deposition:** Sediment deposition was observed upstream, downstream or within the structure at 49 (36%) of the assessed crossings. Sediment deposition can reduce flow conveyance capacity, increase the potential for blockage or clogging during higher flows, and potentially restrict aquatic passage during low-flow conditions.

- **Tailwater Scour Pool:** Forty-two (31%) of the assessed crossings had tailwater scour pools present at the outlet. A tailwater scour pool can indicate inadequate sediment supply due to backwater and/or sediment deposition at the crossing inlet/outlet. A tailwater scour pool may also indicate that an undersized structure is causing an increase in water velocity through the culvert at the outlet. Continuous scour can lead to undermining of the culvert, which can ultimately lead to failure of the structure.

3.2 Vulnerability Assessment

The results of the individual vulnerability assessments and the overall prioritization are discussed in the following sections. *Table 1* summarizes the scoring and prioritization results for each of the highest priority crossings that were included in the vulnerability assessment. The scoring and prioritization results for all assessed crossings are provided in *Appendix C*.

3.2.1 Existing Hydraulic Capacity

Forty-nine (36%) of the crossings assessed are hydraulically undersized under existing precipitation conditions, having insufficient capacity to convey the 10-year peak flow *(Figure 4)*. Another 15 (11%) crossings are hydraulically undersized relative to the 25-year return interval flow *(Figure 4)*. Fifty-one (37%) crossings were found to be sized such that they could pass the 100-year return interval flow under existing conditions (these include some larger structures, as well as some smaller structures where peak flows are low as a result of a smaller watershed area feeding into the crossing).

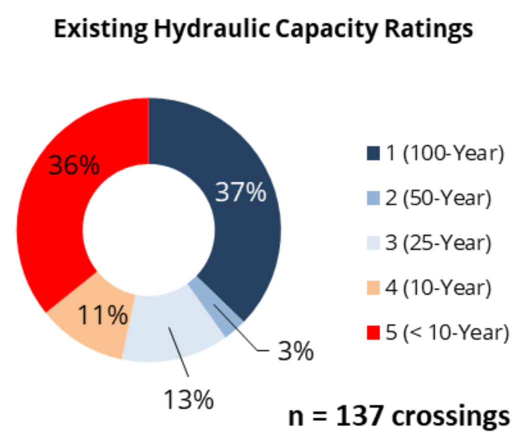

Figure 4. Distribution of hydraulic capacity ratings across all assessed crossings, under existing conditions.

Figure 5 shows the hydraulic capacity scores for the most common types of structures that were evaluated in Walpole. Many round culverts, which were the most frequently seen structure type in the field, are severely undersized and are unable to pass the 10-year flow (37%). However, almost an equal percentage of round culverts are adequately sized to convey the 100-year peak streamflow (34%). Many of these adequately-sized round culverts are receiving flow from watersheds with smaller areas and/or lower peak flows. Thirteen (50%) of the assessed boxes/bridges with abutments were severely undersized and are unable to pass the 10-year peak streamflow. Conversely, 50% of the assessed box culverts and 75% of the assessed open-bottom arch bridges/culverts were adequately sized to convey the 100-year peak streamflow. Many of the open-bottom arch bridges assessed in the field were large structures capable of accommodating larger flows. However, the small number of box culverts and open-bottom arch bridges/culverts assessed in the field (10 box culverts and 8 open-bottom arches) limits the ability to draw conclusions about the hydraulic capacity of these structure types as a group from this assessment.

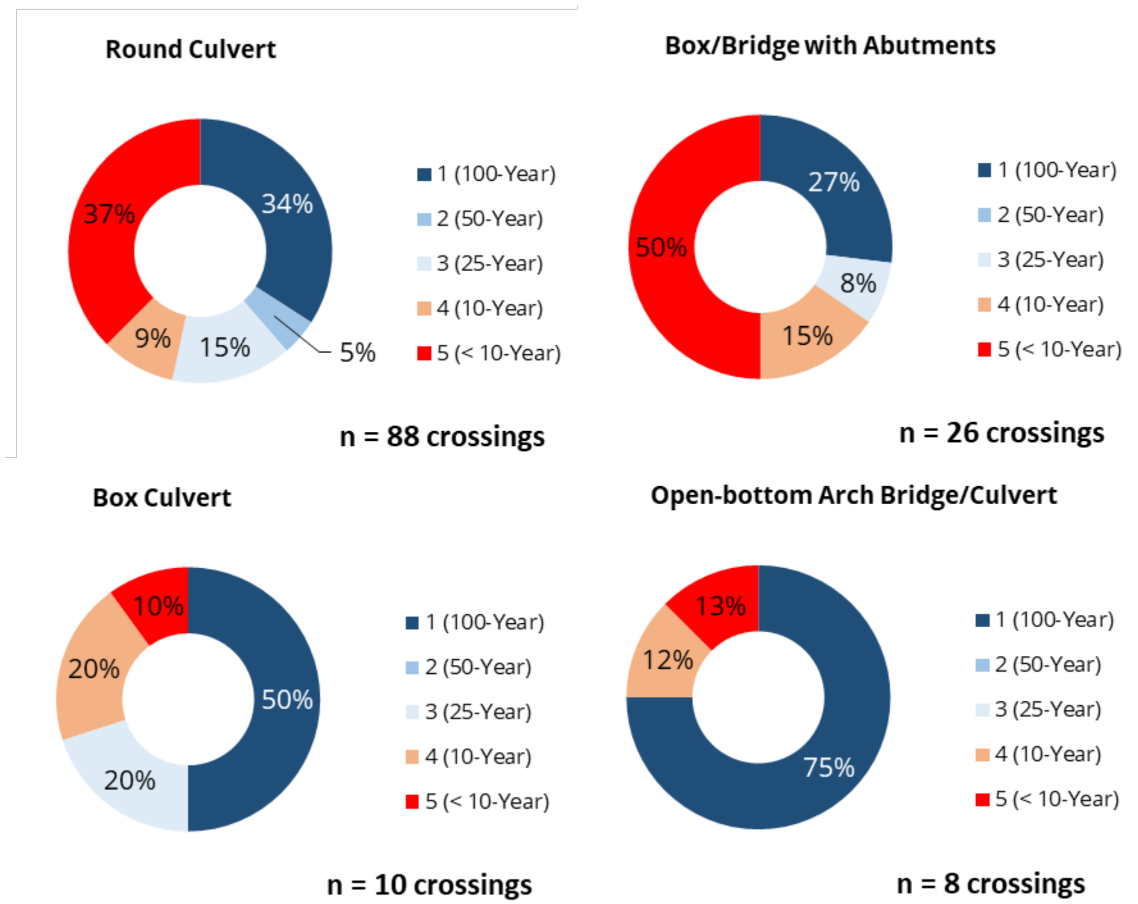

Figure 5. Hydraulic Capacity Scores of Walpole crossings by structure type.

Crossings that received the highest Hydraulic Risk Scores (score of 25 out of 25) include those on West Street, Lewis Avenue, and Elm Street, all of which are over the Neponset River. A crossing on Main Street over an unnamed tributary from Cobbs Pond to the Neponset River also received the highest possible Hydraulic Risk Score, as well as two partially inaccessible crossings that are buried under Warwick Road and Wall Street. All of these crossings are among the highest ranked crossings overall *(Table 1)*. *Figure 6* shows the spatial distribution of Hydraulic Risk Scores throughout Town. The scoring and prioritization of the crossings that received the highest Hydraulic Risk Scores is provided in *Table 2* of *Appendix C*. Many of the assessed crossings received high Hydraulic Risk Scores; 36 crossings (26%) received a Hydraulic Risk Score of 20 or 25, out of a maximum possible score of 25. These results indicate that hydraulically undersized crossings are a widespread problem throughout Walpole, as is the case in many Massachusetts communities with older drainage infrastructure.

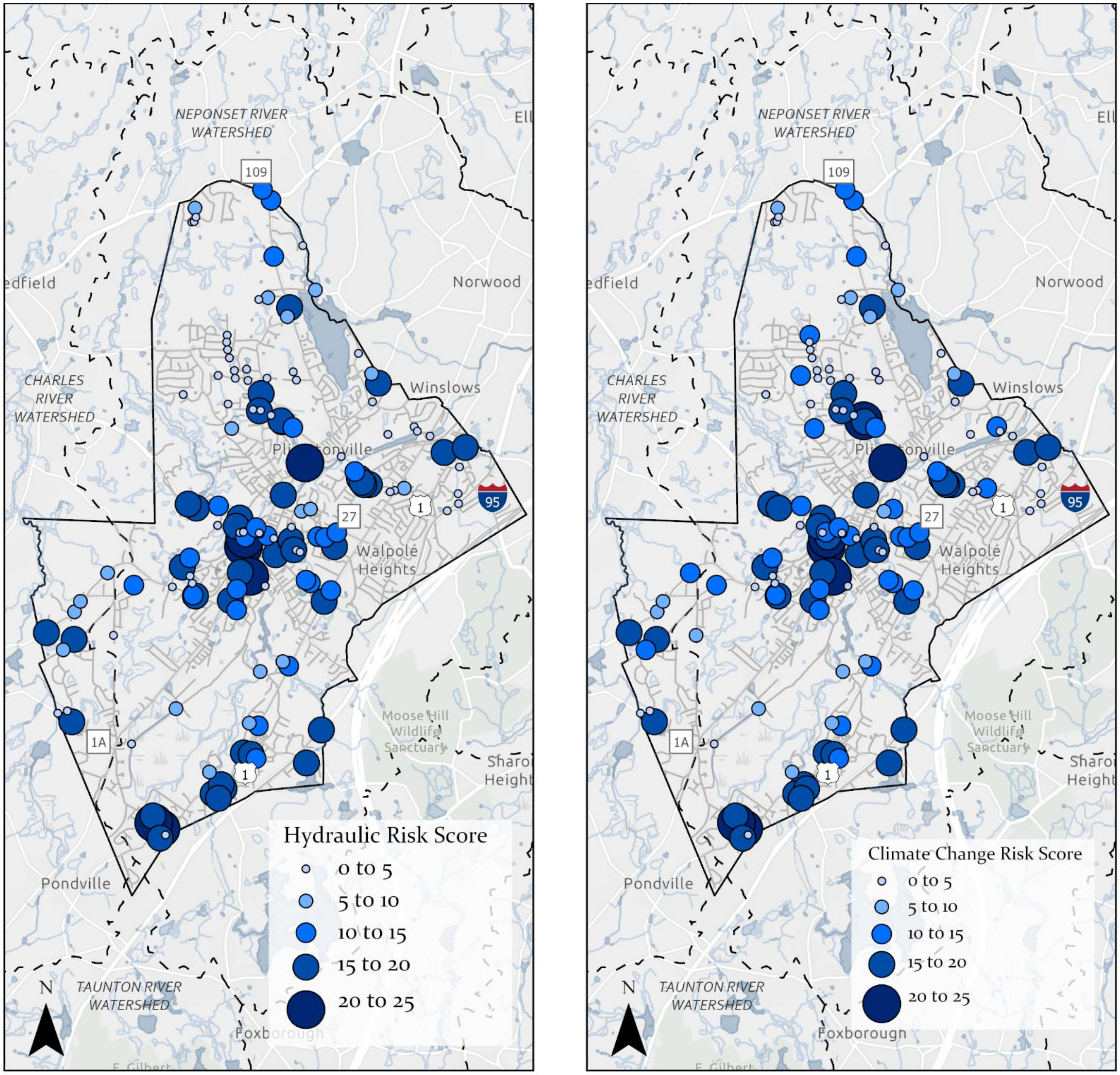

Figure 6. Spatial Distribution of Hydraulic Risk Scores (left) and Climate Change Risk Scores (right) for all assessed crossings.

3.2.2 Climate Change Vulnerability

Under future expected flows, assuming an increase in peak flows of 20%, 58 (42%) crossings are expected to be severely impacted by climate change, another 11 (8%) are expected to be significantly impacted by climate change, and 46 (34%) are expected to have insignificant impacts from climate change *(Figure 7)*. More crossings are expected to be severely hydraulically undersized under future climate change conditions compared to existing conditions (42% compared to 36%).

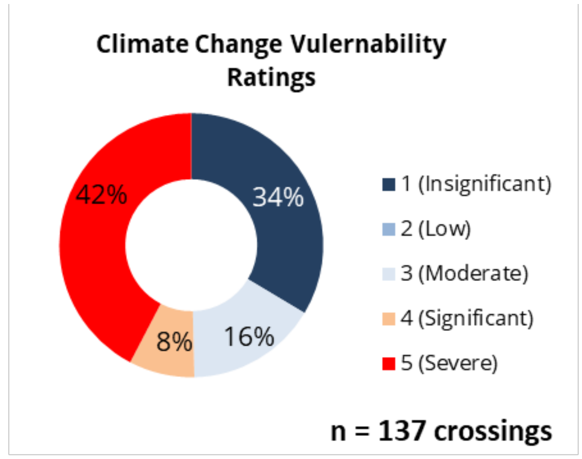

Figure 7. Distribution of climate change vulnerability ratings across all assessed crossings, under expected future precipitation conditions under climate change.

The spatial distribution of Climate Change Risk Scores is shown in *Figure 6*. All 5 of the crossings that received the highest possible Hydraulic Risk Scores also received the highest possible Climate Change Risk Scores. This is consistent with expectations, as the climate change assessment is partially based on applying a 20% increase to peak flows calculated during the existing hydraulic capacity assessment. One additional crossing on Gould Street over an unnamed tributary to Cobb's Pond also received the highest possible Climate Change Risk Score. All of these crossings were among the top-scoring crossings overall *(Table 1)*. The scoring and prioritization of the crossings that received the highest Climate Change Risk Scores is provided in *Table 3* of *Appendix C*. Many of the assessed crossings received high Climate Change Risk Scores; 43 crossings (31%) received a Climate Change Risk Score of 20 or 25, out of a maximum possible score of 25. These results indicate that hydraulically undersized crossings are a widespread problem throughout Walpole that will worsen in the future given projected increases in extreme precipitation resulting from climate change.

3.2.3 Geomorphic Risk

Seventeen (12%) of all assessed crossings were rated as having severe or significant geomorphic impacts, taking into account both observed geomorphic impacts and potential geomorphic impacts *(Figure 8)*. The majority of the crossings (102 crossings; 74%) were rated as having moderate geomorphic impacts. The remaining eighteen (13%) crossings were found to have low geomorphic impacts. Crossings with the highest Geomorphic Risk Scores (indicating high geomorphic impacts and high flood impacts) are located on Smith Avenue over an unnamed tributary to Cobb's Pond, on Bird Drive over an unnamed tributary to the Neponset River, on Summer Street over the Neponset River, and on Route 1 over School Meadow Brook *(Figure 9)*. All of these crossings except for the crossing on Route 1 were among the top-scoring crossings overall *(Table 1)*. Other high-scoring crossings include several near the intersection of North and Gould Streets over unnamed tributaries to Cobb's Pond. Many of these crossings were rated as having severe constriction, smaller stream substrate size, and bank erosion or outlet armoring, which contributed to higher geomorphic risk scores for these crossings, in addition to being located in areas with high potential for flood impacts. The scoring and prioritization of the crossings that received the highest Geomorphic Risk Scores is provided in *Table 4* of *Appendix C*.

3.2.4 Structural Risk

Forty (29%) assessed crossings were rated as critical relative to structural condition, and ninety-seven (71%) were rated as either good or satisfactory *(Figure 8)*. Two crossings received the highest possible Structural Risk Score of 25, indicating critical structural condition and high flood impacts. These crossings are located on Smith Avenue over an unnamed tributary to Cobb's Pond and Warwick Road over an unnamed tributary to the Neponset River. Both of these crossings were among the top-scoring crossings overall *(Table 1)*. Other crossings with high Structural Risk Scores are spread evenly throughout Town *(Figure 9)*. The scoring and prioritization of the crossings that received the highest Structural Risk Scores is provided in *Table 5* of *Appendix C*.

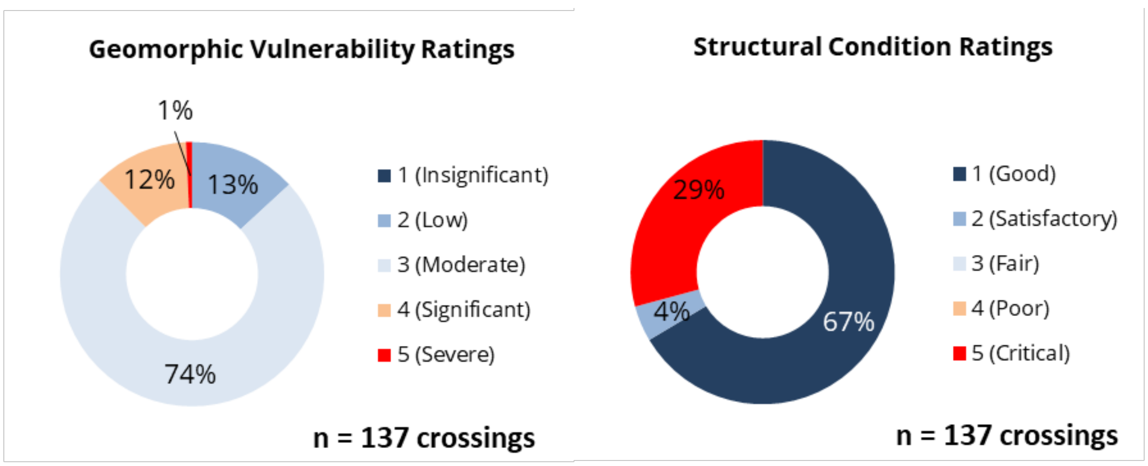

Figure 8. Distribution of geomorphic vulnerability (left) and structural condition (right) ratings across all assessed crossings.

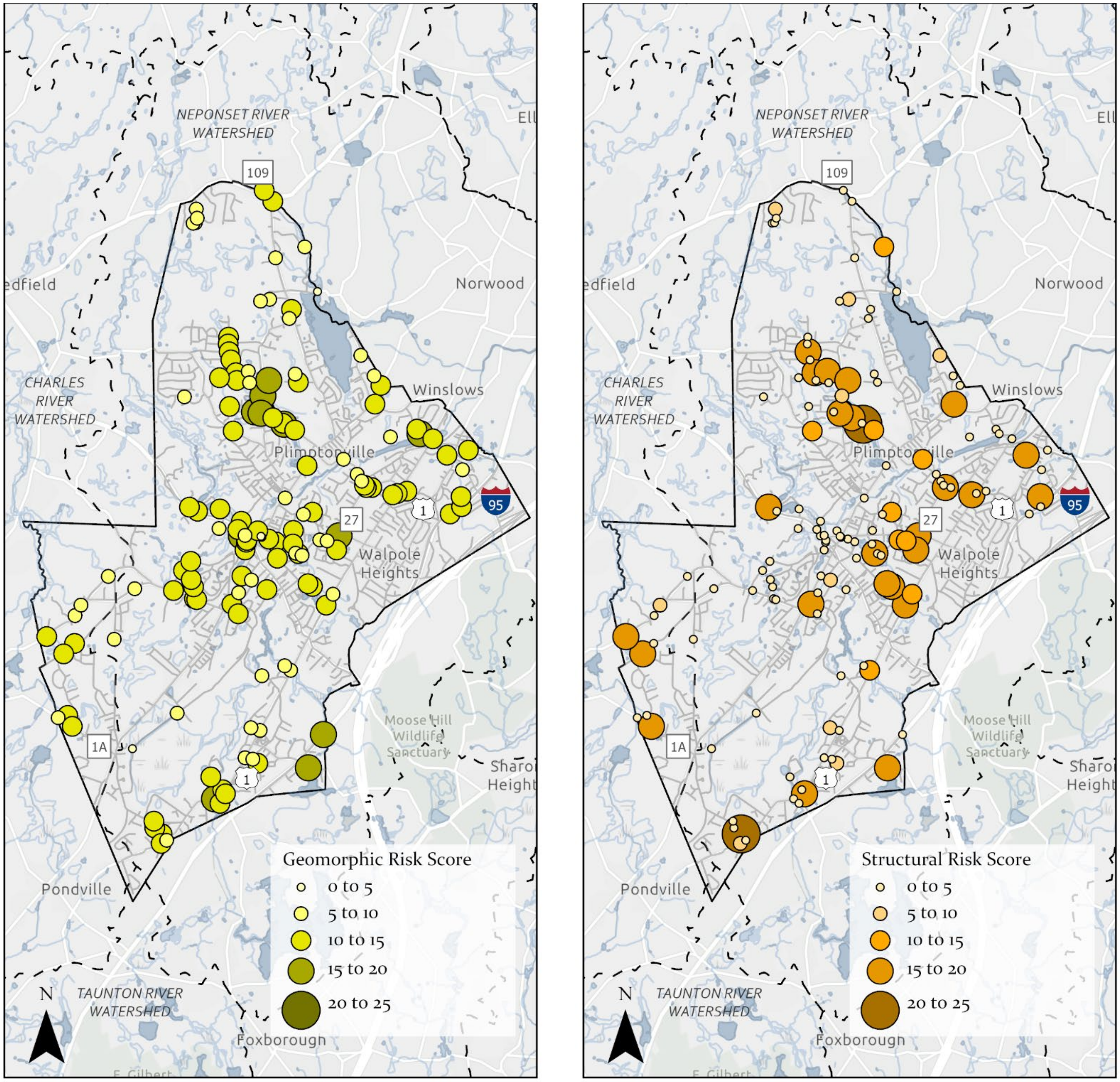

Figure 9. Spatial Distribution of Geomorphic Risk Scores (left) and Structural Condition Scores (Right) for all assessed crossings.

3.2.5 Aquatic Organism Passage

Fifty-six (41%) of assessed crossings are considered moderate or worse barriers to aquatic organism passage, but only 17 (12%) crossings are considered to act as significant or severe barriers *(Figure 10)*. Twenty-nine (21%) are considered to provide full aquatic passage. The two crossings that received the highest AOP benefit scores—that is, crossings which are barriers to aquatic organism passage but which are also at locations where improved passage would have the greatest benefit—are located on Mill Pond Road over Mine Brook and Plimpton Street over Plimpton Pond. The crossing on Plimpton Street was among the top-scoring crossings overall *(Table 1)*. The majority of the assessed crossings received low to moderate AOP Benefit Scores, indicating that the crossings with the most severe aquatic barriers are located in areas where habitat quality and other characteristics likely limit the ecological benefit to crossing removal or replacement. The spatial distribution of AOP Benefit Scores is provided in *Figure 11*.

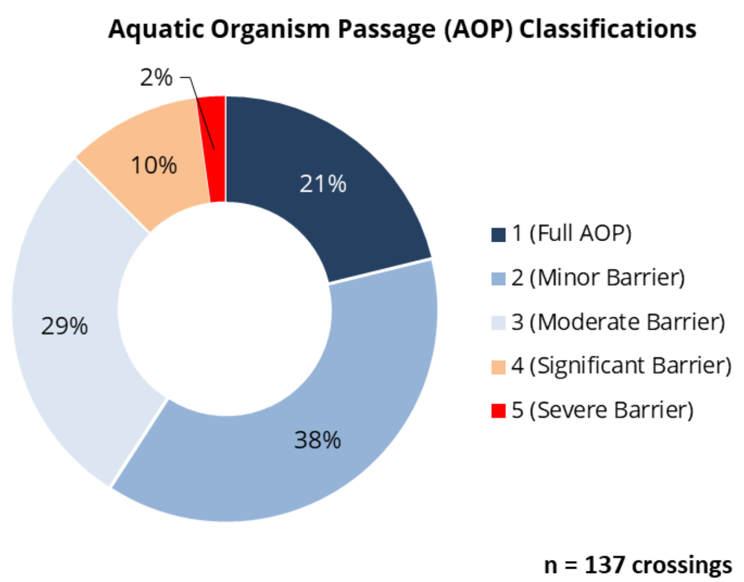

Figure 10. Distribution of Aquatic Passability Scores across all assessed crossings.

3.2.6 Transportation Disruption and Potential Flood Impacts

Because impacts to transportation services were calculated as a function of road classification, the crossings with the highest potential for transportation disruption were found to occur on state roadways, with the highest impact crossings located on Route 1. The sites with the highest potential for flooding impacts were located in densely developed areas, particularly on crossings in the downtown area over the Neponset River. Other crossings that received high Impact Scores (either due to transportation or flooding impacts) include crossings near Bird and Son Pond off of Washington Street, Bird Drive and Hilldene Drive, crossings at the intersection of Gould Street and Smith Avenue, and a crossing on Main Street at the outlet of Cobb's Pond. The spatial distribution of Impact Scores is provided in *Figure 11*.

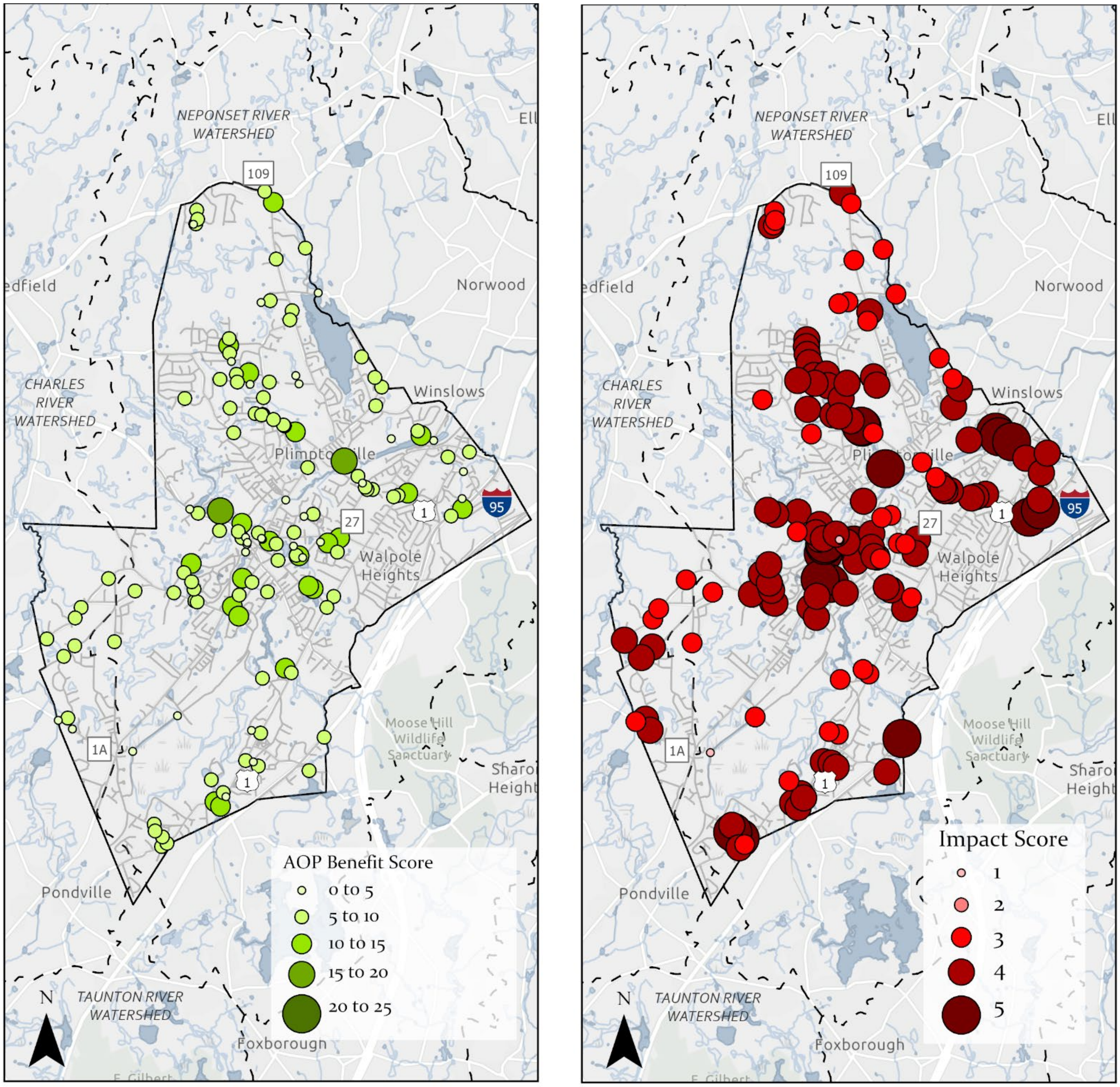

Figure 11. Spatial distribution of Aquatic Organism Passage Benefit Scores (left) and Impact Scores (right) for all assessed crossings.

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3.2.7 Highest-Scoring Crossings

The spatial distribution of the high-scoring crossings is provided in *Figure 12***.** Thirty-two (23%) crossings were categorized as high priority, 86 (63%) were categorized as medium priority, and 19 (14%) were categorized as low priority. *Table 1* summarizes the prioritization score for the 18 highest scoring crossings located in Walpole. The highest-scoring crossings were reviewed by the Project Steering Committee to determine the highest priority for planning-level recommendations, as discussed in *Section 4 Recommendations.*

Three crossings received the highest Scaled Crossing Priority Score of 0.84. These crossings include a crossing on Smith Street near the intersection with Gould Street over an unnamed tributary to Cobb's Pond that received the highest possible Structural Risk Score and is located in an area with high flood impact potential. A crossing off of Warwick Road that conveys an unnamed tributary to the Neponset River and is buried under Wall Street received the highest Scaled Crossing Priority Score as a result of high structural, hydraulic and climate change risk, as well as high potential for flood impacts. The crossing on Main Street over an unnamed tributary to the Neponset River at the outlet of Cobb's Pond is the third crossing to receive a Scaled Crossing Priority Score of 0.84, due to high Hydraulic and Climate Change risk scores and high potential for flood impacts.

Other high-scoring crossings include seven (7) crossings on the main stem of the Neponset River on Lewis Avenue, West Street, Elm Street, Summer Street, Plimpton Street, Main Street, and Robbins Road. The crossings on Lewis Avenue, West Street, Elm Street, Summer Street, Main Street and Robbins Road received high scores due to high Hydraulic and Climate Change Risk Scores and high potential for flood impacts. The crossing on Plimpton Street was among the top-scoring crossings due to a high Aquatic Benefit Score (20) and a moderate Structural Risk Score (15).

Of the 18 highest-scoring crossings, six (6) were among the crossings that received the highest possible Hydraulic Risk Score, seven (7) were among the crossings that received the highest possible Climate Change Risk Score, and two (2) were among the crossings that received the highest possible Structural Risk Score.

All 18 of the highest scoring crossings received an Adjacent Crossing Flag, indicating that another crossing is within the upstream or downstream flood impact area of the crossing. In fact, 117 (85%) of the 137 assessed crossings received an Adjacent Crossing Flag. These results highlight the proximity of the crossings to one another within Walpole and the potential for a single crossing failure to negatively impact nearby upstream and/or downstream crossings.

Four of the top 18 crossings received an Unknown Structural Condition Flag (the two crossings that are buried under Warwick Road and Wall Street, a crossing on Elm Street, and a crossing on Oak Street). This flag indicates that certain aspects of the structural condition could not be assessed in the field and the crossing may therefore be in worse condition than the score represents.

Seven of the top 18 crossings received a Local Knowledge Flag, indicating there is additional information about these crossings that should be taken into consideration during prioritization and upgrade or replacement. The local knowledge associated with these crossings is discussed in *Section 5: Top Priority Crossings***.**

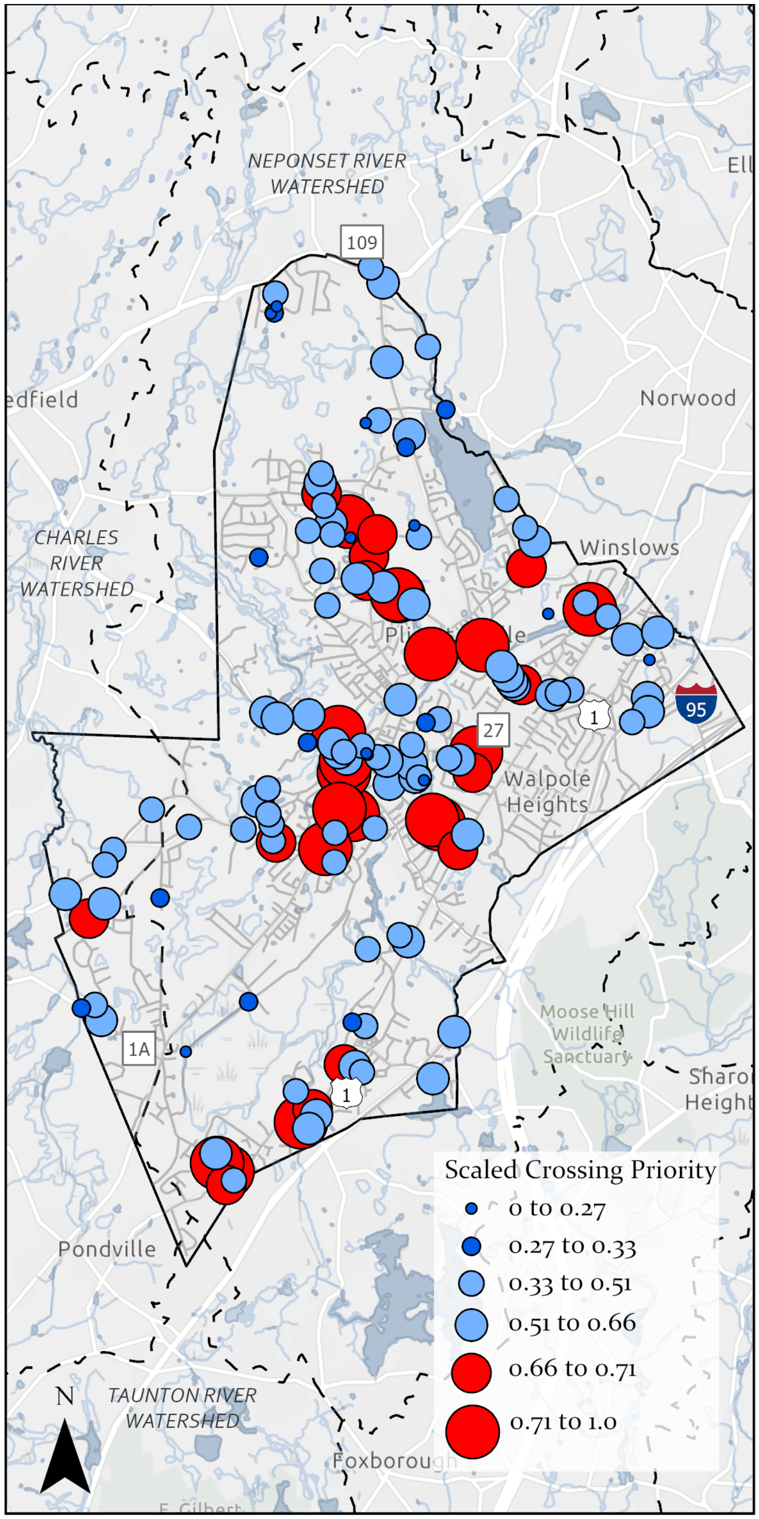

Figure 12. Spatial distribution of scaled crossing priority scores for all assessed crossings. Red dots indicate high priority crossings, light blue dots indicate medium priority crossings, and dark blue does indicate low priority crossings.

Table 1. Top-ranked high priority crossings: road-stream crossing vulnerability assessment and prioritization results summary

Crossing Code	Road Name	Stream Name	Impact Score (1-5)	Existing Hydraulic Risk Score (1-25)	Climate Change Risk Score (1-25)	Geomorphic Risk Score (1-20)	Structural Risk Score (1-25)	AOP Benefit Score (1-20)	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42099387127399	Warwick Road	Unnamed Tributary to Neponset River	5	25	25	15	25	9	25	42	0.84	High
xy42158337124241	**Main Street**	**Unnamed Tributary to Neponset River**	**5**	**25**	**25**	**15**	**5**	**9**	**25**	**42**	**0.84**	**High**
xy42165037124747	**Smith Avenue**	**Unnamed Tributary to Cobbs Pond**	**5**	**20**	**20**	**20**	**25**	**9**	**25**	**42**	**0.84**	**High**
xy42140017125451	**Lewis Avenue**	**Neponset River**	**5**	**25**	**25**	**10**	**10**	**8**	**25**	**41.5**	**0.83**	**High**
xy42165167124759	**Gould Street**	**Unnamed Tributary to Cobbs Pond**	**5**	**20**	**25**	**15**	**5**	**8**	**25**	**41.5**	**0.83**	**High**
xy42100287127547	Wall Street	Unnamed Tributary to Neponset River	5	25	25	15	5	6	25	40.5	0.81	High
xy42144837125583	West Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42146067125557	Elm Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42104937126264	**Summer Street**	**Neponset River**	**4**	**20**	**20**	**20**	**4**	**15**	**20**	**37.5**	**0.75**	**High**
xy42159347123453	**Plimpton Street**	**Neponset River**	**3**	**3**	**3**	**9**	**15**	**20**	**15**	**37.5**	**0.75**	**High**
xy42136137125876	**Oak Street**	**Unnamed Tributary to Neponset River**	**4**	**20**	**20**	**12**	**20**	**12**	**20**	**36**	**0.72**	**High**
xy42138987124132	**Stone Street**	**Spring Brook**	**4**	**12**	**12**	**12**	**20**	**12**	**20**	**36**	**0.72**	**High**
xy42139387124233	**Stone Street**	**Unnamed Tributary to Railroad Pond**	**4**	**12**	**12**	**12**	**20**	**12**	**20**	**36**	**0.72**	**High**
xy42140687125658	**Main Street**	**Neponset River**	**5**	**20**	**20**	**15**	**5**	**12**	**20**	**36**	**0.72**	**High**
xy42147047123565	Peach Street	Unnamed Tributary to Rainbow Pond	4	12	12	16	20	12	20	36	0.72	High
xy42149497125665	**Robbins Road**	**Neponset River**	**4**	**16**	**20**	**12**	**4**	**12**	**20**	**36**	**0.72**	**High**
xy42163417121799	Bird Drive	Unnamed Tributary to Neponset River	5	5	5	20	5	12	20	36	0.72	High
2173527125505	Sunnyrock Drive	Unnamed Tributary to Cobbs Pond	4	4	4	8	20	12	20	36	0.72	High

*Note: Crossings in **bold text** were identified by the Project Steering Committee for planning-level recommendations.*

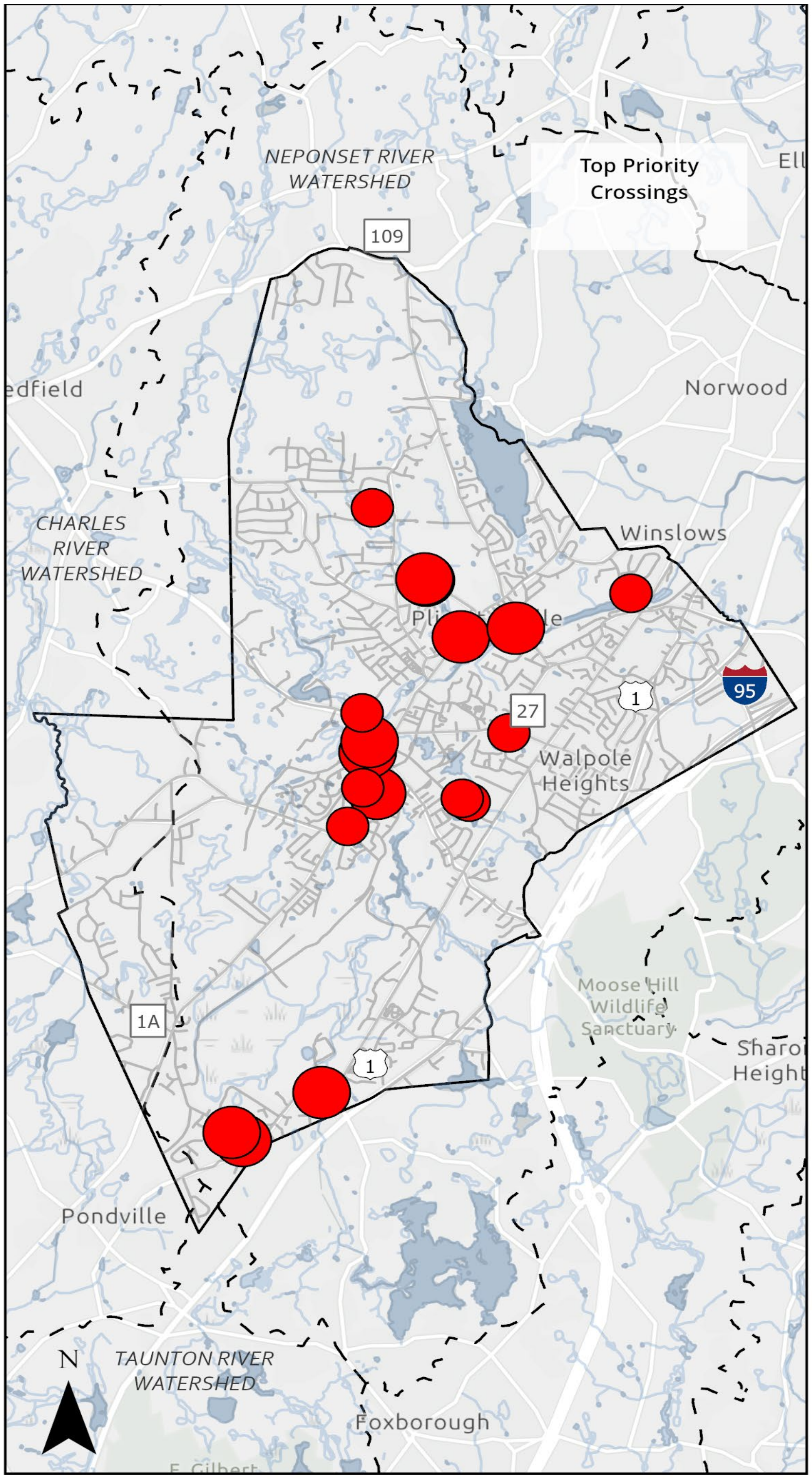

Figure 13. Locations of top eighteen highest-ranked priority crossings. Larger dots indicate higher priority scores.

4 Recommendations

The 18 highest scoring crossings were reviewed by the Project Steering Committee to determine the 10 highest priority crossings for planning-level recommendations. The Project Steering Committee chose the 10 highest priority crossings based on factors such as planned maintenance activates, property ownership (a small number of crossings are associated with private property or privately owned dams) and known recurrent maintenance or flooding issues. Site descriptions and proposed concepts for the 10 highest-scoring crossings are detailed in *Section 5: Top Priority Crossings*.

Specific recommendations were developed for the 10 priority stream crossings that were evaluated as part of this assessment. These planning-level recommendations are intended to enhance the resilience of the stream crossings and river system by withstanding extreme flood events, providing for the passage of debris during floods, and providing for passage of aquatic organisms under normal flow conditions. At several of the crossings, we also recommend channel or floodplain restoration in upstream or downstream areas along with the proposed crossing upgrades to enhance flood resilience, water quality, and aquatic habitat using a combination of natural and infrastructure-based approaches. Proposed recommendations adhere to the Massachusetts River and Stream Crossing Standards.

Planning level cost estimates will be provided for each of the recommendations in the final report. Estimated costs will be presented as screening level cost ranges for the purpose of comparing and prioritizing various alternatives and to help select a preferred alternative based on relative project benefits and costs. The planning level cost ranges will include estimates of the anticipated design and construction costs. Design and construction costs are based on costs of recent similar stream crossing replacement projects in the northeastern U.S.

The following sections provide a summary of the existing issues, recommendations, and screening-level cost ranges for Walpole's top priority stream crossings where upgrades or replacement are recommended.

5 Top Priority Crossings

5.1.1 Gould Street and Smith Avenue (xy42165167124759/xy42165037124747)

An unnamed tributary to Cobb's Pond passes under Gould Street just before its intersection with Smith Avenue, then passes under Smith Avenue immediately downstream. The crossing under Gould Street consists of two 45-foot long, 3-foot diameter concrete pipes *(Figure 14)*. Both the inlet and outlet are significantly narrower than the stream, resulting in severe constriction. The constriction of the stream has led to the development of a large scour pool at the outlet. The structure is in relatively good condition, but is critically undersized. The crossing lacks sufficient hydraulic capacity to pass the 10-year peak flow under existing conditions, and is therefore also undersized for larger peak flows as well as expected increases in extreme flows under projected future climate conditions. The crossing on Smith Avenue received a Local Knowledge Flag because the Town noted that this crossing frequently overtops during heavy rain events and storms.

Figure 14. View of existing crossing outlet on Gould Street (xy42165167124759) taken during field assessment on October 29, 2019.

Figure 15. View of existing crossing outlet on Smith Avenue (xy42165037124747) taken during field assessment on October 29, 2019.

The crossing under Smith Street similarly consists of two 46-foot long, 3-foot diameter concrete pipes, which are also severely undersized compared to the stream channel and is resulting in a large scour pool *(Figure 15)*. This crossing also lacks sufficient hydraulic capacity to pass the 10-year peak flow. In addition, the stone headwall of this crossing is in critical condition at the inlet due to missing stones creating void spaces. The proximity of these two crossings to each other makes it likely that failure of the upstream Gould Street crossing would result in failure of the downstream Smith Street crossing.

Proposed Concept

Replace the existing undersized culverts at both crossings with bridges of approximately 25-foot wide span. Realign the crossings to better match the existing stream channel alignment. Restore the stream channel banks to match the existing stream channel up and downstream of the crossings.

- Provide increased hydraulic capacity to reduce flooding risk
- Reduce geomorphic risk associated with poor crossing alignment
- Protect outlet and surrounding intersection from scour

5.1.2 Lewis Avenue (xy42140017125451)

Lewis Avenue crosses the Neponset River approximately 1,000 feet southwest of Common Street. The crossing consists of two concrete box culverts approximately 6.5-feet wide by 5-feet tall *(Figure 16)*. The bankfull width was estimated to be approximately 22-feet, meaning the structure causes a severe constriction of the stream channel. The existing structures are undersized for the 10-year peak flow under existing conditions, and are therefore also undersized for larger peak flows as well as expected increases in extreme flows under projected future climate conditions. Structural and Geomorphic Risk were not major concerns at this crossing, though the headwall/wingwall condition, joint/seam and armoring condition were rated as poor.

Figure 16. View of existing crossing inlet taken during field assessment on November 21, 2019.

Proposed Concept

Replace the existing undersized culverts with a bridge of approximately 26-foot wide span.

- Provide increased hydraulic capacity to reduce risk of road overtopping

5.1.3 Main Street (xy42158337124241)

Figure 17. Upstream view of Cobbs Pond from the crossing during field assessment on December 6, 2019.

Main Street crosses an unnamed tributary to the Neponset River at the outlet of Cobbs Pond. A flow control structure is present at the inlet due to the presence of Cobbs Pond immediately upstream of the crossing *(Figure 17)*. This flow control structure results in a severe drop at the inlet of the structure. The crossing consists of a 2.5-foot wide by 5.5 foot tall box/bridge with abutments made of rock/stone. The inlet could not be completely assessed in the field due to access restrictions. The structure is significantly narrower than the stream's approximately 20-foot bankfull width, resulting in severe constriction. The crossing is undersized for the 10-year peak streamflow and is therefore also undersized for larger peak flows as well as expected increases in extreme flows under projected future climate conditions. Structural condition was not a major concern at this crossing, but geomorphic risks were considered moderate due in-part to bank erosion along the stream channels. This crossing received a Local Knowledge Flag because this crossing is owned by MassDOT and the Town noted that it is scheduled to be replaced by MassDOT in the near future.

Proposed Concept

Complete a drainage study to determine the overall flooding risk of Cobbs Pond due to the flow control structure which outlets under Main Street as well as investigating the feasibility of dredging Cobbs Pond.

- Understanding risk flooding risk associated with Cobbs Pond
- Evaluate feasibility of dredge project
- Provide increased hydraulic capacity to reduce risks from road overtopping
- Reduce geomorphic risk associated with inlet drop and bank erosion

5.1.4 Summer Street (xy42104937126264)

Summer Street crosses the Neponset River approximately 350 feet west of Neponset Street. A flow control structure is present at the inlet due to the presence of a small pond immediately upstream of the crossing *(Figure 18)*. The stream is heavily channelized downstream preventing the measurement of bankfull width. The crossing consists of a box/bridge with abutments that is a combination of concrete/stone and is approximately 6 feet wide by 5.5 feet tall *(Figure 19)*. The existing structure is undersized for the 10-year peak flow under existing conditions, and is therefore also undersized for larger peak flows as well as expected increases in extreme flows under projected future climate conditions. According to information collected from the Town, this crossing overtopped in the 1970s. There is a freefall present at the outlet of about 1.3 feet to the water surface, which is resulting in a large scour pool at the outlet. There is an extensive outlet apron present, however the scour pool is present where the apron meets the natural streambed. The flow control structure at the inlet is resulting in a freefall as well. The freefall at the inlet and outlet are acting as barrier to aquatic organism passage. The structural condition overall of this crossing was not a major concern, however the headwall/wingwall was rated as poor.

Figure 18. Upstream view from the crossing taken during field assessment on October 30, 2019.

Figure 19. View of existing structure inlet taken during field assessment on October 30, 2019.

Proposed Concept

Reconstruct the stream channel and banks through the crossing to match the existing channel, including stream substrate and slope. Perform repairs to improve the structural integrity and general condition of both the headwall/wingwalls.

- Perform hydrologic and hydraulic study with the goal of understanding the risk of flooding associated with pond storage upstream.
- Provide increased hydraulic capacity to accommodate peak flows and reduce risks from flooding
- Reduce geomorphic risk associated with freefall conditions and the fact that the crossing slope is significantly more than that of the natural channel
- Provided improvements to aquatic passage

5.1.5 Unnamed (xy42136137125876/ xy42137957125730 /xy42134647125771)

An unnamed tributary to the Neponset River enters a culvert under a private driveway off of Oak Street at 43 Oak Street *(Figure 21)*. The stream then enters the storm drain system and exits from an outlet off of Spring Valley Drive, approximately 280 feet from Main Street *(Figure 20)*. The inlet on Oak Street consists of a round, smooth metal culvert measuring approximately 1.5 feet in diameter. Bankfull width could not be measured but the crossing was estimated to severely constrict the stream channel. Severe sediment deposition was present upstream and the level of blockage at the inlet was rated as critical. The crossing lacks sufficient hydraulic capacity to pass the 10-year peak flow under existing conditions, and is therefore also undersized for larger peak flows as well as expected increases in extreme flows under projected future climate conditions. The debris and fencing present at this crossing act as barriers to aquatic organism passage. This crossing received a Local Knowledge Flag due to the fact that the structure is tied into the storm drain system and that the Town noted this crossing frequently clogs and has to be cleaned out to prevent flooding in the surrounding neighborhood.

The outlet on Spring Valley Drive consists of a round concrete culvert measuring approximately 2 feet in diameter. This crossing did not score among the highest scoring crossings but should be assessed in conjunction with the crossing on Oak Street since it serves as the crossing outlet for the buried stream.

The crossing on Audubon Drive should also be included in any further analysis of this system. This crossing consists of an inlet that serves as an overflow structure for the pond at the intersection of Audubon Drive and Oak Street *(Figure 22)*. The outlet of this crossing could not be found but it is likely that this structure is also tied into the storm drain system and also exits from the outlet off of Spring Valley Drive. This crossing should therefore also be included in the replacement assessment/drainage study for this area, even though this crossing did not score among the highest-scoring crossings.

Figure 20. View of existing outlet on Spring Valley Drive crossing (xy42137957125730) taken during field assessment on November 6, 2019.

Figure 21. View of existing inlet on Oak Street crossing (xy42136137125876) taken during field assessment on October 30, 2019.

Figure 22. View of existing inlet on Audubon Drive (xy42134647125771) taken during field assessment on November 22, 2019.

Proposed Concept

Conduct a drainage study to confirm the interconnections of the existing drainage system and the pond outlets at Audubon Drive. The data collected from this study area could then be used to achieve the following goals:

- Replace the existing undersized crossings with a structure appropriately sized to accommodate the bankfull width
- Daylight the buried stream and disconnect the stream from the storm drain system where possible and restore natural stream channel habitat
- Remove barriers to aquatic organism passage by removing the existing fence and installing drainage features which are easier for the Town to maintain.

5.1.6 Plimpton Street (xy42159347123453)

Plimpton Street intersects the Neponset River at a braded section of the river channel, approximately 1,600 southeast of Main Street (as the crow flies). The crossing consists of three structures; two concrete box culverts approximately 10.7 feet wide by 6 feet tall *(Figure 23)* and a corrugated metal open-bottom arch culvert approximately 4 feet wide by 5.6 feet tall *(Figure 24)*. Bankfull width could not be measured due to limited access to the stream and unsafe water conditions. Constriction of the stream channel by the three structures was rated as severe. The crossing was rated as capable of passing the 100-year peak streamflow and is expected to be insignificantly impacted by climate change.

Figure 23. View of existing box culvert outlet taken during field assessment on December 13, 2019.

The two concrete box culverts received a high Structural Risk Score due to poor footing condition and headwall/wingwall condition. The structural condition of the metal arch culvert was rated as adequate for all assessed conditions. There is an outlet drop present on the box culverts of about 2 feet to the water surface and 3.7 feet to the stream bottom. There is also an outlet drop of about 2 feet to the water surface and 3 feet to the stream bottom on the metal arch culvert. The metal arch culvert also has an internal freefall of about 1 foot within the structure. These conditions present barriers to aquatic organism passage at a site which has a high Index of Ecological Integrity Rating, an indicator of stream habitat quality and overall ecological benefit of removing an existing barrier.

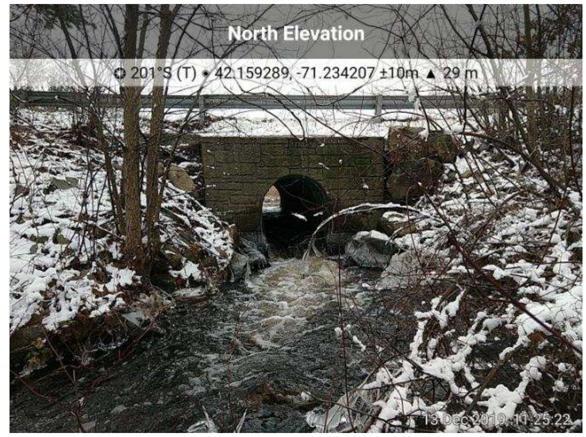

Figure 24. View of existing arch culvert outlet taken during field assessment on December 13, 2019.

Proposed Concept

Replace the two box culverts with a bridge to restore the natural channel bottom crossing substrate. Replace the structural footings and crossing substrate of the arch culvert to address the internal drop and restore aquatic organism passage.

- Eliminate a significant barrier to aquatic passage and improve habitat quality
- Provide increased hydraulic capacity to account for climate change

5.1.7 Stone Street (xy42138987124132/xy42139387124233)

Spring Brook exits Clarks Pond via two round concrete culverts approximately 3 feet in diameter *(Figure 25 and 26)* that pass under Stone Street, approximately 1,300 feet northwest of Washington Street. A flow control structure is present at the inlet. The crossing is causing a severe constriction compared to the 31.5-foot bankfull width, as estimated from the downstream channel. A large scour pool and sediment deposition are present at the outlet. The headwall/wingwall condition was rated as critical at the inlet while barrel condition was rated as poor. The drop present at the inlet is serving as a barrier to aquatic organism passage.

Figure 25. View of existing crossing inlet (xy42138987124132) taken during field assessment on November 11, 2019.

An additional crossing that serves as an overflow structure for Clarks Pond is present on Stone Street approximately 300 feet northwest of the main crossing *(Figure 27 and 28)*. A flow control structure is present at the inlet that restricts flow expect during high flow periods. The crossing consists of a 2-foot diameter, smooth plastic, round culvert. The structure is causing a severe constriction compared to the 14.5-foot bankfull width, as estimated from the downstream channel. A small tailwater scour pool is present at the outlet and bank erosion is present along the streambanks, indicating geomorphic impacts. The stone headwall/ wingwall was rated as in critical condition at the outlet due to void spaces causes by missing stones that are compromising the structural integrity of the headwall.

Figure 26. View of existing crossing outlet (xy42138987124132) taken during field assessment on November 11, 2019.

Figure 27. View of existing crossing inlet (xy42139387124233) taken during field assessment on November 11, 2019.

Figure 28. View of existing crossing outlet (xy42139387124233) taken during field assessment on November 11, 2019.

Proposed Concept

Investigate possible improvements to the outlet structures of Clarks Pond to reduce the risk of flooding during large storm events and improve aquatic habitat.

- Perform hydrologic and hydraulic study with the goal of understanding the risk of flooding associated low-hazard dam impoundment.
- Eliminate a barriers to aquatic passage and improve habitat quality
- Provide increased hydraulic capacity to reduce risk of flooding

5.1.8 Robbins Road (xy42149497125665)

Robbins Road crosses the Neponset River approximately 450 feet northeast of Elm Street. The crossing consists of two round concrete culverts approximately 4 feet in diameter *(Figure 29)*. Bankfull width could not be measured at this crossing but the crossing was assessed as causing a severe constriction of the stream channel. Sediment deposition was present downstream and a drop was present at the inlet. Structural and geomorphic risk are not major concerns at this crossing. The crossing was rated as hydraulically undersized for the 25-year peak flow and is expected to be undersized for the 10-year peak flow under future climate conditions. The crossing is located in a developed area with the potential for high flood impacts.

Figure 29. View of existing crossing inlet taken during field assessment on November 11, 2019.

Proposed Concept

Replace the existing undersized culvert with a structure appropriately sized to accommodate bankfull width and allow for aquatic organism passage.

- Provide increased hydraulic capacity to accommodate peak flows and reduce risks from flooding
- Eliminate inlet drop to improve aquatic organism passage.

5.1.9 Main Street (xy42140687125658)

Main Street crosses the Neponset River approximately 1,000 feet northeast of Spring Valley Drive and 800 feet southwest of Greenwood Road. The crossing consists of a concrete box/bridge with abutments approximately 15 feet wide and 4 feet tall *(Figure 31)*. Bankfull width was estimated as 30 feet, meaning the structure is causing a severe constriction of the stream channel. The crossing was rated as hydraulically undersized for the 25-year peak flow under current and future climate conditions. Sediment deposition was present downstream and a drop was present at the inlet. Structural and geomorphic risk are not major concerns at this crossing. The crossing is located in a developed area with the potential for high flood impacts.

Figure 30. View of existing crossing outlet taken during field assessment on November 21, 2019.

Proposed Concept

Replace the existing undersized culvert with a structure appropriately sized to accommodate the stream channel bankfull width and increase hydraulic capacity.

- Provide increased hydraulic capacity to accommodate peak flows and reduce risks from flooding

1.1.1 Summer Street (xy42097757127417)

The Summer Street crossing is approximately 1,000 feet south along the same unnamed stream which enters a catch basin grate at the south end of Warwick Road (i.e. xy42099387127399/ xy42100287127547). Summer Street crosses this unnamed tributary of the Neponset River just north of Gillette Stadium. The crossing inlet is stone masonry but transitions to a 3 foot diameter concrete pipe, approximately 15 feet from the outlet *(Figure 31)*. A second concrete pipe was observed at the outlet but the inlet of this pipe could not be located during the crossing inspection *(Figure 32)*. Given the extent of debris at the inlet, it is possible that the secondary, smaller pipe inlet is covered with debris, has been abandoned, or conveys discharge from a catch basin present along the road. The crossing was conveying flow at the time of the inspection, however, the inlet constriction was rated as severe and the crossing is undersized to convey the 10-year storm event. A scour pool at the outlet and cascade of approximately 1 foot resulted in a poor geomorphic and aquatic organism passage rating.

Figure 31. View of existing crossing inlet taken during field assessment on October 30, 2019.

Figure 32. View of existing crossing outlet taken during field assessment on October 30, 2019.

Proposed Concept

Perform drainage study to evaluate feasibility of replacing the existing undersized culvert with a structure appropriately sized to accommodate the stream channel bankfull width and increase hydraulic capacity. Study will include assessment of high rated crossing at Warwick Road and Wall Street.

- Perform hydrologic and hydraulic study with the goal of understanding capacity and flooding throughout stream network and neighborhood.
- Provide increased hydraulic capacity to accommodate peak flows and reduce risks from flooding

1.1.2 Willow Street (xy42106397126086)

Willow Street connects Washington Street and Neponset Street, just west of the Boyden School. Approximately halfway along Willow Street, an unnamed tributary of the Neponset River crosses through a 2 foot diameter concrete pipe (*Figure 34)*. The crossing is approximately 300 feet downstream from a medium priority crossing (i.e. xy42105167125931) which runs under Washington Street. The 300 feet of stream channel that interconnects the Washington Street and Willow Street crossings is located on residential properties that have lawn areas or sheds immediately adjacent to the stream channel *(Figure 33)*. Given the density of residential properties adjacent to the stream and severe constriction of the channel caused the road crossing, the Willow Street crossing has a high climate change risk score despite being able to pass the 10-year storm event peak flow. The constriction of the channel and channel erosion at the outlet also contributed to a high geomorphic risk score.

Figure 33. View of upstream channel adjacent to residential properties and sheds.

Figure 34. View of existing crossing inlet taken during field assessment.

Proposed Concept

Perform drainage study to evaluate feasibility of replacing the existing undersized culvert with a structure appropriately sized to accommodate the stream channel bankfull width and increase hydraulic capacity. Study will include assessment of high rated crossing throughout the tributary.

- Perform hydrologic and hydraulic study with the goal of understanding capacity and flooding throughout tributary and residential properties.
- Provide increased hydraulic capacity to accommodate peak flows and reduce risks from flooding.

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Appendix A

Stream Crossing Survey Field Data Form (blank)

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Road-Stream Crossing Assessment Field Data Form

QA/QC INITIALS: ________ DATE: ________

Status ____ FINAL ____ FOLLOW-UP

CROSSING DATA

pp. 4-5

Crossing Code ________ State or Local ID/Name ________ Date ________ Start Time ________ AM / PM

Lead Field Data Collector ________ Asst. Field Data Collectors ________ End Time ________ AM / PM

Municipality ________ County ________ Stream ________

Road ________ Type ☐ MULTI-LANE ☐ PAVED ☐ UNPAVED ☐ DRIVEWAY ☐ TRAIL ☐ RAILROAD

GPS Coordinates (Decimal degrees) ☐☐.☐☐☐☐☐ °N Latitude — ☐☐.☐☐☐☐☐ °W Longitude

Location Description ________

pp. 5-7

Crossing Type ☐ BRIDGE ☐ CULVERT ☐ MULTIPLE CULVERT ☐ FORD ☐ NO CROSSING ☐ REMOVED CROSSING ☐ BURIED STREAM ☐ INACCESSIBLE ☐ PARTIALLY INACCESSIBLE ☐ NO UPSTREAM CHANNEL ☐ BRIDGE ADEQUATE

Number of Culverts / Cells

Photo #____ INLET Photo #____ OUTLET Photo #____ ________ Photo #____ ________

Photo #____ UPSTREAM Photo #____ DOWNSTREAM Photo #____ ________ Photo #____ ________

Photo #____ ROADWAY Photo #____ ________ Photo #____ ________ Photo #____ ________

Flow Condition ☐ NO FLOW ☐ TYPICAL-LOW ☐ MODERATE ☐ HIGH

Road-Killed Wildlife ________ or None

Visible Utilities ☐ OVERHEAD WIRES ☐ WATER/SEWER PIPES ☐ GAS LINE ☐ NONE ☐ OTHER ________

pp. 9-12

Alignment ☐ SHARP BEND ☐ MILD BEND ☐ NATURALLY STRAIGHT ☐ CHANNELIZED STRAIGHT

Road Fill Height ________ Road Crest Height ________

Bankfull Width ________ Confidence ☐ HIGH ☐ LOW/ESTIMATED

Constriction ☐ SEVERE ☐ MODERATE ☐ SPANS ONLY BANKFULL/ACTIVE CHANNEL ☐ SPANS FULL CHANNEL & BANKS

Tailwater Scour Pool ☐ NONE ☐ SMALL ☐ LARGE

HY-8

pp. 8, 13-15

Using HY-8? ☐ YES ☐ NO

Estimated Overtopping Length ________ Crest Width ________

Road Surface Type ☐ PAVED ☐ GRAVEL ☐ GRASS

Channel Slope ________

Side Slope ☐ 5:1 ☐ 4:1 ☐ 3:1 ☐ 2:1 ☐ 1:1 ☐ 0.5:1 ☐ steeper than 0.5:1

Stream Substrate ☐ MUCK/SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

GEO.

pp. 13

Bank Erosion ☐ HIGH ☐ LOW ☐ ESTIMATED ☐ NONE

Significant Break in Valley Slope ☐ YES ☐ NO ☐ UNKNOWN

Sediment Deposition ☐ UPSTREAM ☐ DOWNSTREAM ☐ WITHIN STRUCTURE ☐ NONE

Elevation of Sediment Deposits >= 1/2 Bankfull Height ☐ YES ☐ NO

TIDAL

pp. 16-18

Tidal? ☐ YES ☐ NO ☐ UNKNOWN

Tide Chart Location ________

Tide Prediction ____:____ AM / PM

Tide Stage ☐ LOW SLACK TIDE ☐ LOW EBB TIDE ☐ LOW FLOOD TIDE ☐ UNKNOWN ☐ OTHER ________

Vegetation Above/Below ☐ COMPARABLE ☐ SLIGHTLY DIFFERENT ☐ MODERATELY DIFFERENT ☐ VERY DIFFERENT ☐ UNKNOWN

Tide Gate Type ☐ NONE ☐ STOP LOGS ☐ FLAP GATE ☐ SLUICE GATE ☐ SELF-REGULATING ☐ OTHER ________

Tide Gate Severity ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE ☐ NO AQUATIC PASSAGE

CROSSING COMMENTS

pp. 5

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FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 1

OUTLET

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

pp. 19-35

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED   Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width_________.____ B. Height_________.____ C. Substrate/Water Width_________.____ D. Water Depth_________.____

Outlet Drop to Water Surface__________.____ Outlet Drop to Stream Bottom__________.____ E. Abutment Height (Type 7 bridges only)______________.____

L. Structure Length (Overall length from inlet to outlet)_____________.____

INLET

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

pp. 35-43

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width_________.____ B. Height_________.____ C. Substrate/Water Width_________.____ D. Water Depth_________.____

ADDITIONAL CONDITIONS

Slope % ____________ Slope Confidence ☐ HIGH ☐ LOW | Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER________

pp. 43-56

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN   Height above Dry Passage____________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

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FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 2

OUTLET

pp. 19-35

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width_______.____ B. Height_______.____ C. Substrate/Water Width_______.____ D. Water Depth_______.____

Outlet Drop to Water Surface_______.____ Outlet Drop to Stream Bottom_______.____ E. Abutment Height (Type 7 bridges only)_______.____

L. Structure Length (Overall length from inlet to outlet)_______.____

INLET

pp. 35-43

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width_______.____ B. Height_______.____ C. Substrate/Water Width_______.____ D. Water Depth_______.____

ADDITIONAL CONDITIONS

pp. 43-56

Slope % __________ Slope Confidence ☐ HIGH ☐ LOW

Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER__________

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage__________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 3

OUTLET

pp. 19-35

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width________.____ B. Height________.____ C. Substrate/Water Width________.____ D. Water Depth________.____

Outlet Drop to Water Surface__________.____ Outlet Drop to Stream Bottom__________.____ E. Abutment Height (Type 7 bridges only)______________.____

L. Structure Length (Overall length from inlet to outlet)______________.____

INLET

pp. 35-43

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width________.____ B. Height________.____ C. Substrate/Water Width________.____ D. Water Depth________.____

ADDITIONAL CONDITIONS

pp. 43-56

Slope % ____________ Slope Confidence ☐ HIGH ☐ LOW

Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER________

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage____________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 4

OUTLET

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

pp. 19-35

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED   Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width_________.____ B. Height_________.____ C. Substrate/Water Width_________.____ D. Water Depth_________.____

Outlet Drop to Water Surface_________.____ Outlet Drop to Stream Bottom_________.____ E. Abutment Height (Type 7 bridges only)_________.____

L. Structure Length (Overall length from inlet to outlet)_________.____

INLET

pp. 35-43

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width_________.____ B. Height_________.____ C. Substrate/Water Width_________.____ D. Water Depth_________.____

ADDITIONAL CONDITIONS

pp. 43-56

Slope % __________ Slope Confidence ☐ HIGH ☐ LOW   Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER__________

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN   Height above Dry Passage__________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 5

OUTLET

pp. 19-35

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED   Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width________.___ B. Height________.___ C. Substrate/Water Width________.___ D. Water Depth________.___

Outlet Drop to Water Surface________.___ Outlet Drop to Stream Bottom________.___ E. Abutment Height (Type 7 bridges only)________.___

L. Structure Length (Overall length from inlet to outlet)________.___

INLET

pp. 35-43

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width________.___ B. Height________.___ C. Substrate/Water Width________.___ D. Water Depth________.___

ADDITIONAL CONDITIONS

pp. 43-56

Slope % ________ Slope Confidence ☐ HIGH ☐ LOW   Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER________

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN   Height above Dry Passage________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

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FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 6

OUTLET

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

pp. 19-35

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width________.____ B. Height________.____ C. Substrate/Water Width________.____ D. Water Depth________.____

Outlet Drop to Water Surface________.____ Outlet Drop to Stream Bottom________.____ E. Abutment Height (Type 7 bridges only)________.____

L. Structure Length (Overall length from inlet to outlet)________.____

INLET

pp. 35-43

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width________.____ B. Height________.____ C. Substrate/Water Width________.____ D. Water Depth________.____

ADDITIONAL CONDITIONS

pp. 43-56

Slope % ________ Slope Confidence ☐ HIGH ☐ LOW

Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER________

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN Height above Dry Passage________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

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FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 7

OUTLET

pp. 19-35

Structure Material ☐ SMOOTH PLASTIC ☐ CORRUGATED PLASTIC ☐ SMOOTH METAL ☐ CORRUGATED METAL ☐ CONCRETE ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

Outlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

Outlet Grade (Pick one) ☐ AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ UNKNOWN

Outlet Dimensions A. Width______.___ B. Height______.___ C. Substrate/Water Width______.___ D. Water Depth______.___

Outlet Drop to Water Surface______.___ Outlet Drop to Stream Bottom______.___ E. Abutment Height (Type 7 bridges only)______.___

L. Structure Length (Overall length from inlet to outlet)______.___

INLET

pp. 35-43

Inlet Shape ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

Inlet Type ☐ PROJECTING ☐ HEADWALL WITH SQUARE EDGE ☐ HEADWALL WITH GROOVED EDGE ☐ HEADWALL WITH SQUARE EDGE AND WINGWALLS ☐ HEADWALL WITH GROOVED/BEVELED EDGE AND WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

Inlet Grade (Pick one) ☐ AT STREAM GRADE ☐ INLET DROP ☐ PERCHED ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Inlet Dimensions A. Width______.___ B. Height______.___ C. Substrate/Water Width______.___ D. Water Depth______.___

ADDITIONAL CONDITIONS

pp. 43-56

Slope % ______ Slope Confidence ☐ HIGH ☐ LOW

Internal Structures ☐ NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER______

Structure Substrate Matches Stream ☐ NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

Structure Substrate Type (Pick one) ☐ NONE ☐ SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

Structure Substrate Coverage ☐ NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

Physical Barriers (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING ☐ DRY ☐ OTHER

Severity (Choose carefully based on barrier type(s) above) ☐ NONE ☐ MINOR ☐ MODERATE ☐ SEVERE

Water Depth Matches Stream ☐ YES ☐ NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

Water Velocity Matches Stream ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage______

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

	INLET					OUTLET				
	Adequate	Poor	Critical	Unknown	N/A	Adequate	Poor	Critical	Unknown	N/A
Longitudinal Alignment										
Level of Blockage										
Flared End Section										
Invert Deterioration										
Buoyancy or Crushing										
Cross-Section Deformation										
Structural Integrity of Barrel										
Joints and Seams										
Footings										
Headwall/Wingwalls										
Armoring										
Apron/Scour Protection										
Embankment Piping										

STRUCTURE COMMENTS

pp. 44

FORM PUBLISHED: OCTOBER 18, 2018

Structure Shape & Dimensions

1) Select the Structure Shape number from the diagrams below and record it on the form for Inlet and Outlet Shape.

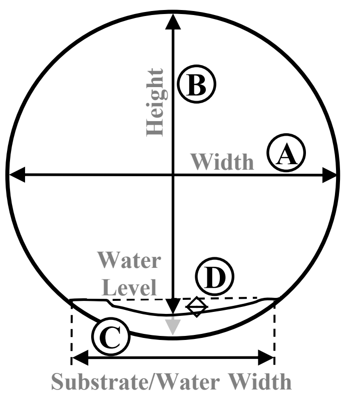
2) Record on the form in the appropriate blanks dimensions **A, B, C** and **D** as shown in the diagrams;
C captures the width of water or substrate, whichever is wider; for dry culverts without substrate, C = 0.
D is the depth of water -- be sure to measure inside the structure; for dry culverts, D = 0.

3) Record Structure Length (**L**) . (Record abutment height (**E**) only for Type 7 Structures.)

4) For multiple culverts, also record the Inlet and Outlet shape and dimensions for each additional culvert.

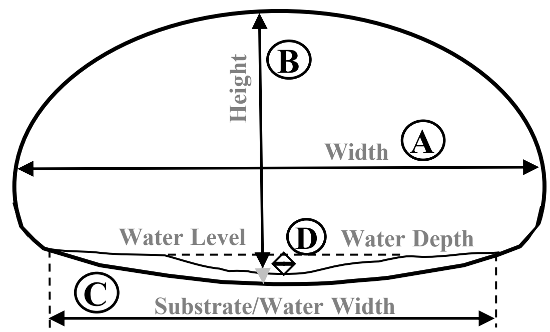
NOTE: Culverts 1, 2 & 4 may or may not have substrate in them, so height measurements (B) are taken from the level of the "stream bed", whether that bed is composed of substrate or just the inside bottom surface of a culvert (grey arrows below show measuring to bottom, black arrows show measuring to substrate).

1



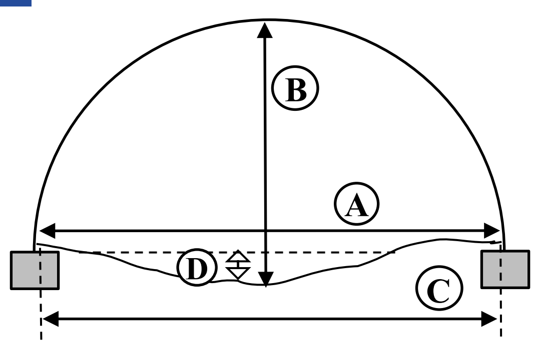
Round Culvert

2



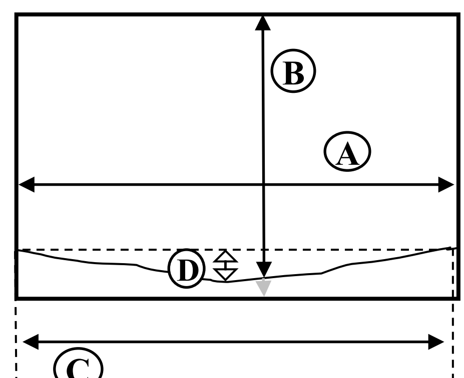
Pipe Arch/Elliptical Culvert

3



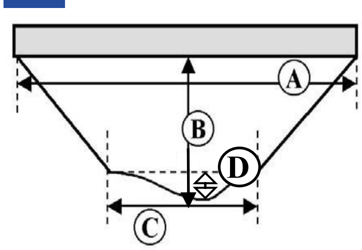
Open Bottom Arch Bridge/Culvert

4



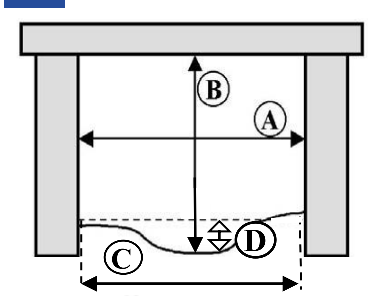
Box Culvert

5



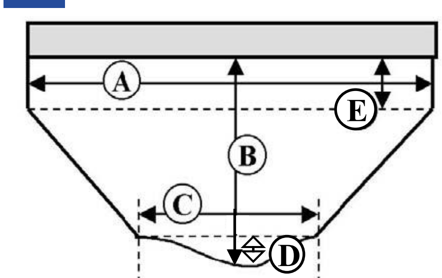
Bridge with Side Slopes

6



Box/Bridge with Abutments

7



Bridge with Abutments and Side Slopes

FUSS & O'NEILL

Appendix B

Road-Stream Crossing Scoring and Prioritization Methods

Hydraulic Capacity Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 1: Headwater Depth at $Q_{failure}$

Road-Stream Crossing Structure Type and Material	Allowable Headwater Depth[1]
Stone Masonry or Wood Culvert	HW = 1.0 x Inlet Height
Smooth or Corrugated Metal or Plastic Culvert	HW = 1.2 x Inlet Height
Concrete Culvert	HW = 1 foot below lowest point in roadway surface
Bridge	HW = 1 foot below lowest point of bottom of bridge deck

Table 2: Tailwater Depth used in Calculating Hydraulic Capacity ($Q_{failure}$)

Crossing Type	Crossing Structure Slope	Tailwater Depth
Non-Tidal Crossings	> 2%	TW = 0.75 x Outlet Height
	< 2%	TW = 0.75 x Outlet Height when HW/Inlet Height < 1.3 TW = 1.0 x Outlet Height when HW/Inlet Height ≥ 1.3
Tidal Crossings	Not Applicable	TW = 1.0 x Outlet Height
Crossings discharging directly into a lake, pond, or wetland[1]	Not Applicable	Based on elevation of receiving water body or wetland
Crossings with cascade or free fall at the outlet with a significant drop to the normal elevation of the downstream channel	Not Applicable	Based on elevation drop at outlet

[1] Situations where the tailwater depth is dictated by the water elevation in the downstream receiving water body or wetland and does not vary with flow, where available.

Table 3: Hydraulic Capacity Score

Hydraulic Capacity Rating (Capacity Ratio > 1.0 for listed Return Interval)	Hydraulic Capacity Score
100-Year	1
50 Year	2
25-Year	3
10 Year	4
< 10-Year	5

Equation 1: Hydraulic Capacity Ratio

$$Capacity\ Ratio_{R.I.} = \frac{Q_{failure}}{Q_{R.I.}}$$

$$Capacity\ Ratio_{R.I.} > 1.0$$

Crossing has sufficient capacity to convey the return interval peak discharge

$$Capacity\ Ratio_{R.I.} \leq 1.0$$

Crossing is undersized for the return interval peak discharge

Climate Change Vulnerability Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 1: Future Hydraulic Capacity Score for Year 2100

Future Hydraulic Capacity Rating (Capacity Ratio > 1.0 for listed Return Interval)	Future Hydraulic Capacity Score (Year 2100)
100-Year	1
50 Year	2
25-Year	3
10 Year	4
< 10-Year	5

Table 2: Hydraulic Capacity Change Score

Future Hydraulic Capacity vs. Existing Hydraulic Capacity	Future Hydraulic Capacity Score (Year 2100)
Existing and future Hydraulic Capacity Ratings are the same.	1
--	2
The crossing Hydraulic Capacity Rating decreases by one rating (e.g. a crossing rated to convey the 100-year peak streamflow under existing conditions can only convey the 50-year peak streamflow under future conditions).	3
--	4
The crossing Hydraulic Capacity Rating decreases by more than one rating (e.g. a crossing rated to convey the 100-year peak streamflow under existing conditions can only convey the 25-year, 10-year, or < 10-year peak streamflow under future conditions).	5

Table 3: Climate Change Vulnerability Score

Maximum of: Future Hydraulic Capacity Score and Hydraulic Capacity Change Score	Future Hydraulic Capacity Score (Year 2100)
1	1
2	2
3	3
4	4
5	5

Equation 1: Future streamflow for a Given Return Interval

$$Q_{R.I,2100.} = Q_{R.I.} \times M_{2100}$$

Where

$$Q_{R.I.,2100} = estimated\ future\ peak\ streamflow\ for\ a\ specified\ return\ interval\ and\ end\ of century\ climate\ change\ scenario$$

$$Q_{R.I.} = estimated\ peak\ streamflow\ for\ a\ specified\ return\ interval$$

$$M_{2100} = flow\ multiplier, projected\ change\ in\ extreme\ precipitation\ for\ end\ of\ century\ climate\ change\ scenario$$

Table 4: Recommended Flow Multiplier

Planning Horizon (Year)	Projected Percent Change in Extreme Precipitation	Flow Multiplier, M_{Year}
2100	20%	1.20

Geomorphic Vulnerability Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 1: Crossing Alignment Impact Potential Ratings

Alignment	Impact Rating
Naturally straight	1
Mild bend	2
--	3
Channelized straight	4
Sharp bend	5

Table 2: Bankfull Width Impact Potential Ratings When Confident Width Measurements are Available

Inlet Width/Bankfull Width Ratio (ft/ft)	Impact Rating
≥1.0	1
1.0-0.85	2
0.85-0.7	3
0.7-0.5	4
≤0.5	5

Table 3: Bankfull Width Impact Potential Ratings When No Confident Width Measurements are Available

Constriction	Impact Rating
None – Spans full channel and banks	1
Slight – Spans only bankfull/active channel	2
--	3
Moderate	4
Severe	5

Table 4: Channel and Crossing Structure Slope Impact Potential Ratings

Slope Conditions at Crossing	Impact Rating
No natural break in slope AND crossing structure slope = channel slope	1
No natural break in slope but crossing structure slope greater than channel slope	2
Natural break in slope present but crossing structure = channel slope	3
No natural break in slope but crossing structure slope less than channel slope	4
Natural slope break present AND crossing structure slope different from channel slope (less than or greater than)	5

Table 5: Substrate Size Impact Potential Ratings

Stream Substrate	Impact Rating
Bedrock	1
Boulder	2
Cobble	3
Gravel	4
Sand or Silt/Muck	5

Table 6: Sediment Continuity Impact Ratings

Sediment Deposition, Elevation of Sediment Deposits, and Tailwater Scour Pool	Impact Rating
No deposition upstream AND no tailwater scour pool	1
Deposition upstream <½ bankfull height OR small tailwater pool	2
No deposition upstream AND large tailwater scour pool downstream	3
Deposition upstream <½ bankfull height AND small tailwater pool	
Deposition upstream ≥½ bankfull height AND no tailwater scour pool	
Both deposition AND tailwater pool present with either deposition ≥½ bankfull height OR a large tailwater scour large pool	4
Deposition upstream ≥½ bankfull height AND large tailwater pool	5

Geomorphic Vulnerability Worksheet (continued)
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 7: Bank Erosion and Outlet Armoring Impact Ratings

Bank Erosion and Outlet Armoring	Impact Rating
No bank erosion or outlet armoring	1
--	2
Low levels of bank erosion and/or Outlet armoring not extensive	3
--	4
High levels of bank erosion and/or extensive outlet armoring	5

Table 8: Inlet and Outlet Grade Impact Ratings

Character of Inlet and Outlet Grade	Impact Rating
Both inlet and outlet at stream grade	1
Inlet drop OR cascade at outlet	2
Inlet drop AND cascade at outlet	3
Perched or clogged/collapsed/submerged inlet	4
Free fall or free fall onto cascade at outlet	
Inlet drop AND either free fall or free fall onto cascade at outlet	5

Table 9: Combined Geomorphic Potential Impact Ratings

Combined Potential Impact Rating	Likelihood for Geomorphic Impacts
4	Very unlikely
5-8	Unlikely
9-12	Possible
13-16	Likely
17-20	Very likely

Table 10: Combined Observed Geomorphic Impact Ratings

Combined Impact Rating	Degree of Observed Geomorphic Impacts
3	None
4-6	Minor
7-9	Moderate
10-12	Significant
13-15	Severe

Table 11: Overall Geomorphic Impact Score

Sum of Geomorphic Potential Impact Ratings and Observed Geomorphic Impact Ratings	Geomorphic Impact score
7	1
8-14	2
15-21	3
22-28	4
28-35	5

Structural Condition Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 1: Level 1 Variables

Number of Variables Marked "Critical" (Inlet, Outlet, or Both)	Condition Score
Any one of the following variables: • Cross Section Deformation • Barrel Condition/Structural Integrity • Footing Condition • Level of Blockage	0.0
None of the above variables are marked "Critical"	1.0

Table 2A: Level 2 Variables – Part I

Number of Variables Marked "Critical"	Condition Score
Any three of the following variables (inlet, outlet, or both): • Buoyancy or Crushing • Invert Deterioration • Joints and Seams Condition • Longitudinal Alignment • Headwall/Wingwall Condition • Flared End Section Condition • Apron/Scour Protection Condition (outlet only) • Armoring Condition • Embankment Piping	0.0
Any two of the following variables (inlet, outlet, or both): • Buoyancy or Crushing • Invert Deterioration • Joints and Seams Condition • Longitudinal Alignment • Headwall/Wingwall Condition • Flared End Section Condition • Apron/Scour Protection Condition (outlet only) • Armoring Condition • Embankment Piping	0.1
Any one of the following variables (inlet/outlet/both): • Buoyancy or Crushing • Invert Deterioration • Joints and Seams Condition • Longitudinal Alignment • Headwall/Wingwall Condition • Flared End Section Condition • Apron/Scour Protection Condition (outlet only) • Armoring Condition • Embankment Piping	0.2
None of the above variables are marked "Critical"	1.0

Table 2B: Level 2 Variables – Part II

Number of Variables Marked "Poor"	Condition Score
Any three of the following variables (inlet, outlet, or both): • Cross Section Deformation • Barrel Condition/Structural Integrity • Footing Condition • Level of Blockage	0.0
Any two of the following variables (inlet, outlet, or both): • Cross Section Deformation • Barrel Condition/Structural Integrity • Footing Condition • Level of Blockage	0.1
Any one of the following variables (inlet, outlet, or both): • Cross Section Deformation • Barrel Condition/Structural Integrity • Footing Condition • Level of Blockage	0.2
None of the above variables are marked "Poor"	1.0

Table 3: Level 3 Variables

Variables marked as "Poor" (inlet, outlet, or both)
Buoyancy or Crushing
Invert Deterioration
Joints and Seams Condition
Longitudinal Alignment
Headwall/Wingwall Condition
Flared End Section Condition
Apron/Scour Protection Condition (outlet only)
Armoring Condition
Embankment Piping

Table 4: Structural Condition Score

Lowest Score Resulting from Level 1, Level 2, and Level 3 Variable Assessment	Structural Condition Binned Score
0.81 - 1.00	1
0.61 - 0.80	2
0.41 - 0.60	3
0.21 - 0.40	4
0.0 - 0.20	5

Equation 1: Level 3 Condition Score

$$Score = 1.0 - (0.1 \times N)$$
$$N = number\ of\ variables\ from\ Table\ 3\ marked\ "Poor"$$

Aquatic Organism Passage Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 1: Component Scores for AOP Field Variables

Field Variable	Level	Component Score
Constriction	Severe Moderate Spans Only Bankfull/Active Channel Spans Full Channel and Banks	0 0.5 0.9 1
Inlet Grade	Inlet Drop Perched Clogged/Collapsed/Submerged Unknown At Stream Grade	0 0 1 1 1
Internal Structures	Baffles/Weirs Supports Other None	0 0.8 1 1
Outlet Apron	Extensive Not Extensive None	0 0.5 1
Physical Barriers	Severe Moderate Minor None	0 0.5 0.8 1
Scour Pool	Large Small None	0 0.8 1
Substrate Coverage	None 25% 50% 75% 100%	0 0.5 0.5 0.7 1
Substrate Matches Stream	None Not Appropriate Contrasting Comparable	0 0.25 0.75 1
Water Depth	No (Significantly Deeper) No (Significantly Shallower) Yes (Comparable) Dry (Stream Also Dry)	0.5 0 1 1
Water Velocity	No (Significantly Faster) No (Significantly Slower) Yes (Comparable) Dry (Stream Also Dry)	0 0.5 1 1

Equation 1: Openness Measurement (feet)

$$\text{Openness Measurement} = \frac{\text{Structure Cross Sectional Area}}{\text{Structure Length}}$$

Equation 2: Openness Score (S_o), for openness measurement (x) in feet

$$S_o = (1 - e^{-5.7x})^{2.6316}$$

Equation 3: Height Score (S_h) for height measurement (x) in feet

$$S_h = min\left(\frac{1.1x^2}{4.84 + x^2}, 1\right)$$

Equation 4: Outlet Drop Score (S_{od}) for outlet drop measurement (x) in feet

$$S_{od} = 1 - \frac{1.029412x^2}{0.26470588 + x^2}$$

Table 2: Weights associated with each variable in the component scoring algorithm

Parameter	Weight
Outlet Drop	0.161
Physical Barriers	0.135
Constriction	0.090
Inlet Grade	0.088
Water Depth	0.082
Water Velocity	0.080
Scour Pool	0.071
Substrate Matches Stream	0.070
Substrate Coverage	0.057
Openness	0.052
Height	0.045
Outlet Apron	0.037
Internal Structures	0.032

Equation 5: Aquatic Passability Score

$$\text{Aquatic Passability Score} = \text{Minimum [Composite Score, Outlet Drop score]}$$

Table 3: Binned Aquatic Passability Score

Aquatic Passability Score	Descriptor	Binned Aquatic Passability Score
1.00	No Barrier	1
0.80 - 0.99	Insignificant Barrier	1
0.60 - 0.79	Minor Barrier	2
0.40 - 0.59	Moderate Barrier	3
0.20 - 0.39	Significant Barrier	4
0.0 - 0.19	Severe Barrier	5

Table 4: Binned Ecological Integrity Score

Aquatic Index of Ecological Integrity (IEI) Value	Binned Ecological Integrity Score
0.0-0.3	1
0.31-0.5	2
0.51-0.7	3
Unknown/No value	
0.71-0.9	4
0.91-1.0	5

Transportation Services Disruption Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Table 1: Transportation Disruption Component Scores

Road Classification (Highway Functional Classification)	Transportation Disruption Score
Local Roads, Trails, Driveways	1
Major and Minor Collectors	2
Minor Arterials	3
Other Principal Arterials	4
Interstates, Freeways, and Expressways	5

Flood Impact Potential Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Equation 1: Stream Buffer Distance as a Function of Bankfull Width (for use where bankfull width available)

$$Stream\ Buffer\ Distance = 2\ \times Bankfull\ Width$$

Table 1: Stream Buffer Distance as a Function of Crossing Structure Width and Degree of Constriction (for use where bankfull width not available)

Crossing Structure Constriction Rating	Stream Buffer Distance (Substitute for Equation 8-1)
Severe	4 x Structure Width
Moderate	3 x Structure Width
Spans Only Bankfull Active Channel	2 x Structure Width
Spans Full Channel and Banks	2 x Structure Width

Table 2: Flood Impact Rating – Developed Area

Percent Developed Area within Potential Flood Impact Area Buffer Polygon	Flood Impact Rating
<5% developed area	1
<10% developed area	2
<25% developed area	3
<50% developed area	4
>50% developed area	5

Table 3: Flood Impact Rating – Upstream and Downstream Crossings

Number of Upstream and Downstream Crossings within Potential Flood Impact Area Buffer Polygon	Flood Impact Rating
0	1
--	2
1	3
--	4
>1	5

Note: -- indicates rating not used

Table 4: Flood Impact Rating for Utilities

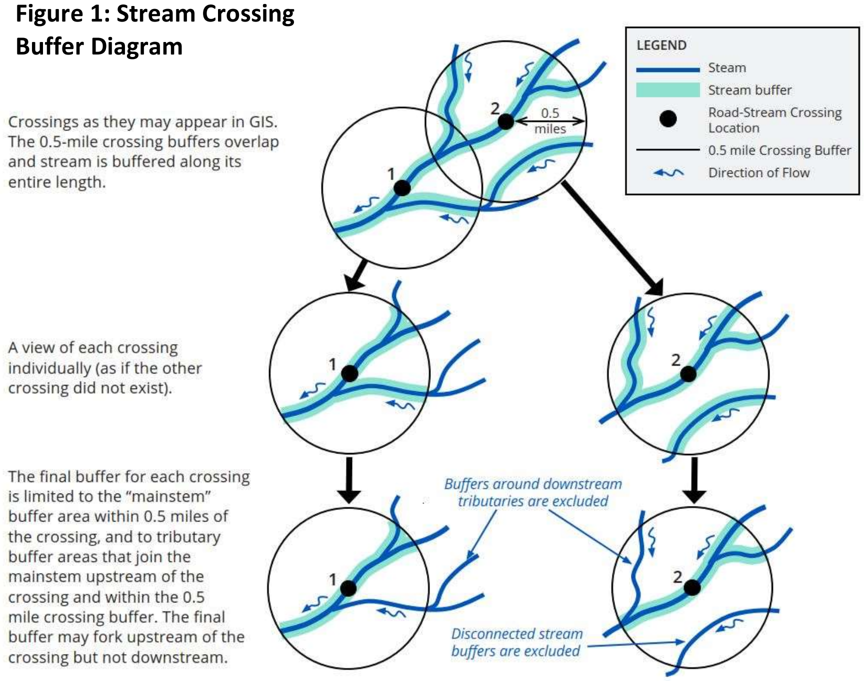
Utilities Present at the Crossing	Flood Impact Rating
None	1
--	2
Single Utility (Gas, Water, Sewer, or Other) attached to or buried within crossing	3
--	4
Two or more utilities attached to or buried within crossing	5

Note: -- indicates rating not used

Table 5: Binned Flood Impact Potential Scores

Sum of Component Flood Impact Ratings	Binned Flood Impact Potential Score
1 – 2	1
3 – 4	2
5 – 6	3
7 – 8	4
9 – 10	5

Figure 1: Stream Crossing Buffer Diagram



Prioritization Worksheet
Road Stream Crossing Assessment
Integrated Road Stream Crossing Vulnerability Assessment, Green Infrastructure Assessment and Climate Resiliency Plan. MVP Action Grant – Town of Walpole
February 2020

Equation 1: Crossing Failure Risk

$$Failure\ Risk = Probability\ of\ Failure \times Magnitude\ of\ the\ Impact\ of\ Failure$$

Equation 2: Impact Score

$$Impact\ Score = Maximum\begin{bmatrix} Transportation\ Disruption\ Score, \\ Binned\ Flood\ Impact\ Potential\ Score \end{bmatrix}$$

Equation 3: Existing Hydraulic Risk Score

$$Existing\ Hydraulic\ Risk\ Score = Hydraulic\ Capacity\ Score \times Impact\ Score$$

Equation 4: Climate Change Risk Score

$$Climate\ Change\ Risk\ Score = Climate\ Change\ Vulnerability\ Score \times Impact\ Score$$

Equation 5: Geomorphic Risk Score

$$Geomorphic\ Risk\ Score = Overall\ Geomorphic\ Impact\ Score \times Impact\ Score$$

Equation 6: Structural Risk Score

$$Structural\ Risk\ Score = Structural\ Condition\ Score \times Impact\ Score$$

Equation 7: Crossing Risk Score

$$Crossing\ Risk\ Score = Maximum\begin{bmatrix} Existing\ Hydraulic\ Risk\ Score, \\ Climate\ Change\ Risk\ Score, \\ Geomorphic\ Risk\ Score, \\ Structural\ Risk\ Score \end{bmatrix}$$

Equation 8: Aquatic Passage Benefit Score

$$Aquatic\ Passage\ Benefit\ Score = Binned\ Aquatic\ Passability\ Score \times Binned\ Ecological\ Integrity\ Score$$

Equation 9: Crossing Priority Score

$$Crossing\ Priority\ Score = MMaximum[Aquatic\ Passage\ Benefit\ Score, Crossing\ Risk\ Score] + Average[Aquatic\ Passage\ Benefit\ Score, Crossing\ Risk\ Score]$$

Table 1: Relative Priority Ratings

Crossing Priority Score (normalized)	Priority Rating
0.55 – 1.00	High
0.35 - 0.54	Medium
0.00 - 0.34	Low

Appendix C

Road-Stream Crossing Scoring and Prioritization Results

Appendix C-Table 1. Road Stream Crossing Scoring and Prioritization Results, organized by Scaled Crossing Priority Score. 1

Crossing Code	Road Name	Stream Name	Binned Existing Hydraulic Capacity Score	Binned Climate Change Vulnerability Score	Binned Geomorphic Vulnerability Score	Binned Structural Condition Score	Binned Transportation Disruption Score	Binned Flood Impact Potential Score	Binned AOP Score	Binned Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating	Unknown Structural Variable Flag	Local Knowledge Flag	Adjacent Crossing Flag	Wildlife Crossing or Roadkill Flag
xy42099387127399	Warwick Road	Unt to Neponset River	5	5	3	5	2	5	3	3	5	25	25	15	25	9	25	42	0.84	High	1	1	1	0
xy42158337124241	Main Street	Unt to Neponset River from Cobbs Pond	5	5	3	1	4	5	3	3	5	25	25	15	5	9	25	42	0.84	High	0	1	1	0
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	4	4	4	5	2	5	3	3	5	20	20	20	25	9	25	42	0.84	High	0	1	1	0
xy42140017125451	Lewis Avenue	Neponset River	5	5	2	2	2	5	2	4	5	25	25	10	10	8	25	41.5	0.83	High	0	0	1	0
xy42165167124759	Gould Street	Unt to Cobbs Pond	4	5	3	1	2	5	2	4	5	20	25	15	5	8	25	41.5	0.83	High	0	0	1	0
xy42100287127547	Wall Street	Unt to Neponset River	5	5	3	1	1	5	2	3	5	25	25	15	5	6	25	40.5	0.81	High	1	1	1	0
xy42144837125583	West Street	Neponset River	5	5	3	1	2	5	1	4	5	25	25	15	5	4	25	39.5	0.79	High	0	0	1	0
xy42146067125557	Elm Street	Neponset River	5	5	3	1	3	5	1	4	5	25	25	15	5	4	25	39.5	0.79	High	1	1	1	0
xy42104937126264	Summer Street	Neponset River	5	5	5	1	2	4	5	3	4	20	20	20	4	15	20	37.5	0.75	High	0	0	1	0
xy42159347123453	Plimpton Street	Neponset River	1	1	3	5	2	3	5	4	3	3	3	9	15	20	15	37.5	0.75	High	0	0	1	0
xy42136137125876	Oak Street	Unt to Neponset River	5	5	3	5	2	4	4	3	4	20	20	12	20	12	20	36	0.72	High	1	1	1	0
xy42138987124132	Stone Street	Spring Brook	3	3	3	5	2	4	4	3	4	12	12	12	20	12	20	36	0.72	High	0	0	1	0
xy42139387124233	Stone Street	Unt to Railroad Pond	3	3	3	5	2	4	4	3	4	12	12	12	20	12	20	36	0.72	High	0	0	1	0
xy42140687125658	Main Street	Neponset River	4	4	3	1	4	5	3	4	5	20	20	15	5	12	20	36	0.72	High	0	0	1	0
xy42147047123565	Peach Street	Unt to Rainbow Pond	3	3	4	5	2	4	4	3	4	12	12	16	20	12	20	36	0.72	High	0	1	1	0
xy42149497125665	Robbins Road	Neponset River	4	5	3	1	2	4	3	4	4	16	20	12	4	12	20	36	0.72	High	0	0	1	0
xy42163417121799	Bird Drive	Unt to Neponset River	1	1	4	1	2	5	4	3	5	5	5	20	5	12	20	36	0.72	High	0	0	1	0
xy42173527125505	Sunnyrock Drive	Unt to Cobbs Pond	1	1	2	5	2	4	4	3	4	4	4	8	20	12	20	36	0.72	High	0	0	1	0
xy42097757127417	Summer Street	Unt to Neponset River	5	5	3	2	2	4	3	3	4	20	20	12	8	9	20	34.5	0.69	High	0	1	1	0
xy42106397126086	Willow Street	Unt to Neponset River	4	5	3	1	2	4	3	3	4	16	20	12	4	9	20	34.5	0.69	High	0	0	1	0
xy42111477125602	Washington Street	Unt to Neponset River	5	5	2	1	3	4	3	3	4	20	20	8	4	9	20	34.5	0.69	High	0	0	1	0
xy42128217129506	West Street	Unt to Neponset River	2	3	3	5	3	4	3	3	4	8	12	12	20	9	20	34.5	0.69	High	0	0	1	0
xy42138047126671	Norfolk Street	Unt to Neponset River	5	5	3	1	3	4	3	3	4	20	20	12	4	9	20	34.5	0.69	High	0	0	1	0
xy42144787123615	Peach Street	Unt to Rainbow Pond	5	5	3	5	2	4	3	3	4	20	20	12	20	9	20	34.5	0.69	High	1	0	1	0
xy42154847122850	Tanglewood Drive	Unt to Plimpton Pond	5	5	3	1	2	4	3	3	4	20	20	12	4	9	20	34.5	0.69	High	0	0	1	0
xy42166587125229	North Street	Unt to Cobbs Pond	5	5	4	5	2	4	3	3	4	20	20	16	20	9	20	34.5	0.69	High	0	0	1	0
xy42166937125207	North Street	Unt to Cobbs Pond	1	1	4	5	2	4	3	3	4	4	4	16	20	9	20	34.5	0.69	High	0	0	1	0
xy42168177122776	Christina Drive	Unt to Neponset River	1	1	3	5	2	4	3	3	4	4	4	12	20	9	20	34.5	0.69	High	0	0	1	0
xy42169587125197	North Street	Unt to Cobbs Pond	5	5	4	2	2	4	3	3	4	20	20	16	8	9	20	34.5	0.69	High	0	0	1	0
xy42172037125068	Covey Road	Unt to Cobbs Pond	1	1	4	5	2	4	3	3	4	4	4	16	20	9	20	34.5	0.69	High	0	0	1	0
xy42176677125923	Homeward Lane	Unt to Cobbs Pond	1	1	3	5	2	4	3	3	4	4	4	12	20	9	20	34.5	0.69	High	0	0	0	0
xy42135937123844	Washington Street	Spring Brook	5	5	3	5	3	4	2	4	4	20	20	12	20	8	20	34	0.68	High	0	0	1	0
xy42101317127567	Winter Street	Unt to Neponset River	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42109867124236	Pine Street	School Meadow Brook	5	5	4	5	2	4	2	3	4	20	20	16	20	6	20	33	0.66	Medium	0	1	1	0
xy42115167123904	Route 1	School Meadow Brook	4	4	4	1	5	2	2	3	5	20	20	20	5	6	20	33	0.66	Medium	1	0	1	0
xy42129917129273	West Street	Unt to Stop River	5	5	3	1	3	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42131027129874	Lincoln Road	Unt to Stop River	5	5	3	5	2	4	2	3	4	20	20	12	20	6	20	33	0.66	Medium	1	0	1	0
xy42141577126917	West Street	Unt to Neponset River	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42143487124893	Stone Street	Unt to Diamond Pond	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	1	0	1	0
xy42144287124496	Diamond Street	Unt to Diamond Pond	5	5	2	5	2	4	2	3	4	20	20	8	20	6	20	33	0.66	Medium	0	0	1	0
xy42153687122406	Adrienne Road	Unt to Traphole Brook	1	1	3	5	2	4	2	3	4	4	4	12	20	6	20	33	0.66	Medium	0	0	1	0
xy42154997122956	East Street	Unt to Plimpton Pond	5	5	3	5	2	4	2	3	4	20	20	12	20	6	20	33	0.66	Medium	1	0	1	0
xy42155177123008	Plimpton Street	Unt to Plimpton Pond	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	1	0	1	0
xy42159937121223	Walcott Avenue	Unt to Traphole Brook	4	5	3	5	2	4	2	3	4	16	20	12	20	6	20	33	0.66	Medium	1	1	1	0
xy42160737120763	Union Street	Pickerel Brook	4	5	3	1	2	4	2	3	4	16	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42166037124982	Gould Street	Unt to Cobbs Pond	1	1	3	5	2	4	2	3	4	4	4	12	20	6	20	33	0.66	Medium	0	0	1	0
xy42171197122646	Main Street	Unt to Willett Pond	5	5	3	1	4	3	2	3	4	20	20	12	4	6	20	33	0.66	Medium	1	1	0	0
xy42173327125776	Sunnyrock Drive	Unt to Cobbs Pond	1	1	3	5	2	4	2	3	4	4	4	12	20	6	20	33	0.66	Medium	0	0	1	0
xy42183447124570	North Street	Unt to Willet Pond	5	5	3	1	3	4	3	2	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42153207124718	Main Street	Neponset River	5	5	2	1	4	4	1	5	4	20	20	8	4	5	20	32.5	0.65	Medium	0	1	1	0
xy42146387125549	East Street	Neponset River	3	4	3	1	4	5	1	4	5	15	20	15	5	4	20	32	0.64	Medium	1	1	1	0
xy42105167125931	Washington Street	Unt to Neponset River	5	5	3	5	3	4	1	3	4	20	20	12	20	3	20	31.5	0.63	Medium	0	1	1	0
xy42111237125430	South Street	Unt to Neponset River	5	5	2	1	2	4	1	3	4	20	20	8	4	3	20	31.5	0.63	Medium	0	0	1	0
xy42116617129323	Winter Street	Unt to Stop River	4	5	3	5	3	4	1	3	4	16	20	12	20	3	20	31.5	0.63	Medium	0	0	1	0
xy42145827124487	Diamond Street	Unt to Diamond Pond	5	5	3	1	2	4	1	3	4	20	20	12	4	3	20	31.5	0.63	Medium	0	0	1	0

Appendix C-Table 1. Road Stream Crossing Scoring and Prioritization Results, organized by Scaled Crossing Priority Score. 1

Crossing Code	Road Name	Stream Name	Binned Existing Hydraulic Capacity Score	Binned Climate Change Vulnerability Score	Binned Geomorphic Vulnerability Score	Binned Structural Condition Score	Binned Transportation Disruption Score	Binned Flood Impact Potential Score	Binned AOP Score	Binned Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating	Unknown Structural Variable Flag	Local Knowledge Flag	Adjacent Crossing Flag	Wildlife Crossing or Roadkill Flag
xy42099387127399	Warwick Road	Unt to Neponset River	5	5	3	5	2	5	3	3	5	25	25	15	25	9	25	42	0.84	High	1	1	1	0
xy42158337124241	Main Street	Unt to Neponset River from Cobbs Pond	5	5	3	1	4	5	3	3	5	25	25	15	5	9	25	42	0.84	High	0	1	1	0
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	4	4	4	5	2	5	3	3	5	20	20	20	25	9	25	42	0.84	High	0	1	1	0
xy42140017125451	Lewis Avenue	Neponset River	5	5	2	2	2	5	2	4	5	25	25	10	10	8	25	41.5	0.83	High	0	0	1	0
xy42165167124759	Gould Street	Unt to Cobbs Pond	4	5	3	1	2	5	2	4	5	20	25	15	5	8	25	41.5	0.83	High	0	0	1	0
xy42100287127547	Wall Street	Unt to Neponset River	5	5	3	1	1	5	2	3	5	25	25	15	5	6	25	40.5	0.81	High	1	1	1	0
xy42144837125583	West Street	Neponset River	5	5	3	1	2	5	1	4	5	25	25	15	5	4	25	39.5	0.79	High	0	0	1	0
xy42146067125557	Elm Street	Neponset River	5	5	3	1	3	5	1	4	5	25	25	15	5	4	25	39.5	0.79	High	1	1	1	0
xy42104937126264	Summer Street	Neponset River	5	5	5	1	2	4	5	3	4	20	20	20	4	15	20	37.5	0.75	High	0	0	1	0
xy42159347123453	Plimpton Street	Neponset River	1	1	3	5	2	3	5	4	3	3	3	9	15	20	15	37.5	0.75	High	0	0	1	0
xy42136137125876	Oak Street	Unt to Neponset River	5	5	3	5	2	4	4	3	4	20	20	12	20	12	20	36	0.72	High	1	1	1	0
xy42138987124132	Stone Street	Spring Brook	3	3	3	5	2	4	4	3	4	12	12	12	20	12	20	36	0.72	High	0	0	1	0
xy42139387124233	Stone Street	Unt to Railroad Pond	3	3	3	5	2	4	4	3	4	12	12	12	20	12	20	36	0.72	High	0	0	1	0
xy42140687125658	Main Street	Neponset River	4	4	3	1	4	5	3	4	5	20	20	15	5	12	20	36	0.72	High	0	0	1	0
xy42147047123565	Peach Street	Unt to Rainbow Pond	3	3	4	5	2	4	4	3	4	12	12	16	20	12	20	36	0.72	High	0	1	1	0
xy42149497125665	Robbins Road	Neponset River	4	5	3	1	2	4	3	4	4	16	20	12	4	12	20	36	0.72	High	0	0	1	0
xy42163417121799	Bird Drive	Unt to Neponset River	1	1	4	1	2	5	4	3	5	5	5	20	5	12	20	36	0.72	High	0	0	1	0
xy42173527125505	Sunnyrock Drive	Unt to Cobbs Pond	1	1	2	5	2	4	4	3	4	4	4	8	20	12	20	36	0.72	High	0	0	1	0
xy42097757127417	Summer Street	Unt to Neponset River	5	5	3	2	2	4	3	3	4	20	20	12	8	9	20	34.5	0.69	High	0	1	1	0
xy42106397126086	Willow Street	Unt to Neponset River	4	5	3	1	2	4	3	3	4	16	20	12	4	9	20	34.5	0.69	High	0	0	1	0
xy42111477125602	Washington Street	Unt to Neponset River	5	5	2	1	3	4	3	3	4	20	20	8	4	9	20	34.5	0.69	High	0	0	1	0
xy42128217129506	West Street	Unt to Neponset River	2	3	3	5	3	4	3	3	4	8	12	12	20	9	20	34.5	0.69	High	0	0	1	0
xy42138047126671	Norfolk Street	Unt to Neponset River	5	5	3	1	3	4	3	3	4	20	20	12	4	9	20	34.5	0.69	High	0	0	1	0
xy42144787123615	Peach Street	Unt to Rainbow Pond	5	5	3	5	2	4	3	3	4	20	20	12	20	9	20	34.5	0.69	High	1	0	1	0
xy42154847122850	Tanglewood Drive	Unt to Plimpton Pond	5	5	3	1	2	4	3	3	4	20	20	12	4	9	20	34.5	0.69	High	0	0	1	0
xy42166587125229	North Street	Unt to Cobbs Pond	5	5	4	5	2	4	3	3	4	20	20	16	20	9	20	34.5	0.69	High	0	0	1	0
xy42166937125207	North Street	Unt to Cobbs Pond	1	1	4	5	2	4	3	3	4	4	4	16	20	9	20	34.5	0.69	High	0	0	1	0
xy42168177122776	Christina Drive	Unt to Neponset River	1	1	3	5	2	4	3	3	4	4	4	12	20	9	20	34.5	0.69	High	0	0	1	0
xy42169587125197	North Street	Unt to Cobbs Pond	5	5	4	2	2	4	3	3	4	20	20	16	8	9	20	34.5	0.69	High	0	0	1	0
xy42172037125068	Covey Road	Unt to Cobbs Pond	1	1	4	5	2	4	3	3	4	4	4	16	20	9	20	34.5	0.69	High	0	0	1	0
xy42176677125923	Homeward Lane	Unt to Cobbs Pond	1	1	3	5	2	4	3	3	4	4	4	12	20	9	20	34.5	0.69	High	0	0	0	0
xy42135937123844	Washington Street	Spring Brook	5	5	3	5	3	4	2	4	4	20	20	12	20	8	20	34	0.68	High	0	0	1	0
xy42101317127567	Winter Street	Unt to Neponset River	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42109867124236	Pine Street	School Meadow Brook	5	5	4	5	2	4	2	3	4	20	20	16	20	6	20	33	0.66	Medium	0	1	1	0
xy42115167123904	Route 1	School Meadow Brook	4	4	4	1	5	2	2	3	5	20	20	20	5	6	20	33	0.66	Medium	1	0	1	0
xy42129917129273	West Street	Unt to Stop River	5	5	3	1	3	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42131027129874	Lincoln Road	Unt to Stop River	5	5	3	5	2	4	2	3	4	20	20	12	20	6	20	33	0.66	Medium	1	0	1	0
xy42141577126917	West Street	Unt to Neponset River	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42143487124893	Stone Street	Unt to Diamond Pond	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	1	0	1	0
xy42144287124496	Diamond Street	Unt to Diamond Pond	5	5	2	5	2	4	2	3	4	20	20	8	20	6	20	33	0.66	Medium	0	0	1	0
xy42153687122406	Adrienne Road	Unt to Traphole Brook	1	1	3	5	2	4	2	3	4	4	4	12	20	6	20	33	0.66	Medium	0	0	1	0
xy42154997122956	East Street	Unt to Plimpton Pond	5	5	3	5	2	4	2	3	4	20	20	12	20	6	20	33	0.66	Medium	1	0	1	0
xy42155177123008	Plimpton Street	Unt to Plimpton Pond	5	5	3	1	2	4	2	3	4	20	20	12	4	6	20	33	0.66	Medium	1	0	1	0
xy42159937121223	Walcott Avenue	Unt to Traphole Brook	4	5	3	5	2	4	2	3	4	16	20	12	20	6	20	33	0.66	Medium	1	1	1	0
xy42160737120763	Union Street	Pickerel Brook	4	5	3	1	2	4	2	3	4	16	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42166037124982	Gould Street	Unt to Cobbs Pond	1	1	3	5	2	4	2	3	4	4	4	12	20	6	20	33	0.66	Medium	0	0	1	0
xy42171197122646	Main Street	Unt to Willett Pond	5	5	3	1	4	3	2	3	4	20	20	12	4	6	20	33	0.66	Medium	1	1	0	0
xy42173327125776	Sunnyrock Drive	Unt to Cobbs Pond	1	1	3	5	2	4	2	3	4	4	4	12	20	6	20	33	0.66	Medium	0	0	1	0
xy42183447124570	North Street	Unt to Willet Pond	5	5	3	1	3	4	3	2	4	20	20	12	4	6	20	33	0.66	Medium	0	0	1	0
xy42153207124718	Main Street	Neponset River	5	5	2	1	4	4	1	5	4	20	20	8	4	5	20	32.5	0.65	Medium	0	1	1	0
xy42146387125549	East Street	Neponset River	3	4	3	1	4	5	1	4	5	15	20	15	5	4	20	32	0.64	Medium	1	1	1	0
xy42105167125931	Washington Street	Unt to Neponset River	5	5	3	5	3	4	1	3	4	20	20	12	20	3	20	31.5	0.63	Medium	0	1	1	0
xy42111237125430	South Street	Unt to Neponset River	5	5	2	1	2	4	1	3	4	20	20	8	4	3	20	31.5	0.63	Medium	0	0	1	0
xy42116617129323	Winter Street	Unt to Stop River	4	5	3	5	3	4	1	3	4	16	20	12	20	3	20	31.5	0.63	Medium	0	0	1	0
xy42145827124487	Diamond Street	Unt to Diamond Pond	5	5	3	1	2	4	1	3	4	20	20	12	4	3	20	31.5	0.63	Medium	0	0	1	0

Appendix C-Table 1. Road Stream Crossing Scoring and Prioritization Results, organized by Scaled Crossing Priority Score. 2

Crossing Code	Road Name	Stream Name	Binned Existing Hydraulic Capacity Score	Binned Climate Change Vulnerability Score	Binned Geomorphic Vulnerability Score	Binned Structural Condition Score	Binned Transportation Disruption Score	Binned Flood Impact Potential Score	Binned AOP Score	Binned Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating	Unknown Structural Variable Flag	Local Knowledge Flag	Adjacent Crossing Flag	Wildlife Crossing or Roadkill Flag
xy42151747126785	Elm Street	Unt to Turner Pond	4	5	3	5	4	3	1	3	4	16	20	12	20	3	20	31.5	0.63	Medium	0	0	1	0
xy42153277120918	Park Lane	Traphole Brook	1	1	3	5	2	4	1	3	4	4	4	12	20	3	20	31.5	0.63	Medium	0	0	1	0
xy42155827123045	Plimpton Street	Unt to Plimpton Pond	5	5	2	1	2	4	1	3	4	20	20	8	4	3	20	31.5	0.63	Medium	0	0	1	0
xy42104177126144	Washington Street Extension	Neponset River	4	4	3	1	2	4	3	4	4	16	16	12	4	12	16	30	0.6	Medium	0	0	1	1
xy42151467126130	Mill Pond Road	Unt to Neponset River	3	3	3	1	2	4	4	4	4	12	12	12	4	16	12	30	0.6	Medium	0	0	0	0
xy42167007125368	Berkeley Court	Unt to Cobbs Pond	1	1	4	1	2	4	3	3	4	4	4	16	4	9	16	28.5	0.57	Medium	0	0	1	0
xy42146277123815	Golf trail off of Rainbow Pond Drive by rainbow pond spillway	Unt to Railroad Pond	5	5	3	5	1	3	4	3	3	15	15	9	15	12	15	28.5	0.57	Medium	1	0	1	0
xy42151727120917	Route 1	Traphole Brook	1	1	3	1	5	3	3	4	5	5	5	15	5	12	15	28.5	0.57	Medium	0	0	1	0
xy42164057124512	Gould Street	Unt to Cobbs Pond	5	5	4	5	2	3	4	3	3	15	15	12	15	12	15	28.5	0.57	Medium	0	1	1	0
xy42200877124962	North Street	Bubbling Brook	5	5	4	1	3	2	4	3	3	15	15	12	3	12	15	28.5	0.57	Medium	0	0	1	0
xy42177897125940	Independence Drive	Unt to Cobbs Pond	1	1	3	1	2	4	5	3	4	4	4	12	4	15	12	28.5	0.57	Medium	0	0	1	0
xy42147097125667	Elm Street	Unt to Neponset River	1	1	4	1	4	3	2	3	4	4	4	16	4	6	16	27	0.54	Medium	1	0	0	0
xy42148157125743	Elm Street	Unt to Neponset River	4	4	3	1	4	4	2	3	4	16	16	12	4	6	16	27	0.54	Medium	0	0	1	0
xy42151107126609	Elm Street	Unt to Turner's Pond	4	4	3	1	4	4	2	3	4	16	16	12	4	6	16	27	0.54	Medium	0	0	0	0
xy42137737123689	Washington Street	Unt to Railroad Pond	5	5	3	5	3	3	3	3	3	15	15	9	15	9	15	27	0.54	Medium	0	0	0	0
xy42156957123167	Plimpton Street	Unt to Plimpton Pond	5	5	3	1	2	3	3	3	3	15	15	9	3	9	15	27	0.54	Medium	0	0	1	0
xy42191707124907	North Street	Unt to Bubbling Brook	5	5	3	1	3	2	3	3	3	15	15	9	3	9	15	27	0.54	Medium	0	0	0	0
xy42125487124608	Washington Street	School Meadow Brook	5	5	3	5	3	3	2	4	3	15	15	9	15	8	15	26.5	0.53	Medium	0	0	1	0
xy42146157124929	School Street	Spring Brook	1	1	3	1	2	5	2	4	5	5	5	15	5	8	15	26.5	0.53	Medium	0	0	1	0
xy42115857125277	Washington Street	Unt to Neponset River	5	5	3	1	3	3	2	3	3	15	15	9	3	6	15	25.5	0.51	Medium	0	0	1	0
xy42138757127973	West Street	Unt to Neponset River	4	5	3	1	3	3	2	3	3	12	15	9	3	6	15	25.5	0.51	Medium	0	1	0	0
xy42150557121156	Route 1	Unt to Traphole Brook	1	1	3	1	5	3	2	3	5	5	5	15	5	6	15	25.5	0.51	Medium	0	0	1	0
xy42150927124128	Heather Lane	Unt to Neponset River	3	4	4	5	2	3	2	3	3	9	12	12	15	6	15	25.5	0.51	Medium	0	0	0	0
xy42163937125832	High Street	Unt to Cobbs Pond	3	4	4	5	2	3	2	3	3	9	12	12	15	6	15	25.5	0.51	Medium	0	0	1	0
xy42164147121873	Holden's Drive	Unt to Neponset River	1	3	3	1	2	5	2	3	5	5	15	15	5	6	15	25.5	0.51	Medium	0	1	1	0
xy42193497124288	Trailside Drive	Bubbling Brook	1	1	2	5	2	3	2	3	3	3	3	6	15	6	15	25.5	0.51	Medium	0	0	1	0
xy42162637121529	Washington Street	Neponset River	1	1	3	1	3	5	1	5	5	5	5	15	5	5	15	25	0.5	Medium	0	0	1	1
xy42146437123976	Rainbow Pond Drive golf cart path	Unt to Railroad Pond.	5	5	3	5	1	3	1	3	3	15	15	9	15	3	15	24	0.48	Medium	0	0	1	0
xy42134647125771	Oak Street	Unt to Neponset River	3	3	3	1	2	4	4	3	4	12	12	12	4	12	12	24	0.48	Medium	1	1	1	0
xy42143077126757	Lorusso & sons entrance	Unt to Neponset River	3	3	3	1	2	4	4	3	4	12	12	12	4	12	12	24	0.48	Medium	1	0	1	0
xy42144217124438	Old Diamond Street	Unt to Diamond Pond	1	1	3	1	2	4	4	3	4	4	4	12	4	12	12	24	0.48	Medium	0	0	1	0
xy42146607125072	Unnamed road behind fire station	Spring Brook	3	3	3	1	1	4	3	4	4	12	12	12	4	12	12	24	0.48	Medium	1	0	1	0
xy42154177122092	Polley Lane	Unt to Traphole Brook	2	3	3	1	2	4	4	3	4	8	12	12	4	12	12	24	0.48	Medium	0	0	1	0
xy42126247124735	Unnamed road to Town sewage treatment plant	School Meadow Brook	5	5	3	1	2	2	3	4	2	10	10	6	2	12	10	23	0.46	Medium	0	0	1	0
xy42110597125322	Irving Street	Unt to Neponset River	3	3	3	2	2	4	3	3	4	12	12	12	8	9	12	22.5	0.45	Medium	1	1	1	0
xy42118397129421	Beethoven Avenue	Unt to Stop River	1	1	3	1	2	4	3	3	4	4	4	12	4	9	12	22.5	0.45	Medium	0	0	1	0
xy42137277126747	Norfolk Street	Unt to Neponset River	3	3	3	1	3	4	3	3	4	12	12	12	4	9	12	22.5	0.45	Medium	0	0	1	0
xy42137957125730	Spring Valley Drive	Unt to Neponset River	3	3	2	1	2	4	3	3	4	12	12	8	4	9	12	22.5	0.45	Medium	1	1	1	1
xy42147917125309	Parking lot behind intersection of East St and Main St	Spring Brook	3	3	3	1	1	4	3	3	4	12	12	12	4	9	12	22.5	0.45	Medium	1	0	1	0
xy42153847122296	Washington Street	Unt to Traphole Brook	1	1	3	1	3	4	3	3	4	4	4	12	4	9	12	22.5	0.45	Medium	0	1	1	0
xy42202647125153	Stonegate Lane and County Street	Bubbling Brook	3	3	3	1	4	2	3	3	4	12	12	12	4	9	12	22.5	0.45	Medium	0	0	0	0
xy42108407126343	Neponset Street	Neponset River	2	3	4	1	2	3	2	4	3	6	9	12	3	8	12	22	0.44	Medium	0	0	1	0
xy42138637125103	South Street	Neponset River	1	1	3	1	2	4	2	4	4	4	4	12	4	8	12	22	0.44	Medium	0	1	1	0
xy42138387127130	Norfolk Street	Unt to Neponset River	1	1	3	1	3	4	2	3	4	4	4	12	4	6	12	21	0.42	Medium	0	0	1	1
xy42138927126698	Crane Road	Unt to Neponset River	1	1	3	1	2	4	2	3	4	4	4	12	4	6	12	21	0.42	Medium	0	0	1	0
xy42140147126751	Pintail Road	Unt to Neponset River	1	1	3	1	2	4	2	3	4	4	4	12	4	6	12	21	0.42	Medium	0	0	1	0
xy42140637128540	Lincoln Road	Unt to Stop River	3	4	3	1	2	3	2	3	3	9	12	9	3	6	12	21	0.42	Medium	0	0	0	0
xy42147987124541	Hartshorn Place	Unt to Neponset River	1	1	3	1	2	4	2	3	4	4	4	12	4	6	12	21	0.42	Medium	1	0	1	0
xy42167937125910	Arlington Lane	Unt to Copps Pond	1	1	3	1	2	4	2	3	4	4	4	12	4	6	12	21	0.42	Medium	0	0	1	0
xy42172077125758	Delaney Drive	Unt to Cobbs Pond	1	1	3	1	2	4	2	3	4	4	4	12	4	6	12	21	0.42	Medium	0	0	1	0
xy42172537126130	Delaney Drive	Unt to Copps Pond	1	3	3	1	2	4	2	3	4	4	12	12	4	6	12	21	0.42	Medium	0	0	1	0
xy42179037125927	Frontier Drive	Unnamed wetland to Cobbs Pond	1	3	3	1	2	4	2	3	4	4	12	12	4	6	12	21	0.42	Medium	0	0	1	0
xy42147187125593	MBTA parking lot off of Elm Street	Neponset River	1	3	2	1	1	4	1	4	4	4	12	8	4	4	12	20	0.4	Medium	0	0	1	0

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Appendix C-Table 1. Road Stream Crossing Scoring and Prioritization Results, organized by Scaled Crossing Priority Score. 3

Crossing Code	Road Name	Stream Name	Binned Existing Hydraulic Capacity Score	Binned Climate Change Vulnerability Score	Binned Geomorphic Vulnerability Score	Binned Structural Condition Score	Binned Transportation Disruption Score	Binned Flood Impact Potential Score	Binned AOP Score	Binned Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating	Unknown Structural Variable Flag	Local Knowledge Flag	Adjacent Crossing Flag	Wildlife Crossing or Roadkill Flag
xy42171727124428	Walden Drive	Unt to Cobbs Pond	1	1	3	1	2	4	1	3	4	4	4	12	4	3	12	19.5	0.39	Medium	0	0	1	0
xy42175407125881	Heritage Drive	Unto to Cobbs Pond	1	1	3	1	2	4	1	3	4	4	4	12	4	3	12	19.5	0.39	Medium	0	0	1	0
xy42136027129123	Lincoln Road	Unt to Stop River	5	5	3	5	2	2	3	3	2	10	10	6	10	9	10	19.5	0.39	Medium	0	0	0	0
xy42176057123080	Bullard Street	Unt to Hawks Brook, Norwood	1	1	3	5	2	2	3	3	2	2	2	6	10	9	10	19.5	0.39	Medium	1	1	1	0
xy42124647125231	South Streeet	Neponset River	4	5	3	1	2	2	2	4	2	8	10	6	2	8	10	19	0.38	Medium	1	0	0	0
xy42134357129263	Lincoln Road	Unt to Stop River	5	5	3	1	2	2	2	3	2	10	10	6	2	6	10	18	0.36	Medium	0	0	0	0
xy42172757122797	Countryside Lane	Unt to Willet Pond	5	5	3	1	1	2	2	3	2	10	10	6	2	6	10	18	0.36	Medium	1	1	1	0
xy42185107125044	Trail on Adams Farm	Unt to Cobbs Pond	5	5	3	5	1	2	2	3	2	10	10	6	10	6	10	18	0.36	Medium	1	0	0	0
xy42098287127298	Summer Street	Unt to Neponset River	1	1	3	1	2	3	3	3	3	3	3	9	3	9	9	18	0.36	Medium	0	1	1	0
xy42199587126617	Starlight Drive	Unt to Mine Brook	3	3	3	2	2	3	3	3	3	9	9	9	6	9	9	18	0.36	Medium	0	0	1	0
xy42116277125471	Barbara Road	Unt to Neponset River	5	5	3	5	2	2	1	3	2	10	10	6	10	3	10	16.5	0.33	Low	0	0	1	0
xy42118697127061	Rail trail west of Industrial Road	Unt to Neponset River	5	5	3	1	1	2	1	3	2	10	10	6	2	3	10	16.5	0.33	Low	0	0	0	0
xy42150617124317	Kendall Street	Unt to Neponset River	5	5	3	2	2	2	1	3	2	10	10	6	4	3	10	16.5	0.33	Low	0	0	1	0
xy42148287126142	Turner Road	Unt to Neponset River	1	1	3	1	2	3	2	3	3	3	3	9	3	6	9	16.5	0.33	Low	0	0	1	0
xy42169487126884	Millbrook Avenue	Unt to Mine Brook	1	1	3	1	2	3	2	3	3	3	3	9	3	6	9	16.5	0.33	Low	0	0	1	0
xy42181977124622	North Street	Unt to Cobbs Pond	2	3	3	1	2	3	2	3	3	6	9	9	3	6	9	16.5	0.33	Low	0	0	1	0
xy42197417126645	Starlight Drive	Unt to Mill Brook	1	1	3	1	2	3	2	3	3	3	3	9	3	6	9	16.5	0.33	Low	0	0	1	0
xy42130567128414	Cedar Street	Unt to Neponset River	1	3	3	1	2	2	3	3	2	2	6	6	2	9	6	16.5	0.33	Low	0	0	1	0
xy42117967129629	Winter Street	Stop River	1	1	3	1	3	2	1	4	3	3	3	9	3	4	9	15.5	0.31	Low	0	0	0	0
xy42186327124002	Brook Street	Pettee Pond	3	4	2	1	2	1	1	4	2	6	8	4	2	4	8	14	0.28	Low	0	0	0	0
xy42157577120881	Coney Street	Traphole Brook	1	1	2	1	2	4	1	3	4	4	4	8	4	3	8	13.5	0.27	Low	0	0	0	1
xy42162947122438	Hound Pack Circle	Unt to Neponset River	1	1	2	1	1	4	1	3	4	4	4	8	4	3	8	13.5	0.27	Low	0	0	1	0
xy42171707125480	Saddle Way	Unt to Cobbs Pond	1	1	2	1	2	4	1	3	4	4	4	8	4	3	8	13.5	0.27	Low	0	0	1	0
xy42173087124494	Emerald Way	Unt to Cobbs Pond	1	1	2	1	1	4	1	3	4	4	4	8	4	3	8	13.5	0.27	Low	0	0	1	0
xy42197337126685	Starlight Drive	Unt to Mill Brook	1	1	2	1	2	4	1	3	4	4	4	8	4	3	8	13.5	0.27	Low	0	0	1	0
xy42198157126604	Starlight Drive	Unt to Mill Brook	1	1	2	1	2	3	2	3	3	3	3	6	3	6	6	12	0.24	Low	0	0	1	0
xy42143977124359	Old railbed	Diamond Pond	1	1	2	1	1	3	1	4	3	3	3	6	3	4	6	11	0.22	Low	0	0	1	0
xy42184767125236	Trail off of Adams Farm	Unt to Cobbs Pond	1	1	3	1	1	2	1	3	2	2	2	6	2	3	6	10.5	0.21	Low	0	0	1	0
xy42112967128026	Abandoned rail trail sw of Industrial Road	Unt to Neponset River	1	1	3	1	1	1	1	3	1	1	1	3	1	3	3	6	0.12	Low	0	0	0	1

Appendix C—Table 2. Top-ranked crossings based on Hydraulic Risk Score.

Crossing Code	Road Name	Stream Name	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42099387127399	Warwick Road	Unt to Neponset River	5	25	25	15	25	9	25	42	0.84	High
xy42158337124241	Main Street	Unt to Neponset River from Cobbs Pond	5	25	25	15	5	9	25	42	0.84	High
xy42140017125451	Lewis Avenue	Neponset River	5	25	25	10	10	8	25	41.5	0.83	High
xy42100287127547	Wall Street	Unt to Neponset River	5	25	25	15	5	6	25	40.5	0.81	High
xy42144837125583	West Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42146067125557	Elm Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	5	20	20	20	25	9	25	42	0.84	High
xy42165167124759	Gould Street	Unt to Cobbs Pond	5	20	25	15	5	8	25	41.5	0.83	High
xy42104937126264	Summer Street	Neponset River	4	20	20	20	4	15	20	37.5	0.75	High
xy42136137125876	Oak Street	Unt to Neponset River	4	20	20	12	20	12	20	36	0.72	High
xy42140687125658	Main Street	Neponset River	5	20	20	15	5	12	20	36	0.72	High
xy42097757127417	Summer Street	Unt to Neponset River	4	20	20	12	8	9	20	34.5	0.69	High
xy42111477125602	Washington Street	Unt to Neponset River	4	20	20	8	4	9	20	34.5	0.69	High
xy42138047126671	Norfolk Street	Unt to Neponset River	4	20	20	12	4	9	20	34.5	0.69	High
xy42144787123615	Peach Street	Unt to Rainbow Pond	4	20	20	12	20	9	20	34.5	0.69	High
xy42154847122850	Tanglewood Drive	Unt to Plimpton Pond	4	20	20	12	4	9	20	34.5	0.69	High
xy42166587125229	North Street	Unt to Cobbs Pond	4	20	20	16	20	9	20	34.5	0.69	High
xy42169587125197	North Street	Unt to Cobbs Pond	4	20	20	16	8	9	20	34.5	0.69	High
xy42135937123844	Washington Street	Spring Brook	4	20	20	12	20	8	20	34	0.68	High
xy42101317127567	Winter Street	Unt to Neponset River	4	20	20	12	4	6	20	33	0.66	Medium
xy42109867124236	Pine Street	School Meadow Brook	4	20	20	16	20	6	20	33	0.66	Medium
xy42115167123904	Route 1	School Meadow Brook	5	20	20	20	5	6	20	33	0.66	Medium
xy42129917129273	West Street	Unt to Stop River	4	20	20	12	4	6	20	33	0.66	Medium
xy42131027129874	Lincoln Road	Unt to Stop River	4	20	20	12	20	6	20	33	0.66	Medium
xy42141577126917	West Street	Unt to Neponset River	4	20	20	12	4	6	20	33	0.66	Medium
xy42143487124893	Stone Street	Unt to Diamond Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42144287124496	Diamond Street	Unt to Diamond Pond	4	20	20	8	20	6	20	33	0.66	Medium
xy42154997122956	East Street	Unt to Plimpton Pond	4	20	20	12	20	6	20	33	0.66	Medium
xy42155177123008	Plimpton Street	Unt to Plimpton Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42171197122646	Main Street	Unt to Willett Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42183447124570	North Street	Unt to Willet Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42153207124718	Main Street	Neponset River	4	20	20	8	4	5	20	32.5	0.65	Medium
xy42105167125931	Washington Street	Unt to Neponset River	4	20	20	12	20	3	20	31.5	0.63	Medium
xy42111237125430	South Street	Unt to Neponset River	4	20	20	8	4	3	20	31.5	0.63	Medium
xy42145827124487	Diamond Street	Unt to Diamond Pond	4	20	20	12	4	3	20	31.5	0.63	Medium
xy42155827123045	Plimpton Street	Unt to Plimpton Pond	4	20	20	8	4	3	20	31.5	0.63	Medium

Appendix C—Table 3. Top-ranked crossings based on Climate Change Risk Score.

Crossing Code	Road Name	Stream Name	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42099387127399	Warwick Road	Unt to Neponset River	5	25	25	15	25	9	25	42	0.84	High
xy42158337124241	Main Street	Unt to Neponset River from Cobbs Pond	5	25	25	15	5	9	25	42	0.84	High
xy42140017125451	Lewis Avenue	Neponset River	5	25	25	10	10	8	25	41.5	0.83	High
xy42165167124759	Gould Street	Unt to Cobbs Pond	5	20	25	15	5	8	25	41.5	0.83	High
xy42100287127547	Wall Street	Unt to Neponset River	5	25	25	15	5	6	25	40.5	0.81	High
xy42144837125583	West Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42146067125557	Elm Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	5	20	20	20	25	9	25	42	0.84	High
xy42104937126264	Summer Street	Neponset River	4	20	20	20	4	15	20	37.5	0.75	High
xy42136137125876	Oak Street	Unt to Neponset River	4	20	20	12	20	12	20	36	0.72	High
xy42140687125658	Main Street	Neponset River	5	20	20	15	5	12	20	36	0.72	High
xy42149497125665	Robbins Road	Neponset River	4	16	20	12	4	12	20	36	0.72	High
xy42097757127417	Summer Street	Unt to Neponset River	4	20	20	12	8	9	20	34.5	0.69	High
xy42106397126086	Willow Street	Unt to Neponset River	4	16	20	12	4	9	20	34.5	0.69	High
xy42111477125602	Washington Street	Unt to Neponset River	4	20	20	8	4	9	20	34.5	0.69	High
xy42138047126671	Norfolk Street	Unt to Neponset River	4	20	20	12	4	9	20	34.5	0.69	High
xy42144787123615	Peach Street	Unt to Rainbow Pond	4	20	20	12	20	9	20	34.5	0.69	High
xy42154847122850	Tanglewood Drive	Unt to Plimpton Pond	4	20	20	12	4	9	20	34.5	0.69	High
xy42166587125229	North Street	Unt to Cobbs Pond	4	20	20	16	20	9	20	34.5	0.69	High
xy42169587125197	North Street	Unt to Cobbs Pond	4	20	20	16	8	9	20	34.5	0.69	High
xy42135937123844	Washington Street	Spring Brook	4	20	20	12	20	8	20	34	0.68	High
xy42101317127567	Winter Street	Unt to Neponset River	4	20	20	12	4	6	20	33	0.66	Medium
xy42109867124236	Pine Street	School Meadow Brook	4	20	20	16	20	6	20	33	0.66	Medium
xy42115167123904	Route 1	School Meadow Brook	5	20	20	20	5	6	20	33	0.66	Medium
xy42129917129273	West Street	Unt to Stop River	4	20	20	12	4	6	20	33	0.66	Medium
xy42131027129874	Lincoln Road	Unt to Stop River	4	20	20	12	20	6	20	33	0.66	Medium
xy42141577126917	West Street	Unt to Neponset River	4	20	20	12	4	6	20	33	0.66	Medium
xy42143487124893	Stone Street	Unt to Diamond Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42144287124496	Diamond Street	Unt to Diamond Pond	4	20	20	8	20	6	20	33	0.66	Medium
xy42154997122956	East Street	Unt to Plimpton Pond	4	20	20	12	20	6	20	33	0.66	Medium
xy42155177123008	Plimpton Street	Unt to Plimpton Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42159937121223	Walcott Avenue	Unt to Traphole Brook	4	16	20	12	20	6	20	33	0.66	Medium
xy42160737120763	Union Street	Pickerel Brook	4	16	20	12	4	6	20	33	0.66	Medium
xy42171197122646	Main Street	Unt to Willett Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42183447124570	North Street	Unt to Willet Pond	4	20	20	12	4	6	20	33	0.66	Medium
xy42153207124718	Main Street	Neponset River	4	20	20	8	4	5	20	32.5	0.65	Medium
xy42146387125549	East Street	Neponset River	5	15	20	15	5	4	20	32	0.64	Medium
xy42105167125931	Washington Street	Unt to Neponset River	4	20	20	12	20	3	20	31.5	0.63	Medium
xy42111237125430	South Street	Unt to Neponset River	4	20	20	8	4	3	20	31.5	0.63	Medium
xy42116617129323	Winter Street	Unt to Stop River	4	16	20	12	20	3	20	31.5	0.63	Medium
xy42145827124487	Diamond Street	Unt to Diamond Pond	4	20	20	12	4	3	20	31.5	0.63	Medium
xy42151747126785	Elm Street	Unt to Turner Pond	4	16	20	12	20	3	20	31.5	0.63	Medium
xy42155827123045	Plimpton Street	Unt to Plimpton Pond	4	20	20	8	4	3	20	31.5	0.63	Medium

Appendix C—Table 4. Top-ranked crossings based on Geomorphic Risk Score.

Crossing Code	Road Name	Stream Name	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	5	20	20	20	25	9	25	42	0.84	High
xy42104937126264	Summer Street	Neponset River	4	20	20	20	4	15	20	37.5	0.75	High
xy42163417121799	Bird Drive	Unt to Neponset River	5	5	5	20	5	12	20	36	0.72	High
xy42115167123904	Route 1	School Meadow Brook	5	20	20	20	5	6	20	33	0.66	Medium
xy42147047123565	Peach Street	Unt to Rainbow Pond	4	12	12	16	20	12	20	36	0.72	High
xy42166587125229	North Street	Unt to Cobbs Pond	4	20	20	16	20	9	20	34.5	0.69	High
xy42166937125207	North Street	Unt to Cobbs Pond	4	4	4	16	20	9	20	34.5	0.69	High
xy42169587125197	North Street	Unt to Cobbs Pond	4	20	20	16	8	9	20	34.5	0.69	High
xy42172037125068	Covey Road	Unt to Cobbs Pond	4	4	4	16	20	9	20	34.5	0.69	High
xy42109867124236	Pine Street	School Meadow Brook	4	20	20	16	20	6	20	33	0.66	Medium
xy42167007125368	Berkeley Court	Unt to Cobbs Pond	4	4	4	16	4	9	16	28.5	0.57	Medium

Appendix C—Table 5. Top-ranked crossings based on Structural Risk Score.

Crossing Code	Road Name	Stream Name	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42099387127399	Warwick Road	Unt to Neponset River	5	25	25	15	25	9	25	42	0.84	High
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	5	20	20	20	25	9	25	42	0.84	High
xy42136137125876	Oak Street	Unt to Neponset River	4	20	20	12	20	12	20	36	0.72	High
xy42138987124132	Stone Street	Spring Brook	4	12	12	12	20	12	20	36	0.72	High
xy42139387124233	Stone Street	Unt to Railroad Pond	4	12	12	12	20	12	20	36	0.72	High
xy42147047123565	Peach Street	Unt to Rainbow Pond	4	12	12	16	20	12	20	36	0.72	High
xy42173527125505	Sunnyrock Drive	Unt to Cobbs Pond	4	4	4	8	20	12	20	36	0.72	High
xy42128217129506	West Street	Unt to Neponset River	4	8	12	12	20	9	20	34.5	0.69	High
xy42144787123615	Peach Street	Unt to Rainbow Pond	4	20	20	12	20	9	20	34.5	0.69	High
xy42166587125229	North Street	Unt to Cobbs Pond	4	20	20	16	20	9	20	34.5	0.69	High
xy42166937125207	North Street	Unt to Cobbs Pond	4	4	4	16	20	9	20	34.5	0.69	High
xy42168177122776	Christina Drive	Unt to Neponset River	4	4	4	12	20	9	20	34.5	0.69	High
xy42172037125068	Covey Road	Unt to Cobbs Pond	4	4	4	16	20	9	20	34.5	0.69	High
xy42176677125923	Homeward Lane	Unt to Cobbs Pond	4	4	4	12	20	9	20	34.5	0.69	High
xy42135937123844	Washington Street	Spring Brook	4	20	20	12	20	8	20	34	0.68	High
xy42109867124236	Pine Street	School Meadow Brook	4	20	20	16	20	6	20	33	0.66	Medium
xy42131027129874	Lincoln Road	Unt to Stop River	4	20	20	12	20	6	20	33	0.66	Medium
xy42144287124496	Diamond Street	Unt to Diamond Pond	4	20	20	8	20	6	20	33	0.66	Medium
xy42153687122406	Adrienne Road	Unt to Traphole Brook	4	4	4	12	20	6	20	33	0.66	Medium
xy42154997122956	East Street	Unt to Plimpton Pond	4	20	20	12	20	6	20	33	0.66	Medium
xy42159937121223	Walcott Avenue	Unt to Traphole Brook	4	16	20	12	20	6	20	33	0.66	Medium
xy42166037124982	Gould Street	Unt to Cobbs Pond	4	4	4	12	20	6	20	33	0.66	Medium
xy42173327125776	Sunnyrock Drive	Unt to Cobbs Pond	4	4	4	12	20	6	20	33	0.66	Medium
xy42105167125931	Washington Street	Unt to Neponset River	4	20	20	12	20	3	20	31.5	0.63	Medium
xy42116617129323	Winter Street	Unt to Stop River	4	16	20	12	20	3	20	31.5	0.63	Medium
xy42151747126785	Elm Street	Unt to Turner Pond	4	16	20	12	20	3	20	31.5	0.63	Medium
xy42153277120918	Park Lane	Traphole Brook	4	4	4	12	20	3	20	31.5	0.63	Medium

Appendix C—Table 6. Top-ranked crossings based on Aquatic Organism Passage Benefit Score.

Crossing Code	Road Name	Stream Name	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42159347123453	Plimpton Street	Neponset River	3	3	3	9	15	20	15	37.5	0.75	High
xy42151467126130	Mill Pond Road	Unt to Neponset River	4	12	12	12	4	16	12	30	0.6	Medium
xy42104937126264	Summer Street	Neponset River	4	20	20	20	4	15	20	37.5	0.75	High
xy42177897125940	Independence Drive	Unt to Cobbs Pond	4	4	4	12	4	15	12	28.5	0.57	Medium
xy42136137125876	Oak Street	Unt to Neponset River	4	20	20	12	20	12	20	36	0.72	High
xy42138987124132	Stone Street	Spring Brook	4	12	12	12	20	12	20	36	0.72	High
xy42139387124233	Stone Street	Unt to Railroad Pond	4	12	12	12	20	12	20	36	0.72	High
xy42140687125658	Main Street	Neponset River	5	20	20	15	5	12	20	36	0.72	High
xy42147047123565	Peach Street	Unt to Rainbow Pond	4	12	12	16	20	12	20	36	0.72	High
xy42149497125665	Robbins Road	Neponset River	4	16	20	12	4	12	20	36	0.72	High
xy42163417121799	Bird Drive	Unt to Neponset River	5	5	5	20	5	12	20	36	0.72	High
xy42173527125505	Sunnyrock Drive	Unt to Cobbs Pond	4	4	4	8	20	12	20	36	0.72	High
xy42104177126144	Washington Street Extension	Neponset River	4	16	16	12	4	12	16	30	0.6	Medium
xy42146277123815	Golf trail off of Rainbow Pond Drive by rainbow pond spillway	Unt to Railroad Pond	3	15	15	9	15	12	15	28.5	0.57	Medium
xy42151727120917	Route 1	Traphole Brook	5	5	5	15	5	12	15	28.5	0.57	Medium
xy42164057124512	Gould Street	Unt to Cobbs Pond	3	15	15	12	15	12	15	28.5	0.57	Medium
xy42200877124962	North Street	Bubbling Brook	3	15	15	12	3	12	15	28.5	0.57	Medium
xy42134647125771	Oak Street	Unt to Neponset River	4	12	12	12	4	12	12	24	0.48	Medium
xy42143077126757	Lorusso & sons entrance	Unt to Neponset River	4	12	12	12	4	12	12	24	0.48	Medium
xy42144217124438	Old Diamond Street	Unt to Diamond Pond	4	4	4	12	4	12	12	24	0.48	Medium
xy42146607125072	Unnamed road behind fire station	Spring Brook	4	12	12	12	4	12	12	24	0.48	Medium
xy42154177122092	Polley Lane	Unt to Traphole Brook	4	8	12	12	4	12	12	24	0.48	Medium
xy42126247124735	Unnamed road to Town sewage treatment plant	School Meadow Brook	2	10	10	6	2	12	10	23	0.46	Medium

Appendix C—Table 7. Top-ranked crossings based on Impact Score.

Crossing Code	Road Name	Stream Name	Impact Score	Hydraulic Risk Score	Climate Change Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Value	Scaled Crossing Priority	Relative Priority Rating
xy42099387127399	Warwick Road	Unt to Neponset River	5	25	25	15	25	9	25	42	0.84	High
xy42158337124241	Main Street	Unt to Neponset River from Cobbs Pond	5	25	25	15	5	9	25	42	0.84	High
xy42165037124747	Smith Avenue	Unt to Cobbs Pond	5	20	20	20	25	9	25	42	0.84	High
xy42140017125451	Lewis Avenue	Neponset River	5	25	25	10	10	8	25	41.5	0.83	High
xy42165167124759	Gould Street	Unt to Cobbs Pond	5	20	25	15	5	8	25	41.5	0.83	High
xy42100287127547	Wall Street	Unt to Neponset River	5	25	25	15	5	6	25	40.5	0.81	High
xy42144837125583	West Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42146067125557	Elm Street	Neponset River	5	25	25	15	5	4	25	39.5	0.79	High
xy42140687125658	Main Street	Neponset River	5	20	20	15	5	12	20	36	0.72	High
xy42163417121799	Bird Drive	Unt to Neponset River	5	5	5	20	5	12	20	36	0.72	High
xy42115167123904	Route 1	School Meadow Brook	5	20	20	20	5	6	20	33	0.66	Medium
xy42146387125549	East Street	Neponset River	5	15	20	15	5	4	20	32	0.64	Medium
xy42151727120917	Route 1	Traphole Brook	5	5	5	15	5	12	15	28.5	0.57	Medium
xy42146157124929	School Street	Spring Brook	5	5	5	15	5	8	15	26.5	0.53	Medium
xy42150557121156	Route 1	Unt to Traphole Brook	5	5	5	15	5	6	15	25.5	0.51	Medium
xy42164147121873	Holden's Drive	Unt to Neponset River	5	5	15	15	5	6	15	25.5	0.51	Medium
xy42162637121529	Washington Street	Neponset River	5	5	5	15	5	5	15	25	0.5	Medium

Appendix C

Green Infrastructure Assessment Technical Memorandum

APPENDIX C
AVAILABLE
UPON REQUEST

Attachment D

Retrofit Design Concepts

Site 8 – Public Works Yard
Bioretention Basin
Washington Street, Walpole, Massachusetts

Site Description

The proposed retrofit location is the northern edge of the paved area of the Department of Public Works yard and buildings, as well as an unpaved parking area. The catchment for the proposed concept consists entirely of surface drainage, flowing to the impaired School Meadow Brook, which feeds public drinking water wells. Flow becomes concentrated as runoff approaches the edge of the yard. The proposed location is currently used for equipment storage, and may approach a wetland at the northernmost edge.

Site Concept Summary

Total Impervious Area: 1.8 acres

Treated Water Quality Volume: 5,876 ft^3

Treatment Depth: 1.02 inch

Estimated Cost (Cost Range)

DPW_BR_1: $56,000
($39,000 - $84,000)

Image 1: Established grassed bioretention basin. *

Proposed Concept

- Install a bioretention basin along the northern edge of the DPW yard to capture stormwater before it flows into a wetland and School Meadow Brook. Where flow enters the basin, include riprap to dissipate energy of concentrated flow.
- Include a sediment forebay or similar pretreatment structure to improve treatment and extend the lifespan of the bioretention basin. The basin would likely be grassed to reduce maintenance requirements.
- Two sediment forebays will likely be required to treat runoff from multiple directions.
- Tree removal would likely be necessary to create sufficient space; however, this a unique opportunity to protect adjacent wetlands and treat stormwater from a heave-use industrial area.

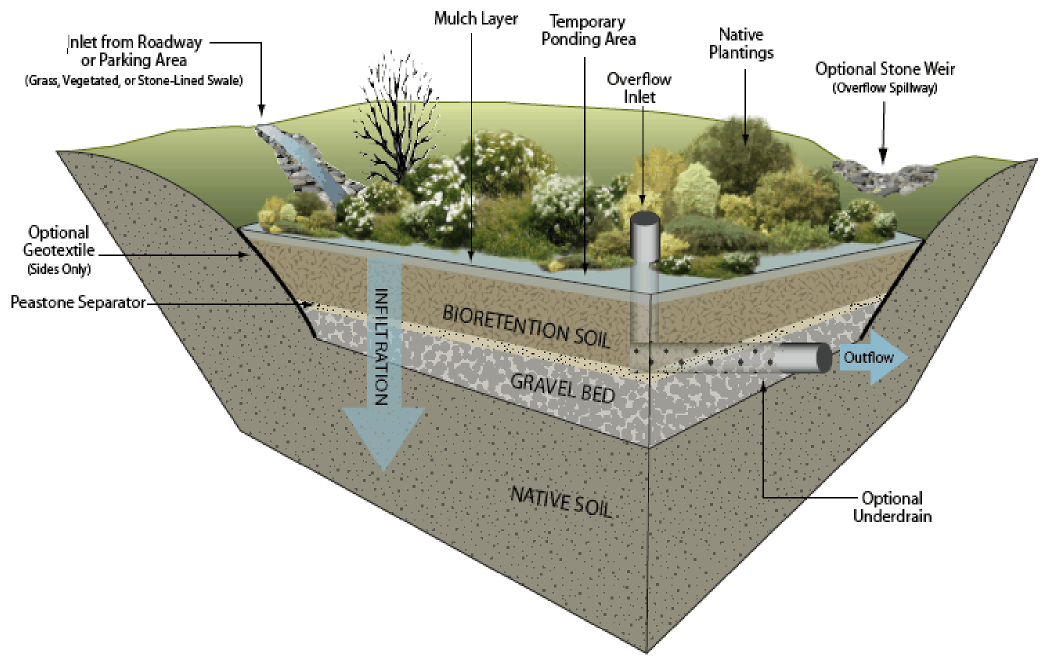

Image 2: Typical bioretention basin cross-section. **

*Photo courtesy of the City of Lenexa, Kansas

**Photo courtesy of mass.gov, Executive Office of Energy and Environmental

Public Works Yard, Walpole, MA

Retrofit Design Concepts

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Site 10 – Jarvis Farm
Bioretention and Subsurface Infiltration
691 Common Street, Walpole, Massachusetts

Site Description

The proposed retrofit location is the open area, known as Jarvis Farm, at the northern end of the Town recreation area below an existing Town-owned outfall. This area is next to an Eversource transmission line. Runoff from Hawthorne Drive, Common Street, and Morningside Drive is collected in a series of catch basins and discharges to an outfall beneath the transmission line. From the outfall, runoff flows overland to a public swimming area, which is in the 500 year floodplain. Evidence of high groundwater may be present during winter.

Proposed Concept

- Install an infiltration basin in the area between the transmission lines and the access road before it reaches the public bathing area.
- Include a sediment forebay or similar pretreatment structure to improve treatment and extend the lifespan of the infiltration basin.
- If groundwater is elevated at Jarvis Farm, an underdrain may be required. Underdrain and/or overflow structure should connect to existing culvert under the access road.
- In the cul-de-sac of Hawthorn Drive, divert flow from the existing catchbasins into an arched chamber subsurface infiltration system.

Site Concept Summary
Total Impervious Area: 3.61 acres
Treated Water Quality Volume: 5,353 ft^3
Treatment Depth: 2.21 inch

Estimated Cost (Cost Range)
JF_SSI_1: $229,000
($160,000 - $344,000)

JF_IB_1: $34,000
($24,000 - $51,000)

Image 1: Existing stormwater outfall (partially obscured by leaves).

Image 2: Proposed infiltration basin area (JF_IB_1) is shown in open area to the left of gravel road.

Jarvis Farm, Walpole, MA

Retrofit Design Concepts

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Jarvis Farm - Hawthorne Drive, Walpole, MA

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Site 15 – Walpole High School
Infiltration, Permeable Pavers and Subsurface Infiltration Chambers
275 Common Street, Walpole, Massachusetts

Site Description

The proposed retrofit location addresses the impervious area associated with the parking lots and tennis courts south of the school. The site slopes generally northwest-to-southeast toward Common Street, with catch basins in the parking lot ultimately discharging to School Meadow Brook. The northern part of the parking lot includes parking spaces separated by landscaped islands. The southern part of the parking lot does not have parking islands. Pavement in the parking lot is in fair condition, and may need replacement within the next 5 to 10 years. Evidence of erosive flow was observed coming from the tennis courts.

Proposed Concept

- Install an infiltration swale between the tennis courts and parking lot to capture runoff from both impervious surfaces. The system can overflow to existing infrastructure.

- Install permeable pavers within walkways throughout the courtyard to treat runoff from the courtyard and school roof.

- Install vault-style infiltration chambers beneath the southeastern parking lot. This system can accept flow from existing infrastructure and overflow to the same catchments as needed before connecting to Common Street.
    - An alternative to the subsurface infiltration system is an infiltration basin in the landscaped island adjacent to Common Street (WHS_IB_2). This infiltration basin would capture water from a similar sized watershed as the subsurface infiltration system but may be less desirable due to the higher maintenance frequency of surface features.

Site Concept Summary

Total Impervious Area: 0.45 acres — Treated Water Quality Volume: 28,559 ft^3

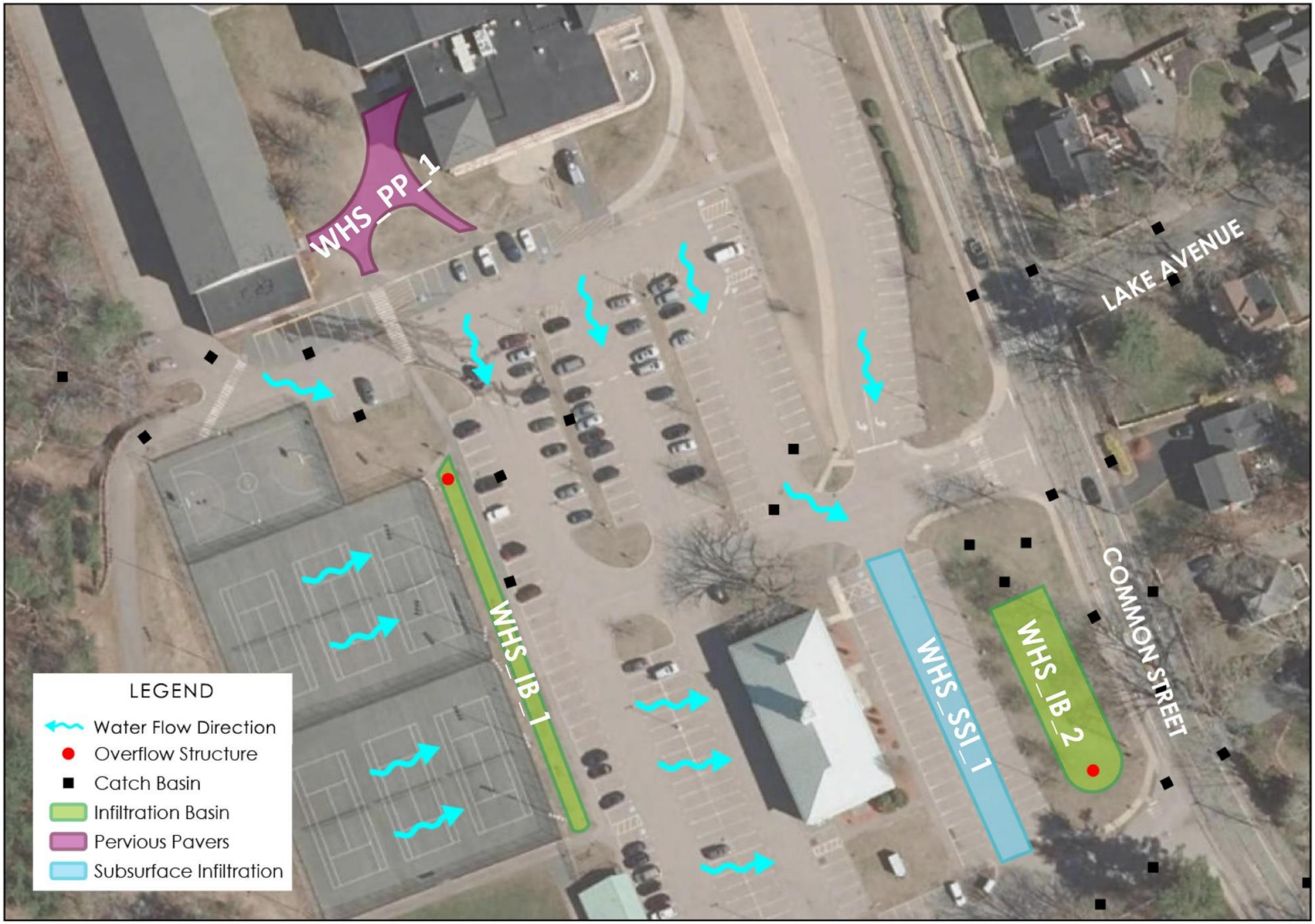
Treatment Depth: 4.11 inches

Estimated Cost (Cost Range)

WHS_IB_1: $42,000 ($29,000 - $63,000)	WHS_PP_1: $73,000 ($51,000 - $110,000)
WHS_SSI_1: $137,000 ($96,000 - $206,000)	WHS_IB_2: $135,000 ($95,000 - $203,000)

Image 1: Area of proposed infiltration swale (WHS_IB_1) along the length of the tennis courts.

Image 2: Installation of interlocking porous pavers.



Walpole High School, Walpole, MA

Retrofit Design Concepts

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Site 17 – The Common
Subsurface Infiltration
Common Street, Downtown Walpole, Massachusetts

Site Description

The proposed retrofit location is the historic Town Common, the crossroad of downtown Walpole. This area serves as an important green space surrounded by commercial and institutional land uses. Several monuments and many mature trees are located on the Common. Located at a relative high point, the Common is divided by several arterial streets, each with parking lanes along at least one side. Drainage at the site is entirely catch basin and pipe, and all streets are curbed. While stormwater mapping at the site is incomplete, the site appears to drain to the bacteria-impaired Neponset River.

Proposed Concept

- Narrow the travel lane on Front Street by up to 12 feet in order to reduce impervious cover.
  - Pavement reduction is one of the most cost effective BMP's, reducing impervious surface and therefore the amount of stormwater requiring treatment

- Install subsurface infiltration along the road, under exiting side-street parking spaces. Include a sediment forebay or similar pretreatment structure to increase treatment and extend the lifespan of the systems
  - Subsurface infiltration chambers will allow for treatment and infiltration of stormwater where none currently exists while preserving the overall aesthetic of the Town Common area which is highly regarded by a majority of residents. This will enhance water quality of the nearby Neponset River and reduce flood frequency as well.

Image 1: Installation of subsurface infiltration chambers under one lane of a municipal right-of-way in Rhode Island.

Site Concept Summary

Total Impervious Area: Approx. 1 acre

Treated Water Quality Volume: 3,760 ft^3

Treatment Depth: 9.02 inch

Estimated Cost (Cost Range)

TC_SSI_1: $51,000
($36,000 - $77,000)

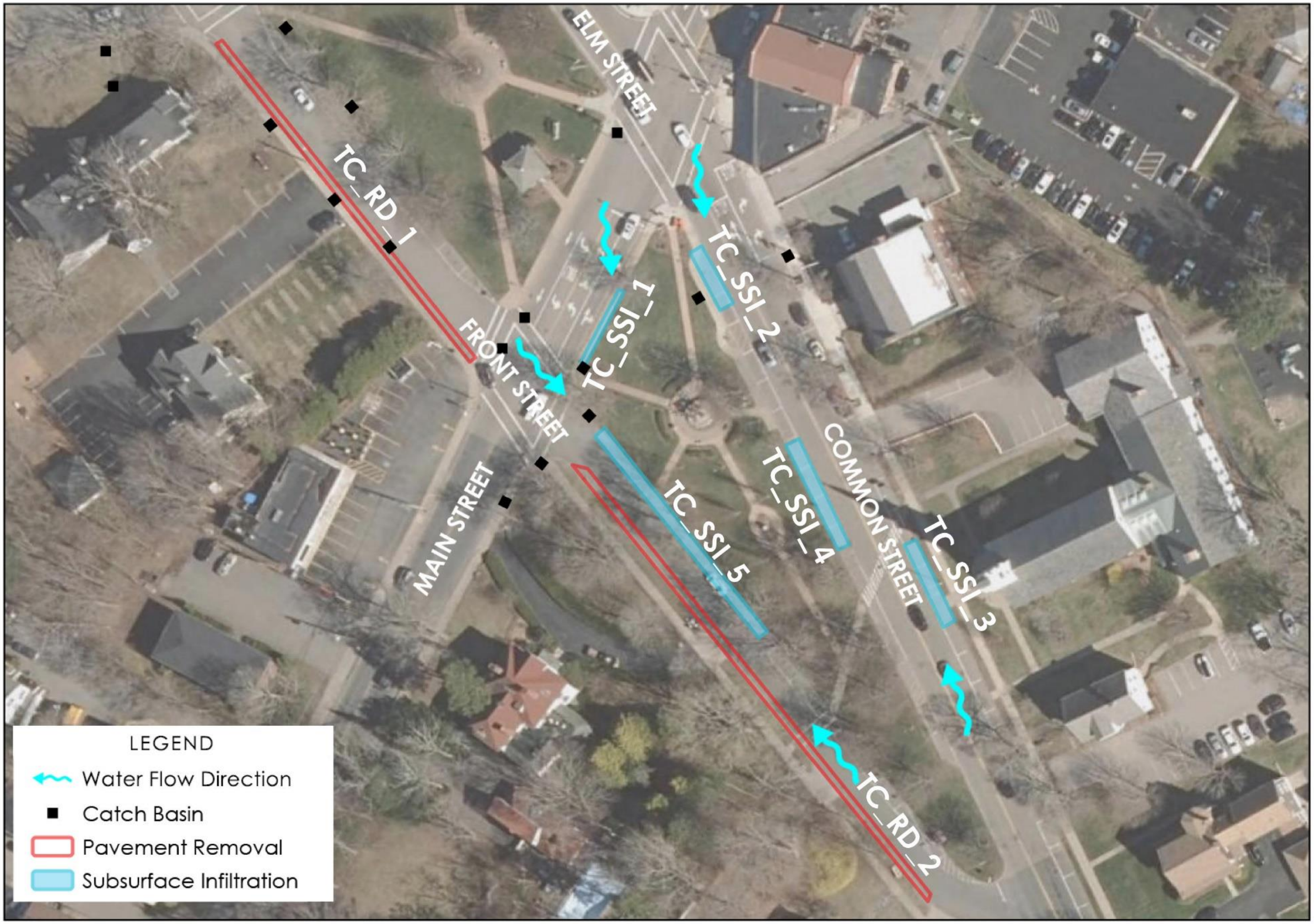
TC_SSI_2, TC_SSI_3, and TC_SSI_4: $68,000 each
($48,000 - $102,000)

TC_SSI_5: $177,000
($124,000 - $266,000)

TC_SSI_6: $34,000
($24,000 - $51,000)

TC_RD_1&_2: $52,000
($36,000 - $78,000)

Subsurface Infiltration Total: ($328,000 - $700,000)



Downtown Area , Walpole, MA

Retrofit Design Concepts

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Site 20 – Town Hall & Municipal Parking Lot
Bioretention and Infiltration
135 School Street & Behind Walpole Fire Station 1 (Stone Street), Walpole, Massachusetts

Site Description

The proposed retrofit locations address impervious surface for the municipal parking lot behind Walpole Fire Station 1 and the Town Hall rear parking lot and roof. Runoff from the 1.2-acre municipal parking lot sheet flows to a single catch basin, which discharges directly into the buried segment of School Meadow Brook. Pavement in the municipal parking lot is in fair to poor condition, likely requiring replacement within the next 10 years. Not only is this project advantageous because it treats stormwater but is also an opportunity to improve the flow and efficiency of all forms of traffic (cars, bikes, and pedestrian) through the parking lot.

Runoff from the Town Hall roof and rear parking lot enter a series of catch basins, which discharge to School Meadow Brook, upstream of the buried segment. Roof leaders from the Town Hall are buried. A sewer manhole is mapped near the rear parking lot. Pavement in the parking lot is in fair condition, likely requiring replacement over the medium term. Park area to north of Town Hall is partially in the 100-year floodplain.

Proposed Concept

- Municipal parking lot redesign, angled parking spaces, infiltration swales in new parking islands.

- Install a bioretention basin or swale north of the Town Hall rear parking lot. Retrofit northernmost catch basins to sediment forebays. Re-lay pipe from southern catch basins to increase invert elevation, include sediment forebay at pipe outlet to increase treatment and extend lifespan of infiltration practice. Install overflow structure that ties into existing pipe and outfall to School Meadow Brook.

- Soils information at both locations is not available on the NRCS database, so systems would need to overflow into existing infrastructure. However, if the soils are found to be suitable during design, infiltration basins are the preferred alternative.

Image 1: Proposed location of bioretention basin north of Town Hall parking lot.

Image 2: Example of integrated parking lot and bioretention basin.

Concept Summary
Total Impervious Area: 2.2 acres
Treated Water Quality Volume: 3,683 ft^3
Treatment Depth: 1.71 inches

Estimated Cost (Cost Range)
Town Hall
TH_BR_1: $70,000
($49,000 - $105,000)

Municipal Parking Area
PP__IB_1: $415,000
($291,000 - $623,000)

Town Hall & Public Parking Area, Walpole, MA

Retrofit Design Concepts

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Site 22 – Old Post Road
Infiltration, Permeable Pavers and Subsurface Infiltration Chambers
275 Common Street, Walpole, Massachusetts

Site Description

The proposed retrofit locations address impervious surfaces at the front and sides of the school, and parking and drop-off circles. Stormwater enters catch basins near the school entrance, parking lot, and drop off circle. Roof leaders are not buried. The Town has said the pavement will likely be replaced in the next 1 to 5 years. The school is situated at the top of a large drainage catchment which discharges to a stormwater pond east of Polley Lane that has experienced historical flooding problems. This catchment ultimately contributes to recurring flooding issues at Bird Park.

Proposed Concept

- When replacing pavement, install a subsurface infiltration system beneath the parking spaces at the center of the bus drop-off area. Replace catch basin with diversion structure to pass water quality volume. Include swirl separator or similar pretreatment structure to increase treatment and extend the lifespan of the infiltration system.

- Install surface infiltration basins in the open areas behind catch basins in drop-off circle. Use a paved swale to divert flow upgradient of catch basins. Direct stormwater in excess of water quality volume to catch basins. Include a sediment forebay or similar pretreatment structure to improve treatment and extend the lifespan of the infiltration basins.

Site Concept Summary

Total Impervious Area: 1.1 acres

Treated Water Quality Volume: 4,182 ft^3

Treatment Depth: 6.49 inches

Estimated Cost (Cost Range)

OPR_IB_1: $14,000 ($10,000 - $21,000)	OPR_IB_2: $8,000 ($6,000 - $12,000)
OPR_IB_3: $9,000 ($6,000 - $14,000)	OPR_SSI_1: $348,000 ($244,000 - $522,000)

Image 1: Example of a low maintenance infiltration basin.

Image 2: Arched chamber subsurface infiltration system, during installation under a parking lot.

Old Post Road School, Walpole, MA

Retrofit Design Concepts

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Site 26 – Johnson Middle School
Infiltration Basin, Pervious Pavement and Native Plantings
415 Elm Street, Walpole, Massachusetts

Site Description

The proposed retrofit locations intercept runoff from four courtyards, two parking lots, an access road, and tennis courts. While the tennis courts were recently repaved, the parking lots will likely require substantial maintenance and/or replacement in the near-term. Runoff from the rear parking lot is captured by two catch basins which connect to an unidentified outfall discharging to Mine Brook. The lower catch basin receives runoff via a paved swale from the rear parking lot and tennis courts. Evidence was observed during a site visit that runoff is bypassing the paved swale and channelizing through the infield of the playing fields behind the school. An additional retrofit location was identified across the street from the school near the faculty parking lot. The faculty parking lot slopes towards the closed conduit drainage system which runs along Robbins Road.

Proposed Concept

- Install an infiltration basin below the tennis courts to capture runoff from the rear parking lot and tennis court. Increase the height of the berm behind the paved swale to prevent bypass of runoff from the tennis courts. Replace catch basin with sediment forebay or similar pretreatment structure. Direct runoff in excess of design volume to existing stormwater pipe via riser. Include fencing between playing fields and infiltration basin for player safety.

- Install an infiltration basin in the unpaved, curbed area at the western side of the faculty parking lot. Direct runoff to practice via a curb cut upstream of the existing catch basin. Include a sediment forebay to increase treatment and extend the lifespan of the infiltration basin. Include an overflow structure to pass runoff in excess of the water quality volume to the existing catch basin.

- Install pervious pavers at the four corners of the building in the location of the existing courtyards.

Image 1: Proposed location of infiltration basin (JMS_IB_1) near faculty parking lot.

Site Concept Summary

Total Impervious Area: 0.16 acres

Treated Water Quality Volume: 11,888 ft^3

Treatment Depth: 4.16 inches

Estimated Cost (Cost Range)

JMS_IB_1: $4,000
($3,000 - $6,000)

JMS_IB_2: $18,800
($13,000 - $28,000)

JMS_IB_3: $24,000
($17,000 - $36,000)

JMS_PP_1: $178,000
($125,000 - $267,000)

Image 2: One of the school's courtyards.
(the red area represents area to be replaced with permeable pavers)

Image 3: Installation of interlocking porous pavers.

Johnson Middle School, Walpole, MA

Retrofit Design Concepts

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Site 28 – Elm Street School
Bioretention, Infiltration, and Native Plantings
415 Elm Street, Walpole, Massachusetts

Site Description

The school is located on top of a hill and stormwater flows off the site in all directions, ultimately discharging to Turner Pond. Drainage consists of catch basins. Catch basins are located along the entrance road, which slopes down to Elm St. At the rear of the school, a paved road slopes to a basketball court and two catch basins, above a playing field. The main parking area discharges to a rip-rap swale on the south-eastern edge of the parcel.

Proposed Concept

- Under the parking spaces in front of the preschool play area, replace the catch basin with an offline subsurface infiltration system, retrofitting the existing catch basin with a weir to control flow into the BMP and with a pretreatment structure to facilitate maintenance.
- North of the back parking lot, tie the existing catch basin into an infiltration basin. Provide deep sumps and baffles to provide pretreatment to the infiltration basin.
- On the south side of the main parking lot, retrofit the existing rip-rap swale to an infiltration swale. Include a sediment forebay to increase treatment and extend the service life of the practice.
- To the right of the school entrance, install an infiltration basin. Include a sediment forebay to increase treatment and extend the lifespan of the BMP. Direct runoff in excess of the water quality volume to the nearby existing catch basin via a riser.
- Install tree filters, which include a subsurface infiltration component, at two low points in the parking lot.
- Incorporate stormwater concepts into the school's curriculum, using the proposed retrofits as real-world examples and sites for hands-on learning.

Site Concept Summary

Total Impervious Area: 1.8 acres
Treated Water Quality Volume: 6,861 ft^3
Treatment Depth: 4.16 inches

Estimated Cost (Cost Range)

Infiltration Basins
ESS_IB_1, _2, & _3: $38,000 total
($27,000 - $57,000)

Subsurface Infiltration
ESS_SSI_1: $172,000
($120,000 - $258,000)

Tree Boxes
ESS_TF_1 & _2: $85,000 total
($60,000 - $128,000)

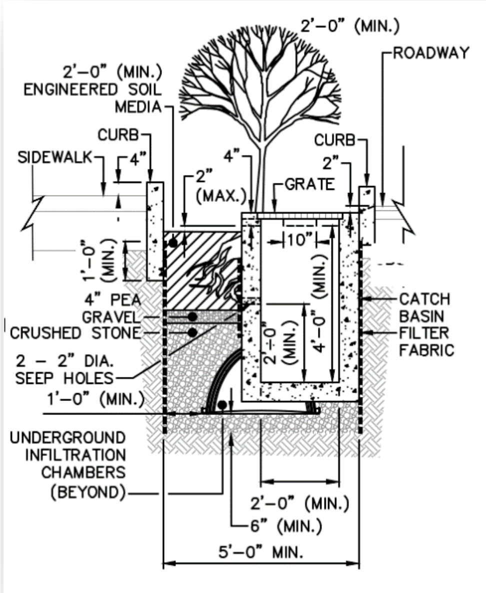

Image 1: Tree filter with storage detail.

Image 2: Proposed location of infiltration swale and basin (ESS_IB_3).

Elm Street School, Walpole, MA

Retrofit Design Concepts

0 15 30 60 Feet

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Elm Street School, Walpole, MA

Retrofit Design Concepts

Disclaimer: This map is not the product of a Professional Land Survey. It was created by Fuss & O'Neill Inc. for General Reference and is not a legally authoritative source. Fuss & O'Neill Inc. makes no warrantee, express or implied, related to the spatial accuracy, reliability, completeness, or currentness of this map. Data Source: Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services. Imagery © Google.

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Site 30 – Ellis Field
Infiltration Basin and Bioretention Parking Lot Planters
East Street, Walpole, Massachusetts

Site Description

The proposed retrofit location is the westernmost part of Ellis Field, owned by the Trustees of Reservations. The area is situated above the playing fields and level for approximately 50 feet before sloping down to the playing fields. Existing storm drains collect runoff from East St, Hemlock St, and part of June St and discharge to the bacteria-impaired Neponset River. Land use in the catchment is residential. Some landscaped flower beds and signage exist to the south of the proposed location. An approximately 27,000 ft^2 compacted dirt and gravel parking area is located to the northeast of the playing fields. The parking lot area could be refurbished with bioretention planters and informational signage. Because this area is accessed frequently by citizens of Walpole, BMPs could serve as a unique public education and outreach opportunity to promote Green Infrastructure.

Proposed Concept

- Install an infiltration basin at the western edge of Ellis Field. Retrofit the existing drainage manhole on June St to a weir or similar diversion structure to pass the water quality volume from existing pipes to the infiltration basin. Pass flows beyond the design volume to the existing storm drain on East Street.
    - If property owner is amenable, consider including native plantings and incorporate educational signage to increase value of BMP.
    - Include a swirl separator or similar pretreatment structure to improve treatment and extend the lifespan of the infiltration basin.

- Retrofit parking area for the playing fields to reinforced gravel paving grids.
    - Flexibility in terms of site features and treatment options based on preferred maintenance responsibility and park aesthetic: permeable asphalt, infiltration with plantings, simple grassed swales or a combination of features could be proposed based on maintenance preferences.

Site Concept Summary

Total Impervious Area: 2 acres

Treated Water Quality Volume: 10,023 ft^3

Treatment Depth: 1.57 inches

Estimated Cost (Cost Range)

EF_IB_1: $39,000
($27,000 - $59,000)

EF_IB_2: $95,000
($67,000 - $143,000)

Image 1: Example of educational signage.

Image 2: Example of a parking lot with a bioretention basin.

Ellis Field, Walpole, MA

Retrofit Design Concepts

0 15 30 60 Feet

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Attachment E

Sizing Calculations

Bioretention/Infiltration Basin Sizing

Site Number	Site Name	BMP ID	Ponding (Surface) Volume			Void (Subsurface) Volume				Total Storage Volume (ft.^{3})	Target Volume (WQv)	Treatment Depth (in.)
			Length (ft.)	Width (ft.)	Depth (ft.)	Length (ft.)	Width (ft.)	Depth (ft.)	Void Space			
8	DPW Yard	DPW_BR_1	185	25	0.5	185	30	2	0.33	5,976	5,876	1.02
10	Jarvis Farm	JF_IB_1	150	25	0.5	150	25	1.5	0.33	3,731	3,467	1.08
15	Walpole High School	WHS_IB_1	240	8	1	240	8	2	0.33	3,187	3,079	1.04
		WHS_IB_2	40	130	1.5	40	130	1.5	0.33	10,374	9,939	1.04
20	Municipal Parking Lot	PP_IB_1	875	4	0.5	875	4	2	0.33	4,060	8,150	0.50
	Town Hall	TH_BR_1	100	10	1.5	100	10	1.5	0.33	1,995	1,842	1.08
22	Old Post Road School	OPR_IB_1	30	45	1	0	0	0	0	1,350	756	1.79
		OPR_IB_2	50	15	1	0	0	0	0	750	708	1.06
		OPR_IB_3	25	35	1	0	0	0	0	875	866	1.01
26	Johnson Middle School	JMS_IB_1	20	15	0.5	20	15	2.5	0.33	398	378	1.05
		JMS_IB_2	150	12	0.5	150	12	2.5	0.33	2,385	2,335	1.02
		JMS_IB_3	80	30	0.5	80	30	1.5	0.33	2,388	2,181	1.09
28	Elm Street School	ESS_IB_1	60	10	1	0	0	0	0	600	1,096	0.55
		ESS_IB_2	35	35	2	0	0	0	0	2,450	1,588	1.54
		ESS_IB_3	30	20	2	0	0	0	0	1,200	1,104	1.09
30	Ellis Field	EF_IB_1	260	13	0.5	260	13	2	0.33	3,921	7,650	0.51
		EF_IB_2	250	9	0.5	250	9	2	0.33	2,610	2,473	1.06

Subsurface Inflitration Sizing

Site Number	Site Name	BMP ID	Soil Type	No. Units	No. Units Wide	No. Units Long	Total Length, L (ft.)	Total Width, w (ft.)	1.2" Recharge Volume (ft.^{3})	Total Storage Volume (ft.^{3})	Treatment Volume, WQv-1.2" (ft.^{3})	Treatment Depth (in.)
10	Jarvis Farm	JF_SSI_1	A	24	2	12	85.40	9.50	943.0	2,134.9	1,886.00	1.13
15	Walpole High School	WHS_SSI_1	*Sized per Manufacturer*							13950	13,528	1.03
17	Town Common	TC_SSI_1	C	6	1	6	42.70	4.75	85.0	469.8	408.24	1.15
		TC_SSI_2	C	8	2	4	28.47	9.50	125.6	626.4	602.90	1.04
		TC_SSI_3	C	8	2	4	28.47	9.50	90.5	626.4	434.23	1.44
		TC_SSI_4	C	8	2	4	28.47	9.50	95.8	626.4	460.07	1.36
		TC_SSI_5	C	21	2	10.5	74.73	9.50	334.2	1,644.4	1,604.14	1.03
		TC_SSI_6	C	4	1	4	28.47	4.75	52.3	313.2	250.85	1.25
22	Old Post Road School	OPR_SSI_1	B	60	10	6	42.70	47.50	1,391.9	4,867.3	4,772.30	1.02
28	Elm Street School	ESS_SSI_1	A	18	6	3	21.35	28.50	731.4	1,601.1	1,462.82	1.09

**Refer to StormTech, Advanced Drainage Systems, Inc. design guidence.*

Permeable Pavement Sizing

Site Number	Site Name	BMP ID	Impervious Area (ft^2)	Porosity, n	Depth of Aggregate Base, d_t (ft)	Design Infiltration Rate, fc (in/hr)	Time to Fill, t (hr)	Surface Area, A_p (ft^2)	Available Surface Area (ft^2)
15	Walpole High School	WHS_PP_1	6,764	0.33	1	0.52	2	248	4,300
26	Johnson Middle School	JMS_PP_1	6,994	0.33	1	0.52	2	257	6,994

**Refer to permeable paving design guidance provided in the Rhode Island Stormwater Design and Installation Standards Manual, Amended March 2015, page 5-38. Equation shown below.*

$$A_p = V / (n8d_t + f_c t/12)$$

Where:

- A_p = surface area (ft^2)
- V = design volume (e.g., WQ_v) (ft^3)
- n = porosity of gravel fill (assume 0.33)
- d_t = depth of aggregate base (separated at least three feet from seasonal high groundwater) (ft)
- f_c = design infiltration rate (in/hr)
- t = time to fill (hours) (assumed to be 2 hours for design purposes)

Tree Filter Sizing

Site Number	Site Name	BMP ID	Treatment Volume, WQv-0.5" (ft.^{3})	Surface Area of Filter Bed (ft.^{2})	Treatment Depth (in.)
28	Elm Street School	ESS_TF_1	524.29	110.38	0.5
		ESS_TF_2	286.59	60.33	0.5

**Refer to tree filter design guidance provided in the Rhode Island Stormwater Design and Installation Standards Manual, Amended March 2015, page 5-48. Equation shown below.*

$$A_f = (WQ_v)\ (d_f)\ /\ [(k)\ (h_f + d_f)\ (t_f)]$$

Where:

- A_f = Surface area of filter bed (ft^2)
- d_f = Filter bed depth (ft)
- k = Coefficient of permeability of filter media (ft/day)
- h_f = Average height of water above surface of practice (i.e., height above the uppermost mulch/organic layer) (ft)
- t_f = Design filter bed drain time (days) (2 days is the maximum t_f for bioretention)

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Attachment F

Planning Level Cost Estimates

Order of Magnitude Cost Estimates

Site Number	Location and BMP Type			Order of Magnitude Cost Range														
				Construction					Planning and Design		Cost Range			Life Cycle				
				Unit Cost	Unit	Adjustment Factor	Quantity	Base Cost	Allowance	Cost	Total Cost	-30%	50%	Lifespan (yrs.)	Annual Cost Over Lifespan	O&M (% Cost)	O&M ($/yr.)	Total Capitalized Cost/Year Over Lifespan
8	Department of Public Works	DPW_BR_1	Infiltration Basin	$6.00	CF Storage Volume	1.2	5,976	$43,027	30%	$12,910	$56,000	$39,000	$84,000	20	$4,120	4%	$160	$4,280
10	Jarvis Farm	JF_SSI_1	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	2,135	$176,138	30%	$52,840	$229,000	$160,000	$344,000	75	$9,670	4%	$390	$10,060
	Jarvis Farm	JF_IB_1	Infiltration Basin	$5.00	CF Storage Volume	1.5	3,457	$25,928	30%	$7,780	$34,000	$24,000	$51,000	20	$2,500	4%	$100	$2,600
15	Walpole High School	WHS_PP_1	Permeable Pavers	$13.00	SF	1.0	4,300	$55,900	30%	$16,770	$73,000	$51,000	$110,000	20	$5,370	4%	$210	$5,580
		WHS_SSI_1	Subsurface Infiltration	N/A	Cost from Vender	1.0	N/A	$105,000	30%	$31,500	$137,000	$96,000	$206,000	75	$5,790	4%	$230	$6,020
		WHS_IB_1	Infiltration Basin	$5.00	CF Storage Volume	2.0	3,187	$31,870	30%	$9,560	$42,000	$29,000	$63,000	20	$3,090	4%	$120	$3,210
		WHS_IB_2	Infiltration Basin	$5.00	CF Storage Volume	2.0	10,374	$103,740	30%	$31,120	$135,000	$95,000	$203,000	20	$9,930	4%	$400	$10,330
17	Downtown Commons	TC_SSI_1	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	470	$38,761	30%	$11,630	$51,000	$36,000	$77,000	75	$2,150	4%	$90	$2,240
		TC_SSI_2	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	626	$51,681	30%	$15,500	$68,000	$48,000	$102,000	75	$2,870	4%	$110	$2,980
		TC_SSI_3	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	626	$51,681	30%	$15,500	$68,000	$48,000	$102,000	75	$2,870	4%	$110	$2,980
		TC_SSI_4	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	626	$51,681	30%	$15,500	$68,000	$48,000	$102,000	75	$2,870	4%	$110	$2,980
		TC_SSI_5	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	1,644	$135,662	30%	$40,700	$177,000	$124,000	$266,000	75	$7,470	4%	$300	$7,770
		TC_SSI_6	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	313	$25,840	30%	$7,750	$34,000	$24,000	$51,000	75	$1,440	4%	$60	$1,500
		TC_RD_1 & _2	Pavement Removal	$30.00	SY	1.0	1,331	$39,931	30%	$11,980	$52,000	$36,000	$78,000	100	$2,120	4%	$80	$2,200
20	The Town Hall	TH_BR_1	Bioretention Basin	$71,036.80	Acres of Imperv. Area Treated	1.5	0.50	$53,278	30%	$15,980	$70,000	$49,000	$105,000	20	$5,150	4%	$210	$5,360
	Public Parking Lot	PP_IB_1	Bioretention Basin	$71,036.80	Acres of Imperv. Area Treated	2.0	2	$318,984	30%	$95,700	$415,000	$291,000	$623,000	20	$30,540	4%	$1,220	$31,760
22	Old Post Road	OPR_IB_1	Infiltration Basin	$5.00	CF Storage Volume	1.5	1,350	$10,125	30%	$3,040	$14,000	$10,000	$21,000	20	$1,030	4%	$40	$1,070
		OPR_IB_2	Infiltration Basin	$5.00	CF Storage Volume	1.5	750	$5,625	30%	$1,690	$8,000	$6,000	$12,000	20	$590	4%	$20	$610
		OPR_IB_3	Infiltration Basin	$5.00	CF Storage Volume	1.5	875	$6,563	30%	$1,970	$9,000	$6,000	$14,000	20	$660	4%	$30	$690
		OPR_SSI_1	Subsurface Infiltration	$55.00	CF Storage Volume	1.0	4,867	$267,685	30%	$80,310	$348,000	$244,000	$522,000	75	$14,700	4%	$590	$15,290
26	Johnson Middle School	JMS_IB_1	Infiltration Basin	$5.00	CF Storage Volume	1.5	398	$2,985	30%	$900	$4,000	$3,000	$6,000	20	$290	4%	$10	$300
		JMS_IB_2	Infiltration Basin	$5.00	CF Storage Volume	1.5	2,385	$17,888	5%	$890	$18,800	$13,000	$28,000	20	$1,380	2%	$30	$1,410
		JMS_IB_3	Infiltration Basin	$5.00	CF Storage Volume	1.5	2,388	$17,910	30%	$5,370	$24,000	$17,000	$36,000	20	$1,770	4%	$70	$1,840
		JMS_PP_1	Perviouse Pavers	$13.00	SF	1.5	6,994	$136,383	30%	$40,910	$178,000	$125,000	$267,000	20	$13,100	4%	$520	$13,620
28	Elm Street School	ESS_SSI_1	Subsurface Infiltration	$55.00	CF Storage Volume	1.5	1,601	$132,083	30%	$39,620	$172,000	$120,000	$258,000	75	$7,260	4%	$290	$7,550
		ESS_IB_1	Infiltration Basin	$5.00	CF Storage Volume	1.0	900	$4,500	30%	$1,350	$6,000	$4,000	$9,000	20	$440	4%	$20	$460
		ESS_IB_2	Infiltration Basin	$5.00	CF Storage Volume	1.5	2,450	$18,375	30%	$5,510	$24,000	$17,000	$36,000	20	$1,770	4%	$70	$1,840
		ESS_IB_3	Infiltration Basin	$5.00	CF Storage Volume	1.0	1,200	$6,000	30%	$1,800	$8,000	$6,000	$12,000	20	$590	4%	$20	$610
		ESS_TF_1	Tree Box	$8,500.00	EACH	1.5	1	$12,750	30%	$3,830	$68,000	$48,000	$102,000	20	$5,000	4%	$200	$5,200
		ESS_TF_2	Tree Box	$8,500.00	EACH	1.5	1	$12,750	30%	$3,830	$17,000	$12,000	$26,000	20	$1,250	4%	$50	$1,300
30	Ellis Field	EF_IB_1	Infiltration Basin	$5.00	CF Storage Volume	1.5	3,921	$29,408	30%	$8,820	$39,000	$27,000	$59,000	20	$2,870	4%	$110	$2,980
		EF_IB_2	Bioretention Basin	$71,036.80	Acres of Imperv. Area Treated	1.5	1	$72,601	30%	$21,780	$95,000	$67,000	$143,000	20	$6,990	4%	$280	$7,270
										Total	***$2,741,800***	***$1,923,000***	***$4,118,000***					

Notes:
Rate of Inflation used = 2%
Interest (discount) rate used = 6%

Costs are based on screening-level evaluations of site characteristics and should be used for planning purposes only. Construction costs could vary significantly.
Quanties were determined through sizing calculations according to recommended formulas. BMP size may vary slightly on the concept sheets provided, as these images are provided for illustrative purposes only.

Unit Costs

Unit Costs Table

Element	2020 Adjusted Cost	Unit	Cost	$YEAR	Source
Green Infrastructure Elements					
New Haven Curbside Bioswale ***project-specific cost***	$ 15,150.00	ea	$ 15,000.00	2019	Recent bids for West River Bioswales were approximately $15,000 per bioswale for 70 bioswales.
New Bioretention or Ideal Bioretention Retrofit (e.g. abundant treatment area located in a depression; use of simple curb cuts to direct runoff; sandy soils; simple planting plan; etc.)	$ 8.96	cf runoff treated	$ 7.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-8) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Large Bioretention Retrofit	$ 13.44	cf runoff treated	$ 10.50	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-8) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Small Bioretention Retrofit (<0.5 acre)	$ 41.60	cf runoff treated	$ 32.50	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-7). **Based on only 1-2 systems in 2006? Possibly an overestimate.** https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Rain Garden (Installation in unpaved setting)	$ 8.18	sf	$ 7.28	2012	Woodard & Curran - Route 1 Falmouth Commercial District Stormwater Management, 2012. Appendix D. https://www.falmouthme.org/sites/falmouthme/files/file/file/january2013report.pdf
Rain Garden	$ 5.12	cf runoff treated	$ 4.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-11 to E-12) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Bioretention	$ 71,036.80	acre impervious cover treated	$ 63,200.00	2012	Houle, J.J., Roseen, R.M., Ballestero, T.P., Puls, T.A., Sherrard Jr., J. (2013). Comparison of Maintenance Cost, Labor Demands, and Syhstem Performance for LID and Conventional Stormwater Management. *Journal of Environmental Engineering* . pp.932-938. The focus of this article is on maintenance costs but the average(?) capital cost from three bioretention basins is listed.
Bioretention (Includes Rain Garden)	$ 12.31	cf storage volume	$ 11.45	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Enhanced Bioretention (aka Bio-filtration Practice)	$ 12.43	cf storage volume	$ 11.56	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Tree Box ***project-specific cost***	$ 6,744.00	ea	$ 6,000.00	2012	UNH Stormwater Center 2012 Biennial Report, adjusted based on professional judgement, inflation, and materials cost. (also reported as $30,000/acre treated) https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf
Tree Filter ***project -specific cost***	$ 8,407.00	ea	$ 8,407.00	2020	Correspondence regarding a "tree filter" design by the municipal engineering department in East Lyme, CT. The tree filter is installed upgradient of an existing catch basin, has the traditional engineered soil filter media, and has an overflow/underdrain that ties back into the existing catch basin. The most recent cost for a tree filter installation was $12,334 per unit ($8,407 for the unit, tree, soil media, milch, crushed stone and pipes, and $3,927 per unit for installation). Schematics were included with the email.
Tree Well ***project-specific cost***	$ 2,896.00	ea	$ 2,896.00	2020	Correspondence regarding a "tree filter" design by the municipal engineering department in East Lyme, CT. Similar to the Tree Filter design but relies solely on infiltration into the existing soils (no engineered soil media) and does not have an underdrain or overflow. It's only appropriate in areas with deep, well-drained soils. Excess water simply backs up into the road through the curb opening and bypasses the tree well. The tree wells were $2,488 per unit. The materials were $388/unit (granite to form the frame, the plant and patch paving). Installation was $2,100/unit; that included soil media, crushed stone and river stone top dressing. The town purchased mulch so I don't have a price for that, but figure about two bags per unit. I don't have a break-out for the material vs labor. A schematic was included with the email.
Stormwater Tree Pit (Tree Box)	$ 89.60	cf runoff treated	$ 70.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Porous Asphalt ***project-specific***	$ 3.36	sf	$ 2.80	2008	UNH Stormwater Center 2012 Biennial Report. Page 12. https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf
Porous Asphalt	$ 4.24	cf storage volume	$ 3.94	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Permeable Pavers (mechanically installed) ***project-specific cost***	$ 4.50	sf	$ 4.00	2012	UNH Stormwater Center 2012 Biennial Report. Page 16. https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf
Pervious Pavers	$ 6.40	sf	$ 5.00	2006	City of Portland Environmental Services, 2006. "Pervious Pavers" https://www.portlandoregon.gov/Bes/article/127477

Unit Costs

Element	2020 Adjusted Cost	Unit	Cost	$YEAR	Source
Permeable Pavers	$ 12.80	sf	$ 10.00	2006	Hathaway, J. and W. Hunt. 2006. Stormwater BMP costs. North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC. Cited in CWP Manual 3 (2007). Not accessed or downloaded - need Center for Watershed Protection Account to login and download. If needed, contact authors.
Permeable Pavers	$ 153.60	cf runoff treated	$ 120.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E.4 and Page E-11) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Porous Pavement - Pervious Concrete	$ 14.39	cf storage volume	$ 13.39	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Reinforced Gravel Parking	$ 6.47	sf	$ 5.84	2020	http://www.boddingtonsonline.com/products/grass-ground-reinforcement/grass-reinforcement-protection/bodpave-85-permeable-gravel-pavers.php; Added $2/sf for installation
Extensive Green Rooftop	$ 288.00	cf runoff treated	$ 225.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-11) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Extensive Green Rooftop	$ 16.00	sf	$ 12.50	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Page E-10) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Extensive Green Rooftop (New Construction	$ 16.00	sf	$ 12.50	2006	City of Portland Environmental Services. (2006). "Ecoroofs (extensive roof or green roof)" https://www.portlandoregon.gov/Bes/article/127469
Extensive Green Rooftop (Re-roofing)	$ 25.60	sf	$ 20.00	2006	City of Portland Environmental Services. (2006). "Ecoroofs (extensive roof or green roof)" https://www.portlandoregon.gov/Bes/article/127469
Intensive Green Rooftop	$ 460.80	cf runoff treated	$ 360.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-11) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Intensive Green Rooftop	$ 40.96	sf	$ 32.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Page E-10) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Subsurface Infiltration	$ 20.56	cf of runoff treated	$ 20.00	2018	Fuss & O'Neill, City of Pawtucket Grant Application, 2018.
Subsurface Infiltration/Detention System (aka Infiltration Chamber)	$ 54.03	cf storage volume	$ 50.26	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1029&context=stormwater
French Drain/Dry Well	$ 15.36	cf runoff treated	$ 12.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4 and Page E-12) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Dry Well/Leaching Catch Basin (installed in exsiting parking lot) ***project-specific cost***	$ 23,562	ea	$ 22,920.50	2018	Engineer's estimate for the installation of 3 dry wells in East Lyme, CT. Tasks included sawcutting (4"-6" depth at $0.50/LF) and patching (4" depth at $4.25/SF) pavement, a catch basin ($3,500) and manhole frame and cover ($800) plus an 8' diameter 8" deep concrete drywell with base slap, icnlduing labor for stone in pits ($4000), and 1.5" crushed stone in drywells ($21/ton)
Dry Well	$ 12,850	ea	$ 12,500.00	2018	Oregon State University, Dry Wells: Low-impact development fact sheet, May 2019. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9200.pdf N.B. this is for a non-residential dry well
Dry Pond or Detention Basin	$ 5.41	cf storage volume	$ 5.04	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1029&context=stormwater
Pond Retrofit	$ 3.84	cf runoff treated	$ 3.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-4) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Pond Retrofit	$ 14,208.00	impervious acre treated	$ 11,100.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-2) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Wet Pond or Wet Detention Basin	$ 5.41	cf storage volume	$ 5.04	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Constructed Wetland	$ 3,712.00	impervious acre treated	$ 2,900.00	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007), cost adjusted, Appendix E (Table E-2 and Page E-6) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/

Unit Costs

Element	2020 Adjusted Cost	Unit	Cost	$YEAR	Source
Gravel Wetland System (aka Subsurface Gravel Wetland)	$ 6.99	cf storage volume	$ 6.50	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Subsurface Gravel Wetland	$ 24.54	cf runoff treated	$ 21.83	2013	Woodard & Curran - Route 1 Falmouth Commercial District Stormwater Management, 2012. Appendix D https://www.falmouthme.org/sites/falmouthme/files/file/file/january2013report.pdf
Rain Barrel	$ 14.72	cf of runoff treated	$ 11.50	2006	Center for Watershed Protection Urban Subwatershed Retrofit Manual 3 v.1.01 (2007) Appendix E (Table E-4 and Page E-11) https://owl.cwp.org/mdocs-posts/schueler-et-al-2007-usrm-manual-3-appendix-e/
Rain Barrel	$ 150.00	ea	$ 150.00	2020	City of Portland Environmental Services, 2006. "Rain Barrels" https://www.portlandoregon.gov/bes/article/127467. N.B. Google search conducted May 2020 used to confirm current rain barrel prices.
Sand Filter	$ 14.29	cf storage volume	$ 13.29	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Infiltration Basin (or other Surface Infiltration Practice)	$ 4.97	cf storage volume	$ 4.62	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Infiltration Trench	$ 9.95	cf storage volume	$ 9.25	2016	Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater
Pavement Removal	$ 30.00	SY	$ 30.00	2020	MassHighway Weighted Bid Prices (All Districts) 5/2019-5/2020 "Old Pavement Excavation" https://hwy.massdot.state.ma.us/CPE/WeightedAverageBook.aspx
Bituminous Pavement Mill and Overlay ***project-specific cost***	$ 25.00	SY	$ 25.00	2020	Cost to mill and repave a public school parking lot approximately 1 acre in area in Belchertown, MA (2020 MVP Action Grant)
Restoration Elements					
Riparian Buffer Restoration	$ 12,482.91	ac	$ 10,543	2010	Oregon Department of Environmental Quality, 2010, Cost Estimate to Restore Riparian Forest Buffers and Improve Stream Habitat in the Willamette Basin, Oregon. Page 20
Stream Channel Restoration	$ 14,602.27	ac	$ 12,333	2010	Oregon Department of Environmental Quality, 2010, Cost Estimate to Restore Riparian Forest Buffers and Improve Stream Habitat in the Willamette Basin, Oregon. Page 20
Remove Invasive Species	$ 3,788.80	acre	$ 3,200	2010	Professional Engineering Experience
Tree Planting	$ 500.00	ea			Street tree cost
Landscape Shrub Plantings	$ 40.00	ea			
Construction Elements					
6" to 12" Rip Rap	$ 50.58	CY	$ 45.00	2012	Professional Engineering Experience
Outlet Structure	$ 4,500	ea	$ 4,500	2013	Professional Engineering Experience
Manhole	$ 2,500	ea	$ 2,500	2013	Professional Engineering Experience
Dam Removal	$ 20,364.80	ea	$ 17,200	2010	Selle, Andy (2010). Dam Removal – A Primer, Presentation; $17,200 is median for dams 1-3 feet high.
Educational Signage	$ 1,200	ea	$ 1,200	2013	Professional Engineering Experience

Unit Costs

Inflation Rates Table

Inflation from	Inflation to	Percent
2006	2020	28.0%
2008	2020	19.9%
2010	2020	18.4%
2011	2020	14.70%
2012	2020	12.4%
2013	2020	10.8%
2016	2020	7.5%
2018	2020	2.8%
2019	2020	1.0%
2020	2020	0.0%

http://www.usinflationcalculator.com/

Project-Specifc Notes
1) Lines highlighted in green indicate base costs selected for use in this particular cost estimation project. They are highlighted for quick reference.

Cost Adjustment Factors (Vermont)

BMP Type	Cost Adjustment Factors
New BMP in partially developed area	1.2
New BMP in developed area	1.4
Difficult installation in highly disturbed setting	2

Source: Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater

Cost Adjustment Factors (Cambridge)

BMP Type	Cost Adjustment Factors
New BMP in partially developed area	1.5
New BMP in developed area	2
Difficult installation in highly disturbed setting	3

Source: Mataleska, Karen, "MS4 Resource: BMP Cost Estimates" (2016). UNH Stormwater Center. 32. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1031&context=stormwater

Unit Costs

BMP Lifespan Table

BMP Type	Average Lifespan (years)	Source	Link
Bioretention	20	Minnesota Stormwater Manual. (2018) "Bioretention Combined" Web page accessed May 6, 2020 "If gardens are properly planned and designed (protected from sediment and compaction and incorporating a sufficient turf pretreatment area), a rainwater basin is likely to retain its effectiveness for well over 20 years. After that time, inspection will reveal whether sedimentation warrants scraping out the basin and replanting it (possibly with salvaged plants)."	https://stormwater.pca.state.mn.us/index.php/Bioretention_combined_
Porous Asphalt	20	National Asphalt Pavement Association. "Porous Asphalt" (webpage). "Even after twenty years, porous pavements show little if any cracking or pothole problems."	asphaltpavement.org/index.php?option=com_content&view=article&id=359&Itemid=863
Porous Asphalt	20	Federal Highway Administration. (2015). TechBrief: "Porous Asphalt Pavements with Stone Reservoirs". FHWA-HIF-15-009. https://www.fhwa.dot.gov/pavement/asphalt/pubs/hif15009.pdf "A number of porous asphalt parking lots have lasted more than 20 years with no maintenance other than cleaning."	https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=948
Extensive Green Roof	40	City of Portland Environmental Services. (2006). "Ecoroofs (extensive roof or green roof)" "Can outlast a conventional roof by 20 years or more" "An ecoroof initally costs more than a conventional roof, but typically last twice as long (about 40 years)	https://www.portlandoregon.gov/Bes/article/127469
Dry Well	30	City of Portland Environmental Services. (2006). "Drywells" "A dry well can last up to 30 years with proper construction and maintenance." Appears to focus mainly on dry wells at private residences; applicability to municipal or large-capacity dry wells is uncertain.	https://www.portlandoregon.gov/bes/article/127480
Subsurface Infiltration Chamber	75	StormTech Deisngn Manual for StormTech Chamber Systems for Stormwater Management	https://www.stormtech.com/download_files/pdf/design_manual_310740780.pdf
Rain Barrels	20	City of Portland Environmental Services, 2006. "Rain Barrels" https://www.portlandoregon.gov/bes/article/127467.	https://www.portlandoregon.gov/Bes/article/127467

Appendix D

Adaption Recommendations Summary, Town of Walpole, MA

Adaptation Recommendations Summary
Town of Walpole, MA

The Town of Walpole is vulnerable to flood-related damages, as evidenced by historical and recent flooding events. The Town of Walpole, in collaboration with Fuss & O'Neill, developed a water infrastructure climate resiliency plan to help mitigate the effects of future flooding events that will become more frequent and intense as a result of climate change. The following is a summary of key findings and recommendations of the town's plan.

Quick Facts – Walpole

- 137 road-stream crossings assessed
- 34 sites assessed for green infrastructure concept development
- 7 road-stream crossings identified for upgrades

Road-Stream Crossings

- 137 road-stream crossings were assessed in Walpole:
- 36% of crossings are hydraulically undersized
- 12% of crossings have significant geomorphic vulnerability
- 69% of crossings limit or restrict aquatic passage
- 29% were rated "critical" for structural condition

Recommendations:

- Replace and upgrade priority crossings (see table below) to meet the flood resilience and aquatic organism passage (AOP)
- Consider other upstream and downstream crossings and dams on the same river system
- In general, replace downstream crossings first
- Perform site-specific data collection, geotechnical evaluation, hydrologic and hydraulic evaluation, and structure type evaluation to support design

High -Priority Stream Crossings (Listed by Priority Ranking)

Road	Stream	Crossing Type
Gould Street and Smith Avenue	Unnamed	Two (2) 3' diameter concrete pipes
Lewis Avenue	Neponset River	Two (2) concrete box culverts 6.5' wide
Main Street at Cobbs Pond	Unnamed	2.5' wide concrete box/bridge
Summer St. at Neponset River	Neponset River	6' wide concrete box/bridge
Oak Street	Unnamed	1.5' smooth metal culvert
Plimpton Street	Neponset River	Two (2) concrete 10.7' wide box culverts and 4' open-bottom arch
Stone Street	Spring Brook	Two (2) 3' diameter concrete culverts
Robbins Road	Neponset River	Two (2) 4' diameter concrete culverts
Main Street	Neponset River	15' wide concrete box/bridge
Summer Street	Unnamed	3' diameter concrete pipe
Willow Street	Unnamed	2' diameter concrete pipe

Green Infrastructure

A screening-level assessment of potential green infrastructure (GI) retrofit sites was performed for 34 sites. Of these, 9 were selected for development of GI concepts. When applied throughout the watershed, GI can help mitigate flood risk resulting from outdated and undersized storm drainage systems and increase flood resiliency, as well as improve water quality.

Sites Identified for GI Concept Development:

- Public Works yard
  - Recommendations: bioretention basin
- Jarvis Farm
  - Recommendations: infiltration basin and subsurface infiltration
- Walpole High School
  - Recommendations: subsurface infiltration, infiltration basin and pervious pavers
- Town Common
  - Recommendations: subsurface infiltration and pavement removal
- Town Hall and Municipal Parking Lot
  - Recommendations: bioretention basin and parking lot redesign with bioretention planters
- Old Post Road School
  - Recommendations: infiltration basin and subsurface infiltration
- Johnson Middle School
  - Recommendations: infiltration basins and pervious pavers
- Elm Street School
  - Recommendations: infiltration basins, subsurface infiltration, tree filters, and bioswale/infiltration basin
- Ellis Field
  - Recommendations: infiltration basin

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